esrel

31st European Safety and Reliability Conference

19-23 September 2021, Angers, France

PROGRAMME & ABSTRACTS

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université angers · POLYTECH ANGERS · LARIS · ESRA · DESTINATION angers

IN COLLABORATION WITH

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Message from General Chairs

Welcome to Angers!

The 31st European Safety and Reliability Conference (ESREL 2021) is held in Angers, France on 19 – 23 September 2021. The annual European Safety and Reliability Conference (ESREL) is an international conference under the auspices of the European Safety and Reliability Association (ESRA).

It is with great pleasure that all the technical and organizing committees and their chairs welcome you here in the city of Angers. We are happy to say that ESREL 2021 can be seen, in its hybrid face-to-face and remote organization, as a double event even if we have tried to synchronize as well as possible so that everyone has the feeling to participate in the same event. The 2 key words of the organization were foresight and resilience.

For those lucky enough to be with us physically, a few words about the city of Angers. Angers, the 17th city in France located in the middle of the western province Région Pays de la Loire, enjoys a good reputation as a desirable place to live. Angers, capital of the Plantagenet dynasty and one of the intellectual hotspots of Europe during the reign of King René d'Anjou in the medieval era, presents an architecture that is both modern and steeped in history. One of its most prestigious monuments is the imposing castle built between the 13th and 14th centuries which houses the biggest medieval tapestry ensemble in the world, the Apocalypse Tapestry. Angers is also part of both the Val de Loire, a world heritage site, and the Loire-Anjou-Touraine regional nature park and opens the doors to the Loire castles. Angers and its surroundings are also well-known for its gastronomy and wines.

ESREL 2021 organized by Université d'Angers is arranged at the Angers Convention Center. The University of Angers can be seen as a young university (we celebrate its 50th anniversary this year) with a very long history (it was created in 1364 by King Charles V and recognized by the Pope in 1436). It trains more than 23,000 students and delivers more than 402 degrees in more than 100 specialties. The Angers Convention Center, totally renovated and located in the heart of the city, is a nice little setting that offers us a very friendly environment for our 5 days of work.

The rich program for this year's conference includes 5 keynotes speakers with international excellence, 8 panels reflecting societal and methodological thoughts and challenges, and 15 sessions with 11 parallel tracks for a total of 593 papers, sharing new insights and ideas within different methods and application areas. Every presentation is filmed, broadcasted live and available for streaming on our platform. The traditional areas for the ESREL are continued, such as Accident and Incident Modeling, Risk Assessment, and Structural and System Reliability with an emphasis on Maintenance and Prognostic and Health Management topics. The program is also reflecting the multidisciplinary aspects of safety science, involving areas such as organizational and human factors, as well as resilience engineering. 24 special sessions with various opening topics proposed and organized by academic or industry researchers are presented in the program. This illustrates the enthusiasm of the community towards the ESREL event and we thank all the contributors at all levels.

We would like to underline the excellent level of support from the Pays de la Loire Region and the numerous local authorities of the Angers area. Thanks also to our sponsors and exhibitors.

Finally, the success of this event is already assured through the quality of your scientific proposal and your numerous participation in person and remotely. We hope for a richness of exchanges with great moments of conviviality. To all of you, authors and participants, we want to express our gratitude and thank you warmly.

Bruno Castanier
General Chair

Marko Cepin
General Co-Chair

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Programme & Abstracts

31st European Safety and Reliability Conference and (ESREL 2021)

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Brief Contents

Preface

ESREL 2021
Angers, France

This book contains close to 600 abstracts of the scientific and industry contributions from the 31st European Safety and Reliability Conference – ESREL 2021 –, held in Angers, France and organised by Université d'Angers and the European Safety and Reliability Association (ESRA). The full papers are published as Open Access papers on the following website: `http://esrel2021.org/en/index.html`.

For more than 30 years now, ESREL has been one of the key annual events for meetings and knowledge exchange in order to innovate for a better control of risks, and safety and optimization of the performance of socio-technological systems. The Conference has become well established in the international community, attracting a good mix of academic and industry participants that present and discuss subjects of interest and application across various industries in the fields of Safety, Reliability and Risk.

This conference comes to France for the fifth time (in addition to an earlier one in 1989 in La Baule). The last edition organized in France was in 2011 in Troyes. Université d'Angers can be seen as a young university (we celebrate its 50th anniversary this year) with a very long history (it was created in 1364 by King Charles V and recognized by the Pope in 1436). It trains more than 23,000 students and delivers more than 402 degrees in more than 100 specialties. Polytech Angers, the engineering school of Université d'Angers has developed undergraduate and graduate programs in quality, reliability and safety engineering and risk management.

This year the theme of the Conference is "Guaranteeing in an accelerating world". The Conference covers a number of topics within safety, reliability and risk, and provides a forum for presentation and discussion of scientific papers covering theory, methods and applications to a wide range of sectors and problem areas.

This year, the Conference programme includes a total of 593 communications (454 full-papers and 139 abstracts) from prestigious authors coming from all over the world, and selected by the Technical Programme Committee to guarantee the quality and the consistency of the program.

The review process was mainly organised by the Technical Area Coordinators (most of which are the Chairmen of the ESRA Technical Committees) and the review process was made by a large number of anonymous reviewers which are gratefully acknowledged for their contributions to the improvement of quality of the papers. The members of the Technical Programme Committee (most of them members of the ESRA Technical Committees) have shared a great part of the review process and are important contributors to the Conference organization.

Bruno Castanier, Marko Cepin, David Bigaud and Christophe Bérenguer
Editors

Editorial by Christophe Béchu

Christophe BÉCHU
Mayor of Angers
President of Angers Loire Metropole

After the last editions held in Hannover and Milan, Angers is very honoured to host and support the 31st international ESREL conference.

In a world challenged by successive crises, risk management and security are fundamental areas of expertise and it is good to see that Angers will be the hub of meetings and knowledge exchange for the 600 industrial and academic specialists, with the purpose of being at the forefront of risk control and optimizing the performance of socio-technological systems.

The numerous topics covered during the conference will perfectly reflect the agility of our territory, in different fields like the Environment and the recent "Ecological transition meetings", digitalization of the companies and the Angers business digital cluster such as the Smart City project conducted at the level of the Angers Loire Métropole urban community.

I am absolutely convinced that the setting of the Convention Centre, a symbol of Angers France's greenest city's DNA, will bring about high-quality scientific exchanges and give birth to fruitful partnerships between all the delegates.

And at a time when the tourism industry remains badly hit by the Covid situation, I am delighted to see that ESREL 2021's organisers, with the help of Destination Angers, have shown agility and foresight in planning an event of that size, in a hybrid format. While staying in Angers no doubt all the participants will enjoy the quality of life, the heritage and all delights of our destination.

Acknowledgement

We would like to thank many people for their support and contributions to ESREL 2021.

We gratefully acknowledge the members of the ESREL 2018 Technical Programme Committee for their support of the scientific programme. We gratefully acknowledge the European Safety and Reliability Association Technical Committee Chairs and Co-Chairs, for volunteering their time and expertise to provide feedback as part of the contributed paper review process and for chairing the sessions at the conference. And last but not least we thank all authors and reviewers who have willingly given some of their time to ensure a high quality of papers for this conference. Every paper was reviewed by anonymous reviewers.

We would like to thank colleagues who organised special sessions of contributed papers and colleagues, who organised workshops and panels. We also thank the ESREL 2021 Plenary Speakers for offering their unique perspectives on safety and reliability at this conference.

The support of the ESREL 2021 sponsors and exhibitors is gratefully acknowledged.

Finally, we would like to thank the respective organisations for supporting the conference: It has been made possible by the close collaboration of LARIS research lab, Université d'Angers, Polytech Angers, Destination Angers and the European Safety and Reliability Association.

Bruno Castanier, Marko Cepin, David Bigaud, Christophe Bérenguer and Abdessamad Kobi
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Special Sessions

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Panel Sessions

Monday, September 20, 2021 / 14:00–15:00 hrs — [Parallel]

Venue	Auditorium
Panel – I	RAM and PHM Synergy
Organizer	Dersin, Pierre, *pierre.dersin@alstomgroup.com — ALSTOM, France, and Luleå University of Technology (LTU), Sweden*
Panel List	Kumar, Uday (Prof.), *uday.kumar@ltu.se — Luleå University of Technology (LTU), Sweden* Tinga, Tiedo (Prof.), *t.tinga@utwente.nl — University of Twente, The Netherlands* Fink, Olga (Prof.), Fink Olga *fink@ibi.baug.ethz.ch — ETH-Zürich, Switzerland* Prof. dr. Marielle Stoelinga, *Professor of risk management for high-tech systems, University of Twente, The Netherlands.*

Abstract

RAM (Reliability-Availability-Maintainability) Engineering is by now a mature discipline, tracing its roots back to the immediate post-World War II period. It deals with statistical properties of a population of assets, characterizes their failure modes and aims at optimizing the design of future equipment based on past experience, analysis and tests. It takes into account maintenance and operations context and also provides inputs to the elaboration of maintenance plans and logistic support.

RAM analysis at the design stage is typically model-based (while exploiting past data), and RAM Monitoring is data-driven but may be supported by models.

PHM (Prognostics & Health Management) emerged at the turn of the 21st century. It deals typically with individual assets which are equipped with sensors and aims at monitoring their health and its progressive degradation, so as to diagnose impending failures, and to avoid them by taking preventive actions when possible. Three main pillars of PHM are detection, diagnostics and prognostics.

PHM relies on model-based, data-driven or hybrid approaches.

Typically the two communities are separate for historical reasons.

The question we would like to raise here is: can the two communities both benefit from stronger links?

For example, the first stage in developing a PHM system is a failure mode, mechanisms and effects analysis (FMMEA), which is typically a RAM task. And one key expected outcome from a PHM strategy is increased availability.

While RAM focuses on estimating the probability distribution of the lifetime of a population, in a given environment with an average mission profile, PHM, on the other hand, focuses on predicting the rate of function loss for an individual asset, with a customized profile and context. RAM deals with discrete events (failures), and metrics such as failure rate and MTTF or MRL (mean residual life); while PHM deals with continuous, degradation data, and metrics such as health indicators (or indices) and RUL (remaining useful life). While RAM leads to maintenance decisions (such as spares management and determination of maintenance intervals) for a whole fleet, PHM supports maintenance decisions for one individual asset. The '*M*' (maintainability) in RAM includes testability, which addresses the ability to detect and diagnose faults– an essential concern for PHM.

The IoT paves the way for individualized monitoring. Both RAM and PHM can be supported by machine learning techniques along with classical statistics. Therefore the borders between the two disciplines may be getting blurred.

Can cross-fertilization occur in both directions? For instance, can PHM not draw on the considerable body of knowledge accumulated by RAM specialists over decades (including the venerable theories of the 'founding fathers', such as Barlow & Proschan, or Gnedenko, which PHM engineers often are not familiar with).

And at the same time, cannot RAM Engineering be rejuvenated by machine learning algorithms and perspectives (which often RAM Engineers do not necessarily have in their toolbox)?

Should corporate RAMS departments give way to RAM/PHM departments? And what are the implications for higher education and research?

Venue	Atrium 2
Panel – II	Aero 1: Reliability & Safety in Aerospace & Space — State of the Art and Evolutions
Moderators	Jean Louis Deschanels

Abstract

Reliabiity and Safety are two key words when it comes to fly. Airplanes are intrinsically safe, much more than any other transportation mode and are indeed the safest transportation mean. How do the industry reached that level of engineering expertise to make the dream of Icare becoming an almost daily routine.

A second panel, on 21rst, 2pm will address the newest, often disruptive development of novel platforms, such as Urban Air Mobility, Air Taxis, etc and the importance of Safety / Reliability culture from early design phase.

Venue	Espace grand angle 2
Panel – III	Autonomous system safety, risk, and security
Moderators	Thieme, Christoph A., *christoph.thieme@ntnu.no — Norwegian University of Science and Technology* Ramos, Marilia, *marilia.ramos@ucla.edu — University of California Los Angeles* Utne, Ingrid B., *ingrid.b.utne@ntnu.no — Norwegian University of Science andTechnology* Mosleh, Ali, *mosleh@ucla.edu — University of California Los Angeles*

Description

This special session will be organized in the format of a panel for discussing autonomous systems safety, risk, and security (SRS). The session will discuss the results of the First International Workshop on Autonomous Systems Safety (IWASS), as well as early findings of the 2nd IWASS. Key experts will be invited to discuss autonomous systems SRS from an interdisciplinary and cross-industrial perspective.

The panel is expected to present the results from IWASS discussions and make them more accessible to a wider audience. Participants may present additional thoughts on the discussions and workshop outcomes.

Motivation

The First IWASS was organized by the Department of Marine Technology at the Norwegian University of Science and Technology (NTNU) and the B. John Garrick Institute for the Risk Sciences at the University of California, Los Angeles (UCLA). IWASS took place in Trondheim, Norway, from March 11th to 13th, 2019. The 47 participants were selected and individually invited to the workshop only and included 47. The subject matter experts came from Europe, Asia, Australia, and the U.S.A., working in both academia and industry. The 2nd IWASS is planned as a virtual event to be held in April 2021.

Autonomous systems on land, in the air and on the sea are being widely applied. The safety issues concerning these systems are the focus of many research projects and publications, yet each industry and academic field attempts to solve arising safety issues on their own. Given the identifiable similarities, could common solutions be envisioned and developed? Answering these and related questions motivates this panel as an opportunity for an interdisciplinary discussion on risks, challenges, and foremost potential solutions concerning safe autonomous systems and operations.

Objective

This session aims at using the results of the First IWASS, early findings of the 2nd IWASS, and participants expertise to discuss autonomous systems SRS, identifying key challenges, and possible solutions for those.

Venue Panoramique

Panel – IV Digital twins to improve decision making in the built environment

Organizer Peter El Hajj – *Head of UK National Digital Twin Programme Delivery*

Panel List Sebastien Coulon – *Cofounder/COO – SpinalCom*
Emmanuel Di Giacomo – *EMEA BIM & AEC Ecosystem Business Development*
Mary Juteau – *Responsable du Service Information Géographique – Angers Loire Métropole*

Description

Digital twins still mean different things to different people, but all descriptions seem to share a common characteristic — connection between the physical and the digital worlds. This panel aims to explore the opportunities provided by digital twins in the built environment. Discussions will address examples, challenges and guiding principles of digital twins like federation, trust and purpose.

Venue Auditorium

Panel – V TC12 on risk analysis and safety of large structures and component

Moderators Leksandar Sedmak, *asedmak@mas.bg.ac.rs — Faculty of Mechanical Engineering, University of Belgrade, Serbia*
Snežana Kirin, *Innovation Center of the Faculty of Mechanical Engineering, Belgrade, Serbia*
Nenad Milošević, *Innovation Center of the Faculty of Mechanical Engineering, Belgrade, Serbia*

Abstract

European Structural Integrity Society (ESIS) is leading association of scientists and researchers who deal with failures, fracture mechanics, structural integrity and related topics like reliability and safety. The ESIS has a number of Technical Committees specialized in different topics, including TC12 on Risk analysis and safety of large structures and component, coordinated by Aleksandar Sedmak & Snežana Kirin, Belgrade, Serbia, José A.F.O. Correia & Abílio M.P. De Jesus, Porto, Portugal and Vladimir Moskvichev & Elena Fedorova, Krasnoyarsk Russia. Ongoing collaborative research covers Fracture Mechanics Applied to the Risk Analysis and Safety of Technical Systems, Degradation Theory of Long Term Operated Materials, Fatigue Evaluation in Offshore and Onshore Structures, Fatigue Analysis in Bridge Structures, Modeling of Offshore Structures, International Symposiaon Risk Analysis and Safety of Complex Structures and Components, Workshop on Risk based Fracture Mechanics Analysis.

Recent Projects include:

(1) The European “FASTCOLD – FAtigue STrength of COLD formed structural steel details” aims to develop design fatigue curves of details made of cold-formed profiles.
(2) The National project called “FIBERBRIDGE – Fatigue strengthening and assessment of railway metallic bridges using fiber-reinforced polymers” aims the fatigue strengthening and assessment of railway metallic bridges using fiber-reinforced polymers.
(3) Research projects financed by the Serbian Ministry for Education, Science and Technological Development: Risk analysis in mining industry and New Advances in Fracture Mechanics and Structural Integrity.

The ESIS TC12 is organized in several working groups: WG1 on Engineering Structures and Technologies, Chairs José António Correia, Grzegorz Lesiuk & Pedro Montenegro,
WG2 on Safety of Technical Systems, Chairs Aleksandar Sedmak & Vladimir Moskvichev,
WG3 on Reliability and Probabilistic Approaches, Chairs: Miguel Calvente & Shun-Peng Zhu,
WG4 on Environmental effect on structural integrity, Chair Elena Federova, and
WG5 on Structural integrity of composite materials and structures, Chairs Lothar Kroll & Wojciech Blaźejewski

Tuesday, September 21, 2021 / 14:00–15:00 hrs — [Parallel]

Venue	Atrium 2
Panel – VI	Aero 2: Urban Air Mobility and newest Aerospace disruptive challenges
Moderators	Clement Audard, *from EASA European Union Aviation Safety Agency*

While Urban Air Mobility projects are booming, the aims of this session is to recall the fundamentals when it comes to carry passengers: safety first ... How could the new players, who do not necessarily have aerospace expertise and so the benefits from the pedigree of century of experience, address those topics incl. newest technologies, such as Lio Ion Batteries, hydrogen, autonomous flights (non-piloted, ...) etc.

Venue	Espace grand angle 2
Panel – VII	Model-Based Safety Assessment approach: Increase trust in models
Organizer	MILCENT Frédéric, *frederic.milcent@naval-group.com — Naval Group*
Panel List	BATTEUX Michel, *Michel.Batteux@irt-systemx.fr — IRT SystemX* DE BOSSOREILLE Xavier, *xavier.debossoreille@apsys-airbus.com — APSYS AIRBUS* PROSVIRNOVA Tatiana, *Tatiana.Prosvirnova@onera.fr — ONERA*

Description

Model-Based Safety Assessment (MBSA) exists since many years now and the advantages of this approach are well known. However, modelers are sometimes confronted with the same old questions: Is the model really valid? Are the results correct? Those questions often take their origins in a lack of knowledge of the MBSA approach but reveal an important issue: how to prove the validity of models and results?

The following topics will be addressed:

(1) Modeling process
(2) Training & Communication
(3) Model representativeness
(4) Model–Checking
(5) Tools & Software
(6) Documentation & Capitalization

Motivation

The aim of this panel session is to give leads to modelers to prove the validity of their models. An example of modeling process will be proposed. Based on this process, few solutions will be presented:

- Plan MBSA to define inputs needed, objectives and development specification
- Model-Based System Engineering (MBSE) / MBSA coupling initiatives (S2C, S2ML...) and others methods to ensure the model representativeness to the corresponding system
- Model-checking for the verification of the consistency of the model
- Validation activities (step-by-step simulation...)
- Provide documentation with model for explanation
- MBSA supporting activities (training & communication) and resources (database, existing patterns...)
- Possibilities offered by MBSA tools & languages to assist modelers

Venue Panoramique

Panel – VIII COVID-19 pandemic: Risk analytics

Organizer Bracke, Stefan, *bracke@uni-wuppertal.de — University of Wuppertal, Chair of Reliability Engineering and Risk Analytics, Gausstrasse 20, 42119 Wuppertal, Germany*

Panel List Bracke, Stefan; *bracke@uni-wuppertal.de, University of Wuppertal*
Van Gulijk, Coen, *coen.vangulijk@tno.nl, University of Huddersfield*

Description

Since December 2019, the world is confronted with the COVID-19 pandemic, caused by the Coronavirus SARS-CoV-2. The COVID-19 pandemic with its incredible speed of spread shows the vulnerability of a globalized and networked world. The first months of the pandemic were characterized by heavy burden on health systems and severe restrictions on public life within a lot of countries, like educational system shutdown, public traffic system breakdown or a comprehensive lockdown. The focus of the panel is the discussion of risk and safety analytics regarding the analyse of several control strategies or combinations of them, like restrictions, medical care actions and medical prevention activities.

Motivation

The COVID-19 pandemic continues to this day. The impact of the pandemic continues to influence life in various countries around the world. Methods from reliability and safety engineering can help regarding the estimation of risks and can be a fundament for finding proper actions to control the pandemic.

Venue Panoramique

Panel – IX Confiance.ai

Organizer Bertrand Braunschweig, *bertrand.braunschweig@ext.irt-systemx.fr, IRT SystemX*

Panel List Bertrand Braunschweig, *scientific coordinator of confiance.ai*
Christophe Bohn, *project coordinator, IRT SystemX*
Francois Terrier, *AI leader, CEA LIST*

Abstract

Artificial intelligence requires a great deal of research and innovation to reach its full potential. In particular, the integration and safe use of AI technologies are essential to support the engineering, development and diffusion of innovative products and services. The Confiance.ai program, an important initiative coordinated by IRT SystemX and supported by major industrials and academics, aims to provide an environment for the design, validation and testing of AI systems to strengthen trust, explainability, dependability and move towards the certification of these systems.

The session will highlight the motivations for the program, its main components and look at the scientific challenges associated with it, especially in the domains of safety and reliability.

Plenary Lectures

Plenary Lecture I

Date/Time Monday, September 20, 2021 / 09:30–10:10 hrs
Venue Auditorium

Title Artificial Intelligence, Safety and Reliability : an old story or a new age?
By Patrice Aknin
Directeur Scientifique, Institut de Recherche Technologique SystemX,
`https://www.researchgate.net/profile/Patrice_Aknin`

Biography

Patrice Aknin is a data science researcher who hold the position of Scientific Director at IRT SystemX since 2013. SystemX is an RTO (Research Technological Organisation) located in Saclay, near Paris, which is positioned as an accelerator of the digital transformation of industry, services and territories. Previously, he was Scientific Director at SNCF, the French national railway company. Between 1988 and 2013, he held various positions as a Researcher and then Research Director at Ifsttar (French Institute of science and technology for Transport, Developement and Networks), which recently became the University Gustave Eiffel. He is professor at Ecole des Ponts Paristech and also at Télécom Paris. He is a member of several scientific councils of prestigious institutions such as ENS Paris-Saclay, Télécom Sud-Paris and ENSTA Paris. He has directed the PhD work of about twenty students. He is the author or co-author of nearly 150 publications in the fields of diagnosis, data science, maintenance, mainly on applications in the field of transport.

Abstract

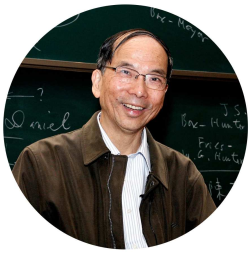
The new proposals of artificial intelligence, and especially data science, are now flooding the scientific field, the industrial field, and, more generally, society. These proposals are not limited to the progress in machine learning itself, especially in deep learning. Indeed, many scientific areas are impacted and are facing significant evolutions: image recognition, scientific computation aggregating physical models and data-based models, data augmentation, natural language processing, optimization and reinforcement learning, new digital twins, cyber-detection by machine learning, supervision of large industrial systems, bidirectional digital assistants (learning from and to the expert), hybridization between symbolic AI and connectionist AI... The fields of safety, maintenance, and reliability are not exempt from this surge and these promises. But is this safety-IA hybridization new? One could say that until now, data science has come to the rescue of safety to help describe aging processes, stochasticity of states and their transitions, ... In its unsupervised versions, it can also be of great help in detecting cases of failure not yet observed in real life. Today, with the explosion in the number of AI algorithms integrated into industrial and service systems, the question arises about their validation and confidence placed in them. Safety sees before it a new field of application of exponential size where the usual tools are helpless in the face of the combinatorial nature of states and operational domains with an increasingly wide spectrum. The talk proposes response elements to these dual-entry questions. It will illustrate them through current applications such as autonomous vehicle validation, fault diagnosis of large critical systems, and rail maintenance.

Plenary Lecture II

Date/Time Monday, September 20, 2021 / 15:20–16:00 hrs
Venue Auditorium

Title From Parameter Design to Data Science
By C. F. Jeff Wu
Georgia Institute of Technology
https://en.wikipedia.org/wiki/C._F._Jeff_Wu

Biography



F. Jeff Wu is Professor and Coca Cola Chair in Engineering Statistics at the School of Industrial and Systems Engineering, Georgia Institute of Technology. He was elected a Member of the National Academy of Engineering (2004), and a Member (Academician) of Academia Sinica (2000). A Fellow of American Society for Quality, of Institute of Mathematical Statistics, of INFORMS, and of American Statistical Association. He received the COPSS Presidents' Award in 1987, COPSS Fisher Lecture Award in 2011, Deming Lecture in 2012. He has won other awards, including the Shewhart Medal (2008), the Pan Wenyuan Technology Award (2008), Class of 1934 Distinguished Professor Award and Sigma Xi Monie A. Ferst Award both at Georgia Institute of Technology in 2020. He was the 1998 Mahalanobis Memorial Lecturer at the Indian Statistical Institutes, received the inaugural Akaike Memorial Lecture Award in 2016 sponsored by the Japan Statistical Society and the Institute of Statistical Mathematics, Tokyo, the 2017 Box Medal from ENBIS, and an honorary doctor degree at the University of Waterloo.

He has published more than 185 research articles. He has supervised 50 Ph.D.'s, out of which more than half are teaching in major research departments in statistics/engineering/business in US/Canada/Asia/Europe. Among them, there are 22 Fellows of ASA, IMS, ASQ, IAQ, and IIE. He co-authors with Mike Hamada the book "Experiments: Planning, Analysis, and Optimization" (Wiley, 3rd ed. 2021) and with R. Mukerjee the book "A Modern Theory of Factorial Designs" (Springer, 2006).

Abstract

In this talk I will first trace the history of my role in the coining of the term "data science". For many years since the early 1980s, I had grown dissatisfied with using the term "statistics" to describe my profession because it is usually connected with descriptive statistics, while what statisticians do can be summarized as a trilogy of data collection, data modeling, and problem solving. Thus I proposed the terms data science and data scientist in a public lecture at the U. of Michigan in 1997. With the explosion of huge data collected through the internet, data science has grown to become a very popular, fashionable and impactful profession. I will describe how it is so different from the traditional meaning and work of statistics. A major new component is the role played by computer scientists and the new emphases on algorithms, coding and huge data they bring in. I will end with some examples about the applications to uncertainty quantification and variation reduction.

Plenary Lecture III

Date/Time Tuesday, September 21, 2021 / 11:50–12:30 hrs
Venue Auditorium

Title Extending the Service Life of Civil and Marine Structures: Role of Monitoring, Probabilistic Life-cycle Management and Risk-based Decision Making

By Dan M. Frangopol
The Fazlur Rahman Khan Endowed Chair of Structural Engineering and Architecture, Professor of Civil Engineering, Department of Civil and Environmental Engineering, ATLSS Center, Lehigh University, Bethlehem, PA 18015-4729, USA,
`http://www.lehigh.edu/~dmf206`

Biography

Dan M. Frangopol is the inaugural holder of the Fazlur R. Khan Endowed Chair of Structural Engineering and Architecture at Lehigh University. Before joining Lehigh University in 2006, he was Professor of Civil Engineering at the University of Colorado at Boulder, where he is now Professor Emeritus. His main research interests are in the development and application of probabilistic concepts and methods to civil and marine engineering. He is recognized as a leader in the field of life-cycle engineering of civil and marine structures under various types of hazards. Dr. Frangopol is the Founding President of the International Association for Bridge Maintenance and Safety (IABMAS) and International Association for Life-Cycle Civil Engineering (IALCCE). He has authored/co-authored 3 books, more than 50 book chapters, and over 420 articles in archival journals including 11 prize winning papers. He is the Founding Editor of Structure and Infrastructure Engineering and of the Book Series Structures and Infrastructures. Dr. Frangopol is the recipient of several medals, awards, and prizes, from ASCE, IABSE, IASSAR, SAE and other professional organizations. He has served as a consultant or advisor to companies in North America, Asia, and Europe. He holds 4 honorary doctorates and 14 honorary professorships from major universities. He is an Elected Member of the US National Academy of Construction, a Foreign Member of the Academy of Europe (London), a Foreign Associate of the Engineering Academy of Japan, a Foreign Member of the Royal Academy of Belgium, an Honorary Member of the Romanian Academy, an Honorary Member of the Romanian Academy of Technical Sciences, and a Distinguished Member of ASCE.

Abstract

Structural deterioration can pose tremendous risk to the functionality, serviceability, and safety of civil and marine structures, considerably limiting their service life. To extend the life-cycle of existing structures under deterioration, rational life-cycle management should be conducted accounting for various uncertainties arising from loads, resistance, and modeling. Compared to conventional inspection methods that are sometimes disruptive and costly, structural health monitoring provides a novel and cost-efficient approach to reducing uncertainties and ultimately facilitating the decision-making process for realizing structural longevity. In this plenary lecture, recent accomplishments in the integration of monitoring, probabilistic life-cycle management and risk-based decision making for extending the service-life of civil and marine structures are presented.

Plenary Lecture IV

Date/Time Wednesday, September 22, 2021 / 11:50–12:30 hrs
Venue Auditorium

Title Cognitive, practical, organisational and regulatory safety challenges of a new era
By Jean-Christophe LE COZE
Safety researcher, Institut national de l'environnement industriel et des risques (Ineris)
`https://ineris.academia.edu/jeanchristophelecoze`

Biography

Jean-Christophe Le Coze is a safety researcher (PhD, Mines ParisTech, HDR) at INERIS, the French national institute for environmental safety. His activities combine ethnographic studies and action research in various safety-critical systems. He is the editor of the book "Safety Science Research. Evolution, Challenges and New Directions" (2019) and author of "Post Normal Accident. Revisiting Perrow's classic" (2020).

Abstract

Safety-critical systems such as offshore platforms, hospitals, aircrafts, nuclear power plants, refineries, bridges, dams, mines . . . rely on a myriad of artefacts, actors and institutions to operate safely. It is an admirable political, technological, social and economic endeavour re-enacted everyday all over the world. But sometimes, when a bridge collapses, a building burns, an offshore platform explodes, a nuclear reactor melts down, a train derails, a ship sinks or a plane crashes, we are reminded how precarious such successes are and we are also reminded of the diversity of practices across countries, sectors and companies. The Boeing 737 Max crashes in 2018 and 2019, the Grenfell tower fire in London in 2017 or the collapse of Vale's dam in Brazil in 2019 are recent reminders of such events. The analysis of these events reveal a number of features which characterise the current operating landscape of safety-critical systems which includes globalisation, digitalisation, externalisation or financialisation. What many safety-critical systems share these days are their properties of 'networks of networks' which requires for safety research to explore their cognitive, practical, organisational and regulatory features together (to which one needs to add their ecological side). This is a complex and ambitious endeavor. The talk will provide insights from a collective book 'Safety Science Research: Evolution, Challenges and New Directions' (CRC Press, 2019) which addresses this problem.

Plenary Lecture V

Date/Time Wednesday, September 22, 2021 / 15:20–16:00 hrs
Venue Auditorium

Title Safer by design concept
By Catherine Mouneyrac
Professor in Ecotoxicology, Vice-Rector for research and valorization (Université Catholique de l'Ouest -Angers, France)

Biography

Catherine Mouneyrac is a Professor in Ecotoxicology, Vice-Rector for research and valorization (Université Catholique de l'Ouest -Angers, France) is titular of a PhD (University of Lyon I, France) in animal physiology, then a DSc in aquatic ecotoxicology (University of Nantes, France). Her general field research concerns the response of organisms to natural and chemical stress, namely nanomaterials. At the interface of fundamental and applied research, she aims to fulfill the gap between ecological and (eco)toxicological approaches, the final objective being to help environmental diagnosis. She collaborates with researchers all around the world and has participated to the conception and realization of numerous national and international scientific projects (NanoSalt; NanoReTox; NANoREG. . .). She is part of the Expert committee on the assessment of the risks related to physical agents, new technologies and development areas at the French Agency for Food, Environmental and Occupational Health & Safety (Anses). She is scientific officer at ANR and has been selected as a decision-makers a to follow the national study course of the Institut des Hautes Etudes pour la Science et la Technologie (http://www.ihest.fr).

Abstract

Because the physicochemical properties of nanoparticles are distinct from their bulk counterparts, the fast growth of nanotechnologies has brought new industrial and business opportunities. The field of nanotechnology has shown a huge expansion during the last decade and the key challenge is how to take into account potential risks to human and environmental health posed by long-term exposure to and accumulation of nanoparticles? However, manufactured nanomaterial production is out pacing the ability to investigate environmental hazard using current regulatory paradigms, causing a backlog of materials requiring testing. Based on results from toxicological and ecotoxicological studies, researchers now have a better grasp on the relationships between the nanomaterials' physicochemical characteristics and their hazard profiles. Nowadays, it is expected that an integration of design synthesis and safety assessment will foster nanomaterials safer-by-design by considering both applications and implications. Multiple case studies will be presented on the safer by design concept.

Organizers

University of Angers
https://www.univ-angers.fr/fr/index.html

Polytech Angers
http://www.polytech-angers.fr/fr/index.html

LARIS
http://laris.univ-angers.fr/fr/index.html

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Rendez-vous sur naval-group.com
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RFI Wise
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Atlanstic 2·0·2·0
Recherche, Formation & Innovation en PAYS de la LOIRE

RFI Atlanstic 2020
https://atlanstic2020.fr/

Atlanstic 2020 federates the regional ecosystem in digital sciences to meet the challenges of the ongoing digital revolution, improve the visibility and attractiveness of the "digital" sector in Pays de la Loire and meet the high demand for recruitment in this sector. Since 2015, Atlanstic 2020 has funded nearly 90 projects in the following research labs LS2N (Nantes), LERIA, LARIS, ESEO (Angers) and LIUM (Le Mans).

ESRA & Social Events

ESRA EVENTS (FOR ESRA REPRESENTATIVES ONLY)

Monday, September 20, 2021	18:00 – 19:00 hrs	ESRA Assembly
Monday, September 20, 2021	19:00 – 20:30 hrs	ESRA Dinner

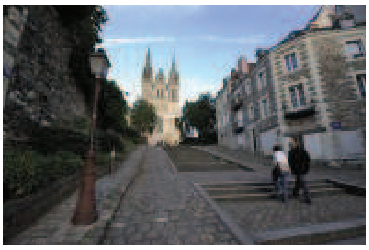
SOCIAL EVENTS

Sunday, September 19, 2021	17:00 – 20:00 hrs	Welcome Reception
Wednesday, September 22, 2021	19:00 – 01:00 hrs	Gala Dinner
Monday & Tuesday, September 20, 21, 2021	17:30 – 19:00 hrs	5 visit tours are organized as part of ESREL 2021. The events were booked during registration.

Angers running tour

A sporting break to explore Angers. In small strides, you will be guided through the city between urban architecture and nature for a moment of meeting and sharing, but above all of decompression around the same passion

Historic visit of Angers



Cross the city of the canons, to discover the Saint-Maurice cathedral, a vestige of Romanesque art and the Plantagenet Gothic style, as well as the famous Adam’s house, a true symbol of Angevin among the timber-framed houses that line the historic centre. You will finish this discovery by tasting a selection of wines from the region.

Tasty visit of Angers

Come and (re)discover the history of the products for which Angers is famous and which represent the imagination of craftsmen and chefs who are passionate about the pleasure of our taste buds!

During this commented tour in the centre of Angers, enjoy a taste break with some Angevin delicacies.

Angers uncut

In the heart of the historic centre, anecdotes, unusual places and secrets of the Angevins will be revealed to you by our guide.

Much more than a visit, it is a discovery of Angers in a different way, an intimate sharing, an experience not to be missed.

Visit of Medieval Castle

The must-see visit that takes you in the footsteps of King René!

Discover the monumental 13th-century fortress, with its 17 schist and tufa towers, which overlooks the Maine and houses the famous Tenture of the Apocalypse, a woven work that is unique in the world.

General Informations

GUIDELINES FOR PRESENTERS AND SESSION CHAIRS

Each presentation has been allocated 15 minutes, with an additional 5 minutes for discussion.. Presenters should upload their presentation onto the presentation computers before their session using a USB memory device. These computers are running under Windows operating system. Please, keep in mind to bring your presentation files as either PowerPoint or PDF. Presenters haven't the possibility to use their own. Conference staff will be there during the breaks to help.

Session Chairs have the responsibility to introduce the speakers, to lead the discussions, and to ensure that the session schedule is observed. Every effort should be made to keep to the 20-minute total time allocation for each presenter to ensure the next talk starts on time.

CONFERENCE APP

A mobile web application for the conference is also available. Here you can access detailed information on the scheduled talks and any last-minute changes to the program. The app allows you to find your personal highlights at the conference and build your personal agenda.

Web app `https://esrel2021.web.app/#/`

Apple Store `https://apps.apple.com/fr/app/esrel2021/id1577010016`

Android `https://play.google.com/store/apps/details?id=com.esrel.inventapp`

INTERNET ACCESS

Free WiFi network access is provided everywhere at the conference locations.
Network: WIFI public CCA, no login and password are needed

REGISTRATION DESK

Sunday, 19th September 2021	17:00 – 20:00 hrs
Monday, 20th September 2021	08:00 – 17:00 hrs
Tuesday, 21st September 2021	08:00 – 17:00 hrs
Wednesday, 22nd September 2021	08:00 – 17:00 hrs
Thursday, 23rd September 2021	08:30 – 11:00 hrs

CERTIFICATE OF ATTENDANCE

If you would like to receive a printed certificate of attendance you can request one at the registration desk.

SECURITY

Your name badge must be worn at all times otherwise you will not be allowed entry to the conference.

HYGIENE AND HEALTH SECURITY MEASURES

EVENT HOSTING at Angers Congress Centre and Exhibitions centre

Health and safety measures

Exceptional measures and arrangements to deal with the health crisis linked to COVID 19

Protection of people

- Wearing of masks is compulsory in the halls and on the move, except for children under the age of 6
- Hydro-alcoholic gel available, reception areas and meeting rooms
- Employees and service providers must wear masks
- Protective screens or visors on reception desks
- Switching off the air conditioning to avoid air mixing

Compliance with barrier measures

- Distance of 1 meter between people with masks and 2 meters when masks are not worn
- Organisation and dimensioning of access control to limit contact
- Re-arrangement of spaces:
  - Use of every second or third seat in conference, meeting and auditorium rooms
  - Indication of capacity at the entrance to each room
- Flow management (to limit crossings)
  - Distinction between entrances and exits
  - Floor markings and physical barriers to respect the distance in queues and in busy areas (reception, restaurants, etc...)
  - Counting system to regulate flows and ensure that maximum gauges are not exceeded
  - Traffic plan, if possible with a one-way system with guide lines and floor markings, or markings on the floor, with directional arrows
  - Leave doors open where possible

Hygiene

- Reinforce cleaning and waste disposal protocol to avoid any infectious risk
- Increasing the frequency of clearing of sanitary facilities disinfection, restocking of soap/paper, cleaning of handles, flushing, taps)
- Cleaning and disinfection of surfaces and contact areas (tables, handles) after use of the areas, with tracing (follow-up document)
- Paper towels and hand dryers should be taken out of service
- Non-sharing of accessories (pencils, paper, ...)
- Renewing air (when possible)

And to do this

- Checking that instructions are compliance with sanitary instructions: a COVID referent per site and per event
- Broadcasting of messages on indoor screens
- Isolation area set up to receive people with fever in case of suspicion
- Posting of instructions and sanitary arrangements (barrier gestures and good practices)
- Regular monitoring and updating of measures in line with the governement recommandations

DESTINATION angers

Technical Programme

Day 1: Monday, 20 September 2021 — [Parallel]

Session [MO1A]—Risk Assessment
Day/Date/Time Monday, 20 Sep. 2021 / 10:25–11:25 hrs
Venue Auditorium

Session [MO1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time Monday, 20 Sep. 2021 / 10:25–11:25 hrs
Venue Amphi Jardin

Session [MO1C]—Maintenance Modeling and Applications
Day/Date/Time Monday, 20 Sep. 2021 / 10:25–11:25 hrs
Venue Espace Grand Angle 2

Session [MO1I]—Foundational Issues in Risk Assessment and Management
Day/Date/Time Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue Giffard

Session [MO1J]—Probabilistic tools for an optimal maintenance of railway systems
Day/Date/Time Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue Botanique 2

Session [MO2I]—Balanced System Reliability
Day/Date/Time Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue Giffard

Session [MO2J]—Risk–Informed Digital Twins and Healthcare and Medical Industry
Day/Date/Time Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue Botanique 2

Session [MO3A]—Risk Assessment
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Auditorium

Session [MO3B]—Risk Management
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Amphi Jardin

Session [MO3C]—Decision-making
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Espace Grand Angle 2

Session	[MO3D]—Uncertainty Analysis
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Panoramique

Session	[MO3E]—Organizational Factors and Safety Culture
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Amphi Jardin

Session [MO3F]—Security
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Espace Grand Angle

Session [MO3G]—Oil and Gas Industry
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Atrium 3

Session [MO3H]—Railway Industry
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Cointreau

Session [MO3I]—AI for safe, secure and dependable operation of complex Systems
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Giffard

Session [MO3J]—Decision Science for Resilience
Day/Date/Time Monday, 20 Sep. 2021 / 16:10–17:30 hrs
Venue Botanique 2

Day 2: Tuesday, 21 September 2021 — [Parallel]

Session [TU1A]—Risk Assessment
Day/Date/Time Tuesday, 21 Sep. 2021 / 08:30–10:10 hrs
Venue Auditorium

Session [TU1F]—Health monitoring and predictive maintenance of offshore systems
Day/Date/Time Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue Espace Grand Angle

Session [TU1G]—Nuclear Industry
Day/Date/Time Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue Atrium 3

Session [TU1H]—Aeronautics and Aerospace
Day/Date/Time Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue Cointreau

Session [TU2K]—Economic Analysis in Risk Management
Day/Date/Time Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue Atrium 1

Session [TU3A]—System Reliability
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Auditorium

Session [TU3B]—Risk Analysis and Safety in Standardization
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Amphi Jardin

Session [TU3C]—Degradation analysis and modelling for predictive maintenance
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Espace Grand Angle 2

Session [TU3D]—Prognostics and Health Management: From Condition Monitoring to Predictive Maintenance
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Panoramique

Session [TU3E]—Risk management for the design, construction and operation of tunnels
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Amphi Jardin

Session	[TU3F]—Probabilistic vulnerability estimation, lifetime assessment and climate change adaptation of existing and new infrastructure
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Espace Grand Angle

Session	[TU3G]—Asset management
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Atrium 3

Session	[TU3H]—Railway Industry
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Cointreau

Session [TU3I]—Model Based Safety Assessment
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Giffard

Session [TU3J]—Seismic reliability assessment
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Botanique 2

Session [TU3K]—Accelerated Life Testing & Accelerated Degradation Testing
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Atrium 1

Session [TU4D]—Prognostics and Health Management: From Condition Monitoring to Predictive Maintenance
Day/Date/Time Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue Panoramique

Session [TU4E]—Socio-Technical-Economic Systems
Day/Date/Time Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue Amphi Jardin

Session [TU4F]—Probabilistic vulnerability estimation, lifetime assessment and climate change adaptation of existing and new infrastructure
Day/Date/Time Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue Espace Grand Angle

Day 3: Wednesday, 22 September 2021 — [Parallel]

Session [WE1A]—System Reliability
Day/Date/Time Wednesday, 22 Sep. 2021 / 08:30–10:10 hrs
Venue Auditorium

Session [WE1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time Wednesday, 22 Sep. 2021 / 08:30–10:10 hrs
Venue Amphi Jardin

Session [WE1C]—Digital twin approach in maintenance and safety engineering
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Espace Grand Angle 2

Session [WE1D]—Flexible Tolerancing Analysis of Complex Structures and Assemblies
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Panoramique

Session [WE1E]—Organizational Factors and Safety Culture
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Amphi Jardin

Session [WE1F]—Civil Engineering
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Espace Grand Angle

Session [WE1G]—Asset management
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Atrium 3

Session [WE1H]—Case Studies on Predictive Reliability: an Industrial Perspective
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Cointreau

Session [WE1K]—Occupational Safety
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Atrium 1

Session [WE2A]—Risk Management
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Auditorium

Session	[WE2B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Amphi Jardin

Session	[WE2C]—Bayesian network for reliability modeling and maintenance optimisation
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Espace Grand Angle 2

WE2C 705 11:05 hrs 145
Quantitative System Risk Assessment from Incomplete Data
Simon Wilson, Cristina De Persis, José Luis Bosque and Irene Huertas Garcia

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Session [WE2D]—Prognostics and System Health Management
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Panoramique

WE2D 396 10:25 hrs 146
New Mixture Distribution Model for Mapping and Analyzing Different Failure Mechanism Caused by Different Stresses
Franz-Georg Neupert and Stefan Bracke

WE2D 426 10:45 hrs 146
Prediction of Remaining Useful Life Via Self-Attention Mechanism-Based Convolutional Long Short-Term Memory Network
Jiusi Zhang, Shen Yin, Hao Luo and Muhammad Gibran Alfariz

WE2D 475 11:05 hrs 146
RUL Prediction of Bearings Using Empirical Wavelet Transform and Bayesian Approach
Bahareh Tajiani and Jørn Vatn

WE2D 521 11:25 hrs 147
A Comprehensive Parameter Study Regarding the Neural Networks Based Monitoring of Grinded Surfaces
Marcin Hinz, Lea Hannah Guenther and Stefan Bracke

Session [WE2E]—Autonomous system safety, risk, and security
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Amphi Jardin

WE2E 113 10:25 hrs 147
Operational Design Domain for Cars Versus Operational Envelope for Ships: Handling Human Capabilities and Fallbacks
Ørnulf Jan Rødseth, Håvard Nordahl, Lars Andreas Lien Wennersberg, Bård Myhre and Stig Petersen

WE2E 193 10:45 hrs 148
Road Marking Characterization for ADAS Machine Vision Reliability
Abdessamad El Krine, Joffrey Girard, Maxime Redondin, Christophe Heinkele, Aude Stresser and Valérie Muzet

WE2E 412 11:05 hrs 148
Cybersecurity Assurance Challenges for Future Connected and Automated Vehicles
Luis-Pedro Cobos, Alastair R. Ruddle and Giedre Sabaliauskaite

WE2E 470 11:25 hrs 149
Resilience in Autonomous Shipping
K. E. Fjørtoft and O.E. Mørkrid

Session [WE2F]—Risk and Resilience Analysis of Interdependent Infrastructures
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Espace Grand Angle

Session [WE2G]—Mechanical and Structural Reliability
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Atrium 3

Session [WE2H]—Railway Industry
Day/Date/Time Wednesday, 22 Sep. 2021 / 10:25–11:45 hrs
Venue Cointreau

Session [WE2I]—Artificial intelligence for reliability assessment and maintenance decision-making
Day/Date/Time Wednesday, 22 Sep. 2021 / 10:25–11:45 hrs
Venue Giffard

Session [WE2J]—Advancements in Resilience Engineering of Critical Infrastructures
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Botanique 2

Session [WE2K]—Autonomous Driving Safety
Day/Date/Time Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue Atrium 1

Session [WE3A]—Risk Assessment
Day/Date/Time Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue Auditorium

WE3A 397 14:00 hrs 160
Covid-19 Pandemic: Analyzing of Different Pandemic Control Strategies Using Saturation Models
Stefan Bracke and Lars Grams

WE3A 423 14:20 hrs 160
A Systemic Approach for Preliminary Risk Analysis of Cybersecurity of Industrial Control Systems
Jean-Marie Flaus and John Georgakis

WE3A 425 14:40 hrs 160
Risk Analysis of Emergency Operations in Presence of Limited Prior Knowledge
Xu An and Huixing Meng

Session [WE3B]—System Reliability
Day/Date/Time Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue Amphi Jardin

WE3B 330 14:00 hrs 161
RAM and Importance Measures Analysis of Offshore Drilling Rigs' Cuttings Dryer
Maria Valentina Clavijo Mesa, Joaquin Eduardo Figueroa Barraza, Luis Felipe Guarda Brauning, Carlos Henrique Bittencourt Morais, Danilo Colombo and Marcelo Ramos Martins

WE3B 378 14:20 hrs 161
Knowledge-Based System Modelling to Enhance Design for Reliability Process: An Application to LNG Industry
Andrea Greco, Irene Gallici and Armin Narimanzadeh

WE3B 482 14:40 hrs 161
Bayesian Cross Entropy Method for Network Reliability Assessment
Jianpeng Chan, Iason Papaioannou and Daniel Straub

Session [WE3C]—Maintenance Modeling and Applications
Day/Date/Time Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue Espace Grand Angle 2

WE3C 480 14:00 hrs 162
Condition-Based Maintenance with Functional Modeling: Challenges and Opportunities
Mengchu Song and Xinxin Zhang

WE3C 594 14:20 hrs 162
Energy Footprint of a Refractory Lining
Roberta Piccinelli, Alessandra Caccamo and Stefano Moratti

Session	[WE3I]—Artificial intelligence for reliability assessment and maintenance decision-making
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Giffard

Session	[WE3J]—Effectiveness, Management and Reliability of Natural Risks Reduction Measures and Strategies
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Botanique 2

Session	[WE3K]—Autonomous Driving Safety
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Atrium 1

Session [WE4A]—Risk Assessment
Day/Date/Time Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue Auditorium

Session [WE4B]—Occupational Safety
Day/Date/Time Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue Amphi Jardin

Session [WE4C]—Petri Nets in reliability, safety and maintenance
Day/Date/Time Wednesday, 22 Sep. 2021 / 16:10–17:30 hrs
Venue Espace Grand Angle 2

Session [WE4D]—Prognostics and System Health Management
Day/Date/Time Wednesday, 22 Sep. 2021 / 16:10–17:30 hrs
Venue Panoramique

Session [WE4G]—Asset management
Day/Date/Time Wednesday, 22 Sep. 2021 / 16:10–17:30 hrs
Venue Atrium 3

Session [WE4H]—Automotive Industry
Day/Date/Time Wednesday, 22 Sep. 2021 / 16:10–17:30 hrs
Venue Cointreau

Session	[WE4I]—Artificial Intelligence for Reliability Assessment and Maintenance Decision-making
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Giffard

Session	[WE4J]—Effectiveness, Management and Reliability of Natural Risks Reduction Measures and Strategies
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Botanique 2

Session	[WE4K]—Manufacturing
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Atrium 1

Day 4: Thursday, 23 September 2021 — [Parallel]

Session	[TH1A]—Risk Assessment
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Auditorium

Session [TH1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time Thursday, 23 Sep. 2021 / 09:00–10:20 hrs
Venue Amphi Jardin

Session [TH1C]—Reliability and Maintenance of Networked Systems
Day/Date/Time Thursday, 23 Sep. 2021 / 09:00–10:20 hrs
Venue Espace Grand Angle 2

Session [TH1D]—Land Transportation // Smart Cities and Systems
Day/Date/Time Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue Panoramique

Session [TH1E]—Human Factors and Human Reliability
Day/Date/Time Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue Amphi Jardin

Session [TH1H]—Automotive Industry
Day/Date/Time Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue Cointreau

Session [TH1I]—Security
Day/Date/Time Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue Giffard

Session [TH2D]—Prognostics and System Health Management
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Panoramique

Session [TH2E]—Organizational Factors and Safety Culture
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Amphi Jardin

Session [TH2F]—Critical Infrastructures
Day/Date/Time Thursday, 23 Sep. 2021 / 10:35–11:35 hrs
Venue Espace Grand Angle

Session [TH2G]—Asset management
Day/Date/Time Thursday, 23 Sep. 2021 / 10:35–11:35 hrs
Venue Atrium 3

Session [TH2H]—Safety and Reliability of Intelligent Transportation Systems
Day/Date/Time Thursday, 23 Sep. 2021 / 10:35–11:35 hrs
Venue Cointreau

Session [TH2I]—Mathematical Models in Maintenance
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Giffard

Session [TH2J]—Energy
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Botanique 2

Session [TH2K]—Reliability and Availability Issues of the 5G Revolution
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Atrium 1

TH3E 655 11:55 hrs 234
Teaching of Safety Engineering during the COVID-19 Pandemic
Zdenek Tuma, Lubos Kotek, Kamil Subrt, Jirá Kroupa, Jirá Kovár, Petr Blecha and Frantisek Bradác

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Session [TH3F]—Critical Infrastructures
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Espace Grand Angle

TH3F 399 11:35 hrs 234
Impact of Distance Rules on Infrastructure Resilience
Corinna Köpke, Daniel Eberhardt, Mirjam Fehling-Kaschek, Nikos Papagiannopoulos and Alexander Stolz

TH3F 431 11:55 hrs 235
ABM-Based Emergency Evacuation Simulation Considering Dynamic Dependency in Infrastructures
Gibeom Kim and Gyunyoung Heo

TH3F 772 12:15 hrs 235
Network Reinforcement Strategy Against Cascading Failures
Jilong Zhong, Zhoulai Lu, Yan He, Bo Fan and Shaoshi Wu

Session [TH3G]—Mechanical and Structural Reliability
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Atrium 3

TH3G 484 11:35 hrs 235
Analysis Over Detection of Areas Responsible for Failure to Crude Oil Transporatation Line

TH3G 555 11:55 hrs 235
Estimation Of The Remaining Lifetime Of Shape Memory Alloy Actuators During Prototype Testing: Analysis Of The Impact Of Different Currents
Philipp Heß and Stefan Bracke

TH3G 636 12:15 hrs 236
Predicting Reliability of Bolted Structure using Monte Carlo Simulation
Mohammed Haiek, Nabil Ben Said Amrani,Youness El Ansari and Driss Sarsri

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Session [TH3H]—Safety and Reliability of Intelligent Transportation Systems
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Cointreau

TH3H 458 11:35 hrs 236
Degradation Assessment of Train Axle Bearing Based on A Deep Transfer Learning
Dingcheng Zhang, Di Cui, Moussa Hamadache and Edward Stewart

TH3H 572 11:55 hrs 237
Certification of Deep Reinforcement Learning with Multiple Outputs Using Abstract Interpretation and Safety Critical Systems
Faouzi Adjed, Frédéric Pelliccia, Mehdi Rezzoug and Lucas Schott

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Session [TH3I]—Cyber Physical Systems
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Giffard

Session [TH3J]—Renewable Energy Industry
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Botanique 2

Session [TH3K]—Reliability and Availability Issues of the 5G Revolution
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Atrium 1

Session [TH4A]—Risk Assessment
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Auditorium

Session [TH4B]—Mathematical Methods in Reliability and Safety
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Amphi Jardin

Session [TH4C]—Maintenance Modeling and Applications
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Espace Grand Angle 2

Session [TH4D]—Uncertainty Analysis
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Panoramique

Session [TH4G]—Nuclear Industry
Day/Date/Time Thursday, 23 Sep. 2021 / 14:00–15:20 hrs
Venue Atrium 3

Session [TH4H]—Maritime and Offshore Technology
Day/Date/Time Thursday, 23 Sep. 2021 / 14:00–15:20 hrs
Venue Cointreau

Session [TH4I]—Human factor in the smart industry
Day/Date/Time Thursday, 23 Sep. 2021 / 14:00–15:20 hrs
Venue Giffard

Session [TH4J]—Resilience Engineering
Day/Date/Time Thursday, 23 Sep. 2021 / 14:00–15:20 hrs
Venue Botanique 2

Session	[TH4K]—Software Reliability
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Atrium 1

ABSTRACTS

Abstracts — Monday, 20 September 2021

Session	[MO1A]—Risk Assessment
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Plenary Room

MO1A: 045 **10:25 hrs**

Model for Managing MOC Risks Through Artificial Intelligence

Marcelo Póvoas[1,a], José Cristiano Pereira[2], Davi da Fonseca Vieira Junior Marinato[1,b] and Antonio de Paula Pedrosa[1,c]

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[2]*Doctor in Engineering, Catholic Universiy of Petrópolis, Brazil. E-mail: josecristiano.pereira@ucp.br*

This study proposes a method to be used in the strategic decision-making process, considering identifying and prioritizing the potential risks of Management of Change (MOC) in an industrial environment. The analytical hierarchy process (AHP) and the Bayesian Belief Networks (BBN) were used to assess the risks that could affect the regular operations, to generate data for an effective decision-making process, in addition, concepts of machine learning and artificial intelligence (AI) were introduced so that the analyzes can be done in a more automated way, generating reports that can assist in decision making. Limited work was found dealing with analysis to prioritize risks arising from MOC in any type of industry. As a result, a global risk matrix was proposed. The factors that most impact effectiveness of the process is Lack of Stakeholder involvement, Lack of risk assessment in the MOC process and Lack of knowledge of employees involved in the MOC process. Culminating 12 steps were created to implement a risk-free MOC process. The study provides a method to be used by professionals, engineers, and decision makers to identify risk factors that could affect companies' operations.

Keywords: Machine learning, AHP, BBN, AI, MOC, Organizational factors, Probabilistic risk assessment.

MO1A: 096 **10:45 hrs**

Simulation Based Probabilistic Risk Assessment (SIMPRA): Risk Based Design

Seyed Hamed Nejad-Hosseinian[1], Tarannom Parhizkar[2,a] and Ali Mosleh[2,b]

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The classical approach to design a system is based on a deterministic perspective where the assumption is that the system and its environment are fully predictable, and their behaviour is completely known to the designer. Although this approach may work fairly well for regular design problems, it is not satisfactory for the design of highly sensitive and complex systems where significant resources and even lives are at risk. In addition it can results in extra costs of over-designing for the sake of safety and reliability.

In this paper, a risk-based design framework using Simulation Based Probabilistic Risk Assessment (SIMPRA) methodology is proposed. SIMPRA allows the designer to use the knowledge that can be expected to exist at the design stage to identify how deviations can occur; and then apply these high-level scenarios to a rich simulation model of the system to generate detailed scenarios and identify the probability and consequences of these scenarios. SIMPRA has three main modules including Simulator, Planner and Scheduler, and it approach is much more efficient in covering the large space of possible scenarios as compared with, for example, biased Monte Carlo simulations because of the Planner module which uses engineering knowledge to guide the simulation process.

The value-added of this approach is that it enables the designer to observe system behaviour under many different conditions. This process will lead to a risk-informed design in which the risk of negative consequences is either eliminated entirely or reduced to an acceptable range. For illustrative purposes, an earth observation satellite system example is introduced.

Keywords: Simulation based probabilistic risk assessment, Complex systems, Risk-based design, Dynamic risk assessment, Planner, Earth observation satellite, Scenario planning, Risk-informed design, Reliability.

MO1A: 116 **11:05 hrs**

Margins Assessment using Dynamic PSA

Jean-Yves Brandelet[a], Thomas Dosda[b] and Cédric Lyard[c]

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The purpose of this communication is to present an innovative method to assess Initiating Event Frequencies usually evaluated with "static modeling" by Fault Trees.

Probabilistic Safety Assessment (PSA) models developed for nuclear industry consider a list as exhaustive as possible of Initiating Events (IE), for all reactor states. Initiating Events induced by the failure of a system used in normal operation are commonly modeled using Fault Trees. This method can lead in some cases to large over estimation between the practically observed Initiating Event frequency (from Operating Experience) and the theoretically built one using Fault trees.

From several years, Framatome is developing dynamic PSA based on Petri nets (see Dosda et al. 2021). Compared to "static modeling" by Fault Trees, the use of dynamic PSA allows more realistic modelling of plant behavior leading to reduce conservatisms and more representative results. This could be of particular interest for slow degradation scenarios, for which it may be possible to take credit for repairs and grace periods.

In this context and for development perspectives, Framatome is experiencing a method for dynamic PSA model of the loss of Heating Ventilation and Air Conditioning (HVAC) Initiating Event. The use of dynamic PSA on this study case leads to a large reduction of the calculated Initiating Event frequency. As initiating Events induced by the failure of systems used in normal operation have important contribution to the Core Damage Frequency (CDF) of reactors, application of this method could lead to non-negligible reductions of this CDF. In this way, dynamic PSA model is a perfect tool to highlight available margins compared to a static PSA model.

The communication presents the main concepts of this approach, its implementation with Petri nets, the first results and concludes with the perspectives.

Keywords: Petri nets, Dynamic PSA, Initiating event frequency, Margins assessment.

Session	[MO1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Atrium 2

MO1B: 005 **10:25 hrs**

Reliability Assessment with a Compound Poisson Process-Based Shock Deterioration Model

Cao Wang

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Existing structures may suffer from resistance deterioration due to repeated attacks. The modeling of resistance deterioration is a crucial ingredient in the reliability assessment and service life prediction of these degraded structures. In this paper, an explicit compound Poisson process-based model is developed to describe the shock deterioration of structural resistance, where the magnitude of each shock deterioration increment is modeled by a Gamma-distributed random variable. The moments (mean value and variance) and the distribution function of the cumulative shock deterioration are derived in a closed form. Subsequently, the overall resistance deterioration is modeled as the linear combination of the gradual and shock deteriorations. The proposed model can be used in the time-dependent reliability assessment of aging structures efficiently. A numerical example is presented to demonstrate the applicability of the proposed deterioration model by considering the time-dependent reliability of an aging bridge.

Keywords: Structural reliability, Resistance degradation, Compound Poisson process, Shock deterioration, Time-dependent reliability.

MO1B: 027 **10:45 hrs**

A Comprehensive Probabilistic Assessment Method of UAS Ground Collision Risk

Théo Serru[1] and Kevin Delmas[2]

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Unmanned Aircraft Systems are widely experienced but using these systems for missions near to populated areas raises new safety challenges. To address these challenges, the European Aviation Safety Agency requires assessing, for a given operational profile, the likelihood of on-ground collision with critical infrastructure or people. Various works use Model Based Safety Assessment to identify the failure contributing to the crash, while some works provide probabilistic estimation methods of an on-ground collision. In these methods the assessment is performed thanks to Monte Carlo simulation known to be time-consuming to estimate the probability of rare events.

This paper will thus provide a comprehensive tooled method to estimate the on-ground collision probability and uses Importance Sampling method to tackle Monte Carlo limitations. Through a comparative study based on a drone usecase, this paper provides a demonstration of the benefits of Importance Sampling over Monte Carlo method. Indeed, this method allows a reduction in the number of simulations and thus the time needed to compute probabilities, with a high confidence in the results. The experiments are based on a safety model formalized with the Open AltaRica platform on an ad-hoc simulator to perform both Monte Carlo and important sampling simulations.

Keywords: Dependability, Safety, Importance sampling, UAV, MBSA.

MO1B: 019 **11:05 hrs**

Bayesian Quantification Of CCF Alpha Factors Model Parameters

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Common cause failure (CCF) are known to significantly contribute to the risk as shown by the probabilistic safety assessments (PSA). They have been taken into consideration since the early ages of PSA developments in the nuclear industry, as in other fields. Nevertheless, the modeling of CCF is also widely recognized to be a challenging part of PSA, especially when the systems' failure is described through a fault tree (FT) structure. Among the most commonly used models for assessment of CCF parameters, the alpha factors model is generally considered to be one of the most relevant for the integration of operating experience feedback (OEF). This parametrization of the CCF is based on two sets of parameters: the total failure rate of each item of the CCF group (due to CCF and independent failures), and the α_k parameters, which are the fraction of the total failure rate associated to k components CCF in a group of size $m > k$.

The evaluation of these parameters based on operating experience is generally difficult: for highly reliable systems such as the ones that are used in nuclear industry, the number of failures is generally very low, and is it is therefore difficult to rely on classical frequentist approaches. In this context, the Bayesian approach is generally recognized as a good alternative to the frequentist approach since it allows for introduction of exogenous data (such as expert judgment, generic data ...) in the evaluation. Moreover uncertainties are naturally considered and evaluated in the Bayesian modeling. The difficulty is that analytical determination of the posterior distribution is generally not possible, except for the very specific case of conjugate prior and likelihood. In this paper, we present a Bayesian quantification of CCF parameters of alpha factors models.

The Bayesian computation is performed using the Stan software. The Stan software is a state-of-the-art tool for statistical modeling, especially Bayesian analysis, based on a Markov Chain Monte-Carlo (MCMC) algorithm for posterior sampling. As a first step, the posterior distribution is sampled from a conjugate prior/likelihood model (Dirichlet/multinomial), using controlled data. Then the alpha factors CCF model parameters are assed in a two-stage (non-analytical) Bayesian model, using OEF data.

Keywords: Reliability, Common cause failure, Bayesian analysis.

Session	[MO1C]—Maintenance Modeling and Applications
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Espace Grand Angle2

MO1C: 062 **10:25 hrs**

Research on Concept Modeling of Mission-based Aviation Equipment Support System of System

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In view of the operational characteristics of aviation troops under the condition of informationization, the concept of aviation equipment support system (SoS) of system and the conceptual models of aviation equipment support system of system are defined. The concept model of mission-based aviation equipment support system of system is established according to the logical main line of the "task-function-entity-relationship".

Task model, function model, entity model and relationship model of aviation equipment support system of system are constructed. Through four categories and seventeen views, the overall conceptual model is described in a more complete and detailed way. The research work in this paper can lay a foundation for the follow-up simulation, evaluation and decision-making of support system operation, and provide help for the aviation combat intelligence support and decision-making.

Keywords: Aviation equipment system of system, Support system of system, Conceptual model, Construction method.

MO1C: 074 **10:45 hrs**

Criticality-Based Predictive Maintenance Scheduling for Aircraft Components with a Limited Stock of Spare Components

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We propose a criticality-based scheduling model for aircraft component replacements.We schedule maintenance for a fleet of aircraft, each equipped with a multi-component system. The maintenance schedule takes into account a limited stock of spare components and the Remaining-Useful-Life prognostics for the components. We propose a component replacement scheduling model with three stages of maintenance criticality: i) critical aircraft that are not airworthy due to a lack of sufficient operational components, ii) predictive alerts for expected component failures, and iii) non-critical aircraft with some failed components. An Adaptive Large Neighborhood Search (ALNS) algorithm is developed to solve this criticality-based aircraft maintenance planning problem. The framework is illustrated for a fleet of aircraft, each equipped with a k-out-of-N system of components. A predictive maintenance planning is obtained within an outstanding computational time (less than 6 seconds for a fleet of 50 aircraft). Moreover, it is shown that the proposed planning with 3-levels of criticality ensures aircraft airworthiness while making cost-efficient use of maintenance slots.

Keywords: Predictive aircraft maintenance, Spare components management, Maintenance criticality.

MO1C: 111 **11:05 hrs**

How to Design Warranty Contracts Based on Customer Segmentation

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Nowadays, the warranty contracts of a products are generally based on expertise and gut feelings, and not designed regarding the use of the products. Within this context, the aim of this paper is to develop a methodology to define customer-specific warranty contracts applicable in an industrial context. This methodology is developed from real data collected on industrial machines. We propose here to extend the work of Ye and Murthy (2016) to take into account the heterogeneity of customers profiles. A process of segmentation from the company's existing database and based on data mining techniques will approach the heterogeneity of customers behavior and therefore the establishment of specific contracts.

Let us recall the existence of a large number of segmentation methods (Konstantinos Tsiptsis (2010)), each with its limitations and advantages. In our case, the proposed segmentation must ensure the best qualification of the various risks (client-supplier). A first analysis of the performance of several clustering methods will therefore be performed. Based on the results of this analysis, we will then propose the development of the methodology to define the various warranty strategies that we will apply on real data.

Keywords: Customer segmentation, Clustering, Warranty contracts, Contracts designing, Customers heterogeneity.

Session	[MO1D]—Prognostics and System Health Management
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Panoramique

MO1D: 105 **10:25 hrs**

Investigation Into Real-Time Influence of Time Varying Operational Conditions and Sensor Signals on Reliability of Engineered Systems

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In spite of recent developments including several applications of machine learning approaches in the field of Prognostics and Health Management (PHM) with particular emphasis on the Remaining Useful Life (RUL) prediction, it still remains a challenge to investigate realtime influence of time-varying operational conditions and sensor signals on system reliability and the corresponding RUL. Since machine learning methods have difficulties capturing this, we propose a hybrid model integrating survival analysis techniques and multivariate time series approaches. This is analyzed using a subset of the C-MAPSS turbofan failure data set, with the aim of identifying the real-time influence of operational conditions and sensor signal variations on the degradation behavior of turbofan units. More specifically, the Cox Proportional Hazards Model (PHM) is employed to generate heterogenous reliability indices for different turbofan units in both the training and test sets. Then, a Vector Autoregressive model with Exogenous variables (VARX) using pairwise Conditional Granger Causality tests for feature selection is employed to model and analyze dynamic degradation behavior of individual turbofan units in both training and test sets. Finally, the time varying effects of operational conditions and sensor signals are investigated by means of the Impulse Response Function (IRF) which is intrinsic in the VARX model. Results show that, compared with baseline methods, the proposed approach is competent in reflecting the real-time influence of operational conditions and sensor signals upon system reliability.

Keywords: Prognostics, Remaining useful life, Time varying operational conditions, Cox proportional hazards model, Vector autoregressive model with exogenous variables, Conditional Granger causality.

MO1D: 139 **10:45 hrs**

A Fast Fault Diagnosis Method for The Unlabeled Signal Based on Improved PSO-DBSCAN Algorithm

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The fault diagnosis of different components with supervised learning method usual requires a large number of training samples. In practical engineering applications, the diagnosis efficiency is low and the failure rate is high due to the small amount of training samples. In order to solve these problems, a step-by-step fast fault diagnosis method based on improved Particle Swarm Optimization (PSO)-Density Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm and Least Squares Support Vector Machine (LSSVM) is proposed. Firstly, the original signal is pre-processed by normalization and wavelet threshold de-noising. Then, the dimensionality reduction by Principal Component Analysis (PCA) is used as the input of the improved PSO-DBSCAN algorithm to cluster the data, and the train samples are formed after the data categories. Secondly, the train samples are used as the input of LSSVM to train the fault classifier. Finally, by using the trained classifier to classify other data, the working state of the component can be obtained. In this paper, by simulating a certain type of engine oil monitoring data, the accuracy of the classification result is 96.67%, which verifies the feasibility and effectiveness of the method, and realizes the fast fault diagnosis of unlabelled signals.

Keywords: Fault diagnosis, Unlabeled signal, Wavelet threshold de-noising, Clustering algorithm, Improved PSO-DBSCAN algorithm, Least square support vector machines.

MO1D: 176 **11:05 hrs**

An Intelligent Fault Diagnosis Method of Gear Based on Parameter-Optimized DBN Using SSA

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As an important component of transmission system, gear usually suffers from complicated fault modes. Although most current methods based on traditional machine learning show good performance in identifying different fault modes, their diagnostic accuracy and generalization ability are obviously insufficient for detecting fault severities with highly similar signal features. Aimed to this problem, an intelligent fault diagnosis method based on deep belief network (DBN) and sparrow search algorithm (SSA) is proposed. Firstly, vibration signals of different gear fault modes and severities are acquired as input samples for the DBN model, then SSA incorporated with elite opposition-based learning (EOBL) is introduced and to search the optimal combination of learning rate and batch size during DBN training. Finally, a parameter-optimized DBN is established for gear fault diagnosis and severity detection. The experiment analysis demonstrate that the proposed method can avoid complicated signal processing and subjective interference. It is proved to have superior feature extraction ability, diagnosis accuracy and stability compared with the methods based on shallow learning and the non-optimized DBN.

Keywords: Gear, Fault diagnosis, Deep belief network, Sparrow search algorithm, Elite opposition-based learning, Parameter optimization.

Session	[MO1E]—Human Factors and Human Reliability
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Amphi Jardin

MO1E: 013 **10:25 hrs**

The Use of Driving Simulator for Training Learner Drivers Belonging to a High-Risk Group

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Immigrant drivers are considered a high-risk group in traffic, especially drivers from Middle East, and Africa are represented more than other groups in road accident statistics There are several factors why this group are at a higher risk than others. First of all, this group often consist of people with another cultural understanding of risk and road safety and a significant different driver training than the Norwegian driver culture and training. In addition, the language and terminology used in driving is different from what they are familiar with. For this reason, the group is specified in the Norwegian national transport plan (NTP) as a group where research-based measures for increasing safety are in demand.

Thus, our research question was: *Can driving simulator be a beneficial measure for safety for the high-risk group migration driver trainers*? Method: Five interviews with driver instructors who used driving simulators to train migration driver trainers were conducted in addition to observations of teaching situations. Grounded theory was used for analysis. Results: The core category was "The simulator could increase safety training" This was based on the 2 main categories "The simulator is used like a car" and "Re-creating knowledge". The conclusion was that simulator, in addition to real life training, could be a good tool for teaching immigrants to drive according to Norwegian standards.

Keywords: Road traffic safety, Driver training, High-risk road users, Simulator, Experiential learning, Simulation learning.

MO1E: 024 **10:45 hrs**

Studying Mental Stress Factor in Occupational Safety in the Context of the Smart Factory

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The use of collaborative robots (cobots) in the industrial setting has grown and continues to grow globally, especially in the context of the smart factory. Humans and cobots are ever increasingly expected to share their workspace and associated issues related to workplace health and safety are expected to rise. This research study seeks to further understand the impact on the workers' mental health, as measured by mental stress, in relation to the variables like task complexity, time constraints, production speed, collaboration duration etc. whilst working alongside the cobot. Non-invasive neuroimaging data acquisition and processing is used to find the correlations of mental stress with respect to variations in work environment conditions. Mental stress often correlates with the brain's alpha rhythms and changes in haemoglobin concentrations and are observable effectively by a multimodal technique such as EEG+fNIRS. These patterns are responsible for increasing the information content of the measured signals and increase the accuracy of the decoding of mental states. The paper demonstrates the strategy for designing the experiments and the initial patterns acquired against the designed tasks.

Keywords: Mental stress measurement, Occupational safety, Human robot collaboration, Collaborative robotics, EEG and fNIRS, Neuroimaging.

MO1E: 085 **11:05 hrs**

Best Practices in Digital Human System Interfaces at Nordic Nuclear Powerplants

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This paper summarises the findings from the project "Best Practices Human-System Interfaces at Nordic Plants" funded by an R&D collaboration between Institute for Energy Technology and Swedish and Finnish nuclear power plant operators. It describes a two-year project with the goal

to collect experiences and good practices from the operators/users of digital interfaces in Nordic power plants' control rooms. Ten units from four different power plants in Sweden and Finland participated in the project and data was collected through observations and interviews with main control room operators, training instructors, and staff involved in design and modernisation projects at the plants. The visits included dedicated times for crew observation in scenarios in the training simulators and visits to the main control rooms of the plants. In this summary paper we present an overview of the best practices that were identified in three main categories: "Alarms and warnings", "process displays", and "navigation, interaction and screen organization". To our knowledge, this is the first effort to map the state of the art in Nordic plants regarding control room digitalisation and as such provides a unique overview of the operating experience with digital interfaces.

Keywords: Digitalization, Human System Interfaces (HSI), Control room, Nuclear safety, Human-machine interaction, Interaction design, Human factors.

Session	[MO1F]—Degradation analysis and modelling for predictive maintenance
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Espace Grand Angle

MO1F: 174 **10:25 hrs**

Conditional Imperfect Maintenance of A Deterioration Process

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We consider a gamma process for degradation modeling of a system, which is periodically inspected. At each inspection, a decision is taken in respect to the level of the degradation process. We consider the following maintenance framework:

(1) The system degradation indicator is more related to a service quality than a health indicator and the system failure is not considered in this paper;
(2) A perfect preventive maintenance is performed if the degradation level exceeds a fixed safety threshold L: the operation leads to a "as good as new" system;
(3) An imperfect preventive maintenance is performed if the degradation level is between L and a preventive threshold M: the imperfect action is modelling to an arithmetic reduction of degradation of order 1. In this later case, the improvement is proportional to the degradation level at the inspection time (with a reduction factor with);
(4) No action is performed if the degradation level is lower than M;
(5) The safety threshold exceeding is not self-announced and this event is detected only during an inspection;
(6) Maintenance actions do not induce a delay. Considering the cost of the inspections, of the perfect and imperfect preventive maintenances, we derive the closed form expression of the average long run cost of the maintenance policy in order to optimize the expected total cost between two CM (thanks to the renewal theory). A sensitivity analysis is performed and the robustness of the optimal parameters with respect to uncertainty.

Keywords: Imperfect Maintenance, Gamma Process, Maintenance Optimization, Degradation Process.

MO1F: 227 **10:45 hrs**

Filtering Noisy Gamma Degradation Process: Genz Transform Versus Gibbs Sampler

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Stochastic processes are widely used to describe continuous degradations, among which the monotonically increasing degradation is most common. However, in practice, the observed degradation path is often perturbed with undesired noise due to sensor or measurement errors. When the noise is Gaussian distributed with constant variance, different approaches such as Monte Carlo integral, Gibbs sampler, and Genz transform can be used to estimate model parameters.

In this paper, we show the limitations of Genz transform and the consequences of its inappropriate use. We also improve the Gibbs sampler by proposing an enhanced rejection sampling algorithm. In the presence of noise, the calculation of likelihood functions involves multivariate normal integrals. Genz transform converts the original integration domain into a unit hypercube. Compared to the Monte Carlo integral, Genz transform is more efficient since it avoids sampling from the domain outside the integration limits. However, suppose during a time interval, the hidden degradation growth is negligible compared to the noise. In

that case, we can prove that there is an accumulating error between the observed path and the sampled paths obtained using Genz transform, and the error cannot be eliminated once it appears. This results in an incorrect evaluation of the expected likelihood, biased estimates of model parameters, and erroneous prediction of the degradation growth.

Keywords: Degradation, Gamma process, Noise, Genz transform, Gibbs sampler, Likelihood.

MO1F: 258 **11:05 hrs**

A Hybrid Maintenance Policy for a Deteriorating Unit in the Presence of Random Effect and Measurement Error

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In this paper, a hybrid condition/age-based maintenance policy is proposed for a deteriorating unit whose observed degradation path is affected by three forms of variability: time variability, unit to unit variability, and measurement error. The perturbed degradation process is modelled by using a gamma-based model with random effect. The unit is assumed to fail when its (hidden) degradation level exceeds a (fixed) given threshold. The failure is assumed to be not self-announcing. So, it is also assumed that a perturbed measurement does not allow to say with certainty whether a unit is failed or not.

The maintenance policy is defined by considering two different scenarios. In the first one, we assume that an optimal age-based replacement time and a single intermediate inspection time are initially planned and that based on the outcome of the inspection it is possible either to immediately replace the units or to postpone its replacement to a given (a priori defined) successive time. After each replacement, the unit is considered as good as new. However, being unable to detect failures, we assume that replacements can occur either at inspection or at the a priori planned replacement time only. The second scenario extends the first one by assuming that a more expensive, not perturbed measurement can be optionally performed at inspection.

Finally, results obtained under the considered scenarios are analysed and compared in terms of long-run average cost rate, to evaluate whether (assumed that the option exists) it is convenient to perform the more costly inspection.

Keywords: Long-run cost rate, Condition-based maintenance, Gamma process, Measurement error, Random effect.

Session	[MO1G]—Nuclear Industry
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Atrium 3

MO1G: 125 **10:25 hrs**

Risks of Power Plants with Small Modular Reactors

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The power plants with small modular reactors (SMR) have been developing several tens of years. Their favorable position is in the first place small installed output. This plus is conditioned by high degree of inherent safety of this power plant. Due to low installed power, it is possible to reduce the emergency planning zone and generally reduce the licensing time due to the greater simplicity of the system towards the large nuclear sources. Since power plants with SMR contain hazardous substances and complex technology, their risks need to be managed in favor of integral safety. The paper shows the sources of their risks and the way in which the risks are managed in the SMR design with Energy Well reactor, which has been creating in the Czech Republic.

Keywords: Power plant with SMR, Risk sources, Integral safety, Terms of references, Risk-based design, Safety culture.

MO1G: 126 **10:45 hrs**

Increase of Safety of Steam Generator by Reconstructing the Water Supply Pipe

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The safety of each nuclear power plant depends on the correct operation of the steam generator, which is conditioned by a highquality supply of water supply. The steam generator is an important part of the technology that physically separates the medi a of the primary and secondary circuits. The temperature and pressure ratios in the steam generator are set in such a way that there is intensive steam development on the surface of the pipes, as well as the need to drive turbo generators. Therefore, the steam generator and the supply pipelines belong to the critical equipment of nuclear power plant. From this reason, they are a subject of risk-based inspection and the risk-based maintenance and, if necessary, remediation is carried out in a timely manner. The work shows the method of technical solution of an unsatisfactory heterogeneous weld connection to the supply water pipe in the nuclear power plant Temelin with reactor WWER 1000.

Keywords: Nuclear power plant, Steam generator, Supply water pipe, Risk-based inspection, Reconstruction.

MO1G: 132 **11:05 hrs**

Method of Extending the Operation of Steam-Generator on Nuclear Installation Under Conditions of Long-Term Station-Black-Out

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The accident at the Fukushima nuclear power plant has demonstrated new challenges for the safety management of a nuclear power plants. The proposed measures aim is to avoid damage to the fuel cladding, which sooner or later will cause fission products to leak outside the nuclear power plant. The nuclear power plant steam generator is used at normal operation conditions to produce steam, which is used to drive the generator turbine. The article describes the long-term measures at accident associated with the loss of power supply from emergency diesel generators. It shows the way how the Feed & Bleed method will be used for removing the residual heat at the Temelin NPP in this case. This technique increases both, the robustness and the resilience; the operating time of the steam generator with coolant extends from 223 to 705, or up to 3500 hours.

Keywords: Nuclear power plant, WWER, Station black-out, Feed & Bleed, Blow-down, Steam generator, Austenitic steel.

Session	[MO1H]—Aeronautics and Aerospace
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Cointreau

MO1H: 050 **10:25 hrs**

Predictive Aircraft Maintenance: Modeling and Analysis Using Stochastic Petri Nets

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Predictive aircraft maintenance is a complex process, which requires the modeling of the stochastic degradation of aircraft systems, as well as the dynamic interactions between the stakeholders involved. In this paper, we show that the stochastically and dynamically colored Petri nets (SDCPNs) are able to formalize the predictive aircraft maintenance process. We model the aircraft maintenance stakeholders and their interactions using local SDCPNs. The degradation of the aircraft systems is also modeled using local SDCPNs where tokens change their colors according to a stochastic process. These SDCPN models are integrated into a unifying SDCPN model of the entire aircraft maintenance process. We illustrate our approach for the maintenance of multi-component systems with k-out-of-n redundancy. Using SDCPNs and Monte Carlo simulation, we analyze the number of maintenance tasks and potential degradation incidents that the system is expected to undergo when using a remaining useful life(RUL)-based predictive maintenance strategy. We compare the performance of this predictive maintenance strategy against other maintenance strategies that rely on fixed-interval inspection tasks to schedule component replacements. The results show that by conducting RUL-based predictive maintenance, the number of unscheduled maintenance tasks and degradation incidents is significantly reduced.

Keywords: Aircraft maintenance, Predictive maintenance, Stochastic Petri nets, Reliability, Modeling, Simulation.

MO1H: 119 **10:45 hrs**

Quality and Safety Performance in a Regional Airport: Comparing Passengers' and Employees' Perceptions with KPI

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In this study, a passengers' satisfaction questionnaire developed for a small regional airport in Italy was modified and adopted to ask employees' perceptions for the quality and safety performance of the airport. Employees' perceptions were elicited on topics aligned to those used in the customers satisfaction survey and the results were compared also considering quality and safety performance indicators as objective anchor point for the performance of the company. The findings indicate interesting areas of differences in the perceptions of the passengers and employees regarding company's services and their performance, both useful in highlighting necessary areas of improvements. A passenger satisfaction model was developed using an ordinal logistic regression approach to verify whether perceptions related to airport performance for safety and security were deemed to be significant in respect to the overall passengers' satisfaction. Notably for passengers comfort and information have a notable positive effect on their satisfaction while characteristics related to safety and security do not have a very considerable effect. Furthermore, the KPI used to check the safety performance of the airport highlighted possible deficiencies in the reporting and safety culture of the airport. The employees were also asked to suggest possible areas of improvement and the redistribution of the workforce for better matching between roles and responsibilities was among the chief aspect highlighted as critical areas of improvement.

Keywords: Airport service quality, Passengers' satisfaction, Stepwise selection method, Passengers' and employees' perceptions, Quality and safety performance.

MO1H: 171 **11:05 hrs**

Research on Suitable Temperature and Humidity Technology Methods for UAV Storage Microenvironment

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In recent years, artificial intelligence, big data and machine learning have developed rapidly. As a new class of technology, UAVs(Unmanned Aerial Vehicles) are gradually applied to the military field for their low cost, easy operation, powerful all-weather and all-airspace reconnaissance and strike capabilities, long range and small size. With the mass production of military UAVs all over the world, the long-term storage of UAVs is facing new challenges. During the storage period of UAV, due to the different storage conditions, the failure modes of UAV systems are various. The root cause is most of the impact of the environment, so there are many environmental factors involved. Among them, temperature and humidity are important parameters of the UAV storage environment. Therefore, based on the UAV storage profile, this article analyzes the characteristics of the UAV storage microenvironment, and through the research on the importance of UAV storage environmental factors, determines the most important environmental factors that affect the UAV during the UAV storage process. On this basis, a technical method to determine the suitable temperature and humidity range of the UAV storage environment. This research provides a suitable storage environment for UAV products and improves the reliability and combat readiness of UAV products during storage.

Keywords: UAV, Storage reliability, Microenvironment, Storage environment, Temperature, Humidity.

Session	[MO1I]—Foundational Issues in Risk Assessment and Management
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Giffard

MO1I: 172 **10:25 hrs**

Actors and Risk: Trade-offs Between Risk Governance and Securitization Theory

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Risk governance and securitization theory are generally thought to offer competing or even incompatible perspectives on risk. Correspondingly, assumptions concerning the actors involved in risk management differ. In risk governance, assumptions about the actor are primarily related to differing conceptions of rationality. In securitization theory, the assumptions relate more closely to the way in which social position and power relations shape the formation of meaning.

Despite these and other differences, this article argues that both theories are useful to researchers, practitioners, and policy makers as they expose different dynamics in issues of risk and security and provide alternative explanations of them. By comparing assumptions about actors' behavior in the two theories the article describes a framework of trade-offs. Treating the differing actor assumptions as trade-offs can enrich empirical study, where risk policy, discourses, governance, and security processes are intertwined in complex relationships, and both rational actions and meaning formations are indispensable to understanding and coping with compound societal challenges.

Keywords: Risk, Securitization, Risk governance, Risk analysis, Actor theories, Agency.

MO1I: 278 **10:45 hrs**

Hybridization of Safety and Security for the Design and Validation of Autonomous Vehicles: Where Are We?

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More and more ground transports are being used (vehicles, trucks, buses, taxis ...) and they remain one of the most dangerous means of transport in the world. However, vehicles are increasingly connected and autonomous with the aim of making travel safer, cleaner and more efficient. They are now able to share and communicate information between themselves and their environment in real time, helping to reduce accidents, traffic congestion and greenhouse gas emissions. These vehicles are Cyber-Physical Systems (CPS), i.e. systems made up of mechanisms that capable of controlling physical entities. In order to guarantee the robustness of such systems, they must meet two main criteria: safety and security. However, safety and security are currently dealt with independently. The reasons for this are both historical and normative. One idea is therefore to combine these two criteria in order to obtain the most robust vehicle possible. In this article, we propose to highlight recent advances in the combined study of safety and security, focused on the autonomous vehicle. To do this, we have carried out a preliminary analysis of the existing situation and a cartographic study listing the articles dealing with this combination. Various qualitative and quantitative analyses of the existing situation are present in the literature, generally focused on CPS. Then, based on this study, we grouped the articles according to two categories: those highlighting the interests and possibilities of such a combination and those presenting hybrid methods in detail.

Keywords: Autonomous vehicles, Safety, Security, Cyber-physical systems, Validation, ITS.

MO1I: 361 **11:05 hrs**

A NaTech Vulnerability Indicator for Local Planners

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The adaptation to climate change in terms of national legislative actions, compensation mechanisms, sectorial risk guidelines is slowly proceeding among EU member states; in this context, local land-use planners lack of adequate tools to properly face Climate-related events. In particular, as far as it concerns NaTech risk, the effective implementation of dedicated measures at local level is difficult to reach; also, the methodologies elaborated till now rarely focused on the management of NaTech risk from the point of view of local urban and land-use planners and managers. An easy-to-use NaTech indicator is here proposed, aiming at providing Local administrations with a survey of the industries exposed to NaTech risk on their territory, and to signal possible critical situations to be managed. The first step for the development of the indicator consists of a questionnaire aimed at identifying potential vulnerable items and hazardous substances detained; then, both items and substances are rated to obtain a classification of potential NaTech vulnerability.

NaTech indicator could be useful to increase the awareness and preparedness of public administrator and planners towards the increasing probability and impact of Na-Tech events; it has the advantage to be easy to use for not expert users and can guide the decision-makers in identifying the most vulnerable Na-tech areas in their territory. The NaTech indicator can be integrated with further in-depth studies, including i.e. the Integrated Quantitative risk-assessment.

Session	[MO1J]—Probabilistic tools for an optimal maintenance of railway systems
Day/Date/Time	Monday, 20 Sep. 2021/10:25–11:25 hrs
Venue	Botanique 2

MO1J: 299 **10:25 hrs**

Propagating Local Measurements Along a Railway Network

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Optimising Track Maintenance is an important issue for railway Infrastructure Managers. This article presents an innovative modelling approach, which aims at predicting Track degradation indicators based on local measurements provided by WTMS. The proposed datadriven approach aims at supporting the continuous improvement of Track Maintenance planning processes, and to anticipate more efficiently the need for tamping operations. Tests have been performed based on real life data, gathered on SNCF Réseau network. Predicting results have been analysed, and have confirmed the relevance of the proposed modelling approach. Tests will be pursued in order to implement the approach on wider datasets and to identify potential interest concerning Rails Maintenance.

Keywords: Wheel/rail contact, Railway track degradation, Machine learning, Propagation, Axle loads.

MO1J: 424 **10:45 hrs**

MAINRAIL: Maintenance Optimization of Railway Infrastructure through Physical Modeling and Advanced Analytics

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Increasing the capacity of railway lines and managing maintenance activities with current practices are preventing the efficient use of the network.

Optimized and efficient management of railway infrastructure is essential for the development of railway services. For that purpose, new tools and strategies are needed to support decision making in the maintenance domain. In this paper, we explore how advances in digitization and commoditization of technologies, e.g., Internet of Things (IoT), Artificial Intelligence (AI) and Cloud Computing are enabling new approaches to optimize the management of railway infrastructure. We propose a new modular tool with enhanced analytics that supports decision-making and enables prescriptive maintenance. It combines physical modeling, formalization in the description of maintenance, and advanced analytics to leverage indicators. By presenting a use case that assesses the life cycle cost and remaining useful life of rails owed to wear, we argue that having Software tools that optimize the maintenance of railway infrastructure is key to support decision-making and enable prescriptive maintenance. A digital twin description of the infrastructure and the use of advanced analytics to generate high-level strategic indicators (e.g. safety, availability, costs and RUL Remaining Useful Life) is a feasible approach for the demands of such a Software tool.

Keywords: Railway infrastructure, Predictive maintenance, Maintenance optimization, CMMS, Asset management, Degradation physical modeling, Digital twins.

MO1J: 596 **11:05 hrs**

Behavioural Modelling of Signalling Constituents

First Author

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Behavioural modelling of signalling components is an indispensable tool for Railway Asset Management. Economic model can be based on these failure model for a subset of the infrastructure as signalling systems. The models are then applied with replacement unit costs in the framework of maintenance or renewal. Any model must consider ageing phenomena to get as close as possible to reality. On this point, the method chosen has considered the data available. Behavioural modelling of signalling components, functions and other families of functions is proving to be an essential tool for the asset management of signalling installations. This is the major interest of this approach.

Keywords: Asset Management, Behavioural model, Cost model, LCC optimisation.

Session	[MO2A]—Risk Assessment
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Plenary Room

MO2A: 192 **11:30 hrs**

Risk Propagation Modeling of Construction Project

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Construction projects are characterized as fragmented, temporary and complex. Therefore, they are exposed to a multitude of varying and interdependent risks that may lead to delays, over costs and other failures which can undermine their successful realization. Project risk management plays then a vital role to increase the probability and impact of positive events, and decrease the probability and impact of negative events in the project [1]. It consists in the risk identification, assessment, prioritization, treatment, monitoring and control.

In this paper, a framework is proposed for construction project risk assessment and prioritization based on multiple criteria decision making methods to define the notion of "Weighted Criticality". A model of risk interactions and propagation behavior is then built using bayesian network, breadth first search algorithm and marginal tree interference. The outcomes of this novel risk analysis provide project managers with a support for decision-making regarding construction project risk management and help them to design more effective response actions.

A case study that concerns the construction of a medium-voltage power line is used to illustrate the effectiveness of proposed approach. It effectively demonstrated the "snowballs" effect of risk propagation on the reliability of the project.

Keywords: Construction project, Project risk management, Weighted criticality, Risk propagation, Risk interactions, Risk prioritization.

MO2A: 194 **11:50 hrs**

Evolved Methods for Risk Assessment

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The foundations of risk assessment tools such as fault tree analysis and event tree analysis were established in the

1970s. Since then, research has made considerable advances in the capabilities of analytical techniques applicable to safety critical systems. Technology has also advanced and system designs, their operation conditions and maintenance strategies are now significantly different to those of the 1970s.

This paper presents an overview of a new methodology developed, retaining the traditional ways of expressing system failure causality, which aims to develop the next generation of risk assessment methodologies. These evolved techniques, appropriate to meet the demands of modern industrial systems, aim to overcome some of the limitations of the current approaches. These new tools and techniques will seek to retain as much of the current methodology features as possible to reduce the learning curve for practitioners and increase the chances of acceptance.

The new approach aims to increase the scope of event tree/fault tree analysis through the incorporation of Petri net, Markov model, and binary decision diagram-based methodologies. Use of these techniques incorporates features such as: non-constant failure rates, dependencies between component failure events, and complex maintenance strategies to boost the capabilities of the methods.

In addition, it considers dedicated routines to analyse the accident risk of transport systems formulated as phased mission models. This type of modelling is demonstrated through the application to an aeronautical system, where the system is modelled as a mission consisting of a series of phases. Mission success requires the successful completion of each of the phases. This approach allows the requirements for success (and therefore failure) to differ from one phase to another. It is also possible to model scenarios whereby a system fault that occurs in one phase of a mission may not affect the system until a later phase of the mission.

Keywords: Risk assessment, Petri Net (PN), Binary Decision Diagram (BDD), Fault tree, Event tree, Phased mission model.

MO2A: 195	**12:10 hrs**

A New Model-based Risk Analysis Approach that Generate Cyberattacks Scenarios and Combine them with Safety Risks

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For many years, the introduction of connected systems and digital technology in critical industries worldwide makes them vulnerable to cyberattacks that can lead to undesirable safety accidents. Thus, analysing these attacks becomes an important matter during risk analysis. In most proposed risk analysis approaches applied in the industries, the safety subjects are taking into consideration without analysing the cyberattack that can lead to the same dangerous phenomenon as a safety incident, the safety and security subjects are treated separately, despite the common consequences and the interdependencies between them. Therefore, there is a strong interest in the development of risk analysis approaches combining safety and security, particularly in the process industry, which is a major potential hazard for local populations and the environment. In this article, a new model-based risk analysis approach is proposed, it presents a new way to generate the cyberattacks systematically based on the modelling system architecture and a list of generic vulnerabilities encountered on industrial systems. A likelihood evaluation for these attacks is presented with their combination with the safety risks.

Keywords: Safety, Cybersecurity, Cyberattack, Accidental situation, Undesirable event, Risk analysis.

Session	[MO2B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Atrium 2

MO2B: 067	**11:30 hrs**

Estimating parameters of the Weibull Competing Risk model with Masked Causes and Heavily Censored Data

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In a reliability or maintenance analysis of a complex system, it is important to be able to identify the main causes of failure. TheWeibull competing risk model is then very often used [1]. However, in this framework estimating the model parameters is a difficult ill-posed problem. Indeed, the cause of the system failure may not be identified and may also be censored by the duration of the study. In addition, the other causes are naturally censored by the first one. For the maximum likelihood method and its variants (EM or SEM), the estimator of the shape parameters has no closed-form expression : it is necessary to use iterative numerical approximations sensitive to the starting point and the censoring rate. For Bayesian methods, there is no conjugated

prior distribution for Weibull distribution when the two parameters are unknown. The estimation of the posterior distribution or its moments requires, here again, approximations by iterative numerical methods. In addition, when data is heavily censored, those classical methods become ineffective in terms of bias and variance.

To adresse this, Bacha and al [2] have proposed the Bayesian restoration maximization (BRM) method. It is based on the restoration of missing data using Bayesian sampling of the parameters and an importance sampling technic [3]: the proposal distribution is obtained from the maximization of the likelihood completed by the missing data. In this work, we first of all propose to improve the BRM method by amending the proposal distribution to make it more effective in terms of variance. In addition a new proposal distribution is obtained from the maximization of the mean of the posterior distribution completed by the missing data. The efficiency of the proposed methods was evaluated by a large number of simulations for different levels of censoring rate. Simulations have shown that the new proposed methods are effective both in terms of relative bias and relative root mean square error. Then, as a comparison, these methods were implemented on a real data set from the literature.

Keywords: Weibull competing risks, Masked causes, Heavy censored data, Bayesian sampling, Importance sampling.

MO2B: 090 **11:50 hrs**

Identifying Critical Failure-Propagation in Function Models of Complex Systems

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Complex interconnected systems have high demands on meaningful analysis of the impact of failures on the actual service provision. This includes the study of obvious and high probable events, but also failures that are difficult to anticipate, e.g. due to cascading effects or combined events. This work introduces a framework for failure analysis that enables the exhaustive identification of combined failures with the strongest impact on the functionality of a system. The framework consists of two principal elements: a method for capturing the propagation of failures in complex systems that are represented via function models, and algorithms for solving the identification problem, which is formulated as combinatorial optimization problem. The feasibility of the approach is verified at hand of a function model of an Offshore Wind Farm (OWF). Both algorithms are then applied to the model of an offshore wind farm in order to identify the failure combinations with the strongest impact on the functionality.

Keywords: Reliability engineering, Function modelling, Failure propagation, Combinatorial optimization, Fault tree analysis, Complex system, Combinatorial optimization.

MO2B: 093 **12:10 hrs**

Adaptive Learning for Reliability Analysis using Support Vector Machines

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A novel algorithm is presented for adaptive learning of an unknown function that separates two regions of a domain. In the context of reliability analysis these two regions represent the failure domain, where a set of constraints or requirements are violated, and a safe domain where they are satisfied. The Limit State Function (LSF) separates these two regions. Evaluating the constraints for a given parameter point requires the evaluation of a computational model that may well be expensive. For this reason we wish to construct a meta-model that can estimate the LSF as accurately as possible, using only a limited amount of training data.

This work presents an adaptive strategy employing a Support Vector Machine (SVM) as a meta-model to provide a semi-algebraic approximation of the LSF. We describe an optimization process that is used to select informative parameter points to add to training data at each iteration to improve the accuracy of this approximation. A formulation is introduced for bounding the predictions of the meta-model; in this way we seek to incorporate this aspect of Gaussian Process Models (GPMs) within a SVM meta-model. Finally, we apply our algorithm to two benchmark test cases, demonstrating performance that is comparable with, if not superior, to a standard technique for reliability analysis that employs GPMs.

Keywords: Reliability analysis, Active learning, Support vector machines, Failure probability.

Session	[MO2C]—Maintenance Modeling and Applications
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Espace Grand Angle2

MO2C: 117 **11:30 hrs**

Modelling the Maintenance of Membranes in Reverse-Osmosis Desalination

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Biofouling of membranes, amplified by recurring algal blooms, significantly reduces the efficiency of reverse-osmosis desalination. Degradation or wear of membranes caused by biofouling manifests as a loss in pressure, and maintenance is required otherwise membranes will fail. In this research, we model membrane wear and maintenance in a novel way, describing the hidden states through time of individual membrane elements in a reverse-osmosis pressure-vessel. Our mathematical model provides the basis for a simulation platform. We estimate parameters of the model using statistical methods, among them the particle filter. Maintenance planning is interesting because membrane elements can be replaced or swapped or cascaded or cleaned, and these differing interventions have different restorative effects. We demonstrate the potential for our model to support decision-making for maintenance planning and to reduce maintenance costs.

Keywords: Maintenance, Reliability, Wear, Cascading, Multi-component system, Desalination.

MO2C: 129 **11:50 hrs**

Accessibility Evaluation Method based on D-H Model and Comfort

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In virtual maintenance, the most widely used accessibility evaluation method is to use virtual human entity accessibility envelope surface to judge and evaluate. However, this method can only give two kinds of evaluation results: reachable and unreachable. There is not enough data and theoretical support for the construction of envelope surface, and the precision and accuracy of evaluation need to be improved. In this paper, a parameterized accessibility evaluation method and the construction method of accessibility envelope surface are proposed. Firstly, a 6-joint and 5-link Denavit-Hartenberg (D-H) link model is established from the waist to the fingertip of the human body, and the range of 10 degrees of freedom and angles of the 4 joints are determined according to ergonomics. Then, the reachable points are generated by Monte Carlo simulation. The accessibility envelope surface is composed of the outermost random reachable points. Then, comfort is introduced to refine the accessibility evaluation level, and a multi-level accessibility evaluation system based on comfort is constructed according to the rapid upper limb assessment (RULA). Finally, the comparison experiment with the reachable envelope provided by DELMIA in virtual environment and real environment shows that the proposed method has better evaluation accuracy and precision. Based on this method, an accessibility evaluation tool has been developed in CATIA and has been applied in some scientific research institutes.

Keywords: Virtual maintenance, Parameterization, Accessibility evaluation, Ergonomics, D-H model, RULA.

MO2C: 142 12:10 hrs

Condition-based Maintenance for Systems with Dependencies: Related Concepts, Challenges and Opportunities

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Many critical systems with dependencies do not collapse immediately due to single-point failures but are more vulnerable to the cascading effects of these failures. Condition-based maintenance (CBM) has been found useful not only in improving availability of technical system but also in reducing the risks related to unexpected breakdowns, including those events related to dependencies, such as cascading failures. The serious disasters created by such failures and increased requirements for CBM policy due to dependencies urges a comprehensive study on current research and future challenges. In this study, a systematic literature review on the implementations of CBM in the systems with dependencies is conducted. Relevant papers are deliberately selected and analyzed in the VOSviewer program, to identify co-occurrences of keywords and so to illustrate basic concepts of CBM. Specifically, considering various types of dependencies, challenges, research advancements and research perspectives are identified. Opportunities of CBM for improving availability and reducing risks of dependent systems are finally explored.

Keywords: Condition-based Maintenance, Maintenance procedure, Dependent systems, Cascading failure, Risk analysis, Riskinformed condition-based maintenance.

Session	[MO2D]—Prognostics and Health Management: From Condition Monitoring to Predictive Maintenance
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Panoramique

MO2D: 136 11:30 hrs

Component Degradation Detection Through Autoencoders Based on Monitoring Data

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In the context of prognosis and health management (PHM) frameworks, deep learning (DL) algorithms have had a strong impact on the development of diagnosis and prognosis techniques. To this end, a common approach is to use monitoring data from engineering systems to find patterns that can help to assess the system's state of health and predict its future behavior. Accurate diagnosis models based on operational conditions can serve as a tool to determine maintenance policies and logistic optimization. Further, a precise system's diagnosis is important to have a baseline for prognosis tasks, such as the estimation of the system's remaining useful life (RUL). The latter relies on accurate RUL labels, which are hard to acquire, especially when dealing with multi-component systems that present few failure instances. Hence, though these models are widely studied in academia, applying them to real complex systems is a challenging task. In diagnosis applications, processing the data to train health state classifiers or damage detection models is an ongoing challenge, which hinders their applicability to real complex systems.

In this paper, we present a methodology to detect a system's degradation states based on monitoring data and maintenance logs. The methodology comprises a data preprocessing stage to separate data from the system's healthy state from possibly degraded or anomalous data. The objective is to obtain a clean dataset to train a deep learning autoencoder (AE). Once trained, the AE is tuned to reconstruct data from healthy states and thus can be used to detect anomalies and the system's degraded states based on the reconstruction error. The proposed methodology is flexible and can easily be adapted to any system with many components. The methodology is validated with a case study corresponding to a vapor recovery unit (VRU) located at an offshore oil production platform. The system is composed

of multiple components where sensor data is collected for a one-year period every 15 seconds. Results show that by analyzing the behavior of the reconstruction error in time, the trained AE can accurately detect degradation on the system's components based on their failure modes.

Keywords: Health state, Diagnostics, Degradation detection, Anomaly detection, Autoencoders, Deep learning.

MO2D: 152 11:50 hrs

Combination of Long Short-Term Memory and Particle Filtering for Future Uncertainty Characterization in Failure Prognostic

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Failure prognostic is generally conducted following two approaches, model-based or data-driven. On the one hand, model-based approaches offer better physical interpretability and may be easily embedded in the structure of Bayesian processors for uncertainty characterization purposes. However, it is challenging to identity degradation models in complex systems, since it is required to understand all the underlying degradation phenomena. On the other hand, data-based approaches are more applicable for monitoring the health condition of complex systems. However, this latter approach suffers from a lack of interpretability and low uncertainty consideration. Nevertheless, these two characteristics are crucial for critical equipment in industries such as transport and energy production. In this paper, we propose a method combining long short-term memory (LSTM) and particle filter (PF), namely PF-LSTM, for handling uncertainty in the estimation and prediction of system states. In detail, a trained LSTM is used to propagate particles for prior system health state estimation. Then, using the Bayes formula, the weight of these particles is updated regarding the in-field measurements. Finally, when a fault is diagnosed, i.e., when the health indicator exceeds the fault threshold, LSTM is used to propagate the last health state posterior distribution to determine the system's remaining useful life.

Keywords: Failure prognostic, Uncertainty management, Bayesian estimation, Particle filtering, Time-series forecasting, LSTM.

MO2D: 209 12:10 hrs

Remaining Useful Lifetime Prediction and Noisy Stochastic Deterioration Process Considering Sensor Degradation

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Condition monitoring is important to ensure system reliability and safety; it is the basis for prognostics (Remaining Useful Lifetime (RUL) prediction) and predictive maintenance. The monitoring data is usually erroneous due to sensor errors. In the literature, these errors are usually neglected or modeled by a Gaussian noise during the prediction of the RUL. However, in the reality, due to the varying operating environments and the ageing effect, the sensor itself will eventually undergo a deterioration and its performance will decrease over time. The use of the Gaussian noise with a constant mean does not permit to model the sensor degradation phenomenon and leads to inefficient forecasts of the RUL. For this reason, the paper focuses on the analysis of the sensor degradation in the RUL prediction process. To this end, we propose first an integrated degradation model that considers not only the system degradation but also the sensor degradation. In the proposed model, the sensor degradation is modeled by a Wiener processes. Finally, to take advantage of the knowledge about the degradation model and the available data, Particle filter was adopted. The performance of the Particle filter is also analyzed by varying different estimation time of the proposed degradation model.

Keywords: Degradation modeling, Sensor degradation, Remaining useful lifetime estimation, Particle filter, gamma process, Wiener process.

Session	[MO2E]—Human Factors and Human Reliability
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Amphi Jardin

MO2E: 184 **11:30 hrs**

The Effect of Imperfect Maintenance on a System's Condition considering Human Factors

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Human Factors (HF) have a significant impact on the maintenance quality and are recognized as a specific cause of Imperfect Maintenance (IM). Technician inexperience, poor procedure quality, or environmental factors are exemplary HF and can lead to insufficient repair or inspection. However, due to limited data, many studies describe HF only qualitatively as a possible cause of IM or highly simplify the effect of HF. This paper attempts to analyze the effect of HF on the system's restoration level in order to provide a more realistic post-maintenance operating system condition. Furthermore, the economic savings potential of a fully automated condition-monitoring approach and the subsequent reduction of adversarial HF within the maintenance process will be analyzed. As use case serves the tire pressure maintenance task of an Airbus A320. Based on fuzzy logic, an IM model is developed, considering the effect of HF individually on restoration and inspection tasks using human reliability assessments. The aircraft maintenance eco-system is simulated with a prescriptive maintenance model to enable the evaluation of monetary and non-monetary performance indicators. A comparative study revealed that perfect maintenance approaches tend to vastly underestimate the maintenance-related cost aspects. Moreover, the study showed that a technician's lack of experience cannot be compensated by an improved working environment. Only the use of an automated monitoring system to replace error-prone inspection tasks resulted in an overall cost reduction. The developed model allows the individual evaluation of the technician's expected performance to enable a more targeted deployment of the available workforce and to improve the effectiveness of maintenance.

Keywords: Imperfect maintenance, Imperfect inspection, Human factor, Human reliability analysis, HEART.

MO2E: 229 **11:50 hrs**

Is the Performance of Control Room Operators Affected by Time on Task or Time of Day?

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The literature on fatigue shows that sustained periods of work can lead to a subjective feeling of fatigue. But whether this feeling is reflected in reduced performance may vary and depends on several factors. It is important to understand to what extent control room work is vulnerable to reduced performance over time due to operator fatigue. This question was examined by using data from six previous simulator studies. To check for effects of reduced performance over periods of sustained work (time on task), data from the first simulator runs of the day were compared to data for the last simulator runs of the day for the same crews. The results from one study showed higher performance in the first runs than in the last runs, as measured by expert-rated performance. But another study showed the opposite result. A plot of expert-rated performance as a function of time of day indicated that time of day (circadian rhythm) may have an influence on performance. The factors time of day and time on task were confounded, and no definitive conclusion could be drawn. However, the results indicate a need for awareness that the performance of control room operators may be influenced by time of day and that operator errors may be more likely in the morning and early afternoon. Further research should be done to verify the results.

Keywords: Mental fatigue, Human performance, Human factors, Circadian rhythm, Simulator study, Meta-analysis, Post-lunch dip.

MO2E: 333 **12:10 hrs**

A Maintenance Performance Framework for the South African Electricity Transmission Industry

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Maintenance performance measurements have always reflected the changes in industry and maintenance revolutions. Industry 4.0 has a strong focus on social dimensions and a clear strategy is needed to measure these social dimensions in a maintenance performance framework. This article summarises maintenance human factors and measurements within the South African Electricity Transmission Industry. These maintenance human factors are the cornerstone of social dimensions that affect the maintenance tech-

nician's ability to perform work at an optimum level. High workload, time pressure, fatigue and communication were found to be the most significant maintenance human factors within the South African Electricity Transmission Industry. Furthermore, an organisational hierarchical maintenance performance framework was developed for this industry. The framework provides a methodology to calculate an overall maintenance performance score that is inclusive of these maintenance human factors. By implementing a maintenance performance framework that includes the up-and-coming social dimensions of Industry 4.0, the successful implementation of Maintenance 4.0 can be improved.

Keywords: Maintenance human factor, Maintenance performance measurement, Maintenance performance framework, Maintenance human factor performance, Electricity transmission industry, Power transmission industry.

Session	[MO2F]—Degradation analysis and modelling for predictive maintenance
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Espace Grand Angle

MO2F: 325 **11:30 hrs**

Analysis of a Condition-Based-Maintenance Policy in Heterogeneous Systems Subject to Periodic Inspections

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A maintenance strategy for heterogeneous systems consisting of degrading and non-degrading components is analyzed. degrading components are subject to a continuous gamma degradation. A degrading component fail when its degradation level exceeds a failure threshold. Times between failures in the non-degrading components follow an exponential distribution. To prevent failures, degrading components state is periodically checked through inspections. In these inspection times, if the degradation level of a degrading component exceeds the preventive threshold, this component is replaced by a new one. When a component fails, repair team is immediately called and performs the replacement of the failed component by a new one after a fixed delay time. In fact, these maintenance times are seen as opportunities for preventive maintenance of the rest of degrading components. If the degradation level of a degrading component exceeds the preventive threshold at the time of another maintenance action, this component is preventively maintained. The expected cost rate for this heterogeneous system is evaluated by assuming a sequence of costs for the different maintenance actions, and using a semi-regenerative approach. A reward is provided by the working degrading components. Numerical examples of the optimization problem are given to find the optimal maintenance strategy. Monte-Carlo simulation method and meta-heuristic algorithms are employed to minimize the preventive thresholds and times between inspections.

Keywords: Condition-based maintenance, Opportunistic maintenance, Preventive threshold, Gamma degradation, Renewal theory.

MO2F: 433 **11:50 hrs**

Parameter Estimation of a Wiener Process of Mechanical Degradation Through Censored Measurement of Timings

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The degradation of a mechanical system as a function of time or of the number of operations performed is often characterized by a timing value, that is the change of the time required to perform a certain operation. This timing value is in many practical cases determined as the difference between a start and an end time stamp, each of which is subject to measurement errors. In order to determine the future evolution of the system with the aim to predict the end of life, given by the first passage time of a critical value, a good estimation of the parameter of the underlying stochastic evolution and measurement error is required.

In this work an analysis is done using as basic model a Wiener process with measurement error. This is motivated by a practical case, where the timing of the opening or closing operation of a mechanical mechanism is used. The two time stamps are measured using two mechanical switches. Such electrical contacts are known to be subject to bouncing, which makes an accurate determination of the instance of time, when they close, difficult. A debouncing algorithm is used in this application: The time stamps are only recorded, if no change of signal is recorded over a certain time interval. As typical settling times are comparable to the changes of timings themselves, the error coming from this effect need to be modeled appropriately.

In a first approach the measurement effect is modeled as interval censoring. A more detailed model takes the random character of the bouncing into account as well. The underlying evolution of the timings is modeled as a Wiener process having both a drift and a variance. The model is similar to the one in Whitmore (1995), but without assuming a normal distributed measurement error.

Bayesian inference using MCMC is used to get the distribution of the different parameters. Due to its practical simplicity a comparison is made with the Whitmore

model, using the normal distributed case, showing when this method can be used instead.

With simulated data the performance of different approaches is confirmed and the algorithm is applied to some real data with an evaluation of the validity of the model assumptions with respect to the prediction of the failure time distribution. The analysis is a specific example how more complex measurement error models can be used together with a stochastic model of the degradation beyond the assumed normal distribution assumption.

Keywords: Degradation model, Wiener process, Mechanical bouncing, Interval censoring.

MO2F: 443 **12:10 hrs**

General Degradation Model with Measurement Errors

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Degradation analysis has become the most important technique and efficient method for developing statistical models of highly reliable products. If there are quality characteristics (QCs), whose degradation of physical characteristics over time (referred to degradation paths) is related to product reliability, an alternative option is the use of sufficient degradation data to accurately estimate the product's lifetime distribution. When there are measurement errors in monotonic degradation paths, the assumption of the non-monotonic model can lead to contradictions between physical/chemical mechanisms and statistical/engineering explanations. To settle the contradiction, this study presents an independent increment degradation-based process that simultaneously considers the intra-unit variability, inter-unit variability, and measurement error in the degradation data. However, the likelihood function of the general degradation model includes high-dimensional integrals, and this results in lots of computing time to obtain the likelihood value of a set of parameters. In order to efficiently estimate the model parameters, we use a quasi-Monte Carlo approach, separate-variable method and parallel computing to overcome high dimensional integrals of the likelihood function. In addition, the study provides a model checking procedure to assess the validity of model assumptions. Some case studies are performed to demonstrate the flexibility and applicability of the proposed models. Especially, the analysis of LED data via proposed model is in agreement with the material theory and empirical experiments.

Keywords: Lévy process, Gamma process, Inverse Gaussian process, Wiener process, Random effects, Parallel computing.

Session	[MO2G]—Nuclear Industry
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Atrium 3

MO2G: 177 **11:30 hrs**

Interpretability Improvement of Convolutional Neural Network for Reliable Nuclear Power Plant State Diagnosis

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When an abnormal event occurs in a system in a nuclear power plant (NPP), it can cause severe safety problems if it is not mitigated. Therefore, an operator diagnoses the abnormality from alarms and monitoring parameters and conducts appropriate action. Among the tasks, diagnosis can increase the workload of the operator because it should be accurately performed as soon as possible to minimize the consequence of the occurred event. Recently, to support the diagnosis task, operator support systems using an artificial neural network (ANN) have developed. However, an ANN which is a black-box model cannot logically infer its prediction. For this reason, an operator cannot back up a misdiagnosis of the model, and they also cannot trust its diagnosis. For this issue, we intend to provide evidence with the diagnosis of the NPP abnormality classification model. To find more appropriate evidence of the NPP state diagnosis, this study verifies the improvement of interpretability when Guided Backpropagation is used with the explanation method. A convolutional neural network that can classify each NPP abnormal state with high accuracy is used as a diagnosis model, and the model calculates each classification contribution of plant parameters in input data using explanation methods. The interpretability of each method is compared by reclassifying the NPP states using each dataset composed of high relevant parameters from calculation results. By making the model more transparent, operators can trust model diagnosis.

Keywords: Nuclear power plant, Abnormal state diagnosis, Convolutional neural networks, Model interpretability.

MO2G: 178 **11:50 hrs**

An Operator Support System Framework and Prototype for Initial Emergency Response in Nuclear Power Plants

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Nuclear power plant operation can be categorized with three: normal, abnormal and emergency operation. Especially in emergency operation, operators are exposed to highly stressful condition, since immediate and appropriate mitigations are required. To reduce human errors in this situation, emergency operating procedures (EOPs) are used, which provide appropriate tasks to mitigate situations and support diagnosing symptoms of nuclear power plants. However, human error is still a major contributor for nuclear power plant accident. In order to reduce human error, many operating automation methodologies are researched. However, in the nuclear field that requires a high degree of safety, it is difficult to quickly apply automation technology, so it is necessary to apply and verify low-level intelligent operator support systems. In this paper, we propose concept of an intelligent operator support system replacing EOPs that have initial responses. The proposed operator support system has a parallel structure that monitoring tasks are conducted simultaneously in contrast with EOPs that are performed sequentially. From this monitored information, the system provides intuitive and accurate information to the operator through the state of critical safety functions and the master logic diagram. In addition, information on latent risks due to auxiliary system failure is also provided to the operator using multilevel flow modelling technique. This system is expected to replace initial response emergency operating procedure and to reduce responding time by the parallel structure.

Keywords: Operator support system, Emergency operating procedure, Operating automation, Multilevel flow modelling, Critical safety function, Emergency operation.

MO2G: 212 **12:10 hrs**

Resilience and Organizational Limits in the High-risk Nuclear Industry Context

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The ongoing COVID-19 crisis renewed scholarly interest in organizational resilience. To ensure resilience, organizations must develop the ability to proactively prepare for ambiguous and unexpected situations (Morel et al., 2008). From this perspective, resilience may be considered as a mindful process leading to reliability (Linnenluecke, 2017) where mindfulness allows to collectively manage stability/vividness tension and extend individual limits of attention (Weick & Sutcliffe, 2006, 2007).

A high level of environmental uncertainty increases the risk and may lead to violations of organizational limits (Farjoun & Starbuck, 2007). In addition to the exogenous environmental limits, organizations are affected by the endogenous limits of cognition and managerial control, and also by the non-cognitive factors such as habitus. However, many questions remain.

Following a recent call for further research on organizing for resilience (Linnenluecke, 2017, p. 26), the aims of our paper is to explore how the organizational limits restraint the development of mindfulness (foresight and cognition) and how organizations deal with those limits to develop the resilience?

We conducted a qualitative case study within a major European nuclear power plant. We wanted to better understand how in a highly controlled and regulated industry managers increase resilience by pushing of organizational limits. Our analysis shows that implemented practices constrained endogenous organizational limits instead of helping to extend them. Our paper highlights the role of mindfulness and attention in building resilience and tensions between managed and regulated safety. The obligation of result (e.g., reliable practice) is in tension with the obligation of means (e.g., procedure to follow). Moreover, our case study illustrates negative effect of organizational context on the extension of the organizational limits. In addition, we enrich the notion of endogenous limits by adding the non-cognitive dimension of habitus of the nuclear energy industry. We believe that a better understanding of organizational limits to develop resilience may offer managers the opportunity to better consider the role of organizational context and to adapt training programs.

Keywords: Resilience, Organizational limits, Mindfulness, Habitus.

Session	[MO2H]—Aeronautics and Aerospace
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Cointreau

MO2H: 196 **11:30 hrs**

Comparison of Readiness to Perform the Task of Aircraft used for Cadet Training

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The main goal of this article is the comparison of readiness to perform the task of aircraft used for cadet training. During their education at the Polish Air Force University cadets use the following aircrafts: Cessna CA-150, Diamond DA-49, Orlik and Iskra. The guarantee of a timely and safety training is closely related to the readiness of the aircraft to perform the task and, consequently, its reliability. As a part of the research, data from the process of operation of the aircraft used in the Military University of Aviation were investigated. As the method of the analysis has been chosens semi-Markov model, which is one of the analytical methods based on the analysis of stochastic processes. It is based on the assumption that a technical object being in different operation states is a random variable. Semi-Markov model allows to determine the probability of aircraft being in one of the states of the operating conditions: waiting, daily-service, flight, hangar service. The results obtained differ in the initial phase depending on the assumed initial state. After about 30 days reach constant levels called limit probabilities.

Keywords: Readiness, Marcov process, Probability, Aircraft, Aviation, Operating condition.

MO2H: 223 **11:50 hrs**

Power Flow Based Fault State Propagation Model and its Application to Aircraft Actuation System

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In order to optimize the layout of sensor measuring points for accurate fault location, this paper establishes the power transfer model from the view of power flow existing in the complex electromechanical system and studies the power-transfer based fault state propagation process. Taking aircraft actuation system as an illustration, this paper analyzes the power flow transferring process from permanent magnet DC motor to piston pump and hydraulic cylinder. Based on the power transfer model, the fault state propagation process is then established and analysed. The detectable condition and the attenuation law of fault detection sensitivity are found by the first-order trajectory sensitivity theory. The results indicate that as the distance between the measuring point of the sensor and the fault location becomes farther, the fault detection sensitivity attenuates. Therefore, it should be detected as close as possible to the fault location. The proposed method in this paper can describe the fault state propagation process of the system and verify the validity and accuracy of the theoretical analysis, which provide the basis for fault location and diagnosis based on power flow.

Keywords: Power flow, Fault state propagation, Sensor measuring point, Power dissipation, Sensitivity, Aircraft actuation system.

MO2H: 236 **12:10 hrs**

DROSERA: A Drone Simulation Environment for Risk Assessment

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The use of Unmanned Aerial Vehicles (UAVs), or drones, appears to be a very effective means for aerial inspection of outdoor infrastructures over large areas and data collection.

For these missions to be authorized, drone operators must ensure that flight paths respect a given level of safety with regard to third parties such as population, transportation networks, critical infrastructures, etc. This paper presents a tool (DROSERA) for probabilistic risk assessment of fixed-wing UAV missions. It aims to calculate the probability of getting casualties for people at ground or accidents on transportation networks due to loss of control of an UAV. This tool integrates several models for such probability calculations, from the literature or developed by the authors. New models are presented here such as specific flight termination strategies for risk mitigation (terminal spiral), time of day sensitivity (people and traffic), effect of wind conditions. A synthesis of these models, their integration into the DROSERA tool, required inputs and calculated outputs are presented and illustrated on an example of UAV mission in a semi-urban scenario.

Keywords: Probabilistic risk assessment, Unmanned Aerial vehicles, Simulation framework.

Session	[MO2I]—Balanced System Reliability
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Giffard

MO2I: 071 **11:30 hrs**

Component Assignment of Circular k-out-of-n: G Balanced System with 2 Sectors Considering Component Degradation

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Balanced systems are widely used in the aerospace and military services featuring the symmetry structure with spatially distributed components, which increasingly becomes an important issue in the research field of the reliability theory. This paper studies a circular k-out-of-n: G balanced system with 2 sectors, which is operating if at least k components in each sector are working. In terms of the definition of a circular k-out-of-n: G balanced system with 2 sectors, we consider that if a component fails in one sector, the other unit of the same pair is forced down immediately to remain the symmetry of this sector. In addition, there is the same number of components in another sector has to be shut down in order to keep balance among all sectors. First, based on the proposed system balance condition, the system reliability model is presented based on minimal path sets. Second, considering the gamma degradation process of components, the optimization model is established to find the optimal component assignment scheme and the assignment time for maximizing the lower boundary of the system reliability during the required mission time. Third, the delta-importance (DI) based heuristics are developed to solve the model. The analytical results and the numerical experiment illustrate the efficiency of models and the solving method, shedding light on making design and maintenance strategy of balanced systems.

Keywords: Balanced systems, Component assignment, Gamma degradation process, Minimal path sets, Importance measure.

MO2I: 372 **11:50 hrs**

Reliability Analysis of Loading-Sharing Consecutive -k-out-of-n:F Balanced Systems by Considering Mission Abort Policies

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This paper considers a consecutive-k-out-of-n:F balanced system composed of m sectors and each sector is composed of n identical components with exponential distributed lifetimes. The lifetime distribution is subjected to a total load that is equally shared by all the working components in the same sector. The components fail due to internal failure or external shocks. If one component fails, one component in the remaining sectors should be forced down or one forced-down component in the same sector should be resumed to keep a balance. In this paper, the balance is achieved when the number of working components in each sector is same and the system fails if there are at least k failed and forced-down components in any sector. To enhance the balanced system survivability, mission abort policies are conducted if the failure risk becomes too high. Moreover, the mission reliability and system survivability are derived. Numerical studies are presented to confirm the obtained results.

Keywords: Balanced systems, Loading-sharing, Consecutive-k-out-of-n:F, Mission abort policies.

MO2I: 534 **12:10 hrs**

Maintenance Optimization of a Balanced System with Tolerance

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In this paper a pair of two rail-wheels which is submitted to degradation due to the unbalanced vibration and wear during long time running is studied. The pair of wheels works under the minimum allowable value of flange thickness and tread diameter. The thickness of flange and the diameter of wheel tread are dependent on each other by maintenance action, referred as reprofiling in this study. In order to keep the thickness of flange above a given value for the sake of safety, when the thickness of flange decreased, the diameter of the tread will be reduced by reprofiling (rotary cut) so as to increase the thickness of flange. The natural degradation of thickness of flange and the diameter are modelled by Wiener process. The dependence between two wheels is based on the wheel diameter difference. The inspection of the wheels is period and perfect. When the thickness of flange degrades under the given threshold, or when the diameter of anyone of the pair of the wheels degrades under the given threshold, the system is regarded as failed. When the difference of diameters between two rail-wheel pairs is greater than the tolerance or the thickness of the flange reduces over the preventive maintenance threshold, a preventive maintenance activity is planned. Hence the preventive maintenance threshold and the maintenance period are optimized by simulations.

Keywords: Wiener process, Symmetric system, Degradation, Maintenance, Tolerance, Rail-wheel.

Session	[MO2J]—Risk–Informed Digital Twins Healthcare and Medical Industry
Day/Date/Time	Monday, 20 Sep. 2021/11:30–12:30 hrs
Venue	Botanique 2

MO2J: 054 **11:30 hrs**

A Cloud-Based Computational Platform to Manage Risk and Resilience of Buildings and Infrastructure Systems

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The primary responsibility of asset managers is to ensure that their assets, such as buildings and infrastructure systems, provide adequate service needed. They have the continuous task of executing interventions to help prevent the loss of service and to restore service after it is lost, which can happen, for example, due to natural hazards such as floods, landslides, and earthquakes. In other words, they have the continuous task of making their assets resilient. To provide optimal mitigation measures, the risk and resilience of buildings and infrastructure systems have to be assessed. Therefore, different computational models from different disciplines have to be executed, and their results have to be brought together in order to make profound quantitative statements. Nonetheless, conducting such assessments can be a particularly challenging task due to numerous scenarios and chains of interrelated events that require considerations, the modelling of these events, the relationships among them, and the availability of support tools to run the models in an integrated way. Cloud-based simulations offer a solution to this problem, by providing almost unlimited storage and computational resources; furthermore, the cloud enables and facilitates collaborative approaches, and provide a Digital Twin of the assets for prediction and disaster management. This paper introduces a computational platform which enables cloud-based simulations to estimate risk and resilience of buildings and infrastructure systems. The setup of the computational platform follows the principles and ideas of systems engineering and allows to incorporate and link different events. The platform is centred on the integration of the spatial and temporal attributes of the events that need to be modelled to estimate the risk and resilience. Furthermore, the platform supports the inclusion of the uncertainty of these events and the propagation of these uncertainties throughout the risk and resilience modelling. Through the modular implementation of the simulation platform, the updating and swapping of computational models from different disciplines – according to the needs of

engineers and decision-makers - is supported. The platform enables high-performance computing for simulation-based risk and resilience assessments, considering the occurrence of time-varying multi-hazard events affecting buildings and infrastructure systems. Beyond the modelling of complex scenarios, the proposed computational platform provide technologies and tools to help decision-makers in determining the best mitigation policies. This is reached by collaborative technologies like data sharing, real-time collaboration, a continual process of creating, editing, and commenting, as well as a cheap and easy way of creating visuals and reports.

Keywords: Cloud computing, Risk, Resilience, Simulation, Infrastructure management, Multihazards, Computational modelling, Natural hazards, Disaster response, HPC, Digital twin.

MO2J: 222 **11:50 hrs**

Digital Twins of Infrastructure

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This paper proposes a systematic approach to create digital twins of infrastructure for regional risk and resilience analysis. A digital twin consists of a virtual representation of infrastructure intended for specific analyses (e.g., in reliability and resilience analyses considering relevant hazards.) We formulate creating digital twins as a model selection problem whose objective is to ensure predicting the response quantities of interest (e.g., infrastructure performance or resilience measures) with the desired accuracy level under computational resources constraints. The virtual representation requires collecting and integrating data about infrastructure physical and operational characteristics from multiple sources. The required data depend on the considered analyses to predict the response quantities of interest (e.g., considering only reliability analysis or also including functionality analysis.) The collected data are typically unstructured and incomplete; so, they need to be processed and synthetically augmented to, for example, capture infrastructure's future developments. Creating digital twins also entails deciding the scales, boundaries, and resolution of the virtual representation and selecting models for intended analyses from multiple candidates, each of different computational fidelities and evaluation costs. A digital twin is hardly a perfect representation of infrastructure reality; there are missing or limited data about infrastructure, and several sources of uncertainty affect predicting infrastructure's states for decades ahead. Uncertainty propagation is an integral part of creating digital twins to understand how missing data and different sources of uncertainty affect predicting the response quantities of interest. Uncertainty propagation requires evaluating the created digital twins at multiple realizations of the sources of uncertainty. However, using a detailed digital twin with high-resolution and high-fidelity models can lead to a high computational cost. The proposed approach guides the creation of statistically equivalent digital twins following two general principles: 1) the selected scale, resolution, and computational fidelities collectively ensure the desired accuracy in predicting the response quantities of interest, and 2) the allocation of computational resources is based on each contribution to the uncertainty of the response quantities of interest.

Keywords: Digital twin, Infrastructure, Model selection scale and resolution, Uncertainty propagation, Resilience.

MO2J: 505 **12:10 hrs**

Predicting Clinical Outcomes of Ovarian Cancer Patients: Deep Survival Models and Transfer Learning

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With the advent of high-throughput sequencing technologies, the genomic platforms generate a vast amount of high dimensional genomic profiles. One of the fundamental challenges of genomic medicine is the accurate prediction of clinical outcomes from these data. Gene expression profiles are established to be associated with overall survival in cancer patients, and this perspective the univariate Cox regression analysis was widely used as primary approach to develop the outcome predictors from high dimensional transcriptomic data for ovarian cancer patient stratification. Recently, the classical Cox proportional hazards model was adapted to the artificial neural network implementation and was tested with The Cancer Genome Atlas (TCGA) ovarian cancer transcriptomic data but did not result in satisfactory improvement, possibly due to the lack of datasets of sufficient size. Nevertheless, this methodology still outperforms more traditional approaches, like regularized Cox model, moreover, deep survival models could successfully transfer information across diseases to improve prognostic accuracy. We aim to extend the transfer learning framework to "pan-gyn" cancers as these gynecologic and breast cancers share a variety of characteristics being female hormone-driven cancers and could therefore share common mechanisms of progression. Our first results using transfer learning show that deep survival models could benefit from training with multi-cancer datasets in the high-dimensional transcriptomic profiles.

Keywords: TCGA, Transcriptome, Survival analysis, Cox model, Deep learning, Transfer learning.

Session	[MO3A]—Risk Assessment
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Plenary Room

MO3A: 197 **16:10 hrs**

TRiceR, a Cloud-based Web Application for Supporting Risk-based Decisions Associated with Ice Falling from Wind Turbine Blades

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The development of wind energy projects situated in an industrial environment or close to cities is a preferred option in regions with high population densities, since it represents some major advantages. On the other hand, it also represents a drawback in terms of safety during winter conditions. Ice accretion on the wind turbine blades represents a major risk as ice fall may cause incidents, even lethal accidents to people in the vicinity. The current common methodology to identify the potentially risky areas around wind turbines uses a deterministic approach which leads to excessively large zones around the turbines without granularity or circumstantial sub-zones. The approach presented in this paper is a probabilistic risk-based Monte Carlo methodology associated with an acceptance framework. Developed by Tractebel, this methodology allows a much more detailed mapping of the risk zones and also enables to model the impact of mitigating measures. This represents a real risk-based decision tool for windfarm developers and operators. The approach is fully compliant with the IEA Wind 'International recommendations for ice fall and ice throw risk assessments' and recent international safety standards. The tool has been translated into a cloud-based application called TRiceR (TRactebel Ice Fall Risk Assessment Digital Application).

Keywords: Ice fall, Wind turbine, Risk assessment, Mitigating measures, Monte-Carlo simulations, TRiceR.

MO3A: 213 **16:30 hrs**

Comparison of Risk Analysis Approaches for Analyzing Emergent Misbehavior in Autonomous Systems

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The evolution of autonomous systems depends on their constituent parts' ability to act, seemingly independently, so that their collective behavior, termed emergent behavior, results in novel properties that appear at a higher level. Although these emergent behaviors can be beneficial, systems can also exhibit unintentionally and intentionally malicious emergent misbehaviors. As systems are becoming more complex and sophisticated, their emergence characteristics may result in a new type of risk, called emergent risk, which would affect both the systems and society. Although there have been several studies on achieving positive desirable emergent behavior, little attention has been given to the risk of undesirable emergence from either the safety or the security perspective. The main objective of this paper is to provide a structured approach to understanding emergent risks in the context of autonomous systems. This approach has been analyzed based on an emergent risk application example – a swarm of drones. We explore different security and safety risk co-analysis methods with a causal interpretation, and provide a comparative analysis based on theoretical factors that are important for assessing the emergence of various threats. The study results reveal each method's strengths and weaknesses for addressing emergent risks, by providing insights into the need for the development of an emergent risk analysis framework.

Keywords: Emergence, Emergent behavior, Risk analysis, Emergent risks, Cyber security, Safety, Autonomous systems.

MO3A: 221 **16:50 hrs**

Risk Assessment of Non-Compliance with General Data Protection Law (LGPD): A Necessary Adjustment for Healthcare Companies That Use Chatbots For Automated Care

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With the publication of the General Data Protection Law - (LGPD) many companies having their headquarters in Brazil need to work on adapting their processes. Most companies are seeking for compliance, however, many still do not know how to proceed. The risk of legal and financial issues related to non-compliance is high. This study reviews the current percentage of companies that use a Chatbot service and are compliant with the LGPD. It also reviews the steps to adjust the Chatbot service used by companies in the European Union to be compliant with the General Data Protection Regulation - (GDPR). As a methodological approach, a search in the state-of-the-art literature was conducted to identify the most recent published related content. A survey was conducted with several companies based in the Rio de Janeiro city which use a Chatbot service and are compliant with the LGPD. As a result, a flowchart showing the steps for adapting a Chatbot service to the LGPD is presented. The risks of non-compliance are also presented. This study addresses a gap observed in the literature since no specific previous work has been found covering this topic. Many companies may benefit from this study by knowing the steps to adapt their Chatbot service to the LGPD requirements, and avoid the risks associated to non-compliance.

Keywords: Chatbot, LGPD, GDPR, Privacy by design, Innovation.

MO3A: 269 **17:10 hrs**

QRA Analysis of Different Liquefied Natural Gas Supply Alternatives: A Case Study

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Nowadays, the number of infrastructures and facilities where natural gas is handled in liquified form is constantly increasing. However, for most of the end users (e.g., power stations), LNG has to be vaporized, usually at high-pressure conditions, back to Natural Gas form. Therefore, in the risk analysis activities for plants involving natural gas both liquid and gaseous accidental Loss of Containment have to be accounted. As well consolidated risk analysis practice, Quantitative Risk Assessment (QRA) is largely used to support design phase of complex technical systems with potential for Major Accidents.

In cases where a small supply of natural gas is required, transportation of LNG can consider road transport, as an alternative to vaporization at harbor and transportation via pipeline. This work proposes the analysis of a case study related to supply natural gas to an onshore located power station from the ship unloading of LNG occurring at a near harbor in gaseous or liquid form. In particular, the present work aims to compare the risk to individuals and population related to supplying natural gas through pipeline with an alternative consisting of supplying LNG through iso containers by trucks. the case study refers to a hypothetical site, and the results achieved can serve as reference case for safety analysts when alternatives solutions of natural gas supply are to be considered, providing useful indications on different risk situations.

Keywords: Natural Gas, LNG, Process safety, Risk analysis, QRA, Case study, Supply alternatives, Gas pipeline, Iso container, Individual risk, Societal risk.

Session	[MO3B]—Risk Management
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Atrium 2

MO3B: 298 **16:10 hrs**

Justifying the Basis of Risk Decisions in a Pandemic – Framing the Issues

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The COVID 19 pandemic has posed difficult and contentious issues for society to deal with. At this scale, the kind of utilitarian calculus that has traditionally underpinned contentious developments in more normal situations, seems no longer to command the unquestioning acceptance of impacted populations. The paper discusses the applicability of Cost Benefit Analysis approaches to a range of issues that have arisen that have implications beyond the pandemic context. One view is that the future costs of lockdowns could be orders of magnitude greater than the immediate benefits. However, there are equally compelling arguments that, in the long run the benefits of lockdowns will exceed the costs. This calculus whichever way it goes, seems to leave out a lot of reasonable caveats and ethical dimensions These decisions have to be taken under considerable degrees of uncertainty and the paper explores the extent and the problems this causes in the different decision dimensions. The examples discussed are taken mainly from decisions taken at the national level, by the Netherlands, Canada and the UK, as there seems to be little consensus on a consistent approach globally. The paper raises the ethical issues emerging from the fundamental approach seemingly required in a market driven society, where numbers must trump people with the implication that, if profit is regarded as represented only by numbers, people may become expendable commodities.

Keywords: QALY, COVID19, Cost benefit analysis.

MO3B: 489 **16:30 hrs**

Achieving Inherent Safety From Inherent Hazard and Risk Factors

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Inherent safety is considered the best approach to risk reduction. Academia and industry personnel have studied this topic for a long time. However, many misconceptions and lack of clarity still exist in the industry. Also, there have been many variations in defining the concepts and principles of inherent safety. The paper aims to analyse the concept in a novel way after reviewing past works on the inherent safety concept. The work focuses on the in-depth and systematic identification of hazards for better understanding. It seeks the factors contributing to creating the hazard to propose inherent safety measures. Identifying inherent hazard and risk factors makes it easier for the user to quickly find an inherently safer solution. This approach draws a clear distinction between three risk reduction measures, inherent, passive and active. Inherent safety measures try to reduce the hazard from origin or try to attenuate inherent hazard and risk factors, while passive and active measures only focus on reducing the consequences of accidents or hazardous events. They do not intend to reduce the inherent hazard and risk factor from the system. This paper presents a new definition of inherent safety with a new perspective and identifies the principles used to achieve inherent safety.

Keywords: Inherent safety, Inherently safer, Hazard, Risk management, Chemical process and systems, Oil and gas industry.

MO3B: 526 **16:50 hrs**

Comment Inclure La Malveillance Dans Les Analyses De Risques

Doctorant au sein de l'UTT, je conduis actuellement des recherches sur la résilience des organisations face aux risques malveillants. L'objectif de cet article est d'expliquer la particularité de ces menaces, de présenter la méthodologie d'analyse choisie pour les analyser et de nous appuyer sur un cas concret pour en déduire les avantages attendus.

MO3B: 529 **17:10 hrs**

Improving Risk Management of Smart City Lighthouse Projects Through Collaborative Governance and An Integrated Risk-Resilience Based Approach

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Smart City Lighthouse projects are a specific European innovation instrument for large-scale deployment and replication of Smart City and energy solutions. This cross-country and multidisciplinary setup fosters innovation, but it also leads to complexity. Risk management represents a key approach for handling this complexity and meet the various types of risks that can occur in smart city lighthouse projects. A review of current risk management practices in smart cities lighthouse projects has been conducted including all the existing seventeen Lighthouse projects. The review showed that the risk management in most lighthouse projects is in line with common standards as described in ISO 31000 and the Open PM2 Project Management Framework highlighting identification, analysis, evaluation, and treatment of project risks. However, the occurrence of several high-profile cybersecurity and privacy related vulnerabilities has uncovered the need to expand the risk management beyond these standards. The present paper investigates how the risk management can be improved through collaborative governance, highlighting stakeholder participation and involvement, and adopting an integrated risk-resilience based approach. A specific smart city lighthouse project is used to illustrate the discussion.

Keywords: Risk management, Smart city, Complexity, Collaborative governance, Resilience, Innovation.

Session	[MO3C]—Decision-making
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Espace Grand Angle2

MO3C: 355 **16:10 hrs**

Using Cognitive Work Analysis to Develop Predictive Maintenance Tool for Vessels

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Implementation of multisource sensors combined with data analysis systems (e.g. machine learning) might provide new solutions for predictive maintenance to improve sociotechnical system reliability. The Seanatic project aims to develop a decision support tool to increase maintenance processes in the maritime field, considering limits and benefits of human factor expertise. Under this perspective, this paper describes the Cognitive Work Analysis (CWA) approach for investigating new key functions that emerge in future maintenance sociotechnical systems. After phase one of the CWA was completed (WDA - Work Domain Analysis), the functions identified were used in the subsequent phases (ConTA - Control Task Analysis and SOCA - Social Organization and Cooperation Analysis) to highlight different implications for human cognitive activities. Realtime and prediction of machine breakdown of a vessel could be significantly reduced by assisting the chief engineer for supervision and planning activities. Based on a CWA approach, ecological design interfaces could support those activities.

Keywords: Cognitive work analysis, Control task analysis, Ecological interface design, Maritime maintenance, Social organization & cooperation analysis, Predictive maintenance, Work domain analysis.

MO3C: 449 **16:30 hrs**

An Overview of Machine Health Management in Industry 4.0

Minh Hung Ho[1,a], Amélie Ponchet Durupt[1,b], Nassim Boudaoud[1,c], Hai Canh Vu[1,d], Arnaud Caracciolo[2,e], Sophie Sieg-Zieba[2,f], Yun Xu[3,g] and Patrick Leduc[3,h]

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Nowadays, the fourth industrial revolution is happening with the new paradigm and technologies. One of the pillars of this revolution is the Industrial Internet of Thing (IIoT), which integrates sensors into the manufacturing system and helps to connect the machines, products and methods as an interconnected system. The amount of available data (5V: Volume, Velocity, Variety, Value, Variability) then continues to increase through various components (sensors, PLCs, etc.) (Iung (2018)). These data are usually used for the purpose of improving the performance of the production system. The important objective is keeping the production systems under continuous monitoring of system's function and corresponding health states. System health state can be found out by observing system behaviour data which are collected from installed sensors. Then we apply diagnostics and prognostics techniques on the observations: Prognostics and Health Management (PHM) (Pecht (2009)). Various precision sensors, high-speed data acquisition devices, computers and servers in IIoT constitute a new development space for PHM (Tianshu et al. (2019)). In this study, we provide an overview of PHM methods. The review focuses on data-driven approaches that rely on available observed data and statistical models.We have two main types of observed data: direct data and indirect data. The direct data are directly related to the system health status while this relation is indirect or partial for the latter (Si et al. (2011)). Thus, our study focuses on two types of models: the direct-observed-state models and the partial-observed-state models. Firstly, we review recent advancements of the direct-observed-state models which can be distinguished into continuous process and discrete processes. Secondly, we focus in more detail on the partial-observed-state models. Thirdly, we illustrate the implementation of PHM methodologies by a real world application where data collected from sensors are exploited to predict system health states. Finally, we identify the gap in this field and highlight future research challenges.

Keywords: Maintenance, Prognostics and health management, Industrial internet of things, Remaining Useful Life (RUL) prediction, Degradation design, Condition monitoring.

MO3C: 537 **16:50 hrs**

A Robust Optimization Model for Maintenance Planning of Complex Systems

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Nowadays, industrial systems become more and more complex[1]. They are usually composed of many dependent components. The component dependencies can be classified into different groups such as economic, stochastic, and structural dependence[2]. Among these dependencies, the economic dependence has been extensively studied because it can help to reduce significantly the maintenance cost when the maintenance activities are grouped. In the literature, a number of grouping optimization models have been developed and successfully applied to different industrial sectors[3]; however, the robustness of the optimal grouping solution has not yet considered. In fact, the grouping solution is usually determined based on the expected values of random variables (failure times, maintenance costs, etc.). This way of calculation does not guarantee the precision of the grouping solution in the short-term. The performance of the existing models is then very sensitive to several dynamic contexts that may occur over system life in real applications[4]. To overcome this limitation, we present in this paper a new grouping maintenance model with consideration of the solution robustness. For this purpose, robust optimization technique[5], which allows taking into account the uncertainties of the optimization model, was applied to find the robust grouping solution. The effectiveness of the proposed model and the robustness of the grouping solution are then analyzed through different numerical examples.

Keywords: Robust optimization, Grouping maintenance, Complex systems, Maintenance decision-making.

MO3C: 709 **17:10 hrs**

Maintenance Selection and Technician Routing on a Geographically Dispersed Set of Machines

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Session [MO3D]—Uncertainty Analysis
Day/Date/Time Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue Panoramique

MO3D: 081 **16:10 hrs**

Identification of Time-varying Parameters using Variational Bayes – Sequential Ensemble Monte Carlo Sampler

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This work presents an extended sequentialMonte Carlo sampling algorithm embedded with a Variational Bayes step. The algorithm is applied to estimate the distribution of time-varying parameters in a Bayesian filtering procedure. This algorithm seeks to address the case whereby the state-evolution model does not have an inverse function. In the proposed approach, a Gaussian mixture model is adopted whose covariance matrix is determined via principle component analysis.

As a form of verification, a numerical example involving the identification of inter-storey stiffness within a 2-DOF shear building model is presented whereby the stiffness parameters degrade according to a simple State-evolution model whose inverse function can be derived. The Variational Bayes - sequential ensemble Monte Carlo sampler is implemented alongside the Sequential Monte Carlo sampler and the results compared on the basis of the accuracy and precision of the estimates as well computational time. A non-linear time-series model whose state-evolution model does not yield an inverse function is also analysed to show the applicability of the proposed approach.

Keywords: Variational bayes, Bayesian model updating, Sequential monte Carlo, Uncertainty quantification, Gaussian mixture model, Markov model.

MO3D: 084 **16:30 hrs**

Robust Tuning of Robbins-Monro Algorithm for Quantile Estimation – Application to Wind-Farm Asset Management

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In uncertainty quantification of numerical simulation model outputs, the classical approaches for quantile estimation requires the availability of the full sample of the studied variable. This approach is sometimes not suitable as large ensembles of simulation runs need to gather a prohibitively large amount of data and computer memory. This problem can be solved thanks to an on-the-fly (iterative) approach based on the Robbins-Monro algorithm. We numerically study this algorithm for estimating a discretized quantile function from samples of limited size (a few hundreds observations). We also define "robust" values of the algorithm parameters in two practical situations: when the final number of the model runs N is a priori fixed and when N is unknown in advance (it can then be minimized during the study in order to save cpu time cost). This method is applied to the estimation of indicators in the field of engineering asset management for offshore wind generation. We show how the proposed algorithm improves the efficiency of the tool to support risk informed decision making in the field of offshore wind generation.

Keywords: Uncertainty, Online statistics, Robbins-Monro, Averaging, Offshore wind, Operations and maintenance.

MO3D: 089 **16:50 hrs**

Consideration of Test Bench Uncertainty in Reliability Predictions using Design of Experiments

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The parameterization of life models developed by using Lifetime-Design of Experiments (L-DoE) requires life data. Usually, the data is obtained using sensors that characterize constantly changing units such as the position of moving objects and the ambient temperature. An important issue here is data variability, which is usually due to experimental and measurement errors. Running processes always exhibit variability due to fluctuations in the factors, such as the ambient temperature. Any uncertainty in the sensors leads to uncertainties in the recorded data. However, since these data are directly used for the development of a test plan on which the failure predictions are based, corresponding uncertainties are to be expected here as well. To

improve reliability predictions, this paper proposes a simulative approach that implements the uncertainties of test bench into the life modelling based on L-DoE. By using the Monte Carlo method, the effect of the uncertainties of the implemented sensors on the experimental design is projected. This allows to derive the uncertainty in the development of life models and to simulate the effect on failure predictions. The result of the simulation is a life model that considers the uncertainties of the sensors used in the test. Using the Proportional Hazard model and a full factorial experimental design it is shown that without consideration of test bench uncertainties uncertain reliability predictions can be expected.

Keywords: Design of Experiments (DoE), Lifetime modelling, Uncertainty, Test bench, Monte carlo simulation.

MO3D: 228 17:10 hrs

Deriving Prior Knowledge from Lifetime Simulations for Reliability Demonstration while Considering the Uncertainty of the Lifetime Model

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Although lifetime simulations are today widely used to predict the failure of a product or component for field operation during early stages of product development processes, the data generated from them are not used as prior knowledge for reliability demonstration due to a lack of adequate statistical content. The results are thus only used to assess design variants and compare requirements to the products' simulated performance. Using an SN curve as a sample lifetime model, it is demonstrated how the necessary reliability statement can be obtained, including a confidence level. Initial work has shown how this can be achieved but has not considered the error in extrapolating the lifetime model to the field load. In this paper, the uncertainty of the lifetime model is therefore taken into account by applying the bootstrap procedure to the test sample data and considering various calculation methods for the lifetime model. Studies indicate that the pearl string method is preferable to the load level method because the load level method can only provide accurate results if the underlying data is appropriate. A Weibull distribution with a confidence interval calculated by following the presented methodology can be turned into a beta distribution and used as prior knowledge for reducing the required number of samples in reliability demonstration testing.

Keywords: Prior knowledge, Lifetime data, Simulation, Confidence level, Bootstrapping, Reliability demonstration, Success run test.

Session	[MO3E]—Organizational Factors and Safety Culture
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Amphi Jardin

MO3E: 015 16:10 hrs

Spontaneous Volunteering During the Utøya Terror Attacks – A Document Study

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During the terrorist attacks in Norway 22th of July 2011, 77 persons was killed and many more injured. The attacks led to massive, multifaceted efforts of civil society, especially concerning the attacks at Utøya, for example - nearby civilians took part in dangerous rescue missions in private boats and more than 250 youths was taken care of in an ad hoc rescue center at a nearby camping. Most of the post-catastrophic research and investigations on the terror attacks have focused on the efforts of the official first responders and their respective authorities, and to a lesser degree highlighting the role of response from community and bystanders. As part of the ENGAGE project, we conduct a document study to shed light on civil society contributions to societal resilience during the terror attacks at Utøya. Based on academic literature investigation reports, newspaper articles and autobiographical books, we represent the Utøya terror attacks from what is known regarding helpers. We emphasize four domains of analysis, where we identify and discuss i) characteristics of the academic literature on the Utøya attacks, ii) a typology of actors, ii) volunteer coping actions, and iii) contextual factors. The findings show a dynamic and autonomous nature of spontaneous volunteering, influenced by contextual factors like degree of trust in formal response organizations, spatial proximity, professional and local knowledge.

Keywords: Volunteer, Terror, Crisis management, Resilience, Utøya.

MO3E: 025 **16:30 hrs**

Super Users as Learning Agents in Organization's Eco-System of Learning?

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Purpose: Even though there are numerous attempts of clarifying crucial factors for successfully implementing technological changes in organizations, research shows that such processes very often are considered unsuccessful (e.g. Dwivedi et al., 2015). Recruiting and using so-called super users when introducing new technology in organizations, has become a common trend (Sitthidah & St-Mauritz, 2016). However, little is known about the criteria that optimally should ground the specifics for choosing a super user. From a safety aspect, having well founded process on how a super user should teach staff how to use new technology, is of utterly importance, as wrong understanding of how it works could potentially have fatal outcome.

Research question: *Which criteria should be emphasized when selecting super users?*

Method: 10 semi-structured interviews were conducted and analyzed using thematic analysis.

Results: The results were that criteria for super users should be (1) availability and local knowledge (2) technological skills (3) pedagogical skills), and (4) proactiveness.

Conclusion: Based on a safety aspect, recruiting a super user internally would help provide the important understanding of local knowledge. Further, recruiting internal staff would provide

learning on an organizational level. This is demonstrated by a model called the organization's eco-system of learning (Ecso-Learn).

Keywords: Safety, Organizational changes, New technology, Organizational learning, Super user, Learning agent.

MO3E: 066 **16:50 hrs**

Professionalization in Safety : Enhancing Socialization by Eliciting Forms of Identity

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Professional socialization is a major challenge for the safety professional throughout his career (Wybo & Van Wassenhove, 2016). In order to capture the complexity of the process of professional socialization of safety practitioners, a useful framework has been established with the concept of forms of identity which encompasses both professional recognition of skills and a satisfactory career path. The forms of identity are the result of a double transaction (biographical & relational) which structures the professional socialization of individuals (Dubar, 1992). On the one hand, the evolution of professional identity is linked to a process of recognition by peers and institution, which can be seen as a relational transaction between the safety professional and the organization. On the other hand, the construction of social identity can be seen as an internal biographical transaction polarized between continuity and rupture. Each safety professional has to deal with their own way of socializing. This paper presents the educational innovation implemented within the PSL-Mines ParisTech post-graduate master "Industrial Risk Management" between 2010 and 2020 as a part of a design that promotes effective learning environment (Foussard & Van Wassenhove, 2019). To support the future safety professional in this sensitive process of professional socialization, several initiatives based on the framework of forms of identity have been set. A discussion on the relevance of this learning device is given on the basis of qualitative feedback of the alumni.

Keywords: Professionalization in safety, Professional socialization, Safety education programs, Forms of identity, Safety culture.

MO3E: 091 **17:10 hrs**

Safety and Security: A Cross-Professional Comparison

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From the theoretical perspectives, traditionally, safety and security represent different contexts, which challenges exchanging ideas, methods, and results between these two scientific fields. Therefore, a distinction between these two contexts, based on the intentionality behind unwanted events, the way risk is understood, and the methods used to assess and manage risk in these contexts. From the practical point of view, distinguish between the roles and responsibilities of these two professional communities are unclear. This study explores the extent of the commonalities and differences in safety and security professionals' current stage. We conduct a qualitative analysis based on 28 semi-structured interviews with the safety and security domain professionals, focusing on the conceptual narratives, responsibilities, and risk assessment approaches from a practical perspective. Our findings indicate that while the professionals in these two fields strongly distinguish between the context of their activities, they share many commonalities regarding their day-to-day tasks. A fundamental common problem in managing risk is that it is difficult to express uncertainty and determine how likely it is that an incident/event happened; we are unable to give strong arguments for specific likelihood assignments of threat occurrence. Yet, a likelihood can always be assigned based on available knowledge. A holistic risk management approach, integrating risk- and resiliencebased thinking, acknowledges this and considers a set of qualitative and quantitative methods to reflect this (lack of) knowledge.

Keywords: Safety and security, Security, Security professionals, Safety professional, Resilience-based risk management, Increase preparedness.

Session	[MO3F]—Security
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Espace Grand Angle

MO3F: 706 **16:10 hrs**

Contrastive Feature Learning for Fault Detection and Diagnostics

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A multitude of faults can occur in operating systems. Some pose a safety-critical problem instantaneously and therefore, require immediate intervention. Others evolve slowly and only require maintenance if they are particularly pronounced. Due to the vast variety of different faults, it is not efficient to react to each detected fault with the same maintenance action. Instead, the maintenance intervention planning needs to take into account which type of fault is detected and how severe the fault is. This allows planning maintenance efficiently. Too early maintenance downtime can be prevented and intervention time can be reduced e.g. by preparing required spare parts.

To achieve this, a fault diagnostics model is required that can accurately isolate different faults and determine their severity. Yet, specific challenges apply when learning data-driven fault diagnostics models. First, an operating asset is exposed to varying operating conditions and external influencing factors that cannot be controlled or known before. This results in high variability of the condition monitoring data within the healthy condition that is not caused by faults. A data-driven model might raise a false alarm for inherently unknown variations in the data if these were not part of the training distribution. Adding complexity to the task of defect diagnostics is that data often lacks detailed labeling to diagnose a fault. For example, the operator might not distinguish between different fault types or different fault severities in its maintenance reports. In that case, detailed information on the fault type and its severity is lacking when training the corresponding models, which essentially makes it an unsupervised learning task. The task of unsupervised fault diagnostic is often approached by clustering a low-dimensional feature representation of the data. Auto-Encoders (AE) are often used to learn a compact feature representation. Yet, the objective when training an AE is to fully reconstruct the input signal i.e. to pass all information about the data through the feature layer including data variations relating to varying operating conditions. This makes them sensitive to changing operating conditions at inference time. Contrastive learning poses an interesting alternative to extract features that explicitly aims to extract

semantic meaning. The feature space is optimized with the triplet loss such that similar data points are closer to each other than dissimilar ones. In its supervised implementation, similar data points correspond to those with the same label whereas dissimilar data points are those with different labels. Hence, the triplet loss explicitly is designed to cluster data in the feature space according to their class label. This results in a compact feature representation.

In this work, we propose contrastive learning for the task of defect diagnostics. Our work is the first that applies the triplet loss to PHM applications. Further, we adapt the triplet loss to the case where no refined labeling is available. The resulting feature representation of the data shows to be particularly suited for defect identification under the limitation that certain operating conditions have not been observed in the training dataset. Our evaluation is conducted on the CWRU Bearing benchmark dataset.

Keywords: Faults detection & diagnostics, Contrastive learning.

MO3F: 175 **16:30 hrs**

Physical Security Risk Analysis for Mobile Access Systems Including Uncertainty Impact

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Protection against car theft, involving organized crime, is a growing threat for car owners as well as fleet management providers. This brings the use of security technologies into automotive industry. The evaluation of security and the justified use of measures to reduce vulnerability of car security systems is perceived as a special challenge for vendors and users of mobile access systems (MAS), as usually only limited resources for design and analysis are available. A lack of adequate reference works and specifications in the form of concrete recommendations for action, guidelines or standards often leads to proprietary security assessments heavily relying on compliance checks. These assessments often lack sufficiency regarding application-specificity and target-orientation in terms of a good cost benefit ratio. This is true for MAS in particular, as they are relatively new products with specific use cases and boundary conditions. The open-available Performance Risk-based Integrated Security Methodology (PRISM) allows a performance-based physical security assessment of critical infrastructures (CRITIS) and initiated a paradigm shift towards performance-based methods within this area. However, PRISM comprises semi-quantitative approaches only and thus does not allow for the consideration of uncertainty impact. Moreover, the approach has not been applied to mobile access systems (MAS) yet. This paper aims at applying the concept of PRISM to the use case of MAS by extending and optimizing it to enable a holistic risk assessment considering uncertainties.

Keywords: Mobile access systems, Security, Risk analysis, PRISM, Uncertainty, Decision making under uncertainty.

MO3F: 231 **16:50 hrs**

Cyber and Electromagnetic Activities and Their Relevance in Modern Military Operations

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The paper examines issues related to coexistence and integration of military activities conducted within the cyberspace and electromagnetic environment, as inseparable parts of our security environment. Contemporary and emerging security threats as well as lessons learned from recent military operations have already proved that in order to achieve operational objectives in the traditional physical domains (land, air, maritime, space) it is crucial to ensure dominance in the non-physical domains, i.e. the cyberspace, electromagnetic environment and information environment. As they overlap each other, while being exploited by multiple military and non-military stakeholders and actors, it is necessary to identify these overlaps. At the same time, to deliver the synergic effect, an operational battle staff need to deconflict, coordinate, synchronize and integrate cyber and electromagnetic activities (CEMA) with other supporting activities (e.g. intelligence, information operations etc.). The authors describe the fundamentals of the CEMA concept, supported by a case study of its practical employment in military operations. They also compare various approaches applied to implementation of this concept by selected armed forces and security organizations. Based on the findings of this comparison, common and specific features of different approaches are specified. The results and findings presented in the article can be used during the implementation process of the CEMA concept not only into the doctrinal documents of national armed forces, but they could also provide specific solutions in support of future deployments of multinational task groups.

Keywords: Cyber operation, Electronic warfare, Information operations, Spectrum management operation, Military operation, Intelligence, Non-physical domains, Threat.

MO3F: 234 **17:10 hrs**

Scenario Analysis of Threats Posed to Critical Infrastructures by Civilian Drones

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Threats posed by civilian drones are becoming an increasing security risk for critical infrastructures as well as events or companies. In order to protect an asset against a drone intrusion a security system is necessary, which in general is described by its capabilities of protection, detection, and intervention. The variety of different threat scenarios posed by drones raises the need for detailed analysis of scenario specific requirements on detection systems. However, there is a lack of comprehensive scenario analyses in the literature that include relevant parameters for detection. Thus, in this paper a scenario analysis is conducted to identify consistent threat scenarios including factors critical for drone detection. The study is based on morphological analysis and applies methods of influence analysis and Cross-Impact Balance analysis. Using these methods, factors that influence the detectability of drones are specified and key factors identified. Potential states of these key factors are determined based on literature reviews or expert interviews. For the assessment of internal consistency of a scenario, a Cross-Impact-Balance analysis is conducted. Exemplarily, the paper shows how a remaining consistent scenario can be applied to derive requirements for a drone detection system or to validate existing systems regarding suitability for feasible threat scenarios.

Keywords: Critical infrastructure protection, Security, Civilian drones, Scenario analysis, Morphological analysis, Cross-impact analysis, UAV, Requirements analysis, Drone detection system.

Session	[MO3G]—Oil and Gas Industry
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Atrium 3

MO3G: 073 **16:10 hrs**

Novel Application of Technology in Subsea Safety Instrumented System: Battery-Based Shutdown System

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The all-electric paradigm shift in the subsea oil & gas industry brings with it several new technologies, including novel use of existing technologies. Key components in this paradigm are battery systems and battery management systems (BMS). This paper investigates features in commercially available BMSs and how they can be used in subsea valve actuation, and more specifically subsea Christmas Tree (XT) barrier valve actuation. In this way, the safety challenges of implementing a battery-based shutdown system are investigated, where motor control systems, batteries and BMSs are vital elements. These technologies are all well-known, though not commonly used in subsea safety valve actuation applications. Consequently challenging the perception of a subsea safety system, as well as the current requirements and regulations. In a case study, the all-electric control system architectures proposed by Okoh et al. (2019) are utilized for discussion on impact and compliance towards functional safety requirements, and oil & gas industry specific requirements. The safety challenges for the architectures can be overcome, however this paper reveals a demand for updated oil & gas specific requirements to accommodate novel application of technology. It is evident that to reach an optimal safety solution for the different architectures, the requirements should be written such that the safety-critical features can be optimized with regards to the true objective of the safety system, enabling complexity minimization through best practice safety engineering.

Keywords: Norwegian continental shelf, Subsea, XT, Functional safety, Battery, BMS, All-Electric, Actuator.

MO3G: 180 16:30 hrs

Rescue of Personnel after Emergency Evacuation from Offshore Petroleum Installations

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The Norwegian Oil and Gas Association in Norway has developed a set of guidelines on how cooperation on area-based emergencyresponse should be practiced. The guideline covers emergency evacuation but has limited focus on rescue of personnel after evacuation. Rescue in this context implies picking up, or escorting, evacuated personnel that are in the water, life-rafts, or lifeboats, to a safe location. Rescue of personnel involves use of shared area-based resources, such as Fast Rescue Craft from emergency response and rescue vessels and search and rescue helicopters. Rescued and injured personnel will be given life-saving first aid and medical treatment and transported to an onshore base. The paper reviews lessons learned from emergency evacuation cases to sea on the Norwegian Continental Shelf and worldwide offshore oil and gas operations. The research is based on a study performed for the Petroleum Safety Authority Norway in 2019, where rescue of personnel from sea after emergency evacuation was one of the main topics addressed. The lessons learned covers topics such as availability of resources; cooperation between resources; responsibilities when utilizing shared resources; and performance influencing factors for successful rescue operations.

Keywords: Offshore installations, Emergency preparedness, Evacuation, personnel rescue, Area-based emergency response, Shared resources, Lesson learned.

MO3G: 188 16:50 hrs

Emergency Communication Challenges in the Oil and Gas Sector of Norway

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The purpose of the work presented in this paper, which was conducted for the Petroleum Safety Authority Norway (PSA), is to give the oil and gas industry a better understanding of the role and vulnerability of communication networks, especially in emergency situations when a defined situation of hazard and accident (DSHA) has occurred. The paper focuses on external communication between offshore and onshore in emergency situations, i.e., emergency communication to land. This is part of a larger project where the main goal has been to gain knowledge about risks, threats, vulnerabilities, and the importance of Information and Communication Technology (ICT) security for industrial systems. The work is mainly based on document reviews, interviews, and work meetings. Interviews were conducted with selected oil companies, rig companies and telecom operators. The work was carried out in an interdisciplinary project team. The content includes: i) the role of external communication networks during DSHAs, ii) risks and vulnerabilities in the communication networks, iii) consequences of the loss of connectivity, and iv) challenges and suggestions for improvements of regulations and standards. Fifteen recommendations are provided regarding measures for the industry, four of which are aimed at changes in standards, and eight recommendations are given regarding measures for the PSA, one of which is aimed at supervision and the other at changes in regulations.

Keywords: Emergency communication, External communication, Emergency preparedness, ICT security, Risk, Vulnerability, Regulations.

MO3G: 245 17:10 hrs

Digitalization in the Norwegian Oil- and Gas Industry: Identified Challenges

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The Norwegian oil- and gas industry is being digitalized in search of more efficient operations, increased extraction of resources, and improved HES. Although offering appar-

ent opportunities, we also face considerable challenges when a traditional and safety-oriented industry applies modern information technologies, including cloud-based services. We have interviewed several actors to understand the drivers for ongoing digitalization processes and to uncover challenges related to the increased coupling between IT (information technology) and OT (operational technology),including safety-instrumented systems. Main findings from interviews and analysis highlight growth in coupling from OT systems to IT systems and further to cloud-based solutions, and increasing amounts of data flowing upwards. We found a sound awareness of not imposing control from IT to OT though, but there are however reasons for concern. These are discussed in the paper. We discuss the main findings and their potential implications and conclude with a series of recommendations to the industry and supervisory authorities.

Keywords: Digitalization, Oil and gas industry, Cybersecurity, Safety, IT-OT integration.

Session	[MO3H]—Railway Industry
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Cointreau

MO3H: 008 **16:10 hrs**

Statistical Assessment of Safety Levels of Railway Operators

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Recently the European Union Agency for Railways (ERA) has received a mandate for "the development of common safety methods for assessing the safety level and the safety performance of railway operators at national and Union level", see EU Directive (2016). Currently, several methods are under development.

It is of interest how a possible candidate would behave and what would be the advantages and disadvantages of a particular method. In this paper, we study a version of the procedure. On the one hand side we analyse it based on the theory of mathematical statistics. As a result we present a statistically efficient method the rate-ratio test based on a quantity that has smaller variance than the quantity handled by the ERA. Then, we support the theoretical results with the help of a simple simulation study in order to estimate failure probabilities of the first and second kinds. In particular, we construct such alternative distributions which the decision procedure cannot distinguish. We will show that the use of procedures that are optimal in the sense of mathematical statistics combined with the use of a characteristics that has small spread – here the number of accidents – is advantageous.

Keywords: Railway operators, Accident reporting, Rateratio test, Safety level, National reference value, Compound poisson distribution.

MO3H: 009 **16:30 hrs**

Application of the Cox Regression Model for analysis of Railway Safety Performance

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The assessment of in-service safety performance is an important task, not only in railways. For example, it is important to identify deviations early, in particular possible deterioration of safety performance, so that corrective actions can be applied early. On the other hand the assessment should be fair and objective and rely on sound and proven statistical methods.

A popular means for this task is trend analysis. This paper defines a model for trend analysis and compares different approaches, e.g. classical and Bayes approaches, on real data. The examples show that in particular for small sample sizes, e.g. when railway operators shall be assessed, the Bayesian prior may influence the results significantly.

Keywords: Cox model, Poisson distribution, Railway safety, Severe accident, Estimator, Bayes.

MO3H: 035 **16:50 hrs**

Research on Fault Propagation Characteristics of Fully Automated Operation System Based on Complex Network

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This paper selects the Vehicle On-Board Controller (VOBC) subsystem of Beijing Metro Yan Fang line fully automatic operation system as the research object. By analyzing the

fault data of the VOBC subsystem, a fault propagation model of VOBC subsystem is established with failure events as nodes and causal relationships between failure events as connections based on the complex network theory, and the statistical characteristics of the established fault propagation model are analyzed. In order to quantitatively analyze the fault propagation path and mine the fault propagation rules, based on the established model, the load-capacity model of Cascading failure in complex networks is adopted to design an algorithm to search the maximum possible fault propagation path in VOBC fault propagation network, and it is found that under the condition of controlling cost, the initial danger degree and danger degree of failure event are reduced by taking certain prevention and control measures, which can shorten the length of the maximum possible fault propagation path and improve the reliability of the system operation.

Keywords: Complex network, Fully Automatic Operation System (FAO), Fault propagation, Cascading failure.

MO3H: 133	**17:10 hrs**

A Case Study on Managing the Complexity of Service Failure Modes in IoT Systems

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With the release of IoT devices an increasing amount of Operation Technology (OT) functionalities is depending on Information Technology (IT) services. Hence, these edge-based or cloud-based IT services can become mission critical. Therefore, we need to include them into the reliability analysis of the system. However, functions of a system, that are partly implemented by OT and IT services are subject to a significant amount of failure modes, which need to be assessed during the reliability analysis. To manage the combinatorial complexity of component failure modes in heterogeneous IoT systems realizing missing critical functionalities, we propose the application of the Component Fault Trees (CFTs) methodology. In this paper, we illustrate the advantages of the CFT methodology for the reliability analysis of complex and heterogeneous IoT systems by a case study in the domain of railway control systems. In this case study, traffic control systems provide crucial functions which are enhanced by a Traffic Management System (TMS). The case study clearly shows how the usage of the CFT methodology eases the analysis of such a complex, heterogeneous IoT system by managing the combinatorial complexity of component failure modes.

Keywords: IoT, Reliability, Fault tree, Component fault tree, CFT, Case study.

Session	[MO3I]—AI for safe, secure and dependable operation of complex Systems
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Giffard

MO3I: 156	**16:10 hrs**

Graph Networks for Power System Dynamics Prediction

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The power system network has been one of the most complex nonlinear systems in the world and predicting, maintaining and improving its reliability has been the pursuit of the entire industry 1. Power system dynamics reflect the stability status of the system and provide critical reference for secure system operation. The physical phenomenon of power system dynamics are normally computed by sophisticated time-domain simulation tools, the accuracy of which largely rely on the modelling precision of the power system components. However, the recent revolution of new technologies in power systems, such as the integration of renewable energy sources, makes the significant challenges in the performance of traditional tools which are not able to provide sufficiently detailed models for new emerging participants. Hence, to overcome these challenges, new prediction methods are requiured to predict the power system dynamic states. With the increasing availability of large amounts of measurement data in power systems, machine learning methods provide a promising direction of training simulators directly using measurement data. These methods explore information from acquired data and are more robust to the introduced uncertainty. However, the end-to-end learning methods show limited performance when facing large state spaces and complex dynamics. Furthermore, the models are inherently 'black-box' models resulting in a limited interpretability. Inspired by the pioneering work in the field of graph networks that combine the learning capability of neural networks with the intepretability of the physical properties 2, we propose 'Graph Network based Simulators'(GNS) for power system rotor angle dynamics. We first model the dynamic state variables at each bus as nodes in the graph. A full connectivity between each node pairs is assumed such that the pairwise electrical correlations are approximated with the message function without any prior knowledge about the physical topology.

The graph networks introduce strong inductive biases motivated by power system properties which improve the performance of the algorithm, reduce the amount of required training data and improve the extrapolation capabilities. Also, the method provided more flexibility compared to the physics-informed neural network-based simulator 3 since it does not need the specific topology connection information in the training. Our framework was validated on a 4-bus power system to accurately simulate rotor angle dynamics under different operating conditions. As further work, we plan to investigate the generalisation ability, data efficiency and scalability of this method.

Keywords: Graph network, Power system dynamics, Prediction.

MO3I: 316	**16:30 hrs**

Semi-Supervised Learning with Temporal Variational Auto-Encoders for Reliability

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Within the field of fault diagnostics and prognostics of industrial machinery and systems, deep learning models have risen in popularity in recent years, mostly due to their ability to automatically extract features from multi-sensor data. Nevertheless, while novel sensing technology has made possible for the mainstream industry to equip their physical assets with plenty of sensors and therefore acquire massive quantities of operational data, the labeling process (i.e., identification of health states) of such data is still an open problem to overcome in order to use it effectively alongside AI techniques. A novel solution to this problem is to develop algorithms with semi-supervised capabilities that can both use the scarce and expensive-to-produce labeled portion of the data as well as the abundant, but unlabeled data samples. In this paper, we present a coupled training algorithm that can be used to conjunctively train a fully unsupervised variational auto-encoder along a fully supervised recurrent neural network to perform fault diagnosis and prognosis as well remaining useful life prediction using time series as input data. The coupled training of the model is capable of encoding information from both the supervised and unsupervised portions of the data into the gradients, effectively performing semi-supervised learning. We demonstrate the proposed approach by a prognosis case study involving turbofan data from the well-known CMAPSS benchmark dataset.

Keywords: Deep learning, Semi-supervised learning, Variational auto-encoders, Reliability, CMAPSS, Prognosis.

MO3I: 413	**16:50 hrs**

Bearing Fault Diagnosis Method Based on Multi-Class Support Vector Machine and Grey Relational Degree

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In modern machinery manufacturing and applications, the components are becoming more and more inseparable. When one of the parts fails, it may affect the normal operation of the entire equipment. That is why the fault diagnosis has become very crucial in industrial applications. Finding the problematic parts as early as possible can avoid costly accidents in time. This paper proposes a new rolling bearing fault diagnosis method based on grey relational degree (GRD) and multi-class support vector machine. First, the public dataset of Bearing Center of Case Western Reserve University (CWRU) and the public dataset of the team at Xi'an Jiaotong University (XJTU-SY) are used to form sample sets and build multi-domain feature sets. Then, we use the ReliefF algorithm to reduce the dimensionality of the feature set to establish a new feature subset. Then, grey relational degree classifier and multi-class support vector machine classifier are used for fault diagnosis, respectively. Lastly, the fault diagnosis effects of the two classifiers were compared. The results show that both of these two classifiers can efficiently identify rolling bearing faults, and the multi-class support vector machine classifier performs better.

Keywords: GRD, Multi-class support vector machine, Fault diagnosis, CWRU, XJTU-SY.

MO3I: 478 17:10 hrs

A Temporal Pyramid Pooling-Based Convolutional Neural Network for Remaining Useful Life Prediction

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Remaining Useful Life (RUL) prediction is a key issue in Prognostics and Health Management (PHM). Accurate RUL assessments are crucial for predictive maintenance planning. Deep neural networks such as Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) have been widely applied in RUL prediction due to their powerful feature learning capabilities in dealing with high-dimensional sensor data. The sliding time window method with a predefined window size is typically employed to generate data samples to train such deep neural networks. However, the disadvantage of using a fixed-size time window is that we might not be able to apply the resulting predictive model to predict new sensor data whose length is shorter than the predetermined time window size. Besides, as the length of sensor data varies, the traditional unchanged and subjectively set time window size may be inappropriate and impair the prediction model's performance. Therefore, we propose a Temporal Pyramid Pooling-Based Convolutional Neural Network (TPP-CNN) to increase model practicability and prediction accuracy. With the temporal pyramid pooling module, we can generate data samples of arbitrary time window sizes and use them as inputs of CNN. In the training phase, CNN can learn to capture temporal dependencies of different lengths since we feed in samples with different time window sizes. In this novel manner, the learned model can be used to test data with arbitrary sizes, and its predictive ability is also improved. The proposed TPP-CNN model is validated on the C-MPASS turbofan engine dataset, and the experiments have demonstrated its effectiveness.

Keywords: Remaining useful life, Deep learning, Convolutional neural network, Temporal pyramid pooling, Time window size.

Session	[MO3J]—Decision Science for Resilience
Day/Date/Time	Monday, 20 Sep. 2021/16:10–17:30 hrs
Venue	Botanique 2

MO3J: 204 16:10 hrs

A Catalog of Change for the Prediction of Posible Scenarios After a Natural Disaster

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This study proposes a novel method to assess damages in the built environment and its corresponding economic impact after a natural disaster, using a deep learning work flow to quantize it. Thanks to an automated crawler, aerial images from before and after a natural disaster of 50 epicenters worldwide were obtained from Google Earth, generating a 10,000 aerial image database with a spatial resolution of 2 m per pixel. The study starts by using the algorithm U-Net [1] to perform semantic segmentation of the built environment from the satellite images in both instances (prior and post-natural disaster). For image segmentation, U-Net is one of the most popular and general CNN architectures. The U-Net algorithm used reached an accuracy of 95.5% in the segmentation. After the segmentation, we compared the disparity between both cases represented as a percentage of change. To create a numerical vector characterizing the events more precisely, the geographical characteristics of the location (climate, hydrography, and population) and feature descriptor of the satellite images were considered. Moreover, we added to these values specific details about the disaster found in the database EM-DAT [2] such as type of event, magnitude, number of people affected, material losses, and investment in the housing sector by humanitarian organizations. The former numerical features were introduced in a clustering algorithm called Self Organizing Maps (SOM) [3] to cluster similar disasters depending on their previously assigned characteristics. In this way, a map of changes is created where the 50 natural disasters are organized according to the change that occurred and the respective response and consequence. After a natural disaster, this map of changes serves as a predictor for future cases, allowing predicting potential changes based on a satellite image and the sector's geographical condition. With this information, an urban planning process can begin immediately to mitigate the impact of the disaster.

Keywords: CCN, U-Net, Change detection, Disaster prediction, SOM, Satellite imagery, Disaster data.

MO3J: 384 **16:30 hrs**

Impact of Distributed Decision-Making on Energy and Social Systems' Resilience: A Case Study of Solar Photovoltaic in Switzerland

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Solar photovoltaic ("PV") adoption has largely occurred as the result of a distributed decisionmaking process, whereby individual people and businesses install the technology on their own property. The decentralization of energy systems decision-making is challenging to energy systems planners, who no longer wholly control systems development. In addition, the factors motivating individual solar adopters may be different than those traditionally governing energy systems infrastructures. Electricity systems and their interdependent critical infrastructures may therefore be exposed to new risk, reliability, and resilience challenges due to solar PV deployment. By contrast, solar PV deployment could also address some of these challenges by providing diversity and flexibility in energy generation, as well as by lowering the cost of energy for self-consumers. Given solar PV's complex impacts, energy system planners ought to be provided with decision-making support for understanding how certain policies will affect overall systems resilience. In that aim, we explore the impacts of distributed decision-making on energy and social resilience using solar PV uptake Switzerland as a case study. Considering the capability of solar PV for providing energy autonomy during normal or emergency operation and financial relief from energy bills, we define a metric for combined energy and social resilience using total energy produced and relative income. We then apply an optimization model to compare historical solar PV deployment to that which might be considered optimal for combined energy and social resilience objective. We also compare our results to those obtained when considering either energy or social equity only. Our methods are readily applicable to decisionmakers in other jurisdictions and can be tailored to account for different policy goals, therefore contributing to resilience-based decision making in practice.

Keywords: Resilience, Solar photovoltaic, Decision-making, Electricity system, Switzerland.

MO3J: 719 **16:50 hrs**

Flood Risk Assessment and Application of Risk Curves to Enhance Resilience

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A transportation network is a critical infrastructure system that serves everyday life, provides the backbone of economy, and is critical to national safety. And careful design of such a system is required to ensure smooth daily operation under stable conditions. However, with everchanging climates, transportation systems are exposed to significant weather-related hazards, with flooding events shown to be the dominant hazard in the U.S. due to their frequency and intensity. While flood events affect state agencies by requiring direct tax-dollar investments to repair damages, they also adversely influence communities by producing substantial indirect losses, and this can motivate state agencies, asset owners, and planners to develop with costeffective mitigation strategies. However, the uncertainty of flooding and the inter-system interdependency between infrastructures (such as roads and bridges) and traffic users on one hand and limited budgetary resources on the other hand, combine to challenge the design of a costeffective risk mitigation strategy. This is exacerbated by the fact that the estimation of indirect losses associated with closures resulting from damaged assets is difficult to achieve. To address such gaps, this paper develops an integrated risk assessment method that synthesizes various inputs, including hazards (here inland flooding), geographic features, spatial distribution of assets, and traffic, to simulate a real-life transportation system. This framework is capable of estimating actual physical infrastructure damages as well as quantitatively evaluating the indirect losses of traffic users such as traffic delays and opportunity costs closely associated with flood risk. Based on risk assessment, a curve fitting of the annual probability of exceeding a state of monetary flood risk can be generated through various simulations of flood scenarios, and decision-makers can use this flood risk curve along with community-based prevention expectations of risk to implement proper mitigation strategies.

MO3J: 771 **17:10 hrs**

Dynamic Credal Networks for Resilience Assessment of Complex Engineering Systems

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Complex engineering systems are of paramount importance for the correct operation of installations that allow functioning of the modern society and its economy. These systems are constantly under uncertain and potentially damaging conditions that may alter their operational performance. New system designs should consider safety aspects that maintain safe operating conditions while coping with disruptive events. In response to this need, the relatively new discipline of resilience engineering has been formulated to improve the safety of such complex systems. Resilience assessments must be carried out to study the system recovery after a disruptive event has occurred. Probabilistic models like fault tree or event tree analyses have been widely applied in safety-critical sectors such as process and/or nuclear industry due to their flexibility to model complex engineering systems and uncertainty quantification. However, such techniques moderate the modelling scope when representing the interdependencies of the components in the system and variations in time over a disruption event. Moreover, additional complications in the resilience assessment process arise when considering the epistemic uncertainty due to the lack of knowledge about the events and the operating conditions.

Dynamic credal networks are proposed in this work to model complex systems whose performance evolves in time. The methodology aims to quantify resilience in terms of the availability of the components. The novelty of this work resides in the development of a resilience assessment framework that allows taking into account the epistemic uncertainty related to the sparse or defective data. The resilience assessment of the key safety systems of an Advanced Thermal Reactor is carried out to evaluate the system recovery after a mishap adopting the dynamic credal network approach. The application of the proposed approach to producing a resilience analysis is described and results presented to demonstrate the applicability of the method.

Keywords: Resilience engineering, Dynamic credal networks, Safety critical systems, Imprecise data sets.

Abstracts — Tuesday, 21 September 2021

Session	[TU1A]—Risk Assessment
Day/Date/Time	Tuesday, 21 Sep. 2021 / 08:30–10:10 hrs
Venue	Plenary Room

TU1A: 270 08:30 hrs

Risk Assessment of Ship Allision in Extreme Fjord Crossings

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Norwegian authorities have an ambition to develop the E39 road as a continuous Coastal Highway Route between Kristiansand and Trondheim without ferries. The western coast of Norway is characterized by deep and long fjords cutting into the mountain landscape. These fjords are to be crossed, but this is challenging since the fjords are long, and up to 1350 meters deep and 5 km wide at favourable crossing points. Floating bridges are probably suitable to cross the fjords, but the coast and the fjords are exposed to significant ship traffic. Some of the new bridges along E39 will, when realized, be the world's largest bridges of their kind, and critical to the future communication in Norway. Hence, the bridges need to be designed such that the risk from severe ship allisions from the ship traffic passing the bridge is within acceptable limits.

The Norwegian rules for bridge engineering demands that the design ship(s) should be assessed in a separate risk analysis, where the design ship size and mass, the ship's speed at collision and the associated accidental actions (impact energy and momentum) are determined such that the risk acceptance criteria for the bridge crossing is fulfilled. The risk assessment includes both frequency analysis, and impact analysis. Previous ship allision research has not focused on floating bridges. Long and slim constructions, like a 5 km long floating bridge, have other challenges than fixed bridges.

This paper reviews and discusses the activities in a risk assessment suitable for floating bridges. We argue that ship allision risk may be a major contribution to the total risk. The risk assessment should pay more attention to the impact analyses of floating bridges, to understand how the bridge responds to a ship impact, like the distribution of the impact energy absorbed in global deformations and the impact energy to be dissipated through crushing of pontoons or bridge girder. The flexibility of floating bridge concepts can be beneficial when subjected to a ship allision, and it is important to understand how the bridge responds, both global and local, to an allision.

Keywords: Risk assessment, Bridge, Ship allision, Impact analysis, Floating bridge.

TU1A: 271 08:50 hrs

Risk Assessment in a Project of Operations Planning in the Context of Industry 4.0 by Using Bayesian Belief Networks (BBN)

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In a market with significant demand for differentiated products and services, the search for technologies that guarantee more efficient processes grows. Furthermore, the advent of Industry 4.0 makes it possible for companies to invest in innovations in the hope of boosting their business. In this context, the concept of reliability as a measure of the expected delivery of the planned results in a given period and under specific conditions becomes essential to reduce the risks that threaten a project in the context of Industry 4.0. This study proposes identifying risk factors that can threaten the success of a project inserted in this scenario. As a methodological approach, a literature review to identify risk factors and a case study of an actual project with a food manufacturer were carried out using Bayesian Belief Networks (BBN) in the analyses. The main risk factors identified were non-compliance with good practices or specific legislation, a low guarantee of efficiency of the solutions proposed by the project, impossibility of integration between obsolete systems and components with 4.0 technologies, and error in project cost planning. This research is valuable for industrial managers who need to anticipate the difficulties in implementing Industry 4.0 projects.

Keywords: Industry 4.0, BBN, Risk analysis, Project management, Risk factors, Food industry.

TU1A: 308 **09:10 hrs**

Functional Safety Assessment of Distributed Predictive Heating and Cooling Systems for Electric Delivery Vehicles

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In modern sustainable transportation, thermal management systems control energy from several sources (internal combustion engine, hybrid- and pure-electric motors and their inverters) as well as waste heat from energy storages and chargers controlled by battery management systems. In battery electric vehicles (BEVs) the main source for generating heat or cold energy is electrical power from the battery. The challenge, in particular in the case of highly dynamic driving profiles, is a well-adapted heat distribution controller to compensate or dissipate high-temperature differences from source to sink components. Several applications have been introduced to use optimal synergized thermal and energy consumption, such as regenerative braking, cabin comfort, cold and hot storage for delivery service. Here we propose an innovative and predictive thermal management system with related cooling and heating elements to intelligently reduce overall energy consumption based on vehicle driving profiles. To ensure the safety of the thermal management functionalities, the safety analysis approach needs to be systematically designed and compliant with international safety standards. This paper provides an assessment methodology. Classical inductive and deductive system analysis methods are involved in the analysis and are interconnected to determine functional safety requirements for the overall thermal management system. Safety margins are identified to deploy waste energy without deteriorating the battery system. The outcomes of the analysis show which functionalities are key to control all identified potential hazards. In addition, reliability requirements regarding intelligent management and sensor capabilities are identified. The approach is exemplarily applied to a small electrical delivery vehicle.

Keywords: Heating and cooling system, Electric vehicle, Intelligent thermal management, Distributed system, Functional safety, System analysis.

TU1A: 348 **09:30 hrs**

Multi-obstacles Influence on High-Pressure Methane Jets

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Accidental high-pressure unignited jets of methane are one of the most dangerous scenarios investigated in industrial risk analysis. Considering a typical industrial plant, it is common that during the dispersion of a flammable gas cloud it interacts with one or more obstacles like buildings or equipment (e.g., columns, tanks, pipe rack, etc.); such interaction could significantly change the relevant damage areas. Due to this, in the industrial safety framework, empirical integral models elaborating only the free jet scenario could resolve in unreliable evaluations. Assuming the importance to correctly approach the scenario of a jet interacting with a series of obstacles the only numerical model able to properly evaluate any obstacle influence is the Computational Fluid Dynamics (CFD). The aim of this work is to investigate how a series of obstacles, in different configurations, can influence the jet cloud extent. Realistic case-studies of industrial plant are analysed: a stationary jet at various pressure impinging a series of cylindrical vertical tanks placed along the axis release. Sensitivity investigation on the obstacles size and distance is performed with CFD simulations through the software ANSYS® CFX®.

Keywords: Methane, Computational fluid dynamics, Obstacle, Accidental release, High-pressure jets.

TU1A: 354 **09:50 hrs**

Comparative Risk Assessment and External Costs of Accidents for Passenger Transportation in Switzerland

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The impact on health caused by accidents is one of the central indicators in a holistic assessment of mobility technologies and systems. Generally, when focusing on risks related to passenger transportation, only vehicle accidents are considered, neglecting other types of risks like, for example, the ones related to the production of the fuel used. The aim of this study is to present a comparative risk assessment for passenger transportation. In particular, it considers for each type of transportation (cars, bus, train, etc.) the combination of the vehicle accident risk and the accident risk that is related to the production and use of the fuel in different drivetrains (e.g., internal combustion, batteries, etc.) in a quantitative manner. This study uses a multi-dimensional accounting method to assess the import-adjusted fatality rates for the different fuels, and a Bayesian model is developed to assess accident risk in the current scenario. The proposed framework is applied to the case study of Switzerland, showing that vehicle accident risk indicators are significantly higher than the ones related to the upstream energy chain, except for airplane. In addition, eBike, eScooter and motorbike show higher risk and external costs compared to passenger car, bus, train and airplane.

Keywords: Passenger transportation, Risk assessment, External costs of accidents, Upstream energy chains, ENSAD, Switzerland.

Session	[TU1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Atrium 2

TU1B: 165 **08:30 hrs**

Importance Measures in Repairable Multistate Systems With Aging

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Within the field of reliability multistate systems represent a natural extension of the classical binary approach. For an extensive introduction to this topic, see Natvig (2011b). Repairable multistate systems quickly become too complex for exact analytical calculations. Fortunately, however, such systems can be studied efficiently using discrete event simulations. See Huseby and Natvig (2012). In the binary case importance is usually measured using the approach by Birnbaum (1969). Several authors have extended the notion of importance measures to multi-state systems. See e.g., Zio et al. (2007) and Huseby et al. (2020). In the latter paper the component state processes were modelled as homogenous semi-Markov processes. Such processes typically reach stationary states very quickly. Thus, most properties of the system can be analysed using asymptotic distributions which typically are determined by mean waiting times and the transition matrix of the built-in Markov chain. In the present paper we follow the approach suggested by Huseby et al. (2020). Here, however, we focus on the non-homogenous case. This is relevant in systems subject to e.g., seasonal variations or aging. In order to model this we use an approach similar to Lindqvist et al. (2003). When the component processes are not homogenous, the analysis should cover the entire time frame, not just the asymptotic properties. This makes comparison of importance more complicated. Several numerical examples are included in order to illustrate the methodology.

Keywords: Multistate systems, Importance measures, Semi-Markov processes, Trend-renewal processes.

TU1B: 185 **08:50 hrs**

Dynamic Grouping Maintenance Policy for the Road Infrastructure

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The quality and the ability of the road infrastructures play a very important role to ensure safe and convenient transportation. Current human needs oblige us to optimize the use of our travel resources. The autonomous driving is proposed as a solution to make the transport more efficient. The autonomous vehicle contains cameras and lidars that can communicate with the road infrastructure to understand the environment where they are traveling. Thus, the existing road infrastructure must therefore be developed and maintained to address the availability needs induced by the new uses of mobility. In consequence, the maintenance of the road infrastructure must be optimized.

In previous work, a maintenance policy for lines and road cracks pavement of the road infrastructure was proposed by considering it as a 4 components system: median strip line, emergency line, broken center line and pavement.

The proposed strategy is based on the individual optimal maintenance plan of each component. Then, over a finite planning horizon, the scheduled maintenance actions are grouped together to ensure both the proper functioning of the system and to minimize the cost of maintenance.

To improve this previous work, a new long-term horizon (30 years) dynamic grouping maintenance strategy is proposed, dynamically considering new monitoring data. This new algorithm is applied to the maintenance optimization of the road infrastructure, using the Long-Term Pavement Performance database and French National Road 4 feedback data.

Keywords: Grouping maintenance, Dynamic grouping, Road infrastructure, Genetic algorithm, Multi-component system, Preventive maintenance, Autonomous vehicle.

TU1B: 201 **09:10 hrs**

Designing Reliability-Informed Customer Surveys

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Because new products enter the market very rapidly, estimating the reliability of these products is challenging due to insufficient historical data. Customer survey data can be used as the prior information in a Bayesian analysis integrated with product returns, reliability tests, and other reliability data sources to improve reliability estimation. Customer surveys are usually designed for purposes other than reliability estimation. Therefore, extracting reliability information from these surveys may be hard or impossible. Even when possible, the extracted reliability information contains significant uncertainties. This study provides an approach for using a reliability-informed customer survey and analyzing the collected data. This paper describes the critical elements of a reliability-informed survey. A generic and flexible mathematical model is then proposed, which utilizes the critical elements to estimate the life distribution. The model converts the various applicable stress profiles into usage cycles/times and estimates the life distribution. The parameters of the life distribution model are estimated through the maximum-likelihood estimation method and Bayesian analysis. The proposed approach is generic and can be used to estimate the life distribution and the reliability of a product at different stress levels and times. A case study is presented in which the approach is applied to a device using a simulated dataset.

Keywords: Reliability, Life distribution, Customer survey, Questionnaire, Bayesian analysis, Drop test.

TU1B: 241 **09:30 hrs**

Fault Trees, Decision Trees, And Binary Decision Diagrams: A Systematic Comparison

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In reliability engineering, we need to understand system dependencies, cause-effect relations, identify critical components, and analyze how they trigger failures. Three prominent graph models commonly used for these purposes are fault trees (FTs), decision trees (DTs), and binary decision diagrams (BDDs). These models are popular because they are easy to interpret, serve as a communication tool between stakeholders of various backgrounds, and support decision-making processes. Moreover, these models help to understand real-world problems by computing reliability metrics, minimum cut sets, logic rules, and displaying dependencies. Nevertheless, it is unclear how these graph models compare. Thus, the goal of this paper is to understand the similarities and differences through a systematic comparison based on their (i) purpose and application, (ii) structural representation, (iii) analysis methods, (iv) construction, and (v) benefits & limitations. Furthermore, we use a running example based on a Container Seal Design to showcase the models in practice. Our results show that, given that FTs, DTs and BDDs have different purposes and application domains, they adopt different structural representations and analysis methodologies that entail a variety of benefits and limitations, the latter can be addressed via conversion methods or extensions. Specific remarks are that BDDs can be considered as a compact representation of binary DTs, since the former allow sub-node sharing, which makes BDDs more efficient at representing logical rules than binary DTs. It is possible to obtain cut sets from BDDs and DTs and construct a FT using the (con/dis)junctive normal form, although this may result in a sub-optimal FT structure.

Keywords: Fault tree analysis, Decision tree, Binary decision diagram, Systematic comparison, Reliability engineering, Decision making, Graph models.

TU1B: 256 **09:50 hrs**

Misspecification Analysis of a Gamma- with an Inverse Gaussian-Based Perturbed Degradation Model by Using a New Expectation Maximization Particle Filter Algorithm

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Gamma and inverse Gaussian degradation processes are often considered equivalent, though this is not true. For this reason, the misspecification of these models is a problem of concern. The point of this paper is evaluating whether and how the presence of measurement error impacts on this model misspecification issue. Mainly due to numerical problems, simulation studies that are carried out to evaluate the performance of maximum likelihood estimators of parameters, and/or functions of parameters, of the gamma and inverse Gaussian processes in the presence of measurement error are typically performed by using a relatively small number of synthetic datasets. In fact, computing the likelihood functions of these perturbed models, which are not available in closed form, requires intensive numerical methods that, at the same time, increase the computational burden and exacerbate convergence issues of numerical algorithms used to maximize the likelihood. In this paper, we propose a new expectation maximization particle filter algorithm, which allows to drastically simplify the estimation task, and present the results of a vast Monte Carlo study carried out by taking advantage of its use. The risk of incurring in a misspecification is evaluated as the percentage of times the Akaike information criterion leads to select the wrong model. The severity of a misspecification is evaluated in terms of its impact on remaining useful life estimates.

Keywords: Gamma process, Inverse Gaussian process, Degradation, Measurement error, Expectation maximization, Particle filter.

Session	[TU1C]—Maintenance Modeling and Applications
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Espace Grand Angle2

TU1C: 162 **08:30 hrs**

Extension of the Concept of Importance To Multi-State Systems with Binary Components

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In this paper the concept of importance of a component in a complex system is generalized from an attribute of a single component to an attribute of a group of components that can fail or be repaired simultaneously (e.g. cascading or common-cause failures can occur). Thus, the assumption that the components are mutually independent, often adopted in reliability analysis, is relaxed. It is also assumed that the considered system is a multi-state one, its states are partially ordered, and its operation can be modeled by a Markov chain. The group importance is defined as the probability that simultaneous failures or repairs of all components in a group G result in a transition from state a to state b, where a>b (if components in G fail) or a<b (if components in G get repaired). It is referred to as the importance of G to a transition from a to b. The paper's main results are the formulas expressing the rates of transitions between the system states in terms of the above defined importances. It is also demonstrated in the last section how the obtained transition intensities can be applied to compute a number of practically important reliability parameters of the considered system. For better understanding, the presented theory is illustrated on the example of a simple three-state power supply system.

Keywords: Multi-state system, Non-binary structure function, Failure/repair rate, Group importance, Markov chain, Transition rate.

TU1C: 169 08:50 hrs

Data Supplement Model for Virtual Simulation of Maintenance Time Test Based on Multilevel Iteration and Neural Network

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Maintenance time reflects the level of product maintainability design, and is a quantitative parameter that must be considered in the stages of product finalization, evaluation and use. At present, the maintenance time of each stage is mainly obtained by statistical test, and then the specified time sample size is used to judge whether the product meets the requirements of maintainability design. However, due to its complex system, high test cost, too many test stages and long test cycle, the time data of aviation product finalization, evaluation and use stage can not reach the minimum sample size required by common statistical methods, which makes it difficult to carry out the maintainability verification of aviation equipment. At the same time, the simulation time data and historical time data of different stages obtained by virtual maintenance methods are not used in maintainability verification, resulting in a waste of resources. Therefore, this paper proposes a maintenance time verification data supplement model based on virtual simulation and multi-stage iteration. Firstly, the model trains the virtual simulation data and maintainability related information through neural network to obtain training data, so as to supplement the time data in the finalization stage. Then, according to the time test data in the finalization stage, the model updates the simulation time data symmetrically and reversely to complete the supplement and update of the maintenance time data in the finalization stage. And with the continuous progress of the stage, the time test data of this stage and the training data of the previous stage are used to complete the supplement and update of the time data of this stage. The model can not only train the time and maintainability data of virtual maintenance by neural network to supplement the time test data of finalization stage, but also continuously supplement and update the maintenance time data of three stages by multi-level iterative model. To sum up, the model fits the actual development process of the product, and has significant significance to reduce the maintenance and verification cost and shorten the development cycle.

Keywords: Virtual maintenance, Maintainability verification, Maintenance time, Iterative update, Multi-stage iteration, Neural network.

TU1C: 253 09:10 hrs

Modelling of Condition-based Inspections and Deterministic Maintenance Delays for Bridge Management

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As a vital element of the Norwegian road network, a total of over 18,000 bridges are distributed across Norway. Their maintenance strategy can be classified as condition-based, where periodic inspections are carried out based on predefined rules and maintenance decisions are made based on the inspection findings. Given the large stock of bridges, it is sometimes difficult to follow all inspection plans due to limited budget and resources. An optimized inspection strategy with fewer inspections while remain an acceptable risk level is therefore highly desired.

Due to administrative advantages, periodic inspections are widely used in the industry. However, it is debatable that a condition-based inspection strategy may lead to improved system performance and reduced total cost. In view of the discrete condition levels and the current repair strategy in Norway, this paper proposed a modelling approach to incorporate condition-based inspections and deterministic maintenance delays in a multi-state Markov process. A case study is carried out based on empirical data from the Norwegian Public Roads Administration. The time-dependent state probabilities are calculated with both the proposed approach and Monte Carlo simulation for comparison and validation.

Keywords: Bridge maintenance, Empirical data, Multi-state system, Markov process, Condition-based inspections, Deterministic maintenance delays.

TU1C: 297 09:30 hrs

A Step-by-Step Method to Analyze Reliability and Maintainability From Historical Data Considering Usage Variables and Expert Knowledge

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The representation of the life and repair behavior of assets is a fundamental topic for understanding a system.

A misrepresentation of the system and its assets could negatively impact the decision-making process from perspectives such as maintenance plans, investments in assets, spare parts strategies, among many others. On the other hand, the characteristics of the real production systems and the historical data registered in the information systems make it difficult to be able to represent realistically the behavior of the assets and the system. That is why this paper proposes a step-by-step method whose main objective is to guide the process for the representation of a productive system from the perspective of its life and repair behavior. This method is based on the development of three phases corresponding to the methodology to identify relevant knowledge, the perspectives for the analysis of the available data, and the analysis of the database using the conceptual model and the asset representation perspective. With these phrases, it is sought to generate the knowledge expressed in a conceptual model, and then integrate each database to the representation of each asset and for the system. With the implementation of this method, it is expected that the experts will reach a consensus on the historical behavior of the assets, which contributes to adequate modeling of reliability and maintainability.

Keywords: Reliability, Maintainability, Usage variable, System representation, Data source, Historical information.

Session	[TU1D]—Reliability, Availability and Maintainability of Safety systems
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Panoramique

TU1D: 233 **08:30 hrs**

Challenges in Reliability Estimation of Modified Technology Using Information from Qualification Testing – An Offshore Well Integrity Solenoid Valve Case

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Continuous improvement is a main principle in modern risk and safety management. To demonstrate technology improvement, for example related to reliability performance, testing could be performed as part of qualification activities. When testing modified drilling and well technology, the designer and technology provider already have a basis from the original technology regarding reliability performance and improvement potentials. In addition, there might also be a strong incentive to demonstrate some target reliability or safety integrity level, which might influence the reliability demonstration and estimation. In this paper, we refer specifically to qualification testing of a solenoid valve as part of a well integrity verification system, as an example case, where a main objective is to identify and discuss challenges related to the test information collected and used to estimate the reliability of modified technology. A main issue discussed is the trade-off between demonstrating acceptable levels with high confidence and the cost of testing. As part of this, we address statistical biases such HARKing and the file drawer problem, and the use of Bayesian updating for mitigation. And we give some reflections regarding the uncertainty of reliability estimates building on such tests in calculation of safety systems per ISO/TR 12489:2013, which could challenge the usefulness of the results.

Keywords: Reliability, Safety systems, Accelerated testing, Bias, Bayesian updating, Modified technology.

TU1D: 353 **08:50 hrs**

The Safety Integrity of Mitigation Functions

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Many companies in the process industry have standardised Safety Integrity Levels (SIL) according to IEC 61508 and IEC 61511 for mitigation functions, e.g. emergency shutdown. In most cases a rationale for the choice of these SILs is lacking, other than field experience and common practice. Mitigation functions differ from process safety functions in that they prevent the escalation of incidents, rather than preventing their occurrence. And whilst process safety functions are normally aimed at preventing a specific incident (e.g. failure of a vessel due to overpressure), emergency functions can mitigate the consequences of many different incidents.

Layer of Protection Analysis (LOPA) is often used to determine the SIL of process safety functions and is typically performed under the assumption that the mitigation functions are working, i.e. that incidents do not uncontrollably escalate. This paper discusses the difficulties in determining the required average Probability of Failure on Demand (PFD) of mitigation functions of process installations and proposes a method for this purpose. The method is based on the observation that in a risk acceptance matrix the required PFD of mitigation functions is directly related to the consequence reduction they have to provide. This method is valid when there are incident scenarios on the border of the low-risk region of the company's risk acceptance matrix and this border shows a linear relationship

between the frequency and consequence categories. It is made plausible that these assumptions are reasonable.

A subsea case study is used to derive SILs of some mitigation functions for isolating production wells. The SILs derived are in line with those proposed in the Norwegian guideline NOG 070.

When the PFD is determined using the proposed approach, it is acceptable to perform LOPA whilst assuming that mitigation functions work as intended.

Keywords: Mitigation function, Probability of failure on Demand, PFD, Safety integrity level, SIL, Layer of protection analysis, LOPA, IEC 61508, IEC 61511, ESD.

TU1D: 382 **09:10 hrs**

On the Importance of Using Realistic Data for Safety System Calculations

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The use of realistic failure data is an essential part of any quantitative reliability analysis of safety systems. It is also one of the most challenging parts and raises several questions concerning the suitability of the data, the assumptions underlying the data and what uncertainties are related to the data. The IEC 61508 and IEC 61511 standards present requirements to safety instrumented systems (SIS) for all relevant lifecycle phases, and have become leading standards for SIS specification, design, implementation, and operation. The IEC 61511 explicitly states that applied reliability data shall be credible, traceable, documented and justified and shall be based on field feedback from similar devices used in a similar operating environment. The paper discusses challenges that arise when collecting and applying field data from operational experience, including how to identify and treat systematic failures such as repeating failures and bad actors. Guidance is provided on use of failure data for different applications such as design calculations versus operational follow-up. The paper is based on extensive reviews of some thirty thousand SIS maintenance notifications from the Norwegian petroleum industry, documented in the new 2021 revision of the PDS data handbook.

Keywords: Reliability data, Data collection, Data reporting, Data classification, PDS data handbook, Systematic failures.

TU1D: 416 **09:30 hrs**

The Benefit of ISO/TR 12489 for Reliability Modeling and Calculation of Safety Systems, Illustrated by Oil and Gas Applications

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Safety systems are widely used to protect industrial installations against undesired events. They are traditionally classified according to their design (conventional or instrumented safety systems) or their mode of functioning (demand or continuous mode of operation). In any case, they should be designed to reach sufficient probabilities of success leading to acceptable safety levels for protected installations. Therefore, it is obvious that relevant methods and tools are needed to do that.

The technical report ISO/TR 12489, issued in 2013 by the ISO/TC67/WG4/PG3 involving eleven countries, provides guidelines for reliability and safety system analysts of the oil and gas industries. The ISO/TR 12489 is in line with the IEC 61508 to deal with the functional safety of safety related systems and aims to close the gap between the state-of-the-art and the application of probabilistic calculations for safety systems of any industries. After gathering the relevant definitions and raising the typical challenges, the technical report explains how to solve them. It also analyses how simplified formulae can be established for simple safety systems and how the common standardized models reliability block diagrams, fault trees, Markovian approach and Petri nets may be used to deal with more complex situations. Moreover, the ISO/TR 12489 details approaches mentioned in the IEC 61508:2010 Part 6 Annex B for SIL related calculations. It also provides guidelines about the multiple safety systems mentioned in the IEC 61511 ed. 2.

The proposed paper presents the benefit of applying the ISO/TR 12489 in industry, notably: the identification and explanation of weaknesses encountered when implementing the IEC 61508 and its derived standards (e.g. IEC 61511) ; the consolidation of the simplified approaches; the demystification of the systemic approaches and demonstration that they are simpler to implement than "simplified" formulae; the identification of difficulties, raise of warnings and provision of extensive solutions to overcome those difficulties; the detailed explanations about the solutions proposed to reliability engineers; the development of typical examples from simple to complex safety system allowing to compare the various approached and to illustrate how to use them; and the development of the evaluation of the spurious failure frequency. These benefits are illustrated using examples of safety systems in gas production and transmission applications.

Keywords: Functional safety, Safety systems, ISO/TR 12489, IEC 61508, IEC 61511, Probability of failure.

TU1D: 511 **09:50 hrs**

Impact of Imperfect Proof Testing on the Performance of Safety Instrumented Functions

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Periodic proof testing (PT) is critical in providing adequate assurances that the Safety Instrument Functions (SIFs) provide the required risk reduction throughout its lifecycle. The purpose of the PT is to detect dangerous undetected failures (λDU) that cannot be detected by diagnostics. However, it is recognized that not all failures can be detected by diagnostics or PT and will only be identified either at equipment overhaul or when a demand is placed on the SIF.

The fraction of failures detected by the proof test is referred to as the Proof Test Coverage Factor (PTC).

This paper shall define proof test coverage, identify areas of consideration as to what can impact the PTC, propose methods for determining the PTC for greenfield and legacy equipment, how the PTC can impact the average probability of failure on demand (PFDAVG). This paper shall conclude that the impact of imperfect proof testing can have a significant impact on the designed risk reduction requirements and the suitability of the defined proof testing method when the PTC is not considered. Therefore, a theoretical and pragmatic approach should be adopted considering the prescribed proof testing methods in the safety manual and its predefined PTC for the selected operation mode. Consideration should also be given to the persons' responsible for writing and conducting the proof testing and their ongoing relevant competency requirements.

Keywords: Functional safety, IEC 61511:2016, Proof test coverage.

Session	[TU1E]—Human Factors and Human Reliability
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Amphi Jardin

TU1E: 335 **08:30 hrs**

Safemode's Approach for Incorporating Human Factors into Risk-informed Design

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Human operators play a key role in the safe and successful conduct of maritime and aviation transport operations. Human error is often reported as a contributor to maritime and aviation accidents. Therefore, the implementation of human-informed design considerations is essential to improve safety and operational performance in both sectors, especially in the maritime sector, where there is a lack of an established framework to systematically consider human factors at the design stage. Therefore, the SAFEMODE project brings together key experts from both aviation and maritime sectors to address this important gap. The SAFEMODE project aims to deliver a framework that includes human factors considerations and enables designers to make risk-informed decisions.

The methodological approach of SAFEMODE builds upon four areas: the collection and analysis of accident data; the development of a toolkit for human performance assurance, the development of Human Factors-based risk models and the creation of a framework to support risk-informed design. The type of safety events considered in SAFEMODE for both domains includes collision and grounding for the maritime sector, and runway collision, taxiway collision and wake vortex during en-route flight phase for the aviation sector. This paper will provide an insight into the efforts conducted as part of the SAFEMODE project to assess the human contribution to risk and the benefits of applying these models to support risk-informed decisions in design and operations.

Keywords: Human factors, Safety, Risk assessment, Design, Maritime, Aviation.

TU1E: 404 **08:50 hrs**

Estimating Human Error Probabilities From Performance Measures: Demonstration Via Bayesian Belife Networks

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In state-of-the-art Human Reliability Analysis (HRA), the analysis of operator (or more generally of personnel) tasks is scenario- and plant-specific, informed by the plant design, thermo-hydraulic analyses, procedural guidance, and so forth. Observations of crew performance in simulators also informs a plant-specific HRA, for instance, on the timing of operator actions, on the critical decision points and emerging failure modes. Yet, actual performance evidence from simulator (e.g. number of successes, failures, response difficulties) is not used, mostly because very few failures are observed in the highly reliable operator performance.

At the Paul Scherrer Institute, the Risk and Human Reliability Group is investigating methods to incorporate plant-specific performance evidence into the plant's HRA. The idea is to go beyond failure counts and adopt performance measures such as crew situation awareness and task performance measures e.g. from ref 1. In this paper, the concept is implemented via a Bayesian Belief Network. Numerical examples demonstrate how incorporation of performance measures allows informing the HEP on performance measures, going beyond the simple counting of (rare) failures (and even in case of no failures observed). In the demonstration, the model addresses a single performance measure (Lack of Situation Awareness): future work will extend to the multiple performance dimensions. A foundational assumption of the model is that a relationship exists between the HEP and the performance measure. In particular, a linear relationship is assumed between the logarithmic of the HEP and the measure, with some noise to represent uncertainties. Another future challenge will be to calibrate the relationship.

Keywords: Human reliability analysis, Simulator data, Control room simulators, Human error probability, Performance measure, Bayesian belief network.

TU1E: 405 **09:10 hrs**

An Approach to Sharing Human Performance Data and Findings in the International Nuclear Research Community

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The study of human performance and reliability is based on a multiplicity of methods with varying degrees of empirical base. In the nuclear field a lot of attention has been placed on control room operators, especially in safety critical situations. One of the most used methods to produce empirical data on operator performance in emergency, events that fortunately are very rare in reality, is by utilizing human-in the loop simulators. Simulations produce huge amount of data that are often analyzed only in light of the simulation's specific research questions, leaving the mass of collected data largely under-exploited. Aggregating, comparing, integrating and reanalyzing data collected at different simulators with different research questions and analyzed by different methodologies, could bring new insights that the original analyses, designs, and evaluations overlooked or could not achieve. To support this, we designed a repository following the entire data life cycle of human performance simulator studies, aiming at further sharing the data and findings produced among the international community of experts affiliated to the OECD/NEA Halden Human Technology Organization Project (formerly the Haden Reactor Project). In this paper we shortly describe the repository and summarize the challenges behind it.

Keywords: Human performance, Human reliability analysis, Human factors engineering, Human-in-the-loop simulation, Smart repositories, Complex data management, Taxonomies.

TU1E: 417 **09:30 hrs**

A Metamodel Extension to Capture Post Normal Accidents in AR-equipped Socio-technical Systems

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In the past twenty to thirty years, organizations have extremely changed and these changes in addition to technological changes such as use of augmented reality (AR) introduce new system risks. Post normal accidents theory describes that organizations are more globalized and digitalized and are formed as networks of organizations, which would lead to post normal accidents such as network failure accident. In addition, it states that strategies and organizational structures are more financialised and networked respectively and technology and task are more digitalized and standardized. These organizational factors affect also on human performance. Organization and human are considered as the socio parts of socio-technical systems. Metamodels should provide the modeling elements required for modeling human and organizational factors in new AR-equipped socio-technical systems. Current metamodels do not consider factors that would lead to post normal accidents. In this paper, we elaborate the theory of post normal accidents and we extract the influencing factors leading to post normal accidents. We also consider global distance including geographical, temporal and cultural distances, as an influencing factor on human performance. Then, we use the extracted influencing factors for extending modeling elements in our previously proposed conceptual metamodel for modeling AR-equipped socio-technical systems.

Our proposed extended metalmodel can be used by analysis techniques in order to perform risk assessment for AR-equipped socio-technical systems.

Keywords: Socio-technical systems, Augmented reality, Post normal accidents, Conceptual metamodel, Risk assessment, Network failure accidents.

TU1E: 418 **09:50 hrs**

Evaluating Electroencephalogram Channels using Machine Learning Models for Drowsiness Detection

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The oil and gas (O&G) industry has suffered several catastrophic accidents over the years, and many of which are attributed to human factors. Indeed, human operators continue to play a central role in performing complex tasks in which cognitive functions influence their performance, especially in emergency situations. However, operators may not effectively respond when presenting tiredness, such as mental fatigue and/or drowsiness. Therefore, the development of a drowsiness detection system is desirable for industries dealing with safety-critical tasks, such as control rooms in O&G context. In this paper, we analyzed two electroencephalogram (EEG) channels: Fz and Pz. The data are processed based on distinct time-domain signal representation, analyzed through four well-known Machine Learning (ML) classification techniques in order to identify patterns related to drowsiness in different subjects submitted to monotonous tasks. We perform all analysis and comparisons considering a real and public database for human drowsiness. For most of the subjects analyzed, the ML models achieved a balanced accuracy (BA) greater than 95% when considering information of a single channel, which makes the drowsiness detection system less invasive, and then opens the possibility of using it in an actual environment.

Keywords: Human reliability, Drowsiness, EEG, DROZY, Machine learning, Classification techniques, Oil and gas industry.

Session	[TU1F]—Health monitoring and predictive maintenance of offshore systems
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Espace Grand Angle

TU1F: 379 **08:30 hrs**

Internet of Underwater Things to Monitor Offshore Wind Turbines Fields

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Internet of Underwater Things (IoUT) has gained large popularity [1]. The real time supervision requirement of both ecosystems and offshore infrastructures explains this world wide interest. Large offshore wind projects are now launched off the French coasts and among them, the first farm will be installed by 2023 offshore St Nazaire harbour, providing an opportunity to establish an IoUT in an industrial environment. The paper is presenting some preliminary results of the Blue IoT – Eolia project which has the objectives to design and to test an underwater acoustic network dedicated to the supervision of subsea infrastructures and environmental parameters needed to ensure safety and reliability of wind turbines. Typical sensors (force and pressure sensors, inclinometers, thermometers, etc.) and different acoustic modems are tested to illustrate the capacities of such underwater networks to accommodate various parameters. Strategies to avoid collisions in the different acoustic channels are developed using a Medium Access Control (MAC) layer, some results and analyses being presented in the paper [2;3]. Finally a first experimentation in a natural environment conducted during summer 2021 (in the river Erdre at Nantes, France) will be detailed, illustrated and compared with the literature [4;5]. A demonstration underwater network is expected to be installed during 2022 in real conditions on SEM-REV, the marine renewable multi-technology field test site of Centrale Nantes, located offshore Le Croisic (France).

Keywords: Offshore floating wind turbines field, Internet of Underwater Things (IoUT), Acoustic channels, Network protocols, System reliability, Renewable energy industry.

TU1F: 735 08:50 hrs

A Model-Based Approach for Structural Health Monitoring of Wind Energy Assets

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This paper presents a model-based approach to monitor loads in wind turbine components. The workflow presented on Figure 1 is composed of an offline training phase and a diagnosis phase and is fed with data from SCADA and possibly from sensors time series. Different tools dedicated to the approach will be presented :

- Surrogate modeling from dynamic simulations in order to link available input data (typically 10 min SCADA statistics, sensors time series) to required outputs (fatigue or extreme loads). These surrogate models are used in the diagnosis phase in order to evaluate the loads in the required component.
- Sensors time series condensation in order to generate scalar features to be used as inputs of the workflow. These features are used to extract relevant information from time series typically to characterize stochastic loading from wind and waves.
- Data assimilation with an online parameter inference approach based on a Bayesian filtering method, such as the Ensemble Kalman Filter, for performing parameter estimation. Data assimilation can be used to characterize uncertain parameters related to the structure (static or quasi-static behavior) or to the loading (dynamic behavior).

Different applications will be presented such as fatigue loads estimation at wind turbines blades root validated with on-site measures and structural and environmental parameters estimation performed with a data assimilation approach.

Keywords: Structural health monitoring, Surrogate modeling, Data assimilation, Digital twin.

TU1F: 760 09:10 hrs

Incorporating Reliability Assessment in the Design Development & Optimization Of Floating Structures

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Offshore wind turbines are exposed to fluctuating environmental loads and have to deal with aero-hydro-servo-elastic coupled dynamics. Such complex engineering systems need thorough design processes, as well as sophisticated monitoring and maintenance approaches. The current development trend towards floating support structures for offshore wind turbines makes maintenance and repair work more difficult. This is, on the one hand, as access to, transfer of personnel to, and work of technicians on floating systems are complicated and entail additional hazards. On the other hand, floating wind turbines can be located further from the shore, which significantly reduces the allowable weather windows for offshore work. Thus, researchers and industry must not only focus on efficient maintenance strategies but also put more emphasis on the design process of such offshore structures, focusing on reliable systems ab initio.

For reliability assessments of highly complex engineering systems, the combination of different techniques – building on approaches for creating approximate system representations and subsequent reliability analysis and calculation methods – is most promising[1]. The development and assessment of floating wind turbine systems, however, also requires numerical modeling to correctly represent and simulate the fully coupled dynamics. The Modelicalibrary for Wind Turbines MoWiT (www.mowit.info), developed at Fraunhofer Institute for Wind Energy Systems IWES, allows for component-based modeling and can be coupled to a framework, programmed in Python, for automated simulation and optimization[2]. To incorporate the computationally intensive reliability assessment within the highly iterative optimization process, a methodology is developed, by which means approximate models in form of response surfaces for a few potential system geometries out of the entire optimization design space are created ahead of the optimization, corresponding response surfaces for any other system designs are derived based on an interpolation approach, and, finally, the reliability is determined timeefficiently within the optimization procedure, using Monte-Carlo simulation[3]. This methodology is applied to a floating wind turbine to obtain a reliability-based optimized support structure, accounting for uncertainties in environmental conditions directly within the design development and ensuring that the structure, including the mooring lines, fulfills certain reliability constraints[3]. Furthermore, the numerical framework allows developing digital twins by optimizing the numerical model based on measurements. Such dig-

ital twins are highly suitable to assess the system condition and estimate, e.g., the damage or remaining lifetime.

Keywords: Floating structures, Offshore wind turbines, Reliability-based design optimization, Monte-Carlo simulation, Uncertainty modeling, Digital twin, Complex engineering systems.

TU1F: 764 **09:30 hrs**

A New Methodology For Fast Lifespan Prediction Of Offshore Structures

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Offshore structures monitoring meets crucial economic and environmental issues. Simulations are performed to estimate the behavior of offshore structures. However, simulations are based on assumptions on operating conditions, which are not always sufficient to take into account all the complexity of the real time-dependent environment and structural properties. Efficient monitoring and maintenance operations relies on data gathered from sensors, which provides real conditions and behavior of the structure. Simulations may be too expensive and timeconsuming to estimate the updated lifespan from large dataset of measurements.

To address these issues, Phimeca and Principia had developed a methodology based on measurements to obtain rapid and updated prediction of the structure's lifespan.

This methodology was successfully applied to the monitoring of a riser of a FPSO (Floating Production Storage and Offloading). First, the episodes of motion measured on the FPSO for 2 years were used to simulate the damage of the riser. The time series describing these episodes were transformed, by applying a combination of machine learning methods, so that the problem dimension was drastically reduced: with initially thousands of variables, only two explain the simulated damage efficiently. Finally, an emulator (metamodel), has been trained and validated to be embedded into the FPSO and to estimate the lifespan of the structure during its life. The dimension reduction makes the emulator numerically light enough to be embedded into the structure and to be compatible with constrained systems.

This methodology enables offshore structure owners and operators to obtain a fast updated lifespan prediction from an embedded light software, without any delay due to complex simulations. Thus, decision can be made faster to ensure structural and environmental safety in case of a dangerous event.

Keywords: Offshore structure, Monitoring, Dimension reduction, Lifespan prediction, Digital twin, Machine learning.

TU1F: 710 **09:50 hrs**

Berthing Criteria for Wind Turbine Crew Transfer Vessel with Low or High Friction Fender

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Boat access against a boat landing is realized by means of fenders made of rubber. Depending on their stiffness, the behaviour of the boat with the waves will be different. The works performed use the following methodology:

(1) Calculate the efforts of a monochromatic wave applied against the boat in the case she can heave (low friction) or not (high friction).
(2) Calculate the fender friction coefficient against the boat landing.
(3) Compare the berthing criteria with those from another publication.
(4) Compare the berthing criteria for a low or high friction fender.

The following results are found for a 27m catamaran: low (high) friction fender berthing is possible for 1.5m (0.5m) Hs, or for 2m Hs with small wave periods.

Keywords: Operation and maintenance, Crew transfer vessel, Offshore wind turbine, Significant wave height, Wave period.

Session	[TU1G]—Nuclear Industry
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Atrium 3

TU1G: 216 **08:30 hrs**

Probabilistic Modeling in a Bayesian Framework of Nuclear Containment Buildings Structural Tightness

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Structural tightness constitutes one of the main function of French 1300-1450 MWe nuclear power plant reactor buildings, which is provided by a reinforced and prestressed concrete inner wall without steel liner, and an outer wall ensuring protection against external effects. Tightness is evaluated through the measurement of the inner wall leakage rate during periodic pressurization tests. The leakage rate should not exceed a regulatory threshold value. Under several physical processes related to concrete ageing and operating loads, structural tightness may evolve during the operational phases. In this context, the development of a numerical methodology aiming at assessing the time evolution of the containment buildings tightness will contribute to an improved anticipation of potential repair works, as well as decision aid in the framework of containment structures maintenance.

In recent years, many studies have been performed in order to provide physical modeling approaches of the thermo-hydro-mechanical and leakage (THML) behaviour of concrete in large containment structures. These approaches involve numerous uncertain parameters. However, *in-situ* observations of the structure's response are available in significant quantity. Thus, they allow an inverse uncertainty quantification in a Bayesian framework. It combines a prior state of knowledge and noisy observations of the system response, in order to derive an a posteriori state of knowledge which summarizes available information at a given moment of the structure life. In this context, a Bayesian probabilistic modeling strategy is proposed, aiming at assessing the structural tightness of containment buildings, based on a physical THML modeling strategy. The forecasts of mechanical and leakage responses are sequentially, using Markov Chain Monte Carlo algorithms. In order to accelerate these algorithms, sparse polynomial chaos expansions surrogate models are built. The risk of exceeding regulatory leakage rate thresholds is then assessed in a reliability-based framework. The proposed approach enables to deal with a complex physical model with numerous uncertain parameters, and several types of in-situ observation data with varying quantity and measurement noise. Application results regarding a 1:3 scale nuclear containment building mock-up show accurate leakage forecasts with a significant reduction of uncertainties throughout the structure's operational phase.

Keywords: Bayesian inverse problems, Nuclear containment buildings, Structural tightness, polynomial chaos expansions, Markov chain monte carlo, Stochastic finite elements, Thermo-hydro-mechanical modeling.

TU1G: 321 **08:50 hrs**

Risk Assessment Based on Event Tree for Loss of Cooling Accident at a vSMR

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Small modular reactors (SMR) are smaller than conventional reactors and are designed to produce up to 300 MWe. Very small modular reactors (vSMR) (about 10 to 50 MWe) are a type of SMR. These reactors can be manufactured and assembled at the factory and then transported to the place where they will be installed – which makes them cheaper and built faster. Plants equipped with this type of reactor can be used in water desalination, heat generation and energy production in remote locations. As with other nuclear installations, risk analysis is necessary to assist in the design and implementation of vSMR. The Level 2 Probabilistic Safety Assessments (PSA) of nuclear power plants (NPP) identify the pathways, magnitude and frequency of radionuclide release through containment during an accident. The end states of the event tree provide significant insights on accident prevention and mitigation, pointing to measures with great potential to improve the design and operation of an vSMR. This paper describes a model under development with Computer Aided Fault Tree Analysis System (CAFTA) to quantify the risk during a loss of coolant circulation accident in the spent fuel pool (SFP) of a generic pressurized water reactor (PWR) - type vSMR with a 45 MWthe 10 MW(e) in Low Power and Shutdown (LPS) operating mode, as part of a Level 2 PSA.

Keywords: Probabilistic safety assessments, Small modular reactors, Fault tree, Event tree analysis, LPS.

TU1G: 327 09:10 hrs

Operational Safety Analysis of HANARO Research Reactor using STAMP/STPA

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The operational policy of nuclear facilities including commercial nuclear power plants and research reactors established and practiced by the utility is required to give safety the utmost priority, overriding the demands of production and project schedules. To date, the probabilistic safety assessment (PSA) has been used as one of the standard tools for the safety evaluation; however, concerns have been raised about its capability to treat the complex interaction between human operators, digital systems, and diverse plant processes. This paper proposes an operational safety analysis procedure based on system theoretic accident model and process/systems-theoretic process analysis (STAMP/STPA). The effectiveness of the proposed procedure is demonstrated with the case study of a cold neutron source system installed in High-Flux Advanced Neutron Application Reactor (HANARO). In result, 127 unsafe control actions (UCAs) were derived for 51 control actions regarding spurious trip scenario. The UCAs were reviewed by the HANARO operators and found new scenarios that requires further investigation for reducing the possibility of a spurious trip. The proposed procedure is expected to provide an integrated viewpoint for operational safety analysis and further used to suggest recommendations for the safety enhancement of nuclear facilities.

Keywords: Operational safety analysis, STAMP/STPA, Unsafe control action.

TU1G: 477 09:30 hrs

Evaluation of Risk Dilution Effects in Dynamic Probabilistic Risk Assessment of Nuclear Power Plants

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Probabilistic risk assessment (PRA) is a method of effectively evaluating risks in nuclear power plants and is used in various agencies. Dynamic PRA is attracting considerable attention, as it enables realistic assessment by reducing the assumptions and engineering judgments related to time-dependent failure probability and/or human action reliability. However, it is difficult to remove all assumptions and engineering judgments. Therefore, their effects on assessment results should be understood. This study focuses on the "risk dilution effect," which arises from assumptions about uncertainty. Results showed that this effect causes a difference of about 10% to 20% in the relative change of the conditional core damage probability in the station blackout scenario. This effect should be fully considered when using dynamic PRA in critical decision-making, such as that on regulations.

Keywords: Probabilistic risk assessment, Dynamic PRA, Nuclear power plant, Risk dilution.

TU1G: 479 09:50 hrs

Multi-Step Prediction Algorithm for Critical Safety Parameters at Nuclear Power Plants Using BiLSTM and AM

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In abnormal or emergency situations at nuclear power plants (NPPs), operators are expected to recognize the situations and sometimes take effective safety measures quickly. Under these situations, the appropriate situation awareness affects the effective mitigation of events. Especially, Level 3 Situation Awareness, i.e., the prediction of future plant behavior, is critical, but one of the most difficult tasks to the operators. In order to help the operators' situation awareness, some studies have proposed prediction algorithms using artificial intelligence techniques. However, those methods were focused on the single-step prediction so that they could not perform long-term prediction. Multistep prediction is known to be difficult and challenging because of the lack of information and uncertainty or error accumulation. In this light, this study suggests an algorithm using a sequence-to-sequence network that combines

bidirectional long short-term memory(BiLSTM) and attention mechanism (AM) for predicting the multi-step parameters. AM is an excellent method in handling serialized data such as speech recognition, machine translation, and part-of-speech tagging. The AM can make the neural network focus more on crucial temporal information by assigning higher weights. BiLSTM is used for extracting temporal features of time series data. The suggested algorithm is also tested to demonstrate prediction performance. The algorithm is implemented using a compact nuclear simulator for Westinghouse 930 MWe NPP.

Keywords: Nuclear power plant, Multi-step prediction, Deep learning, Prediction algorithm, Bidirectional long short-term memory, Attention mechanism.

Session [TU1H]—Aeronautics and Aerospace
Day/Date/Time Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue Cointreau

TU1H: 441 **08:30 hrs**

Research on Reliability Management and Control Method of Aeronautical Product Development Based on Systems Engineering Management Plan

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The SEMP (systems engineering management plan) is a management program that controls the entire product development process by managing the entire manufacturing process. The development risk of existing aerospace products is highly related to its complexity and maturity, which are mainly reflected in requirements demonstration, design analysis and test verification. Therefore, based on the theory of SEMP, this paper puts forward a quality control scheme from three aspects of requirement demonstration, design analysis and test verification, and establishes a management and control method for quality characteristics of aerospace product development, such as reliability. It can help product development enterprises to manage and control their product development process more comprehensively, so as to reduce the risk of product development, which is of great significance to improve the overall quality of aviation products and reduce the risk of development. This method can also provide a new idea for the development and control of aviation products in the future, which is helpful to avoid risks and improve the quality of aviation products.

Keywords: SEMP, Evaluation, Process control, Management, Reliability, Quality.

TU1H: 466 **08:50 hrs**

AUTOSAFE: Automatic Fault Tree Synthesis for Cyber- Physical Systems

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Safety analysis is a key pillar of compliance demonstration for aircraft and other complex cyber-physical systems with the safety requirements of the certification authorities. Fault tree analysis is a well-established and accepted methodology for this purpose. However, with the growing complexity of systems, consisting of software and complex electronic hardware and their inter-dependencies, it is becoming increasingly challenging and costly to manually conduct fault tree analysis. It is not only time consuming and error prone but also the quality (e.g. consistency and correctness) of the analysis is highly dependent on the ability of the individual Engineer. In order to address this issue, a software tool AUTOSAFE is being developed to automate the fault tree generation process.

In AUTOSAFE, a domain-specific model is used to model system hardware structure and functions, as well as the failure propagation. An algorithm is developed to automatically generate fault trees. Key issues for the trustworthiness of generated fault-trees are completeness and understandability. Completeness is addressed with semi-automated inclusion of external events from an external events database into the automatically generated fault tree. Understandability is addressed with a novel requirements model and rigid naming conventions that are automatically considered during fault tree generation. In addition, a web-based tool architecture provides multiuser modeling. AUTOSAFE will not only decrease the time required to develop fault trees but also improve their consistency and correctness.

In this paper, the concept and methods of the AUTOSAFE tool are introduced. Additionally, the workflow of system modelling, failure propagation modelling, and auto-generation of the fault tree are demonstrated with an exemplary system study.

Keywords: Safety analysis, Safety critical system, Fault tree analysis, Fault tree generation, Automation, External event, Cyber-physical systems, MBSA.

TU1H: 474 **09:10 hrs**

A Machine Learning Approach to Assess Runway Conditions Using Weather Data

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Contamination of runway surfaces with snow, ice, or slush causes potential economic and safety threats for the aviation industry during winter season. The presence of these materials reduces the available tire-pavement friction needed for retardation and directional control. To activate appropriate safety procedures, pilots need accurate and timely information on the actual runway surface conditions. Previous research on how available runway friction is affected by weather conditions and runway contamination has mainly been reduced to engineering- or physics-based models. The complexity of the physical relationships controlling the surface friction and their dependency on each other makes this a difficult task. Machine learning methods have in several occasions shown to be able to model complex physical phenomena with a good accuracy, when domain knowledge is included. In this paper, we build a model using the state-of-the-art boosting algorithm XGBoost, to predict runway conditions using weather data and runway reports. The model is trained to predict the runway surface conditions represented by the tire-pavement friction coefficient. Our model is compared to a currently in-use system at several Norwegian Airports, which is a scenario-based model created based on meteorological and runway knowledge. The machine learning model is tested and compared using cross validation, and the results show the strong abilities of machine learning to find and use patterns to model physical phenomena.

Keywords: Aviation risk assessment, Machine learning, Runway friction, Scenario models, Weather data, Flight data, XGBoost.

TU1H: 481 **09:30 hrs**

A Data-Driven Method of Predicting Hard Landing Based on RFECV and XGBoost

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Aircraft hard landing means that the impact load of the landing gear on the ground exceeds the specified limit at the moment of landing. As a common flight accident, hard landing poses a huge threat to flight safety. The mass production and storage of flight data is also a challenge to the existing analysis methods. In this study, we took the flight parameter data during the landing process of the aircraft as the research object, and established a hard landing prediction model based on historical data and machine learning. First, we established a flight parameter selection method combining data cleaning and recursive feature elimination with cross validation (RFECV), aiming to identify the key parameters that affect the flight landing state and quantify parameter importance. Second, we build a hard landing prediction model based on the ensemble learning method XGBoost. The results of the evaluation metrics shows that the method proposed in this study can effectively predict the aircraft hard landing to realize safety warning. The trained model can be used in flight practice. When the key parameters of the aircraft are input, the model can assist the pilot to adjust the aircraft attitude, and prevent the occurrence of a hard landing.

Keywords: Hard landing, Machine learning, Risk prediction method, Data mining, RFECV, XGBoost, SHAP.

TU1H: 510 **09:50 hrs**

How to Enhance Safety Culture and Safety Management at Airports – The Safety Culture Stack

Tom Reader and Barry Kirwan

Safety culture relates to how an organization values and prioritizes safety: for example, in terms of shared norms about the importance of safety, management commitment to safety, and systems for ensuring organizations capture and learn from incidents. Research in aviation has tended to focus on the norms and values within specific industry sectors: for example airlines, air traffic control, and airports. Yet, a systems-approach to safety management recognizes that safety is often a product of interactions between the

different organizations that need to collaborate in order to deliver a service. For aviation, this means that the safety culture of different organizations within the aviation system should not be studied in isolation: rather an approach should be taken where organizations are considered synchronously. This is most obviously the case at an airport, where many key players – the airport authority, airlines, air traffic services and ground handling services – must interact. At a regional airport this may entail fifty or so companies who must collaborate to ensure safe and efficient operations. At a larger international airport it can easily be two hundred and fifty organisations. Surveying every single organization's safety culture independently would be an arduous and possibly never-ending task, and would miss the essential interactions and safety interfaces where the roots of accidents and resilience are often found. A more integrative, encompassing, and yet agile approach is needed.

In 2016, utilizing the validated EUROCONTROL safety culture methodology used to measure safety culture in air traffic management, an adapted version of the safety culture survey was distributed across airlines (cabin crew, pilots, support staff), air traffic control (air traffic controllers, engineers, support staff), airport staff, ground handling companies, and other key participants (e.g., emergency services) at one of London's regional airports (London Luton Airport). Focus groups with staff and management from the whole spectrum of airport activities were also used to dive deeper into the issues raised by the survey, leading to an Action Plan for improving the safety culture of the airport as a whole. A number of these actions aimed to help certain airport companies learn from others who exhibited best practices in key areas such as Just Culture, Reporting and Learning, etc. The Luton Safety Stack, as it has become known, has seen a transformation in 'the way safety is done' at the airport, with competitive companies (e.g. ground handling services) working together for safety, each company, no matter how small, now feeling it has a 'voice' in safety discussions, and implementation of a Just Culture Framework that encompasses more than seventy organisations at the airport. What started out as a safety culture initiative has also changed a number of safety management processes related to incident management and risk reduction, as well as collaborative use of safety-related equipment and resources, and harmonized procedures across the airport for all ground handling activities.

The Safety Stack process has been applied successfully to a second UK airport, and is scheduled for application to two international airports in 2021. The paper will focus on how the Stack is formed, how it works, and the tangible benefits seen so far at the two airports who now have an operational Safety Stack.

Session	[TU1I]—Model Based Safety Assessment
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Giffard

TU1I: 301 08:30 hrs

Multi-Core Processor: Stepping Inside the Box

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The last decade has seen the emergence of multi-core and many-core processors replacing historical uni-processors in most of the applicative domains. There is no doubt that the next generation of aircraft will rely on these technologies raising major issues especially with regard to safety assessment. Indeed, currently, a processor is considered as a black-box component where any single internal failure leads to the loss of all executed software. Due to the numerous resources provided by such platform, position papers like the CAST-32A promote a finer analysis of the safety impact of internal component failures. Hence there is a necessity to open the box and see such a processor as a sub-system. We introduce a formal modeling framework capturing the main characteristics of software/hardware failure propagation. This framework is applied on a simplified UAV control use-case.

Keywords: Dependability, Safety, Multi-core processor, MBSA.

TU1I: 324 08:50 hrs

Model-Based Safety Assessment of an Insulin Pump System with AltaRica 3.0

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The safety analysis of a system is a classical field of engineering, with its well-known processes and tools (e.g. fault trees, event trees, reliability block diagrams or a combination among them). Nevertheless, the increasing complexity of systems has to be handled with appropriate approaches and tools: for example the so called Model-Based Safety Assessment approach. In this publication, we present the modelling and assessment of an insulin pump system. Also

called "artificial pancreas", this system is a medical device and a typical example of a cyber-physical system. It contributes to reduce the constraints of diabetic patients caused by their illness. The system is composed of three main parts in close loop. The safety assessment of this system has to be finely analyzed since failures may result in severe harms to the patient. We use the AltaRica 3.0 modeling language, which is such a solution of the Model-Based Safety Assessment approach, to realize the safety assessment of the Insulin Pump System.

Keywords: Model-based safety assessment, AltaRica 3.0, Cyber-physical system.

TU1I: 671 **09:10 hrs**

Efficient Modeling of Large Markov Chains Models with AltaRica 3.0

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Markov chains are one of the modeling formalisms used in reliability engineering. Even if it is powerful, from a mathematical point of view, one of its big issue is the design of models for large scale systems. In fact, designing a Markov chain of a system with several components, each one may be in several states, is an important amount of job. There are no structural constructs to efficiently design such a model (e.g. composition, synchronization, etc.). In this publication, we present how the AltaRica 3.0 modeling language can be used to design efficiently large continuous time Markov chains. We consider an example of a system composed of combinations of series-parallel components, combining different states for components and different modes for parts of the system. We show that the design of the model is very efficient thanks to the advanced structural constructs of the AltaRica 3.0 modeling language. Finally, we use assessment tools available for AltaRica 3.0, e.g. the stochastic simulator, to evaluate the model of the system.

Keywords: Markov chains, AltaRica 3.0, Model-Based safety assessment, Production system.

TU1I: 680 **09:30 hrs**

Altarica 3.0 Modeling Pattern for Production Systems Availability Assessment

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The design and assessment of production models is often delicate because the production of a unit may depend not only on its internal state but also on flows circulating downstream and upstream the production line.

In this article, we present a modeling pattern to address this issue. It consists in using controllers working on three flows: a diagnosis flow moving forward from source units to a controller, a command flow moving backward from a controller to source units, and finally a production flow moving forward from source units to target units. The production depends on the command, which depends itself on the diagnosis. We present the implementation of this new modeling pattern using AltaRica 3.0 - a high level formal modeling language dedicated to risk and performances assessment.

We demonstrate, by means of an example of a production system, the ability of this pattern to represent such a system. Finally, we show how to evaluate the system availability over a given period of time using the assessment tools available for AltaRica 3.0, e.g. the stochastic simulator.

Keywords: AltaRica 3.0, Production systems, Modeling patterns, Stochastic simulation.

TU1I: 718 **09:50 hrs**

Binding Fault Logic to System Design: A SysML Approach

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To gain the benefits of MBSA within MBSE, traditional fault logic models need to align closely to the system's functional decomposition. To achieve this in a consistent fashion, we have developed a new SysML safety profile based on the functional blocks provided to us by system design. Functional deviations derived from the FHA (which is modeled

in SysML using the same profile) are propagated between blocks through ports defined by the system engineers, and the associated fault logic (including hardware generated base events) is modeled in standard internal block definition diagrams. Functional failures represent only part of the failure model (which will always include events and scenarios outside the functional requirements), but it ensures that for functional deviations at least, fault logic models follow the functional hierarchy and use the same design blocks as the system engineers. It means that specification changes to functional blocks or ports can be picked up and flagged to the safety team as requiring inspection, and it enables direct traceability within the SysML repository of derived safety requirements from the PSSA / FHA through to the fault logic used to demonstrate acceptable mitigation of risk. We demonstrate the new profile's use in the context of a gas turbine control system design, and discuss the advantages and shortfalls it provides in an industrial setting.

Keywords: SysML, Fault logic, Fault trees, Safety analysis, MBSE, MBSA.

Session	[TU1J]—Natural Hazards
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Botanique 2

TU1J: 048 **08:30 hrs**

Exploring Sensitivity Analysis to Support Urban Flood Risk Prioritization Under a Multidimensional Perspective

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Flood accident reports worldwide have demonstrated that many factors (such as climate change, and urbanization) act as catalysts that aggravate the many impacts of flooding on urban systems. Therefore, decision models should consider these complexities, in which a decision maker's (DM's) preferences deal with multiple criteria to plan adaptive measures and reduce damages from urban flooding and this should also include taking a long-term perspective. Given this context, sensitivity analysis (SA) is a useful tool that supports DMs by assuring them to what extent they can rely on the recommendations provided by quantitative models. This paper discusses a global SA based on a multidimensional decision model, which uses Multi-Attribute Utility Theory and Decision Analysis, to prioritize urban areas according to risks from flooding they face. The SA simulated three groups of parameters: (i) uncontrolled factors, i.e., the influence of climate effects on estimating rainfall patterns; (ii) urban population growth and its correlation to the consequences of floods; and (iii) the DM's preferences, which means the compensatory relation among criteria. Statistical and graphic visualization tools evidence how robust the original risk ranking is according to how the parameters are set. The SA runs 100,000 replications which generate 14 different rankings. An in-depth analysis has shown that the original ordering of flood risks is reasonably robust, but some urban areas are sensitive mainly to climate change and urbanization. Furthermore, additional detailed discussion indicates how DMs can benefit from this analysis when implementing strategic decisions on preventing floods and mitigating their impacts.

Keywords: Urban flood, Multidimensional risk, MAUT, Decision analysis, Sensitivity analysis, Monte Carlo simulation.

TU1J: 161 **08:50 hrs**

U.S. National Risk Index-A Foundational Review

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The U.S. recently created the National Risk Index, a tool intended to provide a nation-wide assessment of natural risks. This method provides county and census tract level estimates of economic losses, a measure of social vulnerability, and a measure of community resilience. These three measures are then combined as a "risk" estimate. This paper provides a critical perspective on the National Risk Index reviewing in three area:

(1) the conceptualization and definition of risk used,
(2) what is actually being measured, and
(3) how it is actually measuring those quantities.

We find that there is significant room for improvement in all three areas.

TU1J: 310 **09:10 hrs**

Large Scale Landslide and Flooding Hazard Susceptibility Assessment Using Semi-Automated Frequency Ratio (FR) Model

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As extreme weather events become more frequent and world's population is growing an increasing number of built areas and critical infrastructure networks are challenged by natural hazards like heavy rain, urban flooding or landslides. At the same time, the quantity and quality of remote sensing data delivering earth observation products is continuously increasing and widely accessible. With the help of high-resolution, open access data and fast engineering approaches new options arise to investigate objects at risk. This study presents a semi-automated fast engineering approach, deploying only open access tools and data to create a large-scale hazard susceptibility assessment. The model objectives include its ability to rapidly identify critical areas, which will further allow to derivate the exposure of critical infrastructures to hazards. A bivariate frequency ratio (FR) model is applied for flooding and landslide susceptibility mapping on two study sites within the German federal state of Bavaria. Flood and landslide conditioning factors are selected based on performance criterions. For improved comparability of the results different normalization approaches are used. The resulting hazard susceptibility maps are validated in both cases by hazard inventories and statistical analysis of the area under the receiver operator characteristics curve (AUROC). Further, the susceptibility is partitioned into five defined zones. The results lead to the following conclusions: (i) the model is able to produce overall sufficient predictive accuracy, (ii) a higher number of parameters does not necessarily lead to enhanced model performance, and (iii) a higher resolution of the digital elevation model (DEM) can significantly improve the predictive performance. Moreover, the automation is a large benefit regarding the preparation and validation of the model independently of the employed resolution.

Keywords: Hazard susceptibility, Remote sensing, Frequency ratio, Open source, Flooding, Landslide.

TU1J: 618 **09:30 hrs**

Hurricane Damage to Interior and Contents in Mid/High-Rise Buildings due to Wind-Driven Rain Ingress

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The increasing population concentration in coastal cities exacerbates the vulnerability of infrastructure to hurricane damage. The subject of this paper is vulnerability of residential mid/high-rise buildings (MHR), 4-story or higher, to hurricane-induced interior and content damage from wind-driven rain ingress. A new physics-based methodology was developed to extend previous work on low-rise buildings. The methodology combines estimates of impinging and surface run-off wind driven rain, envelope defects and breaches, interior water distribution and propagation, and component cost analyses to produce realistic estimates of interior and contents damage in mid/high-rise buildings. The physics mechanisms of rainwater ingress, distribution and propagation provide the basis for a probabilistic vulnerability model (MHR model). At the heart of the MHR model is a Monte Carlo simulation engine which runs simulations for combinations of wind speed and direction for a variety of building classes. Key parameters (component capacity, water ingress, etc.) are treated as random variables. The resulting vulnerability and fragility curves and surfaces, when used in a catastrophe model, can lead to improved loss projections and facilitate the evaluation of the effectiveness of mitigation measures. The paper describes the model, and presents its vulnerability functions. It also describes its different variables with their uncertainty and discusses the overall uncertainty attached to the process.

Keywords: Probabilistic vulnerability model, Interior and contents damage, Mid/high-rise building, Uncertainty, Monte carlo simulation.

TU1J: 678 09:50 hrs

Italian Seismic Risk Maps Based on Code-Compliant Design

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This paper discusses the Italian seismic risk assuming that the existing buildings portfolio is substituted by new code-conforming structures. The seismic risk is quantified, at municipality scale, via the evaluation of failure rate per building class. This requires: (i) the probability that the structures fail for a given ground motion intensity value, that is, the fragility functions and (ii) the hazard curves resulting from probabilistic seismic hazard analyses. The adopted fragility functions come from the Italian research project RINTC – *Rischio Implicito delle Strutture progettate secondo le NTC*, in which a large set of buildings was designed for three sites representative of different seismicity. Thus, the Italian municipalities were divided in three seismic classes and it was assumed that fragility functions from RINTC are representative of new design (residential) structures, according to a replacement criterion that was established to associate the structural typologies of the existing buildings to those considered in the project. The failure rates per building typology were computed first, combining the structural fragility functions and the computed hazard curves. Then, the failure rates were averaged over the building typologies and the percentages of soil conditions characterizing each municipality. The results, presented in the form of maps, show that the fragility of masonry structures have the main impact on the maps, which are also affected by the identification of the hazard and soil classes of the sites.

Keywords: Code-conforming structures, Building classes, Seismic failure rates, Fragility functions, Probabilistic seismic hazard analysis.

Session	[TU1K]—Accident and Incident Modeling
Day/Date/Time	Tuesday, 21 Sep. 2021/08:30–10:10 hrs
Venue	Atrium 1

TU1K: 148 08:30 hrs

Man to Machine (MTM) Accident Model Based on Multiple Regression Analysis of Process Industry Machineries through a Scientific Questionnaire Design

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Accidents in process industries are increasing rapidly whereby it affects the employees and the productivity as well. A questionnaire is designed to evaluate the risk of machinery safety and accidents of employees in a 2700MW coal fired power plant. Thirty-one statements involving machinery reliability, equipment aging and operational control method elements are included with an open-ended statement for suggestions from the respondents chosen in the workplace. Reliability analysis is later performed and a Cronbach Alpha value of 0.9103 was recorded from the questionnaire which marks the effectiveness of the questionnaire. Data analysis shows that the accident level is higher in the area of machine reliability and employees have a lower awareness level on machinery reliability compared to equipment aging and operational control method. A Man to Machine (MTM) model is designed based on the results which involves the correlation of the relationship between employee and equipment using Multiple Regression Analysis (MRA). The model involves the accident root causes of a process equipment and the major hazards in the area of the equipment. The R^2 value of 0.559 is obtained from the MRA Statistic Data which determines that most statements from machine reliability contribute to the increase of accident rate of the power plant. The MTM model is synced to fit to the reduction of accidents under machine reliability and to increase the awareness among employees.

Keywords: Accident, Machine safety, Data analysis, Machine reliability, Awareness, Model.

TU1K: 153 08:50 hrs

Safety in Road Tunnels: Analysis of Fire Accident Location inside the Gran Sasso Tunnel in Italy

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The aim of this research is to analyze the fire events occurred inside the Gran Sasso unidirectional highway tunnel in Italy. The Gran Sasso tunnel consists of two parallel one-way tubes with a length of about 10100 m. The tunnel, managed by Strada dei Parchi S.p.A., is one of the 14 tunnels belonging to the A24 and A25 motorways subject to the application of the European Directive 2004/54/EC. This Directive requires a Quantitative Risk Analysis (QRA) for tunnels belonging to the Trans-European Road Network and longer than 500 m. This study analyzed the fires and fire principles (which failed to develop into fire) that occurred in the left tube of Gran Sasso tunnel during the period 2007-2020, which consists of an uphill section of about 4500 m followed by a slightly downhill one. These events involved both light and heavy vehicles; their location along the tunnel and the possible causes were considered. Out of the 12 events analyzed (6 fires and 6 fire principles) it was observed that 11 events occurred in the uphill section while only one event occurred in the downhill section. The results of this study can be used for the implementation of risk analyses according to the European Directive but can also represent a useful tool for tunnel managers to evaluate the possible increase in the number and location of fire detection devices and/or fire suppression/control systems.

Keywords: Road tunnel, Tunnel safety, Tunnel accident rate, Tunnel fire, Quantitative Risk Analysis, Road accident, Risk, Safety, Vehicle fire, Tunnel operations.

TU1K: 182 09:10 hrs

Time to Failure Estimation of Cryogenic Liquefied Tanks Exposed to a Fire

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The density of different gaseous fuels can be increased for storage and transportation purposes trough the liquefaction process. The gases are converted to cryogenic fluids if liquefied by reducing their temperatures (e.g. for liquid hydrogen, LH2, and liquefied natural gas, LNG). Therefore, these cryogenic fuels must be stored in extremely well insulated tanks (double walled type with evacuated insulation). The ignition of an accidental fire in the vicinity of the cryogenic tank might cause the loss of integrity of the vessel. This event might lead to the catastrophic rupture of the vessel and provoke a major accident with many severe consequences. For this reason, the estimation of a potential time to failure (TTF) of the container in the worst-case scenario is critical.

In this study, an analytical model was developed based on well-known thermodynamic equations, to estimate the heat transfer between the cryogenic tank and the surrounding fire in the worst-case scenario. The thermal conductivity of the double walled tank insultation is one of the most complex and critical parameters to evaluate. Different uncertainties regarding the vessel insulation were highlighted in the manuscripts. The outcomes of this model were validated against experimental results. Additional experimental tests are necessary to thoroughly validate the model and understand the behavior of the cryogenic vessels when exposed to a fire. This type of tests will be conducted for LH_2 during the Norwegian project SH_2IFT.

Keywords: Cryogenic fluids, Liquid hydrogen, Liquefied natural gas, Loss of integrity, Catastrophic rupture, Time to failure, Analytical model, Emergency responders, Explosion, BLEVE.

TU1K: 293	09:30 hrs

Experimental Validation of a CFD Gas Release Model in a Wind Tunnel

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This paper presents the experimental validation process of an innovative CFD approach, called SBAM ("Source Box Accidental Model"), developed in ANSYS Fluent and aimed at a more efficient characterisation of accidental high-pressure gas releases in congested environments (e.g. offshore Oil&Gas, nuclear plants).

In this work, the experimental setup, methodology and a preliminary CFD-experimental data comparison are described.

The campaign has been carried out in the SEASTAR-WT wind tunnel, realized at the Environment Park in Turin (Italy) and completed at the beginning of October 2020. This subsonic, open-cycle tunnel with a total installed power of approximately 100 kW allows a range of air speeds between 0 and ∼8 m/s in the test chamber. A 1:10 scaled Oil&Gas platform mockup, equipped with flow and gas sensors, was built and installed inside the wind tunnel, allowing to reproduce, through a custom scaling procedure, the conditions of dynamic similarity with the real cases. Preliminary tests were performed to calibrate the tunnel and be acquainted with sensors behaviour and accuracy. The core of the campaign has been devoted to a set of gas releases meant to validate the concentrations and velocities predicted by the CFD modelling.

For most of the case studies, first results have shown that normalised concentration profiles present a good consistency with CFD simulation results. New tests are ongoing to validate also absolute concentration values and improve the understanding of the physical phenomena in such a complex setup.

The activity has been funded by the Italian Ministry of Economic Development (MiSE) and carried out at the SEADOG laboratory of the Politecnico di Torino.

Keywords: Oil & Gas, CFD, ANSYS fluent, High-pressure gas, Experimental validation, Wind tunnel, Accidental release.

TU1K: 495	09:50 hrs

A STAMP-Game Model for Accident Analysis of an Oil Spill and Explosion Accident

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Accidents in oil and gas storage and transportation are generated by complex socio-technical factors. Conventional accident models regard the accident evolvement as event chains, which have limitations in analyzing systems with increasing complexity and coupling. Thus accidents in complex systems can be investigated from the viewpoint of system engineering. System-Theoretic Accident Model and Processes (STAMP) is widely used to provide insights into the accident causation and risk prevention. Simultaneously, game theory can be adopted in accident analysis to depict the competition and cooperation relationships between stakeholders. This is due to that the stakeholders in STAMP can be regarded as players in game. This paper provides a new perspective to analyze accidents in the storage and transportation of oil and gas by the integration of STAMP and game theory (i.e., STAMP-Game model), with a case study of the oil spill and explosion accident in Dalian, China on July 16, 2010. The STAMP analysis uncovered the in-depth accident causal factors. Based on STAMP results, game theory was applied to analyze roles that government and companies played in the Dalian accident. Our results demonstrate that the STAMP-Game model is feasible for the causal investigation, risk prevention, and control of accidents in the storage and transportation of oil and gas.

Keywords: Oil spill, Accident model, System engineering, STAMP, Game theory.

Session	[TU2A]—Risk Assessment
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Plenary Room

TU2A: 360 **10:25 hrs**

Critical Success Factors for Risk-Based Inspection of Corrosion-loop Pipelines

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Petrochemical companies use equipment like vessels, reactors, furnaces, heat exchangers and pumps during the production of petroleum fuels, oil & gas, and other chemicals. Processing plants also use pipelines to transport the various process mediums within and outside the plant. Equipment that are used in plants are susceptible to deterioration due to a variety of damage mechanisms, depending on the fabrication materials, process mediums and process parameters. Risk-based inspection (RBI) is an engineering methodology or tool that determines and ranks the risk of failure associated with the operation of physical assets. This paper discusses the identification and ranking of the critical success factors (CSFs) for implementing RBI of corrosion-loops at a petrochemical facility in South Africa. Some 27 critical success factors for RBI were identified from literature. A questionnaire was developed and sent to RBI stakeholders, requesting respondents to rank the importance of 27 CSFs for a successful corrosion-loop RBI program. Some 231 completed questionnaires were returned by respondents. The most important CSF as ranked by the respondents was "Data collection" and the 2nd most important factor was "Record keeping". Comparison of the CSFs of single equipment RBI and corrosion-loop RBI showed "Data collection" to be the most important factor in both RBI types. The results of this study are useful for maintenance and reliability engineers to assess the importance of success factors for the implementation of a pipeline corrosion-loop RBI.

Keywords: Critical success factors, Corrosion-loops, Risk-based inspection, Processing plant.

TU2A: 390 **10:45 hrs**

On The Meaning and Use of The Plausibility Concept in A Risk Analysis Context

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The plausibility concept has gained increasing attention in recent years in risk analysis settings. A number of definitions exist, some of which interpret plausibility as an expression of uncertainty, whereas other definitions relate the concept of plausibility to the quality of knowledge. The concept is frequently referred to in scenario analysis, as well as emerging risk and systemic risk contexts, which are characterized by large uncertainties. The difficulty of assigning probabilities in such cases has led some to claim that plausibility, by offering a purely qualitative approach, is a more suitable tool for measuring uncertainty. However, a proper clarification of what the plausibility concept means in a risk analysis context is missing. Furthermore, current definitions lack a clear distinction between the meaning of plausibility per se, and how it is measured. The present paper aims to rectify these issues by i) reviewing and discussing how the plausibility concept is interpreted and used in the literature, ii) providing a suggested interpretation of the concept in a risk analysis context, and iii) giving our recommendations on how the practical application of the concept can be enhanced by drawing on contemporary risk science, specifically with regards to highlighting the knowledge and surprise dimensions of risk.

Keywords: Uncertainty, Plausibility, Probability, Knowledge, Risk analysis.

TU2A: 394 **11:05 hrs**

Reliability Methods For Analyzing Covid-19 Pandemic Spreading Behavior, Lockdown Impact And Infectiousness

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In 2021, the COVID-19 pandemic continues to challenge the globalized world. Restrictions on public life and lockdowns of different characteristics define life in many countries. This paper focuses on the first year of the COVID-19 pandemic (01-28-2020 to 01-15-2021). As a transfer of methods used in reliability engineering for analyzing the occurrence of infection, Weibull distribution models are used to evaluate the spreading behavior of COVID-19.

Key issues of this study are the differences in spreading

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behavior in the first and second pandemic phase and the various impacts of lockdown measures with different characteristics (hard, light). Therefore, the occurrence of infection in normed time periods with and without lockdown measures are analyzed in detail on the example of Germany representing the spreading behavior in Europe. Additional information in comparison to classical infection analyzes models like the SIR model is generated by the application of Weibull distribution models with easily interpretable parameters and the dynamic development of COVID-19 is outlined.

In a further step, the occurrence of infection of COVID-19 is put into the context of other common infectious diseases in Germany like Influenza or Norovirus to evaluate the infectiousness. Differences in the spreading behavior of COVID-19 in comparison to these wellknown infectious diseases are underlined for different pandemic phases.

Keywords: COVID-19 pandemic, Data analytics, Lockdown impact, Infection spreading behavior, Infectiousness, Influenza, Weibull distribution model.

TU2A: 395 11:25 hrs

COVID-19 Pandemic: Analyzing of Spreading Behavior, the Impact of Restrictions and Prevention Measures in Germany and Japan.

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In December 2019, the world was confronted with the outbreak of the respiratory disease COVID-19. The COVID-19 epidemic evolved at the beginning of 2020 into a pandemic, which continues to this day. The incredible speed of the spread and the consequences of the infection had a worldwide impact on societies and health systems. Governments enforced many measures to control the COVID-19 pandemic: Restrictions (e.g. lockdown), medical care (e.g. intensive care) and medical prevention (e.g. hygiene concept). This leads to different spreading behavior of the COVID-19 pandemic, depending on measures. Furthermore, the spreading behavior is influenced by culture and geographical impacts. The spreading behavior of COVID-19 related to short time intervals can be described by Weibull distribution models, common in reliability engineering, soundly. The interpretation of the model parameters allows the assessment of the COVID-19 spreading characteristics. This paper shows the results of a research study of the COVID-19 spreading behavior depending on different pandemic time phases within Germany and Japan. Both countries are industrial nations but have many differences concerning historical development, culture and geographical conditions. Consequently, the chosen government measures have different impacts on the control of the COVID-19 pandemic. The research study contains the analyses of different pandemic time intervals in Germany and Japan: The breakout phase in spring 2020 and subsequently following waves until winter season 2020/2021.

Keywords: COVID-19 pandemic, Data analytics, Germany japan comparison, Spreading behavior, Government measures, Social life.

Session	[TU2B]—Risk Analysis and Safety in Standardization
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Atrium 2

TU2B: 118 10:25 hrs

Effect of Sunlight Exposition on Impact Resistance of Thin Polycarbonate Sheets

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The design of guards has a fundamental role for safety of machinery. One of the purposes of the safety guards is to mitigate the risks of ejection of workpieces or tool parts.

The ISO 14120:2015 standard represents the state of the art for the design, construction and selection of guards utilizable either to avoid access to tools and moving parts as to protect people from ejection of objects. In this standard the impact resistance of a guard is tested through a single impact of a projectile of standardised shape hitting perpendicularly the surface of a flat plate. Whether or not the panel is perforated determines the suitability of a given material with a given thickness to be used for the construction of protective panels.

The aim of this study is to analyse the possible influence of aging on polycarbonate guards due to a long-time storage before their use. During the storage period, the material may be exposed to different environmental conditions, the worst of which, involves the exposure to direct sunlight. In order to verify the possible effect of aging due to irradiation caused by exposure to sunlight, a simulation of this influence was performed using ultraviolet (UV) fluorescent lamps in a machine for accelerated tests. The aging cycle chosen for the simulation requires continuous exposure under constant lamp irradiation and temperature without condensation cycles. The accelerated test was designed to obtain an aging equivalent at least to a period of one year of exposure being the panel placed in a vertical position and stored outdoors under direct sunlight but without rain on it. The reference solar irradiation conditions were chosen to replicate the same amount of energy typical of the centre of Italy. The conditions fixed for the accelerated aging tests will be fully explained on the paper.

The impact resistance of the aged panel is tested through impact tests on two sets of panels: a set of aged panels and a set of the same material without aging, in order to compare the results and highlight the possible effects of sunlight exposition. The tests were performed using the gas cannon at INAIL laboratories in Monte Porzio (Rome). The impact resistance of the panels was analysed with the well-known Recht & Ipson (R&I) equation.

The data obtained from the tests proved that, under the described conditions, it is not possible to claim an aging effect of the sun light.

Keywords: Machine tools guards, Safety of machinery, Ejection risk, Aging due to solar radiation.

TU2B: 150 **10:45 hrs**

Withstanding Capacity Tests of Roller Covers, Bellows and Aprons as Guards for Machines

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Roller covers, bellows and aprons are generally used in order to protect machines from coolants and swarf and even people from noise but they are usually not designed in order to protect against impacts due to ejections of work-pieces or tool parts. In addition, these protections are often designed ad-hoc for a specific machine because of strict space requirements. Consequently, manufacturers design a lot of specific roller covers, bellows and aprons with several and not homogeneous characteristics. Even if the initial aim is to protect against the effects of coolants, swarf and noise, it is possible that these components have to be considered as guards as requested by Machinery Directive (2006/42/CE) because of whole design even considering specific tasks of the life of the machine (e.g., maintenance, setting…).

In the first part of this paper, we discuss about safety requirements of these protections with non-homogeneous characteristics. We show that it is very hard to accomplish standard requirements and we are often obliged to limit or interpret normative documents in order to get reproducible tests.

In the second part of the paper some tests performed on a roller cover made of aluminium solid stripes hinged with plastic connectors will be presented. We propose an adapted version of the standardized test of ISO 14120:2015 annex B in order to get repeatable tests able to discover the withstanding capabilities of such components when used as guards.

Finally, thanks to the use of high-speed images of impacts, we make considerations about impact phenomenology of these components.

Keywords: Machine tools guards, Safety of machinery, Ejection risk, ISO 14120:2015, Safety test, Covers, Bellows, Aprons, Curtains.

TU2B: 264 **11:05 hrs**

Safety of Machinery – Risk Estimation for Technical Failures of a Gravity-loaded Axis

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Risk estimations in occupational safety are usually only qualitative, so that a comparison with other risks in scaled form is often not possible, although risk comparisons are indispensable in the legally prescribed risk assessment of machines. In the following considerations, a general possibility for scaling risks in occupational health and safety will be explained for a typical safety function (SF) in machine tools, which is: the safe standstill of a gravity-loaded axis (GLA). For simplicity, the considered causes of dangerous failures of this safety function will be an electronic control (A) in combination with a mechanical component (B). For the former, the probability density function PDF_A is assumed to be an Exponential distribution, for the latter PDF_B a Weibull distribution. As for a GLA, we are taking it for granted that the two failure modes are connected in parallel. Thus, if only one of the two components A or B fails, a hazardous event, such as a lowering movement of a tool spindle by gravity, is still prevented by the other component. Only when both components fail, significant hazards must be assumed, such as crushing and shearing. By connecting A and B in parallel, the probability of failure of the SF at a time t can be determined from the integrals (i. e. cumulative distribution functions, CDF) of the two probability density functions: $F_{SF}(t) = f[CDF_A(t), CDF_B(t)]$.

For the scaling of the probability that a hazard H_{SF} can actually arise from a failure of the above safety function, the parameter O, the socalled "occurrence probability of a hazard" according to ISO 12100, is used. For this purpose, a uniform distribution is to be assumed, so that O always has the same value, independent of all conceivable situations. Consequently, at a time t, the time-dependent hazard $H_{SF}(t) = O \cdot F_{SF}(t)$ results.

For a dangerous failure to become a hazard, however, a person must be exposed to a danger, i.e. the person needs to approach the hazard to such an extent that an injury could occur. This would be the case, for example, if an operator were to perform manual operations in the work area of a machine tool under a GLA, e.g., to manually change a workpiece in order to clamp another raw part after completing the part from before. Such operations are often recurring on machine tools. Their frequency distribution can be described with a Possion distribution, from which an expected value of the mean frequency of exposure events can be assumed N_{Ex}. As for the occurrence of a hazard H_{SF} due to a failure of the safety function assumed above, an independence between the failure and the presence of the operator in the hazardous area shall be assumed. This results in a multiplication of the two probabilities (or expected frequencies).

The relative hazard exposure Ex is composed of the frequency of exposure events NEx and their respective duration D_{Ex} in the form of a product formation $Ex = N_{Ex} \cdot D_{Ex}$ with its probability $P(Ex)$. A log-normal distribution is to be assumed for D_{Ex}, so that there are many short-term activities (with low exposure durations) and few moderate activities and very few activities of long duration. Thus, the mean expected frequency of hazard exposures Ex is the product of the expected values of a Poisson distribution and a log-normal distribution. The last element between a hazardous event and the occurrence of an injury is the so-called controllability with the parameter C. The expression (1-C) as an "inverse controllability" is directly connected to the expected frequency of injuries. For this non-controllability, a Gaussian distribution is to be taken as a basis on the one hand, and on the other hand it is assumed that the non-controllability is independent of the other risk elements. Then it follows that the Gaussian distribution is used by its mean $(1\text{-}C)_{average}$.

For simplicity, the severity of an injury is assumed here to be scalar with a value of S, ignoring the fact that the severities of machine tool injuries are typically distributed between minor injuries and severe injuries in their frequencies over four powers of ten. That is to say, for a total of approximately 10,000 injuries, there are typically around ten severe irreversible injuries and one fatal injury.

This paper answers the question of how often injuries are to be expected on average with the assumptions made in a given time frame (e.g. a service life of 10 *years* or, and for comparison, 30 *years*). This produces a plausible result, which can be compared with other occupational risks, and it enables to prioritize different risk reduction measures.

Keywords: Safety function, Risk estimation, Occupational safety, Gravity-loaded axis, Hazard, Exposure, Pandemic control.

TU2B: 268 11:25 hrs

An Innovative Integrated Smart System for the Safe Management of De-Energization in Maintenance Activities of Assemblies of Machinery

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In the Machinery Directive 2006/42/EC the risk management of the maintenance activities is particularly important, because the operators face several hazardous situations. The safe entrance into the danger zones of the machinery assemblies often requires the isolation from energy sources and the dissipation of stored energies to assure the avoidance of release of energy, the unexpected start-up of the machinery and harmful incidents. In this context conventional well-known procedures, such as Lock Out/Tag Out (LOTO), are widely exploited by the employer. Their actual effectiveness in terms of prevention of incidents depends strongly on the correct application by the operators and currently several dramatic events still occur. So, we present a novel smart system, based on the paradigm of Industry 4.0, which supports the operators and guides the procedure step-by-step with the aim of mitigating the error probability and the consequent risk.

The proposed smart system exploits the Radio Frequency IDentification (RFID) technology to measure the real-time position of workers through a synthetic-array method. A cloud-based software supervises and manages all activities. Based on the tracking results, it communicates step-by-step to the operators the safe procedures on remote devices such as smartphones and receives feedbacks about the right execution. In this way the de-energization procedure can be carried out in safe way with low level of error risks for all operators involved in the maintenance activity.

Keywords: Lock Out Tag Out, Industry 4.0, Smart device, Hazardous energy, Maintenance safety, RFID localization.

Session	[TU2C]—Adaptative Optimization of Maintenance Strategies for Complex Systems
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Espace Grand Angle2

TU2C: 254 **10:25 hrs**

Grouping Maintenance Strategies Optimization for Complex Systems: A Constrained-Clustering Approach

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Maintenance actions constitute critical tasks that ensure the availability of industrial systems and improve their operating safety. However, maintenance faces numerous challenges and is no longer limited to guarantying availability. It has become a strategic concern and abides by imposing quality, safety, and cost requirements. Finding optimal grouping strategies of maintenance activities is an *NP*-hard problem that is well studied in the literature, and for which various economic models and optimization approaches are proposed.

While most models found in literature use heuristics, such as evolutionary algorithms, to locate cost-reducing grouping strategies, context-specific constraints that could arise within each system are not taken into consideration. For large complex systems, heuristic approaches cannot guarantee the convergence to a feasible solution. Therefore, we propose a new scalable and adaptive optimization algorithm based on a clustering approach to group maintenance activities in multi-component complex systems. The proposed Constrained Clustering-based approach takes into consideration domain-dependant constraints and provides grouping strategies in negligible times.

Keywords: Grouping maintenance strategies, Maintenance optimization, Multi-component systems, Meta-Heuristics, Constrained-clustering, Linear programming.

TU2C: 490 **10:45 hrs**

Fault Detection in a Multi Sensors Context by 3D Object Descriptors Method

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The monitoring of an asset in an industrial context is a real challenge today, as data are more and more available, and computation power becomes cheaper with time. However, if we want to use data from different sensors to detect if there are anomalies of any kind, it is usually needed to individually consider a whole time series, or the values of several time series at a particular moment. In this article, we propose an adaptation of 3D objects descriptors to the detection of unknown faults in a multi-sensors context for features extraction. Then, classical outliers detection methods such as *Local Outlier Factor*[1] and *isolation forests* [2] are used. This allows us to detect an unknown problem to come on an asset monitored by several sensors. To our knowledge, this problem has not been completely solved yet, and opens new opportunities in class disequilibrium contexts. Final performances confirm the interest of the proposed approach adapted to a real time industrial context, and allow to consider a new way for extracting features in the pretreatment of multi-time series.

Keywords: Anomaly detection, Outlier detection, 3D object descriptor, Fault detection.

TU2C: 541 **11:05 hrs**

Simulation of Complex System Based on Optimization Methods for Maintenance Scheduling

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Industrial systems are subject to faults and failures on their components, which can lead to the unavailability of the systems and increase costs due to interventions. A suitable maintenance strategy is therefore a good solution so to reduce such costs, and also to increase the availability of the system. Combination of different kinds of maintenance policies on components of a system can be a good solution. Nevertheless, it has to be finely analyzed, so to search the optimal maintenance strategies on the system, according to specified criteria (e.g. availability, cost, etc.).

In this publication, we illustrate how the combination of a simulation tool, based on stochastic discrete event systems, and an optimization algorithm can be used to find (one of) the best strategy of maintenances. The simulations are led by an optimization algorithm We propose a solution that optimizes system availability, and cost with systemmaintenance constraints using an exact mathematical formulation. A stochastic simulator performs calculations according to parameters provided by an optimization algorithm, which plans preventive maintenance schedules. The optimization algorithm provides the optimum maintenance scenario defined by the kind of maintenances to apply and the suitable schedules. The experiments show that the simulation based optimization algorithm gives more flexibility to the decision maker.

Keywords: Maintenance policies, Optimization, Simulation, AltaRica 3.0.

TU2C: 721 **11:25 hrs**

Optimal Planning Of Preventive Maintenance Tasks On Electric Power Transmission Systems

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Any component of an electricity power system is susceptible to failure. The power transmission system connects the generating units to the local distribution systems, and its central operational role means that the scheduling of preventive maintenance of transmission lines must be carefully planned. This planning aims to ensure uninterrupted power supply by reducing equipment failures and accidents, increasing the quality of the energy supplied, and generally maintaining network reliability. The transmission maintenance scheduling problem is concerned with selecting the optimal periods to remove specified transmission lines from operation to carry out preventive maintenance.

We propose a mixed-integer linear optimization formulation of this problem for a planning period of one year. From an operational point of view, when scheduling preventive maintenance it is important to keep the transmission system connected as well as to consider the possibility of an unexpected line failure elsewhere in the system. The resulting largescale optimization problem is solved using a decomposition algorithm that divides the large model into two smaller optimization problems. One of these problems is solved with CPLEX through Benders decomposition, and the second is a means to validate the solution. We report computational results with the IEEE 24-bus system that demonstrate that the algorithm achieves the required accuracy and solves the problem more efficiently than if the complete formulation is solved without decomposition.

Keywords: Preventive maintenance, Power transmission system, Network reliability, Mathematical optimization, Decomposition methods.

Session	[TU2D]—Prognostics and System Health Management
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Panoramique

TU2D: 181 **10:25 hrs**

CNN Based Analysis of Grinded Surfaces

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The optical perception of high precision, fine grinded surfaces is an important quality feature for these products. Its manufacturing process is rather complex and depends on a variety of process parameters (e.g. feed rate, cutting speed) which have a direct impact on the surface topography. Therefore, the durable quality of a product can be improved by an optimized configuration of the process parameters. By varying some process parameters of the high precision fine grinding process, a variety of cutlery samples with different surface topographies are manufactured. Surface topographies and colorings of grinded surfaces are measured by the use of classical methods (roughness measuring device, gloss measuring device, spectrophotometer). To improve the conventional methods, a new image processing analysis approach is needed to get a faster and more cost-effective analysis of produced surfaces. For this reason, different optical techniques based on image analysis have been developed over the past years. Therefore, fine grinded surface images have been generated under constant boundary conditions. The gathered image material in combination with the classical measured surface topography values is used as the training data for machine learning analyses.

Within this study the image of each grinded surface is analyzed regarding its measured arithmetic average roughness value (Ra) by the use of Convolutional Neural Networks (CNN). CNNs are a type of machine learning algorithms which can particularly be applied for image analysis. For the determination of an appropriate model, a comprehensive parameter study is performed. The approach of optimizing the algorithm results and identifying a reliable and reproducible CNN model which operates well independent of the choice of the random sampled training data is presented in this study. The classification is part of the development of a condition monitoring tool for the fine grinding process of knives.

Keywords: CNN, Image analysis, Artificial intelligence, Machine learning, Surface analysis, Optical inspection, Parameter study, Condition monitoring.

TU2D: 187 **10:45 hrs**

Method of Calibration Period Determination for Temperature Chamber based on Risk Analysis

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The temperature box is the main equipment for temperature testing, and its accuracy affects the quality and credibility of the test results. Currently, temperature chambers are calibrated regularly, but too long a calibration period will result in too high calibration risk, and too short a calibration period will result in too high calibration costs. In order to formulate a scientific and reasonable calibration cycle and provide a theoretical basis, the following formulating methods are proposed. First, a combination forecasting model that integrates similar product information is proposed, in which GM(1,1) is used for overall prediction, Markov model is used for residual prediction, combined weighting is used to obtain the prediction sequence of calibration data, and the specific temperature box is calculated with the same kind The Euclid distance between temperature boxes is based on the similarity function to determine the specific temperature box prediction model to predict the drift trend of performance parameters in the next calibration cycle; secondly, the probability density function and reliability model of the calibration parameters are used to establish the reliability function in a certain period, consider the aging of the temperature box, combine the actual use time and the number of calibration cycles to establish a hybrid failure rate evolution model, and derive the reliability function in the prediction period based on the existing reliability function and failure rate, The specific change time of the calibration cycle is refined according to the reliability function; finally, the validity of the proposed strategy is verified according to the case analysis.

Keywords: Temperature box, Calibration period, Calibration risk, Fusion similar information prediction model, Reliability, Aging factor.

TU2D: 189 **11:05 hrs**

An Objective Weight Determination Method Based on Model Healthy status Recognition Rate

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Health measurement model is used to objectively and accurately express the current healthy status of the product. In this paper, three common equipment health measurement models with different description forms are analysed, and the health measurement model based on Mahalanobis distance and the health measurement model based on overlapping degree are optimized on the basis of practical application. Then according to the application of these health measurement models, a set of rule reasoning process for model selection is established and automatic model selection is realized. In the process of analysing and optimizing the models, this paper also finds several subjective factors of different degrees in these models, which are parameter values determined by the experts' experience. In order to eliminate such subjective factors, a method for determining subjective model factors based on healthy status recognition rate is proposed based on the objective operation data of different healthy status and the identical healthy status of equipment. Finally, taking the weight determination method in the health measurement model based on Euclidean distance as an example, a mathematical model and its optimization objective are explained in detail.

Keywords: Equipment health, Health representation, Health index, Health measurement, Objective weight determination, Status recognition rate.

TU2D: 260 **11:25 hrs**

Detection of Defects on Printed Circuit Boards Using Instance Segmentation

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Printed circuit boards (PCBs) are very important parts for almost every electronical device since they are the most frequently used interconnection technology for components in electronic products. Due to that fact, the reliability of PCB is very important. In order to guarantee the quality of a PCB, the single manufacturing steps have to be monitored. One of the most important manufacturing steps is the tinning process of the copper pads using hot air leveling. The impor-

tance of this process lies in the fact that oxidization of the copper pads has to be avoided, and the solderability of the PCB needs to be ensured. For this reason, uncoated copper pads must be prevented.

In a previous study a model for the automatic detection of uncoated copper pads has been developed using a patchbased classifier. The model showed good results, but the approach was not suitable to be implemented in an industrial application. In this present study an instance segmentation approach was used to tackle the problem. The basis of the model is a R-CNN with mask prediction that has to be trained using image data. A PCB inspection unit was employed to generate the image data. Due to the high expense of the instance labeling, an approach adopted from active learning was used as strategy to select images that extend the training dataset efficiently. Evaluation of the developed model shows, that the great majority of defects is detected correctly. The future goal is to improve the model such that it can be included in an automatic fault detection system as part of an online quality control unit in the manufacturing process of PCBs.

Keywords: Online fault detection, AOI of PCB, Computer Vision, R-CNN, Instance segmentation, Reliability engineering.

Session	[TU2E]—Risk management for the design, construction and operation of tunnels
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Amphi Jardin

TU2E: 281 **10:25 hrs**

Discussion on Possible Approaches for the Management of Pollutants in Tunneling in Rock Formations Containing Asbestos Minerals

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Workers' exposure to asbestos minerals is a major factor in the Occupational Safety and Health risks typical of tunneling. For, as well as being a carcinogen, the distribution of asbestos minerals in rock formations is highly irregular since their possible formation during the metamorphic process depends on various parameters. This makes a special risk assessment and management necessary. Many case studies of specific risk assessment and management of pollutants applied in tunneling are available in literature, so the aim of this research study is to define which can be implemented in case of formations containing asbestos minerals, in combination also with other solutions, and organize them in hierarchical order. Initially, to achieve this goal, a literature review was carried out in accordance with the PRISMA statement, to select the current solutions used to manage possible workers' exposure to asbestos minerals. Subsequently, the various solutions selected (e.g., specific excavation techniques, catcher systems near the source, ventilation systems etc.) were given a hierarchy by order of priority and compared to each other. The selection of solutions and the priority order were achieved by taking into account the safety requirements for the construction of the base tunnel of the Turin-Lyon railway line. The study highlighted the fact that despite technological progress there are still some critical aspects in the management of pollutants and in particular of asbestos minerals.

Keywords: Occupational safety and health, Tunneling, Asbestos, Risk assessment, Risk management, Literature review.

TU2E: 388 **10:45 hrs**

Development of a Proactive Tool for Dangerous Goods Management in Tunnels

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As a rule, tunnels are considered safe road infrastructures. Nevertheless, when an accident occurs inside a tunnel it can maximize its impact and casualties due to its constrained space of occurring events. Undoubtedly, fire accident events are the greatest threat to road tunnel systems and destructive experiences such as the Mont Blanc fire in France (1999) or the fire in Yanhou, China (2014) are indicative of the severity of such incidents. The use of automated deep learning and data mining algorithms that can provide accurate detection, frequency patterns and concentration predictions of dangerous goods passing through tunnels, is a significant fire incident restriction factor. To achieve automated detection, a post processing image detection tool has been developed, that identifies and marks the passage of dangerous goods through tunnels. This tool receives input from toll camera images and offers timely information of vehicles carrying dangerous goods, since such vehicles are signalled with a proper ADR label number (ADR vehicles). Knowing the exact number of ADR vehicles along with their carrying substance at any particular time, followed by classification and associated rules to fire incident occurrences, can lead to an effective management of the passage of such vehicles and consequently to an effective preventive management of fire incidents in tunnels.

Keywords: Tunnels, Risk management, Dangerous goods, Deep learning algorithms, Data mining, Image processing.

TU2E: 530 11:05 hrs

Employing Serious Games to Increase Safety in Driving Through Road Tunnels

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Research has shown that tunnel safety is a matter of great importance. Recent studies have shown that, while driver behavior is one of the decisive factors in road tunnel accidents, drivers hardly receive proper education about the particularities of the tunnel environment, and they also exhibit deficiencies on how to deal with emergency situations inside a tunnel. As a means of tackling this challenge, the present research endeavor develops a software tool based on the concept of serious games, to educate and inform potential users on the specific rules and behavioral patterns that should govern driving through tunnels. To do so, the initial step was the determination of the basic instructions that a user must be familiar with, while driving through tunnels. The proper behavioral patterns were gathered from the relevant standards and guidelines and the specific needs for education have been explored through previous studies. Subsequently, the research proceeded with the development of an innovative tool for the purpose of users' training, consisting of a game environment which simulates from a first-person perspective the task of driving through a tunnel. Within this environment various different scenarios were developed with the aim of evaluating the knowledge of users as well as educating them. The ultimate aim is to further increase safety within road tunnels, focusing on driver behavior as one of the most crucial parameters.

Keywords: Road tunnels, Road safety, Serious games, Simulation environment, Driver behavior, Behavioral patterns.

TU2E: 557 11:25 hrs

The Concept of Learning in Virtual Reality in the Context of Tunnel Fire Evacuation Knowledge

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This paper aims to explore how and what kind of learning is emphasized in the use of virtual reality to develop fire evacuation knowledge among participants. Experiences from several large tunnel fires in Norway highlight the need for deeper knowledge on tunnel fire evacuation. Virtual reality technology has developed rapidly in recent years and is regarded a powerful tool among fire evacuation researchers. The advantage of virtual reality is to give participants experiences with fire and smoke conditions without exposing them to real risk. A literature study was set up to examine learning from virtual reality. Our understanding of learning is based on a combination of cognitive and sociocultural perspectives. Virtual reality technology provides a safe context for behavioral challenges in different constructed and simulated tunnel fire scenarios. The complexity of real fire evacuation situations challenges the use of virtual reality, both as a validation tool and for learning required evacuation behavior in real situations.

Keywords: Learning, Virtual reality, Learning transfer, Evacuation knowledge.

Session [TU2F]—Probabilistic vulnerability estimation, lifetime assessment and climate change adaptation of existing and new infrastructure
Day/Date/Time Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue Espace Grand Angle

TU2F: 276 **10:25 hrs**

Adaptation Management of Coastal Bridges Subjected to Extreme Waves Considering Climate Change

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Coastal bridges are crucial traffic components and vital to the social economy. However, they are susceptible to enlarging risks from hurricane-induced surges and waves due to the increasing temperature and humidity, rising sea-level, and amplification of hazard intensities. An understanding of how to mitigate the potential risks of coastal bridges from natural hazards is a critical step toward reliable transportation systems; while relative adaptation measures were seldom discussed. This study conducts a comprehensive analysis of the effects of different adaptation measures to help the bridge resist hurricane-induced risks under climate change scenarios. The long-term loss assessments associated with different retrofit measures are evaluated by considering deep uncertainty in future climate change. Different retrofit measures are investigated and compared, including inserting air venting holes, enhancing connection strength, and elevating bridge structures. Specifically, a Computational Fluid Dynamics (CFD) model is established to compute wave-induced forces on the coastal bridge. Vulnerability curves are derived based on the deck unseating failure mode, and long-term losses are assessed considering the stochastic occurrence of hurricanes and climate change scenarios. The effects of retrofit adaptations on reducing long-term losses are examined and compared according to the proposed framework. Such a study results in systematic evaluations of different adaptation measures, which could help optimal and robust designs of coastal bridges and modifications of existing ones.

Keywords: Coastal bridge, Adaptation measure, Climate change, Long-term loss, Hurricane, CFD model.

TU2F: 371 **10:45 hrs**

Effect of Climate Change on Railway Maintenance: A Systematic Review

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According to international reports and publications, the effects of climate can cause rail failures and consequently leading to disrupt travel schedules and unforeseen delays. Extreme heat, cold and snowfall are among the most important climate changes conditions that affect the normal railway operation. Thus, in order to determine the appropriate maintenance strategy that reduce the social and economic impact of the repair interventions, it is fundamental to identify and predict in advance the potential points of failure. This paper compares and analysis different published studies related to railways failures by measuring the effects of weather on rail defect.

Keywords: Climate change, Railway maintenance, Performance, Railway infrastructure.

TU2F: 407 **11:05 hrs**

Pressure Distribution Patterns Between the Ballast and the Concrete Slab in Railway Trough Bridges

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In Sweden, a substantial amount of railway bridges is approaching their intended lifespans and are planned to be replaced. However, it is not sustainable neither from a financial nor an environmental perspective to replace these bridges if they are still sound and safe. Thus, an evaluation of their actual capacity is required with the aim of extending their lifespans. A way to obtain a more accurate capacity is to determine the loads that are acting on them. Available literature points out the lack of experimental investigations on sleeper-ballast contact pressure, as well as on the stress distribution along and across the ballast. Consequently, railway bridge design has been based on tradi-

tional rather than rational assumptions, which can be quite conservative. In this paper, a review of models is carried out for evaluating stress patterns on the surface of the slab on ballasted concrete bridges. Then, a simplified finite element model of a concrete trough bridge, a common type of structure in Sweden, is used in a parametric analysis aimed to understand how the identified pressure distribution patterns affect the performance of this type of structure. Finally, with the purpose of studying how some parameters influence the bridge safety, a probabilistic reliability analysis is used. The reliability index beta (β) is obtained using the polynomial response surface method and its value is compared for different boundary condition scenarios. Also, the sensitivity factors for the considered random variables are compared and analyzed. Results show that the assumption of support condition and pressure pattern has a significant impact on the capacity, failure mode and probability of failure of this type of structure.

Keywords: Ballast, Load distribution, Trough bridges, Pressure patterns, Internal forces, Reliability analysis.

TU2F: 468 **11:25 hrs**

Design of Structures in the Changing Climate

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The biggest contributors to the inherent uncertainty in the estimation of climate projections include natural variations in climate due to solar activity, future emissions of greenhouse gases and other harmful resources and uncertainties related to decision on effective reduction of emissions of greenhouse gases. The aim is to analyse how anticipated changes in European climate could affect the assessment of design weather parameters, including the partial factor design approach for structures according to Eurocodes, based on current knowledge concerning projection models of future climate in Europe.

Keywords: Climate changes, Design weather parameters, Probabilistic structural analysis, Partial factors, Target reliability, Corrosion of structures, Eurocodes.

Session	[TU2G]—Oil and Gas Industry
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Atrium 3

TU2G: 323 **10:25 hrs**

Decisions in a Condition of Uncertainty Involving the Development of Offshore Oil Fields: A Proposal of a Framework for a Decision Support Systems

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Operating under the condition of uncertainty is intrinsic to the oil industry. Moreover, the field competition increases the pressure to obtain better results with diminished investment and costs. In this environment, the introduction of new technologies is mandatory. The insertion of new technologies has the objective to increase profits, but they also increase risks since they are not proven in the field. Project managers must deal with this dilemma without the necessary tools to clearly understand the big picture. A Decision Support System (DSS) is an interesting software tool that could help managers decide better in the presence of such uncertainties, dynamics, and many concepts. This paper presents discusses the characteristics of a DSS intended to contribute to project manager decision, presents some simulation tools, proposes a preliminary architecture, and discusses its internal components. The paper concludes that the development of such DSS is also a complex project that must follow some rules to have a greater chance of success.

Keywords: Oil field development, Risk management, Decision analysis, Decision support systems.

TU2G: 328 **10:45 hrs**

Uncontrolled Release of Crude Oil in the Groundwater from a Storage Tank – Critical Issues and S-EMS Improvements Linked to Seveso-IED Interfaces

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During environmental monitoring/control activity of the soil, close to a crude oil extraction/storage plant, polluted water with hydrocarbons have been found inside a sewage pipeline of the consortium that managed the wastewater treatment plant (WWTP). Same finding was noticed inside the WWTP by the operators, and in the ground area around the plant. Following investigations assured that a loss of containment occurred from the bottom of a tank, causing the pollution of 26000 m^2 area from top surface down to groundwater level, with consequent strong environmental impact. Almost 400 tons of crude oil have been released in the environment. All plant activities have been suspended for 90 days during which inspections, checks and monitoring phases took place. The event has had a slow and long evolution, and was discovered only after months from the starting of the release. The accident is still under investigation, but interesting critical issues elements, linked to the root-causes of the accident, have been highlighted. Important Safety&Environmental-Management- System improvements have been carried out after Seveso and IED inspections. The accident put also in evidence, in order to avoid situations as the one occurred, the need to find ways to improve communication between Seveso and IED control activities and to adopt common approaches when dealing with the operation of an establishment in the respect of both safety and environmental issues.

Keywords: Crude oil, IED, Impact, Inspection, Maintenance, Release, Seveso, Storage tank.

TU2G: 625 **11:05 hrs**

Degradation of Process Safety Cultures – An Experience Based Perspective

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Due to the critical significance of "process safety culture" concept within industrial safety management domains, it is imperative to identify and discuss various factors that can cause positive safety cultures to degrade over the time. The concept of "safety culture" has been defined in different ways (Botheju et al, 2015; Botheju & Abeysinghe, 2015); but for the purpose of this paper, "the process safety culture" can simply be explained as the embedded psychosocial and cultural medium within which the decision makers who are crucial in making important process safety design decisions have to operate. Through long term experience, authors have seen how some of the worlds' best safety cultures have evolved over the time, as well as how the same safety cultures are eventually started to degrade due to various reasons. The economic pressure, absence of major accidents over a long duration, impact of globalized human resources, lack of regulatory intervention willpower, and natural degradation without reinforcing actions are recognized as the key factors needing attention in this regard. The persisting economic pressures in the oil and gas industry has exerted dramatic downturns in some of the worlds best organizational safety cultures. Safety cultures can also become stagnant and passive due to the long absence of accidents or serious incidents within its operating domain. It's a challenge to maintain good safety cultures at their maturity state without constant efforts; learning from past accidents and the accidents happening elsewhere must be used to the fullest extent to maintain essential moral within the organization. The cultures can change when human resources are recruited in significant scales without proper orientation to the new culture; especially when such employees are coming from more negative safety cultures. This can become a more prominent issue during the times of greater economic pressures. The regulatory intervention must exert its pressure proportional to the trends and dynamics in the industry. More relaxed intervention strategies cannot be continued in the times when safety cultures begin to erode. The safety cultures are subjected to natural degradation if not actively maintained. Continuous improvements and constant learning are key aspects of maintaining a positive safety culture. Degrading safety cultures can have long term repercussions on process safety, as some of the poor design decisions could result in major accidents decades after their implementation, especially towards aging assets and changed operating conditions. The full version of this article is considered to be useful for those involved in designing or managing industrial safety systems and management tools, or for any stakeholders directly connected to the process industry sector.

Keywords: Degradation of safety culture, Major accident, Petroleum industry, Process safety, Safety management.

TU2G: 294 **11:25 hrs**

Automatic Fault Trees Generation And Analysis for Thousands of Gas Transmission Units

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GRTgaz owns and operates the longest high-pressure natural gas transmission network in Europe. The industrial assets of GRTgaz include more than 32,000 km of pipes, 26 compression stations, about 4,800 shut-off stations and more than 5,000 pressure reduction stations (notably for delivering public distributions and industrial consumers). In particular, the pressure reductions stations can have one two lines, each line having one or two pressure regulators, plus safety devices (shutdown valves and/or safety relief valves), and other items (filters, manual valves, gas meters). In addition, each type of device exists in different models (technology, manufacturer, sizes, parameters) so that there are probably no two stations that can be assumed alike. Since GRTgaz must transport natural gas on behalf of all its customers while ensuring optimum safety, cost and reliability, risk assessments need to be performed for thousands of these stations.

Keywords: Fault Tree Analysis, Weibull Distribution, Risk Assessment, Asset Management, Gas Network.

Session	[TU2H]—Maritime and Offshore Technology
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Cointreau

TU2H: 200 **10:25 hrs**

Safe Speed for Maritime Autonomous Surface Ships – The Use of Automatic Identification System Data

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Introduction: All vessels are required by law to proceed at a safe speed while at sea. However, there is no acceptable method of determining what value of speed could be considered safe. One way of determining safe speeds in different conditions could be the utilization of Automatic Identification System (AIS) data to create a safe speed model that maritime autonomous surface ships (MASS) could follow.

Objectives: Investigate if MASS can determine the safe speed without human support by utilizing historic AIS speed data of other vessels. Investigate further if AIS and visibility data show a strong relationship between visibility and vessel speeds, and if vessels generally show a reduction of speed in restricted visibility.

Methods: AIS and visibility data was collected and merged in an area off Western Norway in the period between 27 March 2014 and 31 December 2020. A simple linear regression was calculated and supplemented by two graphical methods for revealing relationships between two variables.

Results: A significant regression equation between visibility and speed was found. This relationship was not strong. Average transit speed was highest when visibility was below 1,000 meters.

Conclusion: The problem of quantifying the safe speed of a vessel in different conditions does not seem to be solvable by only using historic AIS data to create a model of normalcy which a MASS can follow.

Keywords: MASS, AIS, Safe, Speed, COLREG, Visibility.

TU2H: 472 10:45 hrs

A Hybrid Early-Warning System for Unsafe Crew Acts Detection and Prediction

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Around 70% of maritime accidents have been attributed to crew unsafe acts (Chauvin, Lardjane et al. 2013). Human unsafe acts may be predicted and analyzed through the identification and assessment of factors that influence human error, namely performance shaping factors (PSFs). This paper presents a hybrid early-warning system that integrates a detection model for procedure violation, and a prediction model for unsafe acts resulting from skill-based errors, decision errors, and perceptual errors (Figure 1). The early-warning system utilizes voluminous datasets collected from multi-source sensors, including on-body wearable sensors, video cameras and microphones placed on board. The prediction model is human error type specific and established using PSFs covering personal characteristics, task characteristics, environmental conditions, and ship characteristics. The PSFs and corresponding relative importance are collected from a literature review, historical maritime accident reports review, and questionnaires among experienced seafarers. A set of indicators are further proposed to rate the PSFs for quantifying the probability of unsafe acts. The hybrid early-warning system is planned to be installed and validated on a cruise ship to detect, predict, and early warn the unsafe acts of crews to prevent accidents from happening.

Keywords: Unsafe acts, Early-warning, Human error, Maritime accident.

TU2H: 149 11:05 hrs

Sources of LNG Bunkering Leak Frequencies

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A cleaner future for maritime transport relies on the ability to refuel ships with liquefied natural gas. Risk assessments of this LNG bunkering are sensitive to the likelihood of accidental leaks. While several sources offer leak frequencies for LNG transfer, few acknowledge their uncertainties. This paper investigates the available sources and synthesises them to estimate an uncertainty distribution for LNG bunkering leak frequencies.

The paper first compares the leak frequencies that have been used in published LNG bunkering quantitative risk assessments and guidance documents, finding that they vary over 3 orders of magnitude. It then traces the original sources of the leak frequencies, which are rarely acknowledged, and sometimes incorrectly transcribed. Understanding of the original source, together with the judgements (and sometimes errors) that have been added to it, is necessary to appreciate the quality of any leak frequency. The paper proposes a set of criteria indicating high-quality leak frequencies, and uses them to rank the quality of the available sources. This provides a way of combining the available sources to estimate an uncertainty distribution for the leak frequency.

Until improved leak frequency models are available, this "wisdom of the crowd" estimate provides a better understanding of the likelihood of leaks than any single existing approach. It also highlights the importance of uncertainties when evaluating the need for additional safety measures in LNG bunkering.

Keywords: Risk assessment, LNG, Bunkering, Uncertainties, Hoses, Failure rates, Leak frequencies.

Session	[TU2I]—AI for safe, secure and dependable operation of complex Systems
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Giffard

TU2I: 597 **10:25 hrs**

New Probabilistic Guarantees on the Accuracy of Extreme Learning Machines: An Application to Decision-Making in a Reliability Context

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This work investigates new generalization error bounds on the predictive accuracy of Extreme Learning Machines (ELMs). Extreme Learning Machines are a special type of neural network that enjoy an extremely fast learning speed thanks to the convexity of the training program. This feature makes ELMs particularly useful to tackle online learning tasks. A new probabilistic bound on the accuracy of ELM is prescribed thanks to scenario decision-making theory. Scenario decision-making theory allows equipping the solutions of data-based decision-making problems with formal certificates of generalization. The resulting certificate bounds the probability of constraint violation for future scenarios (samples). The bounds hold non-asymptotically, distribution-free, and therefore quantify the uncertainty resulting from limited availability of training examples. We test the effectiveness of this new method on reliability-based decision-making problem. A data set of samples from the benchmark problem on robust control design is used for the online training of ELMs and empirical validation of the bound on their accuracy.

Keywords: Extreme learning machines, Scenario theory, Generalization bounds, Reliability, Decision-making, Machine learning.

TU2I: 675 **10:45 hrs**

Safety of Autonomous Ships – Interpreting High Confidence Mistakes of Deep Neural Networks using Heat Maps

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Deep Neural Networks (DNN) are used for image recognition in safety-critical functions of autonomous cars and ships. Car accidents have exposed DNN's lack of robustness to irregular events like unusual image objects and scenes. A misclassification with a high score, which we term a high confidence mistake, is of a particular concern to autonomous ships where we foresee a remote, land-based human operator in the loop who can intervene if warned. A high confidence mistake will not generate a warning to the human operator. To assess the safety of the classifier, we need as a minimum to understand why the classifier fails. This study evaluates the Layer-Wise Relevance Propagation (LRP) heat mapping method, applied to maritime image scenes. The method is evaluated on a classifier, trained using transfer learning to classify marine vessels into one of four different vessel categories. As a part of this, test images have been manipulated to deliberately provoke failures in the classification module. The resulting heat maps have then been used to investigate the cause of the failures. The results suggest that heat maps help us better understand what features are relevant for the classification which is an important first step. Further research is however required to provide an assurance framework to assess the safety level or to assist in debugging a DNN.

Keywords: Deep neural networks, Safety-critical systems, Autonomous ships, High confidence mistakes, Heat mapping, Explainability.

TU2I: 706 **11:05 hrs**

Contrastive Feature Learning for Fault Detection and Diagnostics

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A multitude of faults can occur in operating systems. Some pose a safety-critical problem instantaneously and therefore, require immediate intervention. Others evolve slowly and only require maintenance if they are particularly pronounced. Due to the vast variety of different faults, it is

not efficient to react to each detected fault with the same maintenance action. Instead, the maintenance intervention planning needs to take into account which type of fault is detected and how severe the fault is. This allows planning maintenance efficiently. Too early maintenance downtime can be prevented and intervention time can be reduced e.g. by preparing required spare parts.

To achieve this, a fault diagnostics model is required that can accurately isolate different faults and determine their severity. Yet, specific challenges apply when learning data-driven fault diagnostics models. First, an operating asset is exposed to varying operating conditions and external influencing factors that cannot be controlled or known before. This results in high variability of the condition monitoring data within the healthy condition that is not caused by faults. A data-driven model might raise a false alarm for inherently unknown variations in the data if these were not part of the training distribution. Adding complexity to the task of defect diagnostics is that data often lacks detailed labeling to diagnose a fault. For example, the operator might not distinguish between different fault types or different fault severities in its maintenance reports. In that case, detailed information on the fault type and its severity is lacking when training the corresponding models, which essentially makes it an unsupervised learning task. The task of unsupervised fault diagnostic is often approached by clustering a low-dimensional feature representation of the data. Auto-Encoders (AE) are often used to learn a compact feature representation. Yet, the objective when training an AE is to fully reconstruct the input signal i.e. to pass all information about the data through the feature layer including data variations relating to varying operating conditions. This makes them sensitive to changing operating conditions at inference time. Contrastive learning poses an interesting alternative to extract features that explicitly aims to extract semantic meaning. The feature space is optimized with the triplet loss such that similar data points are closer to each other than dissimilar ones. In its supervised implementation, similar data points correspond to those with the same label whereas dissimilar data points are those with different labels. Hence, the triplet loss explicitly is designed to cluster data in the feature space according to their class label. This results in a compact feature representation.

In this work, we propose contrastive learning for the task of defect diagnostics. Our work is the first that applies the triplet loss to PHM applications. Further, we adapt the triplet loss to the case where no refined labeling is available. The resulting feature representation of the data shows to be particularly suited for defect identification under the limitation that certain operating conditions have not been observed in the training dataset. Our evaluation is conducted on the CWRU Bearing benchmark dataset.

Keywords: Faults detection & diagnostics, Contrastive learning.

TU2I: 767 11:25 hrs

AI Factory – A Framework for Digital Asset Management

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Advanced analytics empowered by Artificial Intelligence (AI) contributes to the achievement of global sustainability and business goals. It will also contribute to global competitiveness of enterprises through enablement of fact-based decisionmaking and improved insight. The digitalisation process currently ongoing in industry, and the corresponding implementation of AI technologies, requires availability and accessibility of data and models. Data and models are considered as digital assets (ISO55K) that impact a system's dependability during its whole lifecycle. Digitalisation and implementation of AI in complex technical systems such as found in railway, mining, and aerospace industries is challenging. From a digital asset management perspective, the main challenges can be related to source integration, content processing, and cybersecurity. However, to effectively and efficiently retain the required performance of a complex technical system during its lifecycle, there is a need of appropriate concepts, methodologies, and technologies. With this background, Luleå University of Technology, in cooperation with a number of Swedish railway stakeholders – fleet managers, railway undertakings, infrastructure managers and Original Equipment Manufacturers (OEM), has created a universal platform called 'the AI Factory' (AIF). The concept of AIF has further been specialised for railway industry, so called AI Factory for Railway (AIF/R).

Hence, this paper aims to provide a description of findings from the development and implementation of 'AI Factory (AIF)' in the railway context. Furthermore, the paper provides a case-study description used to verify the developed technologies and methodologies within AIF/R.

Keywords: Digitalisation, Asset management, Dependability, Availability, Cybersecurity, Artificial Intelligence (AI).

Session [TU2J]—Resilience Engineering
Day/Date/Time Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue Botanique 2

TU2J: 021 **10:25 hrs**

Logistics of Critical Supply and Resilience During the Covid-19 Pandemic in Norway

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The covid-19 pandemic has challenged the logistics of critical supplies such as food, fuel, and necessary medical supplies. A research project was executed to document how regional actors in the transport sector handle the logistic challenges during the pandemic in 2020, in Mid-Norway. Key research questions were: (1) How is demand and logistics impacted by the pandemic (especially on critical supplies); (2) What is the impact on and between transport modes (e.g. air, sea, road, rail), and their ability to operate as normal; and (3) What is the effect on Norwegian import and export activities? This paper presents the results of a limited literature review on the risks of a pandemic on critical supplies, and systematic interviews of key actors in transportation and logistics. Eleven candidates were interviewed in the period April to June 2020 and then analysed. In addition, nine candidates were approached for more informal conversations. All candidates were interviewed minimum two times to identify possible effects from the pandemic over a period. Key findings show that logistics of critical supplies have been identified as an area in national risk assessments but has not been prioritized through actual action plans. Furthermore, the project discovered poor emergency preparedness and poor preparedness in logistics operations, although mitigated by the ability to improvise and use of existing resources to ensure necessary supply of critical items.

Keywords: Logistics, Transport Systems, Critical Supplies, Resilience, Safety, Covid-19 Pandemic.

TU2J: 039 **10:45 hrs**

How Far is from Fully Automatic Operation to Unmanned-Driving? : Comparison of Operating Resilience of Fully Automatic Operation Systems with Communication Based Train Control Systems

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Recently, Fully Automatic Operation (FAO) system is so widely used (, especially in China,) that the train with the system is even called "unmanned driving train" in many medias, as FAO system can provide automatic operation for whole journey from outbound to inbound. However, at present FAO system is rarely running in driverless mode, i.e. Grades of Automation4 (GoA4) level, in China. In order to look in detail operators' scruples, this paper, in comparison with the traditional Communication Based Train Control (CBTC) system, values the performance of FAO systems under abnormal conditions owing to its obvious advantages under normal circumstances. The study introduces the concept of resilience and a set of system-based metrics to describe impacts of disruptions and evolution of the system performance. The Multi-agents DES models of the train's operation process are proposed for resilience calculation. The results of the calculation of FAO and CBTC in selected degrade scenarios are compared on the basis of the real layout of a metro line in Beijing. It is held that the lack of autonomous perception and decision-making ability of trains in dynamic uncertain environment is the bottleneck of FAO system running in GoA4.

Keywords: Fully Automatic Operation (FAO), Unattended Train Operation (UTO), Resilience, Artificial Intelligence (AI), Grades of Automation (GoA), Communication Based Train Control (CBTC).

TU2J: 040 **11:05 hrs**

Research on Resilience Evaluation Method of Train Operation Control System Based on Random Failure

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In order to avoid the one-sidedness of the resilience evaluation for the train operation control system under a sin-

gle failure scenario, the Monte Carlo simulation method is adopted in this work to simulate the randomness of the disturbed equipment and the degree of performance degradation, so as to provide a probabilistic resilience evaluation method for the train operation control system. Taking Beijing Yanfang line as an example, collect failure data from Signal System and Integrated Supervision Control System in the past three years, the fault frequency of each equipment is taken as the probability of the equipment suffering from disturbance. Meanwhile, determine each equipment's probability distribution function of failure recovery time. In order to quantify each performance state, the "state virtual value" is set for each performance level of the equipment. The output data flow weight of the equipment is the same as the "state virtual value", and the change in the total data flow weight of the system represents the fluctuation of system performance. Using Zobel's resilience measure, after 105 times of Monte Carlo-based disturbance simulations, the estimated resilience value of the train operation control system is 0.9896. Furthermore, perform separate simulations for each equipment to obtain multiple probability cumulative distribution curves of system resilience, it can be seen that when CI, ATP and ZC are disturbed alone, the resilience of the system fluctuates greatly, and lower resilience value may appear. When ATO, ISCS and Axle Counter are disturbed, the system resilience is relatively stable, and the resilience value remains above 0.97.

Keywords: The train operation control system, Resilience evaluation, Monte Carlo simulation, Lognormal distribution, State virtual value.

TU2J: 108 **11:25 hrs**

The Kaleidoscope for Integrative System Analysis – KISA

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Integrative system analysis requires a tool that facilitates both an investigation of systems from a holistic perspective and research that scrutinizes particular aspects of a specific system while retaining a holistic understanding. This paper proposes such a tool – a novel, multi-perspective kaleidoscope that constitutes a conceptual framework for integrative system analysis. This theoretical frame of reference synthesizes the results of a previous literature analysis that yielded a detailed conceptualization of the terms system, infrastructure and governance in the realm of critical infrastructure protection (CIP). The multi-perspective kaleidoscope for integrative system analysis (KISA) considers four perspectives: system, infrastructure, process and governance. These four perspectives are founded on three layers that mirror the ability of the perspectives to adjust the special focus on the micro, meso or macro level of a system of interest. The presented KISA model contributes a systemic perspective that can guide the exploration of complex issues in society to acquire beneficial, multi-faceted knowledge and a multi-perspective understanding. The integrative system perspective that this study originates will be a valuable tool for a variety of assessments in the context CIP and beyond.

Keywords: Multi-perspective kaleidoscope, KISA, Critical infrastructure, Complex systems, Governance, Integrative system analysis, Conceptual modelling.

Session	[TU2K]—Economic Analysis in Risk Management
Day/Date/Time	Tuesday, 21 Sep. 2021/10:25–11:45 hrs
Venue	Atrium 1

TU2K: 068 **10:25 hrs**

Towards Economically Efficient Security Risk Reduction

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Real systems contain potential vulnerabilities which can be exploited by adversary(ies) attempting to disrupt system operations. Highly aggregated macroeconomic Gordon-Loeb (G-L) optimization model for cyber security investments [1] assumes known system-level return on the security investment, measured by the corresponding macroeconomic utility. A missing link in application of the G-L model to a specific system is derivation of this macroeconomic utility from the system-specific microeconomic model for cybersecurity investments. This microeconomic model should identify the optimal mixture of investments in elimination/mitigation of specific vulnerabilities, given the aggregate level of security investments. In this paper we report on work in progress on developing microeconomic optimization model for security investments for system with monotonic structures [2], which produces the system-specific macroeconomic utility to be used in the G-L model. Our analysis reveals intricacies of the problem, which deserve further investigation. In particular, Figures 1a-b depict the optimal investment in the system security reduction z^{opt} as a portion of the cost of complete risk elimination C vs. the exogenous risk ρ. Figures 1a-b demonstrate that system structure critically affects the sensitivity of the optimal investment to the exogenous risk, which justifies and quantifies earlier phenomenological observations [3].

We discuss practical implications of this phenomenon for risk management.

Keywords: Security, Economics of risk reduction, Microeconomic model, Gordon-Loeb model.

TU2K: 098 **10:45 hrs**

Prevented Damage as Efficiency Indicator of Inspection and Control Activity

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The paper deals with the problem of effectiveness of inspection and control activities assessment. The analysis of various criteria for evaluating the effectiveness of control activities of hazardous industrial facilities is carried out. The analysis showed that the value of prevented damage can be used as one of the indicators of effectiveness. One of the approaches to assessing the prevented damage can be a pattern identified in the Heinrich-Berd pyramid. Examples of using this approach in solving various practical safety and reliability problems are given. A methodological approach to the assessment of prevented damage as one of the indicators of the effectiveness of inspection and control activities using the methodology of building the Heinrich-Berd pyramid is proposed. In addition to the traditional 4-level classification of events in the field of industrial safety, it is proposed to introduce the 5th level related to the identification of inconsistencies as a result of inspection and control activities. Identified inconsistencies are prerequisites for events of the 4th level of classification. Based on the analysis of statistical data of events at industrial hazardous facilities in the gas industry, a theoretical relationship between events of 1–5 classification levels (1-3-30-300-3000) is proposed. It is assumed that the elimination of identified inconsistencies (level 5) can "potentially" lead to the prevention of events at levels 1–4. A formula is proposed for calculating the expected prevented damage (direct and indirect), taking into account the ratio between events of different levels and the level of elimination of identified inconsistencies. Estimated calculations of the total prevented damage to industrial hazardous facilities in the gas industry were performed. The calculations showed the adequacy and practical significance of the proposed approach based on Heinrich-Berd pyramid.

Keywords: Industrial safety, Inspection and control activity, Efficiency assessment, Risk-oriented approach, Proactive approach, Safety pyramid, Prevented damage.

TU2K: 101 **11:05 hrs**

Towards Economically Efficient Mitigation of Systemic Risk of Undesirable Contagion

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Economics drives two major evolutionary trends in networked system design/operation [1]. The first trend is movement towards the boundary of the system capacity/operational region, where all system resources are fully utilized, by matching expected demand with available resources through demand pricing and resource provisioning. The second trend is an increase in the system interconnectivity allowing for enlargement of the capacity/ operational region through dynamic resource sharing. This trend is driven by incentive to mitigate both unavoidable variability of the exogenous demand and limited reliability of system components by dynamic load balancing. However, numerous recent systemic failures in various performance-oriented networked systems, e.g., power grids, cloud, and financial systems [2], have demonstrated that these economic benefits often heighten risk of cascading failures/overloads. These empirical observations pose problem of systemic risk management while maintaining economic viability. Following [1], we model networked system by a Markov process with locally interacting components, where interactions are due to individual component failure/ overload risk transfer to the neighboring components. We analyze this Markov process under mean-field approximation and natural assumption that risk transfer results in aggregate risk amplification. We show that risk propagation is described by a positive operator. We argue that a system operating point should be close to the triple point on the system phase diagram, where the following three regions converge: two regions where the normal (failed/overloaded) equilibrium state is globally stable and a region where these equilibrium states coexist as locally stable, i.e., metastable. We demonstrate that systemic risk of cascading failures/overloads of this operating point can be naturally quantified in term of the Perron-Frobenius, i.e., leading, eigenvalue of the corresponding linearized risk propagation operator and the corresponding eigenvector. This allows us to state and discuss the optimization problem for the systemic risk of cascading failures/overloads management subject to maintaining system economic viability. Solution to this problem yields the Pareto optimal frontier of the feasible systemic risk vs. economic efficiency region. We illustrate our results on an example of spontaneous recovery in networked systems [3]. In the future, in

addition to applying the proposed methodology to specific networked systems, we are planning to investigate a possibility of dynamic assessment/management of systemic risk with the ultimate goal of dynamic contagion containment.

Keywords: Networked system, Cascading failures/overload, Systemic risk mitigation, Economic efficiency.

TU2K: 438 **11:25 hrs**

Contagion Model for Multi-Layer Financial Network Considering Heterogeneous Liquid Asset

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The liquid asset of a financial institution consists of cash, loan, realizable stock and bond. In the research of risk contagion caused by the liquid asset, i.e. the counterparty default risk, all the liquid assets are seen as the same kind, therefore the heterogeneity of the liquid asset and its influence for the is ignored. The systemic risk assessing method for multi-layer financial network proposed in recently study could analysis heterogeneity of the settlement time of the liquid asset, however, hardly analysis the heterogeneity that some kinds of asset price may fall down with the market price (stock and bond) while the other (cash and loan) would not. In this paper, we propose a model to describe the risk contagion of the multi-layer financial network consist of different liquid asset types. Firstly, we construct a multi-layer financial network withMlayer and N financial institutions, each layer represents a kind of asset and every financial institution will trade with other on each layer. Secondly, we describe two kinds of contagion in the contagion model, counterparty default risk and devaluation of the liquid asset. Finally, the difference between contagion result of the proposed heterogenous model and the homogenous model is compared through simulation. We find that the heterogeneity of the liquid asset will increase the contagion extent. The proposed model can analysis the effect of fluctuation in prices for heterogenous assets, and will further support the study of the contagion mechanism in the heterogenous financial network, and offer guidance for making a reasonable macroprudential regulation policy.

Keywords: Multiplex networks, Financial risk contagion, Counterparty default risk, Risk propagation, Cascading failure.

Session	[TU3A]—System Reliability
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Plenary Room

TU3A: 051 **15:20 hrs**

Operation Strategy Optimization for Two-unit Warm Standby Systems Considering Periodic Active Switching

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Concerning the operation of standby systems in most ground systems, the standby units usually switch to the operating state after the active units fail. However, a periodic active switching strategy that differs from this common strategy is employed for the gyroscope standby system in satellite engineering. For this problem, this paper proposes an operation strategy optimization model for two-unit warm standby systems considering periodic active switching. The model comprehensively considers periodic switching and perfect switching, and based on the virtual age theory, derives the reliability function and mean time to failure (MTTF) of the twounit warm standby subsystem, which can be applied to units or systems with arbitrary time-to-failure distributions. Then, with MTTF maximization as the optimization goal, the optimal periodic switching interval is determined. Finally, a case study of a gyroscope warm standby subsystem is provided to illustrate the applicability of the model, and sensitivity analysis is carried out to identify the useful conclusions.

Keywords: Warm standby system, Periodic active switching, Operation strategy, Optimization, Reliability, Mean time to failure.

TU3A: 063 **15:40 hrs**

NATO Dependability Standard: Overview of Recent Publications and Future Works

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This paper first introduces NATO AC327 (NATO Life Cycle Management Group) group and ARMP/ADMP (Allied Dependability Management Publications) expert team that elaborates some documents in order to address specific military needs (chapter 1). The last symposium paper on NATO dependability standards dates back to 1993 (Hockley and Comer 1993). The paper describes how these standards evolved from 1993 to 2021 (chapter 2). The present baseline consists in STANREC 4174 2021, ADMP-01 2021, ADMP-02 2021 and ADMP-03 2021. STANREC 4174 is the umbrella document that lists recommended practices regarding dependability for military programs conducted by NATO countries. This paper presents the most important aspects of ADMPs (chapter 3).

Keywords: NATO, Standard, Dependability, ADMP, STANREC 4174.

TU3A: 114 **16:00 hrs**

A Seamless Functional Hazard Analysis for a Fuel Cell System Supported by Spreadsheets

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The development of safety-critical systems requires the hazard identification and risk assessment during early development phases. For this task, Preliminary Hazard Lists (PHL) or Preliminary Hazard Analysis (PHA) can be used. Innovative systems can be found considering those hazards in a smart systems engineering. During development, the problem may arise that the information exchange is document-based only. If document-based development is unavoidable, an approach is required to enable a seamless data exchange among development tools. We describe a seamless approach used in FLHYSAFE during the Preliminary System Safety Assessment. Due to the widespread use of Excel, a template is created to perform the Functional Hazard Analysis (FHA). FHLYSAFE is used as an example project to show how the FHA can be integrated in the applied model-based development. Additionally, results of the seamless lean FHA as well as findings in system development are described.

Keywords: Functional hazard analysis, Preliminary system safety assessment, Seamless safety engineering, Excel data exchange, Safety.

Session	[TU3B]—Risk Analysis and Safety in Standardization
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Atrium 2

TU3B: 307 **15:20 hrs**

Manually Clamping Workpieces – Identification of Safety-Relevant Parameters

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In most cases, an inadequate workpiece clamping is the cause for released workpieces in machine tools. The standstill clamping force effectively available during operation is decisive for the safe machining of workpieces clamped with jaw chucks. Fundamental to a sufficient clamping effect during machining is knowledge of the influence of time-dependent parameters, such as the possibly reduced efficiency (due to inadequate lubrication condition, wear, dirt, etc.) of the jaw chuck used. Furthermore, design-related parameters can influence or limit the standstill clamping force, as well as the selected operating mode. In this paper, the influence of safety-relevant parameters as regards the standstill clamping force is determined by means of static clamping experiments. Subsequently, the relevance and effect of the identified influencing parameters on the clamping force were statistically analyzed. The scientific question is how the actual degree of utilization of a jaw chuck can be determined and how the maximum achievable standstill clamping force can be predicted before the clamping process occurs. Corresponding safety measures (instructions) are to be defined and user test are being prepared to prove their practical suitability.

Keywords: Clamping safety, Standstill clamping force, Jaw-chuck, Clamping experiments, Statistical evaluation, Influencing parameters.

TU3B: 386 **15:40 hrs**

Standardization in Risk Management Regulations: What Can We Learn from Scientific Literature?

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The structural set-up and key characteristics of regulatory regimes for risk management vary between countries, technical domains and application areas. Risk regulations come in different forms, ranging from a highly prescriptive ("hard") approaches including explicit requirements on key risk management components, to "softer" approaches requiring risk to be managed without defining how. Risk regulations are subject to continual development. Increased standardization is observed in diverse risk domains such as land-use planning, terrorism and security risk management, cyber security, and disaster risk management. This development is contested and the question of what form of standardization and whether a low versus high level of standardization is the most beneficial for effective and efficient risk management risk management is debated. Using a scoping study approach, this paper presents an overview of standardization of risk in scientific literature. The aim of this paper is to provide insights related to the arguments, effects, and experiences of using standards or standardized approaches for managing risk. The results indicate that effects of standardization in risk regulations are not extensively covered in research. The paper contributes to the knowledge base for judging the appropriate level and form of standardization in risk regulations but more research is needed.

Keywords: Standardization, Risk, Scoping study, Literature review, Risk management, Risk governance, Regulation, Safety.

TU3B: 389 **16:00 hrs**

Experimental Investigation of the Kink Effect By Impact Tests on Polycarbonate Sheets

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In machine tools, machine guard windows provide an insight into the working process of the machine and protect the user against possible ejection of parts during operation, such as chips, tools and workpiece fragments [1, 2]. To ensure the safety of the machine operator, impact tests can be used to determine or verify the impact resistance of the machine guard. Polycarbonate is the most commonly used material for machine guard windows due to its high toughness compared to other transparent materials. In general, an increase in sheet thickness results in an improved impact resistance. However, the studies of CORRAN ET AL. (1983) [3] show that for an increased sample thickness a reduction of the impact resistance occurs. The authors called this phenomenon Kink Effect. This contribution focusses on the investigation of the Kink Effect for monolithic polycarbonate sheets up to a thickness of 18 mm and a lathe standard projectile with a mass of 2.5 kg. Experiments were carried out to compare the material behavior of polycarbonate sheets under projectile impact for the dimensions of 300 mm (height) × 300 mm (width) and 500 mm (height) x 500 mm (width). The experiments were further evaluated using the RECHT & IPSON (1963) [4] method. Furthermore, explicit dynamic impact simulations were performed to enable the investigation of "close-to-edge" impacts.

Keywords: Impact test, Kink effect, Machine guard, Safety of machinery.

Session	[TU3C]—Degradation analysis and modelling for predictive maintenance
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Espace Grand Angle2

TU3C: 079 **15:20 hrs**

Condition-Based Maintenance for Systems with Degradation Processes and Random Shock Under Warranty

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A condition-based maintenance strategy is developed for systems subject to two dependent causes of a failure such as degradation and random shock. The degradation threshold shock model for systems have been developed under warranty considering repair service and replacement service. We investigate the relationships between random shock and degradation process which are modeled by a time-scaled covariate factor and the relationship between various degradation processes. Fatal shock which needs replacement service for system immediately and nonfatal shock which needs repair service for failed parts are considered. For a nonfatal shock, there are two direct effects, slowly accelerations and sudden accretion jumps on the degradation levels. There are degradation limits for repair service and for replacement service, respectively. Degradation level may jump to the degradation limit for the replacement service or/ and may increase to the other degradation limit

for repair serivce. In this study, we consider not only the degradation process but also random shock model and decision variables are determined for the degradation threshold shock model. Total expected cost is minimized to determine an optimal maintenance cycle and optimal length of warranty period for the warranty cost analysis. Additionally, warranty service time for repair service and replacement service is considered with warranty service time limit to increase customers' satisfaction. Suppose that the system deteriorates with age, we illustrate the proposed approach using numerical applications and investigate the influence of relevant parameters on the optimal solutions for the maintenance policy.

Keywords: Cost model, Expected cost rate, Optimal replacement age, Repair-replacement policy.

TU3C: 088 15:40 hrs

Modeling Multivariate Degradation Processes with Time-Variant Covariates and Imperfect Maintenance Effects

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In this article, we develop two degradation models to characterize multivariate degrading systems subject to time-variant covariates and imperfect maintenance activities. We first construct a multivariate Wiener process to serve as a baseline model, on top of which two types of models are developed to meaningfully describe the time-variant covariates and imperfect maintenance effects. The underlying difference between the two models lies in the way of formulating the impacts of covariates and maintenance: The first model reflects these influences in the degradation rates/paths directly, whereas the second one describes the impacts by modifying the time scales governing the degradation processes. In each model, we present two particular imperfect maintenance models that differ in the extent of reduction in degradation level or virtual age. The two degradation models are then compared in certain special cases. The proposed multivariate degradation models pertain to complex industrial systems whose health deterioration can be characterized by multiple performance characteristics and can be altered or affected by maintenance activities and operating/environmental conditions.

Keywords: Degradation path adjustment, Imperfect maintenance, Multivariate Wiener process, Piece-wise constant covariates, Time scale adjustment.

TU3C: 120 16:00 hrs

Degradation Modelling for Predictive Maintenance Under Various Operating and Environmental Conditions

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This article deals with the estimation of the reliability and the remaining potential of equipment subject to wear whose degradation level are directly or indirectly observable. Based on accelerated non-stationary Lévy processes, reliability is estimated under various operating and environmental conditions, considering that wear level is included between the current state observed and an acceptable threshold. Among the existing models, the Variance Gamma process shows great flexibility to depict the diversity of degradation phenomena and is therefore well suited for predictive models' developments. However, its adjustment is difficult because its likelihood function includes a Bessel function in its expression and can thus have several local optima. Hybrid optimisation (global/local) then appears more precise than the local methods generally used. The industrial application case presented in the communication was carried out as part of the RYTHMS project funded by the European Union's Clean Sky2 research program. It seeks to characterise optoelectronic components through accelerated testing.

Keywords: Predictive maintenance, Prognosis, Remaining useful life, Gamma variance process, Accelerated testing.

Session	[TU3D]—Prognostics and Health Management: From Condition Monitoring to Predictive Maintenance
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Panoramique

TU3D: 214 **15:20 hrs**

Degradation Modeling Analysis for Microrobots Flexure Hinges Using Intracorporeal Surgeries

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The new generation of instruments in the field of medical robotics aims to use devices that are less and less invasive for the patient. However, some of these microrobots are in underdevelopment and must undergo several tests in order to obtain the mandatory certifications to be used on patients. Indeed, one of the main tests to be validated is the accurate determination of their reliability and remaining useful life (RUL) in order to ensure optimal performance during the surgical procedure. This paper is focused on obtaining a degradation modeling for a microrobot dedicated to intracorporeal laser surgeries. For this purpose, simulated degradation data is collected from a four-bar complaint mechanism that fulfills the same behavior of a flexure hinge. For it, our work is based on the pillars of the Prognostics health and management (PHM). Knowing that a flexure hinge of the microrobot is a critical element and knowing that it is possible to have measures of the evolution of its performance and therefore of its degradation, we propose a data-driven degradation modeling by considering the normal life distribution in order to assess the reliability and the RUL. In conclusion, a data-driven model within the PHM study for lifetime estimation was presented.

Keywords: Data-driven, Degradation modeling, Remaining useful life, Reliability, Surgical microrobots, Flexure hinges.

TU3D: 282 **15:40 hrs**

State of Health Estimation for Lithium-ion Battery by Incremental Capacity Based ARIMA – SVR Model

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With the increase in the use of Lithium (Li)-ion batteries for Electric Vehicles (EV) applications, it is imperative to think about using it sustainably. The circular economy suggests to reuse or re-purpose the End of Life (EoL) EV batteries in less demanding applications. The State of Health (SoH) is an essential indicator in making decisions while reusing or repurposing EoL Li-ion batteries of EVs. Conventional SoH estimation often requires capacity measurement from the battery's full charge to cut-off state, which is quite challenging. In this paper, we propose an Incremental Capacity (IC) curve based SoH estimation system for Li-ion batteries. The model employs a Kalman filter and a finite differencing method for measurement noise attenuation. A novel method that combines Support vector regression (SVR) and the Autoregressive Integrated Moving Average (ARIMA) model is utilized to model the relationship between IC and the SoH. A use case is created on the NASA AMES open-source battery data. The case study shows that the proposed model can obtain accurate SoH prediction results without needing the State of Charge information of the battery.

Keywords: ARIMA, Diagnosis, Electric vehicles, Li-ion batteries, Prognosis, SoH, SVR.

TU3D: 303 **16:00 hrs**

Defining Degradation States for Diagnosis Classification Models in Real Systems based on Monitoring Data

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As the complexity of modern engineering systems increases, data-driven approaches have become valuable tools to aid maintenance decision-making. However, raw data collected from monitoring sensors require a comprehensive and systematic preprocessing to separate healthy from faulty states before

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their use in data-driven models. Frequently, anomaly detection models implemented for this purpose are based on statistical relationships or rule-based thresholds, rather than on information provided from maintenance logs related to the internal operation of the system. In this work, we propose a framework to establish a link between the recorded sensor data behavior and the system's degradation processes. In particular, this framework aims to obtain a labeled degradation dataset from raw monitoring data to train a diagnosis classifier for a system with multiple failure modes. A dataset obtained from two years of sensor monitoring and reported failure logs of a copper mining process line is used to exemplify the framework. Different machine learning classifiers are presented for each failure mode, individually and combined. Results show that the degradation labelling procedure is effective, and classifiers obtain up to 95% accuracy for the detection task for a two-class problem. Cross-comparison of the classifiers per failure mode allows the identification of problematic classes, showing the benefits of addressing each failure mode individually rather than for the entire system simultaneously.

Keywords: Diagnostics, Classification, Machine learning, Machinery data processing, Degradation detection.

Session	[TU3E]—Risk management for the design, construction and operation of tunnels
Day/Date/Time	Tuesday, 21 Sep. 2021 / 15:20–16:20 hrs
Venue	Amphi Jardin

TU3E: 608 **15:20 hrs**

Barriers and Drivers for Safety Related Innovation Within the Norwegian Tunneling Industry

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Working on innovative processes in the tunneling industry is interesting but demanding. This paper presents the outline of a regional program for developing new solutions and becoming a national and international knowledge Centre on tunnel safety. The Capacity Boost Tunnel Safety (KATS) aims to increase competitiveness and value creation in the Norwegian regional tunnel safety industry. The project is a cooperation between private and public businesses, authorities and research communities, building on a strategy of developing and making use of research-based knowledge to improve tunnel safety, both nationally and internationally. However, safety, especially fire safety related to major incidents is challenging to communicate. Norway has not experienced major accidents. In fact, no one has been killed from heat loads or smoke intoxications in Norwegian road- and railway tunnels. The growth in tunneling have led to a greater need for expertise, particularly within tunnel safety. Rogaland is developing some of the most complex tunnel systems in the world. New solutions must therefore be found, and new chains of values understood. This paper analyses the background state of knowledge of KATS and the three years of activities to assess barriers and drivers for developing innovative solutions in the tunnel safety business. The core of safety considerations is part of the analysis, in which we introduce prerequisites for active involvement by the important stakeholders in the tunnel industry.

Keywords: Tunnel safety, Complexity, Systems thinking, Safety innovation.

TU3E: 623 **15:40 hrs**

Capacity Boost Tunnel Safety – Using the SSM Approach to Increase Impact

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Capacity Boost Tunnel Safety (KATS) is a capacity enhancing project that aim to increase competitiveness and value creation in the Norwegian tunnel safety industry. KATS builds on an acknowledgement that improving tunnel safety is a task characterized by considerable complexity. A major goal for the project is to make lasting improvements and we strongly believe that developing new joint activities is a means for achieving this. Developing R&D applications for project funding with relevant partners is one example of joint activities. Although quite specific, this task has the potential of being quite complex. We argue that this can be considered as a messy situation due to many involved actors with possibly conflicting goals and difficulties with defining both what the problem is as well as the solution. This led us to Soft Systems Methodology (SSM) which was developed as a learning tool, to make better sense of complex, messy situations where the search for a clear-cut problemand the single optimal solution is futile. In this paper, we report on our experience of exploring SSM as a tool to gain better understanding of what KATS should prioritize the coming three years. Our exploration is tested by trying to improve the problematic situationof developing research and development concepts that improves the industry's position for future projects as a case. We conclude

that creating rich pictures contribute to an increased understanding of our knowledge gaps. Furthermore, SSM was useful in this context and worth developing further where KATS (as a whole) is defined as the problematical situation that needs improvement.

Keywords: Tunnel safety, Complexity, Systems thinking, Soft systems methodology.

TU3E: 626 **16:00 hrs**

A View on Asset Management Best Practices, Challenges and Risk in the Norwegian Oil & Gas and Tunnel Industry

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Norwegian Road tunnels and Oil & Gas (O&G) industry are going through major digital transformations as the technology evolves. Asset Management is relatively a new concept in the tunnel industry when it comes to the application of Asset Management principles, whereas the Norwegian O&G is more experienced in implementing this concept. Cross-industry knowledge transfer of Asset Management practices can significantly contribute to enhance safety, reduce cost, and improve Operations & Maintenance (O&M) practices. This paper is a novel attempt to map and bridge Asset Management practices between the two industries. This paper presents comparative views on (a) Asset Management in the O&G and Tunnel industry with special focus on O&M, (b) legislative requirements, (c) best practices and standardization bodies, and (d) risks, trends, and challenges. It is observed that both industries have developed guiding standards and assigned safety regulatory authorities. Best practices for the Norwegian tunnel industry are uncommon, where other road authorities have attempted to outline their practices. Risks in both industries are similar, however the understanding and application varies. Trends of digitalization in both industries have significant value but comes with added challenges and threats. To conclude, both industries have realized the potential gains of Asset Management and are heading towards the right direction in implementing it.

Keywords: Asset management, Best practices, Offshore oil & gas, Norwegian industry, Operations & maintenance, Road tunnels, Trends & challenges.

Session	[TU3F]—Probabilistic vulnerability estimation, lifetime assessment and climate change adaptation of existing and new infrastructure
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Espace Grand Angle

TU3F: 539 **15:20 hrs**

Quantitative Assessment of the Impact of Climate Change on Creep of Concrete Structures

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Creep of concrete structures is in most cases regarded as a serviceability problem that may have impacts on maintenance and repair costs but cannot lead to structural collapse. However, several structural collapses during the past decades have been, at least partly, attributed to excessive creep deformations. Recent studies suggest that concrete creep may be further exacerbated by climate change. The current study demonstrates how this effect can be quantitatively assessed. For this purpose, six different creep models (i.e, Model Code 1999, Model Code 2010, MPF, B3, B4, and B4s models) are used under considerations of historical and future climatic conditions in southernmost Sweden as given by a regional climate model. Furthermore, two different simulations were performed as follows: 1) considering only climate uncertainty represented by the climate model, and 2) considering climate uncertainty, parameter uncertainty, and creep model uncertainty. The highest impact of climate change on end of century creep coefficient is observed using model B4 where the 75th percentile of the increase in creep coefficient is found to range from 8% to 14% depending on the climate scenario. The results of the assessment in this

article show that the uncertainty related to climate change on creep of concrete structures (higher effect in RCP8.5 than in RCP2.6 and RCP4.5 which have very similar results) is much smaller than uncertainties resulting from creep modelling.

Keywords: Climate change, Long-term deformations, Creep, Creep models, Creep coefficient, Parameter uncertainty, Model uncertainty, Infrastructure safety, Infrastructure performance.

TU3F: 549 **15:40 hrs**

Influence of Concrete's Mechanical Properties on the Cracking of Concrete Dams

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Analytical methods of structural stability assessment of concrete dams are often too simple and thus conservative in their predictions. Without the actual foundation geometry, capacity for some rigid body failure modes are underestimated. This is problematic when deciding upon remediation activities of a dam that is considered unstable and may divert the restoration activities from where they are most impactful. In a previous study by Sas et al. 2019 where a section of an existing dam was scaled down and tested experimentally, the model indicated that several areas were experiencing large stresses, potentially leading to failure. This raised the research question whether another type of failure would occur for different material properties. Therefore, this paper delves into a probabilistic numerical approach, through finite element analysis, to evaluate dam stability based on randomization of a number of material properties such as modulus of elasticity, tensile strength, compressive strength, and fracture energy. The variation of the aforementioned material properties did not impact the failure mode, which was consistent among a broad range of material strengths.

Keywords: Concrete dams, Model test, Numerical analysis, Material randomization.

TU3F: 591 **16:00 hrs**

The Indirect Impact of Flooding on the Road Transport Network: A Case Study of Santarém Region in Portugal

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The indirect impacts of flooding on transportation networks include, among others, consequences of the service disruption for the users. Indirect impacts are of a wider scale and with a longer incidence in time than direct impacts. The key aspect for the quantification of indirect impacts of flooding is the assessment of the disruption of the transportation service, with social and economic consequences. In this work, a traffic model for a pilot zone is constructed for accurate quantification of the functionality of the network after the failure of infrastructure components such as road segments and bridges. A mesoscopic simulation, which is capable of building a road network model, assigning trip paths with the impact of road closures, and evaluating travel time and vehicle volume redistribution in a given disruption scenario, was used to identify the traffic disruption in the face of flood events. Modelling outputs from a case study in the Santarém region of Portugal indicate which roads are more congested in a day. A comparison between the baseline and a flood scenario yields the impacts of that flood on traffic, estimated in terms of additional travel times and travel distances. Therefore, simulating and mapping the congestion can largely facilitate the identification of vulnerable links.

Keywords: Road networks, Traffic disruption, Indirect flood impacts, mesoscopic simulation.

Session [TU3G]—Asset management
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Atrium 3

TU3G: 082 15:20 hrs

Assets Management for Software Development Systems

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With the continuous evolution of production systems towards Cyber Physical Systems and the existence of completely digital production systems, i.e., banking and ecommerce, support codding production systems are born to satisfy the need for new code that keeps their systems updated and competitive in an ever-evolving context. IT projects for digital factories are managed through Agile methodologies that allows to manage volatile requirements, nevertheless, due to the nature of agile methodologies to assign a small amount of time for grooming and planning, it is a challenge to provide a reliable estimation and planning for large scale projects and thus there is an obvious gap between planning and the real production schedule performed. This scenario difficult the quantification of production prioritization change's consequences which difficult the company's directors to take adequate decisions. To address such challenge, a methodology is presented in which the development teams of a same company are interpretated as a production system, noting their similarities and differences with a physical production system. This representation allows the user to perform and apply several of the asset management tools, which allows to perform better impact analysis and quantify the effect prioritization changes.

Keywords: IT planning, Assets management, IT development cells system modelling, Prioritization.

TU3G: 083 15:40 hrs

Framework for the Implementation of Smart Maintenance

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Recent developments in sensor technology and systems for connecting digital and physical systems, often associated with the terms Industry 4.0 and cyber-physical systems, are expected to bring substantial changes to how maintenance and asset management will be conducted in the coming years. Most of the research related to Industry 4.0 and maintenance have focused on technical aspects, and less attention has been given to how to organize and manage maintenance in order to take advantage of the new possibilities offered by the fourth industrial revolution. While many claims have been made about the potential improvements related to maintenance that can be achieved from implementing Industry 4.0, empirical studies suggest that industry practitioners are struggling to realize these improvements. There are also signs that there exists overall a poor understanding of how to implement Industry 4.0. The contribution of this paper is to address these sociotechnical challenges with a multidisciplinary framework for the implementation of Smart Maintenance. The framework is divided into three levels: strategic, tactical, and operational, and is influenced by lean production, systems engineering and maintenance management.

Keywords: Industry 4.0, Predictive Maintenance (PdM), Plan-Do-Study-Act (PDSA), Systems engineering, SPADE, Smart Maintenance, Cyber-Physical Systems (CPS), Prognostics and Health Management (PHM), Maintenance management, Lean Production (LP), Hoshin Kanri (HK).

TU3G: 121 16:00 hrs

Improving Visual Inspection Reliability in Aircraft Maintenance

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Visual inspection is a fundamental safety critical task in the air transport industry. This study investigates how a visual search strategy with a specific eye scanning pattern can be used to improve the observation of aircraft defects during visual inspection tasks. $N = 100$ aircraft maintenance technicians were recruited and $N = 48$ were allocated to a control condition. This group conducted preflight visual inspections on aircraft, using their normal cus-

tom and practice. The remaining $N = 52$ experimental group participants were trained to use a specific eye scanning pattern during their pre-flight inspection called systematic visual search. Prior to inspections, the number of observable defects on each aircraft has been ascertained by the researchers. The results demonstrated that the use of systematic visual search increased the mean number of defects observed from circa 36% to circa 56%. The experimental group were then tasked with further visual inspections using systematic visual search in order to investigate the effect of practice and feedback. This resulted in mean defect observation rates increasing to a plateau of circa 70%. The results clearly demonstrate that; by using a set eye scanning pattern as directed by the systematic visual search method, visual inspection reliability can be improved.

Keywords: Visual, Inspection, Hazard, Defect, Observation, Improving, Search, Reliability.

Session [TU3H]—Railway Industry
Day/Date/Time Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue Cointreau

TU3H: 141 **15:20 hrs**

STPA-Based Safety Analysis of Virtual Coupling Scenarios

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Virtual coupling comprehensively uses technologies such as computer, communication, and automatic control, and needs to consider multiple levels of conditions such as lines, trains, signals, and transportation, and break the original constraints by increasing perception and other means to finally complete functions and performance indicators. Compared with common urban rail transit systems, virtual coupling scenarios have higher requirements for safety. Leading indicators can give early warnings when any aspect of the system starts to deviate from the right track, so as to prevent it from having a major impact on the safe operation of the system. At present, the research on leading indicators of rail transit systems is still immature. The System-Theoretic Process Analysis (STPA) method searches the cause of the accident based on the extended accident causal model. Based on the causal scenario and safety constraints, propose relevant leading indicators. It also proves that the leading indicators can effectively observe and prevent risks, and solve the problem that the current risk analysis results are difficult to use directly.

Keywords: Urban rail transit, Virtual coupling, STAMP/STPA, Accident prevention, Leading indicator.

TU3H: 167 **15:40 hrs**

A Framework for Definition of Operational Design Domain for Safety Assurance of Autonomous Train Operation

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In recent years, the research of next-generation railway focuses on enhancing the autonomy of unmanned train with AI techniques to identify, analyze and safely handle uncertain environments and emergencies. Due to the limitation of sensors and machine learning algorithms, it is essential to clearly and completely specify the operation condition under which the train control system is designed to work and ensure trains are always safely operating in this domain. This domain is well-defined as operational design domain (ODD) for autonomous vehicles firstly, but is often limited by the uncontrolled environment and the complicated traffic situation. In the field of urban rail transit, a clear definition can be assured by the closed operating environment and organized operation. Thus, this article gives the definition and structure of the ODD of rail transit to describe the safety constrains and assumptions. The factors that are relevant to the identification of ODD have been described and a framework for defining hazardous scenario of train operation based on ODD semantic is proposed. Further, a case of ODD identification and analysis for the typical scenario in unmanned train control system is used to demonstrate its contribution to safety assurance.

Keywords: Operational Design Domain (ODD), Scenario generation, Risk defense model, Autonomous train, Unmanned system.

TU3H: 290 16:00 hrs

Formal Modeling of A New On-Board Train Integrity System ETCS Compliant

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Several European railway actors are committed to develop a new train monitoring system that is implemented onboard trains, to replace the trackside integrity monitoring function. Having such an on-board integrity monitoring system is key issue toward operation in moving block, namely as in ERTMS Level 3. Such an operation allows not only for increasing the capacity of the line, but also for achieving substantial cost saving as various trackside equipment can be removed. Using an on-board control-command system for the train integrity functionality, transfers more responsibility, in terms of train operation safety, from infrastructure managers to railway operators. To ensure the implementation of a safety critical functions, such as the on-board train integrity (OTI) function, a particular care should be paid to its specifications. The present paper falls in this context and proposes formal verification of the OTI specifications to ensure their completeness and correctness, while tackling ambiguity inherent in textual specifications. Model checking is brought into play to check various types of properties automatically, in particular safety properties. This automatic formal verification technique allows for exhaustively checking the system behavior. An extended variant of timed automata that are supported by the UPPAAL tool are used as a modelling notation.

Keywords: On-board train integrity, Railways signaling, ERTMS/ETCS, Moving block, Railway safety, System specification, Formal verification, Timed automata.

Session	[TU3I]—Model Based Safety Assessment
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Giffard

TU3I: 232 15:20 hrs

"K6 Telecom", a Dynamic Component Library to Lead Model-Based Safety Analysis for Critical Communication Networks

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The Electrical Grid (EG) is one of the largest industrial systems in the world. It is required to be reliable, available and safe at all times, immediately and everywhere. Major transformations of the EG are underway, in particular integrating news practices thanks to information and communication technologies (IT&C) by enabling interoperable information exchanges and controllable parts of the EG. EDF's Research and Development has been designing formal methods and tools to lead operational safety studies for complex systems and their constituent assets. This article presents the new "K6 Telecom" component library developed by EDF R&D for the KB3 platform, which allows RAMS analysis of telecommunications and interconnections networks. It also presents EDF's MBSA methodology, modelling tools and calculation engine used, characteristics, components and parameters of the library. Then, the article shows a RAMS analysis using "K6 Telecom" library performed on a case study: a large telecommunication network interconnecting industrial sites to data centers. This paper presents some results on the reliability, availability and failure sequence indicators. Finally, feedback on the usefulness and limitations of the current "K6 Telecom" library are announced at the end of this article before concluding.

Keywords: Model based safety analysis, Component library, Telecommunication networks, Interconnections networks, RAMS analysis, Markov chains.

TU3I: 682 **15:40 hrs**

Benefits of Graphical Animation of Advanced AltaRica 3.0 Models

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Most system engineers today use graphical representations to represent their system models. This is important to better understand and to communicate not only on the system, but also on the model itself.

AltaRica 3.0 is a high level formal modeling language dedicated to probabilistic risk and safety analyses of complex technical systems. Models written in AltaRica 3.0 are textual. So according to the following adage “a good image is worth a thousand words”, graphical representations of these models are necessary for good communication; but the reference remains the text. Moreover, beyond simple graphical representations, graphical simulation of models can be used to perform virtual experiments on systems, helping to better understand the system behavior.

In this paper, we show how to model graphical representations using the high level modeling language GraphXica. GraphXica has the same structural constructs as AltaRica 3.0. It enables to describe graphical primitives (lines, rectangles, circles, etc.) and their animations (color change, scale, rotation, translation, etc.). Moreover, we illustrate how the graphical models of GraphXica can be coupled with AltaRica 3.0 models, and how their animations communicate with the stepwise simulator of AltaRica 3.0.

Finally, we demonstrate, by means of an example, the benefits of graphical animation of the textual AltaRica 3.0 models in order to perform virtual experiments by visualizing the incident or accident scenarios.

Keywords: AltaRica 3.0, GraphXica, Graphical simulation of models.

TU3I: 561 **16:00 hrs**

Flexibility of Analysis Through Knowledge Bases

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Model-based safety analysis (MBSA) offers multiple advantages for the stakeholders. The close link between a system description and the model that supports safety or dependability analysis allows automated model building and facilitates model reviews. Maintenance of the model benefits from a high-level system description with assumptions presented explicitly as an integral part of the model. Finally, the analysis process can utilize various properties of the system that are encapsulated in the components and their interactions. This paper focuses on the flexibility of analysis that does not require large remodeling or even building a new model when the question to be answered calls for additional or different system aspects to be considered. We show how knowledge bases built in the Figaro modeling language enable this flexibility on several examples from various application domains and for multiple specific system features. The modeling effort becomes to a large part decoupled from the analysis. An analyst building a model does not have to keep a specific analysis method in mind and might not even be aware of methods that will be required in the future.

Keywords: Knowledge base, High-level modeling, Figaro, Automated model generation, MBSA.

Session	[TU3J]—Seismic reliability assessment
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Botanique 2

TU3J: 471 **15:20 hrs**

Methodology on the Combination of Seismic Correlation Coefficient for Probabilistic Seismic Risk Assessment

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Seismic fragility assessment has a procedure to combine random variables of response and capacity to produce the relationship between a failure probability and a seismic intensity. In order to evaluate the probabilistic seismic safety of a critical system, the probability of failure to the system is calculated from the seismic fragility of components according to the accident scenario. The evaluation of the failure probability of simultaneous multiple failure for more than two components has assumed that the failure probability of each component is independent. However, there should be a correlation because several random factors have same cause such as similarity of seismic properties. The multiple failure probability can be different depending on the correlation. It used to be unconservative without considering seismic correlation. Therefore, a practical methodology for fragility assessment with seismic correlation and the correlation coefficient for each random variable should be evaluated. In nuclear power plant, to prevent core damage, two or more major safety-related components that perform the same function are equipped to ensure redundancy. These components will have correlations with each other and the correlations will change with the random variable. In this study, the components inside the auxiliary building of the example nuclear power plant was selected in order to evaluate the seismic correlation coefficient. And several random variables related to the seismic response were selected for numerical evaluation of the seismic correlation coefficient which can be estimated by numerical analysis. The correlation coefficient of each random variable was estimated by evaluation of the floor response spectra at the component locations. The entire correlation coefficient was combined by correlation coefficients of each random variable and it was compared with the method without separating variables. As a result, the method to evaluate correlation coefficient by combination procedure was validated and the effect of modeling fidelity was discussed.

Keywords: Probabilistic seismic risk assessment, Seismic correlation, Multiple failure, Response spectrum.

TU3J: 559 **15:40 hrs**

Dynamic Updating of Building Loss Predictions using Regional Risk Models and Conventional Post-Earthquake Data Sources

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Earthquakes can cause widespread damage to the built environment, disrupt the function of many residential buildings to provide safe housing capacities and thus, potentially induce severe long-term societal consequences. Rapid recovery significantly improves the short-term resilience of communities after an earthquake. However, time pressure and scarce information on the severity and the spatial distribution of damage complicate the decision-making. Therefore, early damage estimates are produced using regional earthquake risk models with rapid earthquake intensity data and typological building vulnerability functions. While the precision of the former depends, amongst other issues, on the density of seismic network stations and the region-specific geological knowledge, the typological classification of buildings often involves attribution models correlating exposure data, such as building height and age, with typological seismic vulnerability classes. Typological attribution models are approximate and locally add to the uncertainties resulting from the average representation of buildings forming one building class. Employing probabilistic machine-learning tools, the continuous inspection data inflow is leveraged to dynamically update initial regional earthquake risk predictions by updating simultaneously the functions that govern typological attribution and building damage. Hence, while completing inspection of all affected buildings may take several weeks, the limited information becoming available in the first days following an earthquake helps constraining underlying uncertainties. This leads to more reliable rapid estimates of losses of building functions and their respective spatial distribution. The framework is demonstrated on a region in Switzerland subjected to a fictitious earthquake scenario.

Keywords: Rapid loss assessment, Earthquake recovery, Spatial damage distribution, Typological building classification, Community resilience, Gaussian process.

TU3J: 659	16:00 hrs

Modelling Seismic Damage Accumulation and Recovery in Aftershock Sequences

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Civil structures' life-cycle may entail performance degradation, due to point-in-time events such as earthquakes and/or continuous aging, as well as the enforcement of maintenance and/or retrofitting policies. The current performance-based approach to the life-cycle analysis requires consistent modelling of uncertainty involved in the degradation and healing. Recent research efforts, based on the theory of age- and state-dependent stochastic processes, has explored modelling structural deterioration[1] and structural recovery;[2] only a few were devoted to a unified approach addressing the two jointly.[3,4] The presented study, focussing on the case of structures subjected to a possibly-damaging major seismic event (i.e., the mainshock), addresses a discrete-time discrete-state Markovian process to model both damage accumulation during the aftershock sequence and the damage restoration; i.e., the resilience of the structure. To this aim, the paper first discusses the considered phenomena acting on the structure, especially the peculiarities of the recovery, as observed after recent major seismic sequences; then, it shows how a Markov-chain, already adopted to model seismic damage accumulation,[5] can be adapted to also describe the resilience curve. Finally, a single transition matrix is developed to describe the combined effects of both damage progression due to aftershocks as well as recovery. An illustrative application, calibrated on data from the Italian L'Aquila seismic sequence of 2009 (mainshock magnitude 6.3), and referring to a code conforming reinforced-concrete building, shows the capabilities of the holistic model.

Keywords: Resilience, Markov-chain, Performance-based earthquake engineering, Earthquakes, Aftershocks, Structural reliability.

Session	[TU3K]—Accelerated Life Testing & Accelerated Degradation Testing
Day/Date/Time	Tuesday, 21 Sep. 2021/15:20–16:20 hrs
Venue	Atrium 1

TU3K: 359	15:20 hrs

Life Prediction and Test Verification of Bearings Based on Wiener Degradation Model and Bayes Method

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Bearings are core components of space moving parts, and their working accuracy and performance may gradually degrade under long-term continuous operation, which will affect the stable operation of the spacecraft. Therefore, it is important to predict the life of bearings to guarantee the reliability of spacecraft. In this paper, a life prediction method of bearings based on data-driven strategy is proposed. Firstly, the degradation model based on Wiener process is constructed, and expressions of probability density function and mean value of residual life are obtained. Secondly, a prior estimation method of super parameter based on EM (Expectation- Maximum) algorithm is proposed, and the Bayes method is used to estimate and update the parameters of the degradation model and residual life in real-time. Finally, a test rig is designed and a life test of bearings is carried out to obtain the failure time of various specimens. The life of the specimens are predicted through the method presented in the work, and the maximum error is 33.85when using first 30% of test data, and 12.94% when using 50% of test data, which eventually verify the effectiveness of the method.

Keywords: Bearing, Data driven, Wiener degradation model, Bayes method, Parameter estimation, Life prediction, Test verification.

TU3K: 138 **15:40 hrs**

Parameter Estimation of Accelerated Lifetime Testing Models Using an Efficient Approximate Bayesian Computation Method

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Accelerated lifetime testing is widely used for the estimation of high-reliability products. In this paper, the inverse power acceleration law is coupled to the Birnbaum-Saunders distribution assuming that both scale and shape parameters are stress dependent. The parameters estimation is approached with a new variant of Approximate Bayesian Computation method based on an ellipsoidal nested sampling technique. It is a promising and flexible alternative to deal with parameters estimation through numerous distances (metrics) that measure the similarities between simulated and empirical data. The proposed method ensures a good exploration of the parameters space and it is easy to implement. Moreover, it provides a good approximation of the posterior distributions. We compare the proposed method with the maximum likelihood method using real lifetime data sample. Finally, the goodness of fit of the model with different metrics is investigated.

Keywords: Accelerated lifetime tests, Parameters estimation, Approximate Bayesian Computation, Nested sampling, Acceleration law, Maximum likelihood, Metrics.

TU3K: 003 **16:00 hrs**

Solid State Drive (SSD) End to End (e2e) Reliability Prediction, Characterization and Control

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A flaw or drift from expected operational performance in one component (NAND, PMIC, controller, DRAM, etc) may affect the reliability of the entire Solid State Drive (SSD) system. Therefore, it is important to ensure the required quality of each individual component through qualification testing specified using standards or user requirements. Qualification testing is time-consuming and comes at a substantial cost for product manufacturers.

A highly technical team, from all the eminent stakeholders is embarking on reliability prediction from beginning of new product development, identify critical to reliability parameters, perform fullblown characterization to embed margin into product reliability and establish control to ensure the product reliability is sustainable in the mass production.

The paper will discuss a comprehensive development framework, comprehending SSD end to end from design to assembly, in-line inspection, in-line testing and will be able to predict and to validate the product reliability at the early stage of new product development.

During the design stage, the SSD will go through intense reliability margin investigation with focus on assembly process attributes, process equipment control, in-process metrology and also comprehending forward looking product roadmap. Once these pillars are completed, the next step is to perform process characterization and build up reliability prediction modeling.

Next, for the design validation process, the reliability prediction specifically solder joint simulator will be established. The SSD will be stratified into Non-Operating and Operating tests with focus on solder joint reliability and connectivity/component latent failures by prevention through design intervention and containment through temperature acceleration and cycling test (TCT). Some of the SSDs will be subjected to the physical solder joint analysis called Dye and Pry (DP) and Cross Section analysis. The result will be fedback to the simulation team for any corrective actions required to further improve the design.

Once the SSD is validated and is proven working, it will be subjected to implementation of the monitor phase whereby Design for Assembly (DFA) rules will be updated. At this stage, the design change, process and equipment parameters are in control.

Predictable product reliability at early product development will enable on-time sample qualification delivery to customer and will optimize product development validation, effective development resource and will avoid forced late investment to bandage the end of life product failures.

Understanding the critical to reliability parameters earlier will allow focus on increasing the product margin that will increase customer confidence to product reliability.

Keywords: e2e reliability prediction, SSD, TCT, Solder joint reliability, NUDD, Connectivity issues, Qualifications, Characterization and control.

Session	[TU4A]—System Reliability
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Plenary Room

TU4A: 122 **16:30 hrs**

Evaluating the Application Availability of Intelligent Optical Networks Based on the Network Evolution Model

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The demand for availability evaluation of application in Intelligent Optical Networks (IONs) has become prominent increasingly, while the dynamic and heterogeneous features of applications in IONs make the current availability models fail to make effective analysis. This paper proposes a novel application availability evaluation method based on the Network Evolution Model (NEM) containing the following three aspects: the evolution objects, evolution conditions and evolution rules of the network system. Taking the Automatically Switched Optical Network (ASON) framework-based network and two types of application within actual Service Level Agreements (SLAs) as case study, the verification and validation of the model is analyzed versus the results of exact methods firstly, then discussing the efficiency for evaluating the availability of large-scale network and multiple applications. The results show that the model is not only accurate for estimating the availability of traditional static application in small networks, but also effective for acquiring the availability of IONs' application with dynamic behaviors, especially for large-scale networks with different SLAs. Furthermore, the model is versatile for the availability analysis in that the components of the network can be failure-prone with arbitrary failure probability distributions and maintainability schemes, and the applications' protection schemes can be described as any combination of network evolution rules.

Keywords: Application availability evaluation, Network evolution model, Intelligent optical network, Dynamic restoration, ASON framework-based network.

TU4A: 217 **16:50 hrs**

Adaptive Faults Diagnosis and Reasoning Method Based on MFM

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Multilevel Flow Modeling (MFM) is an abstract hierarchical model of the complex process industrial system based on the system goal and the functional subject to achieve the goal. In a specific MFM model, there are two different modes of influence between function and objectives. In the first mode, the failure of a component or function will immediately lead to the failure of the final objective, while the second mode is the opposite. Namely, the importance of sub-goals and components to the overall or specific goals is not same. In this paper, we purposed an adaptive fault diagnosis and reasoning method combining MFM and improved Analytic Hierarchy Process (AHP) . Firstly, the MFM model is established, which already has the function of preliminary fault diagnosis according to the signal and process parameters. Secondly, the improved AHP algorithm is introduced to calculate the weights of components and functions under typical failures. Finally, the importance of components and functions are sorted, and the MFM modeling method expands the ability of quantitative analysis, which is of great significance for assisting faults diagnosis and risk management. To better illustrate the structure and execution process of the proposed method, a case study on a lubrication system of a plunger pump is analyzed and displayed, which verifies the feasibility of this method for fault diagnosis and quantitative evaluation.

Keywords: Multilevel flow modeling, Analytic hierarchy process, Fault diagnosis, Weight calculation, Quantitative analysis lubrication system.

Session	[TU4B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Atrium 2

TU4B: 286 **16:30 hrs**

Self-Exciting Jump Processes as Deterioration Models

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Several different approaches to modelling stochastic deterioration for optimising maintenance have been suggested in the reliability literature. These include component lifetime distributions, which have the disadvantage of being binary, in the sense of only telling whether the component has failed or not. Failure rate functions model ageing in a more satisfactory way than lifetime distributions. However, failure rates cannot be observed for a single component, and are therefore not tractable in practical applications. To mitigate this, a theory for modeling deterioration via stochastic processes developed. Various processes have been suggested, such as Brownian motion with drift and compound Poisson processes (CPP) for modeling usage and damage from sporadic shocks and gamma processes to model gradual ageing. However, none of these processes are able to capture jump clustering. To allow for clustering of jumps (failure events), we suggest an alternative approach in this paper: To use self-exciting jump processes to model stochastic deterioration of components in a system where there may be clustering effects in the degradation. Self-exciting processes excite their own intensity, so large shocks are likely to be followed by another shock within a short period of time. Furthermore, self-exciting processes may have both finite and infinite activity. Therefore, we suggest that these processes can be used to model degradation both by sporadic shocks and by gradual wear. We illustrate the use of self-exciting degradation with several numerical examples. In particular, we use Monte Carlo simulation to estimate the expected lifetime of a component with self-exciting degradation. As an illustration, we also estimate the lifetime of a bridge system with independent components with identically distributed self-exciting degradation.

Keywords: Self-exciting stochastic processes, Jump processes, Stochastic deterioration, Maintenance modeling.

TU4B: 369 **16:50 hrs**

Estimating Fatigue Curves with Mixture Fatigue-Limit Model

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Empirical results from fatigue data, particularly on steels, ceramics, and titanium alloy, suggest that specimen tested under a particular stress level are unlikely to fail. This limiting stress level is called ‘fatigue limit’ or ‘threshold stress’. When fatigue limit exists, S-N curve, a log-log plot of cyclic stress (or strain amplitude) S versus the median fatigue life N, often exhibits curvature at lower stress levels. Moreover, the standard deviation of fatigue life is often modeled as a monotonic decreasing function of stress. Thus, in the presence of fatigue limit, the relationship between fatigue life and stress can be better modeled by including a fatigue-limit parameter in statistical models (Pascual and Meeker 1997, 1999). Nevertheless, it is also important to note that fatigue behavior is extremely complex, and multiple failure modes in fatigue test may be present because of the influence from mechanical, structural and environmental factors. It is no longer appropriate for fatigue data to be described by a single distribution. In this paper, we propose a mixture fatigue-limit model to expand the general fatigue-limit models and improve their performance by identifying the potential multiple failure modes from observations. First, we follow the basic idea of formulating the log fatigue life as a linear function of the difference between stress and fatigue limit (in log scale). Then we assume the fatigue life is modeled as a mixture distribution at each stress level. Finally, we use some EM (Wu 1983) algorithm-based steps to estimate model parameters. In E-step, we update the posterior probability of each observation. In M-step, we firstly estimate the fatigue-limit through optimizing the likelihood of a parametric survival regression model and then the rest of parameters. The customized EM steps are repeated until the convergence criterion is achieved. For the simulated datasets, we study the convergence of log-likelihood at each iteration, and the effects that test length and sample size have on the estimation. For the nickel-base superalloy data, we found that the mixture fatigue-limit model with 2 components is superior to the situation when assuming a single failure mode by comparing their AIC values. Also, we explore the lower and upper confidence bounds for 0.05 quantile of fatigue life, which is of interest for engineers. The analyses for both cases demonstrate that the proposed model is effective and robust, and can provide some engineering insights.

Keywords: S-N curve, Mixture distribution, Fatigue-limit model, EM algorithm, Right censoring.

Session	[TU4C]—Maintenance Modeling and Applications
Day/Date/Time	Tuesday, 21 Sep. 2021 / 16:30–17:30 hrs
Venue	Espace Grand Angle2

TU4C: 381 **16:30 hrs**

Optimal Maintenance Interval for An Aging Distributed Generation System

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The aging is the inherent nature of mechanical systems, e.g., wind turbine. Therefore, maintenance is performed to return the generator to its optimal functioning. Analyzing an aging distributed generation system (DGS) is valuable to onlooking stakeholders where the economic value is of greater importance. This paper introduces a Wiener process with unit-to-unit variability to model the generator's degradation path. Then, the aging DGS is simulated via a power flow model which outputs the energy not supplied and operation costs. A maintenance model is developed based on the difference of the real and expected operation costs, which is then optimised to determine the best maintenance interval that gives the lowest long-run cost rate (LRCR). Because the LRCR is not explicit which means the deterministic approaches or classical ones about the maintenance of a group of components are not applicable here, the optimal interval is decided by GA and PSO, as the benchmark. To avoid running the aging DGS for per interval, the problem of optimizing LRCR is converted into a model that can be solved by reinforcement learning (RL) algorithms. The solutions determined are for a DGS in Corvallis, Oregon, USA. The optimal interval for above DGS was around 2.716 years to return the lowest LRCR. The results will be compared to these of GA and PSO to show why the proposed RL based decision system is superior.

Keywords: Aging, Maintenance, Long-run cost rate, Distributed generation system, Power flow model, Reinforcement learning.

TU4C: 454 **16:50 hrs**

A Disassembly Path Planning Method for Mechanical Products in Narrow Passages Based on Improved RRT-connect Algorithm

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The narrow installation space and complex assembly relationships of mechanical products bring difficulties to disassembly and maintenance. However, during product design process, it is difficult for designers to intuitively judge whether there is a product disassembly path in virtual environment. For such high-dimensional configuration space path planning problems, sampling-based algorithms such as Rapidly-exploring Random Tree (RRT) and its variants are widely used. However, due to the uniform sampling strategy of these algorithms, there are two problems: the planning performance is significantly reduced because of the low sampling probability in narrow passages, and the direction of products are random. Therefore, we improve the RRT-connect algorithm for disassembly path planning in narrow passages. First, we propose a narrow-biased sampling strategy to improve the sampling density in narrow passages. We use the bridge test to identify narrow passages, and modify the extend function of RRT-connect algorithm to make the tree extend to narrow passages with higher probability. We also propose a rotation constraint method to facilitate the disassembly and carrying of products. The rotation parameters are represented by unit quaternions and are changed only when necessary. When the sampling point is in wide space, the rotation parameters of the point are not changed. And when the sampling point is in narrow passage, the rotation parameters are changed to the direction perpendicular to the bridge (which means parallel to the narrow passage). Our method improves the efficiency of path planning in three-dimensional narrow space, and reduces unnecessary rotation of the product during random sampling.

Keywords: Disassembly path planning, RRT-connect, Narrow passage, Sampling strategy, The bridge test, Rotation constraint.

TU4C: 455 17:10 hrs

Joint Optimization of Maintenance Scheduling and Performance of Networked Systems

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Critical urban infrastructures such as energy grid and transport network have the following characteristics: 1) These networkbased systems have to fulfil continuous and stable transmission demand. The network-based systems are complex with many nodes and arcs. 2) Either system break or maintenance will lead to regional supply shutdown or shortage.

In this paper, we consider a network-based system with single-origin and single-destination. The degradation of the arc is caused material aging and degeneration. When some components are failed, the load that they took has to be shared by the other components to hold the contracted demand. The early/potential failures are hidden until some consequences are evident to be detected/monitored.

On one hand, the maintenance activities take some regional shutdown. On the other hand, the system performance should be maintained at a given threshold. Due to the arcs locate in different region of the whole networked system, and then the maintenance sequence is important when the maintenance time duration is considered. Eventually the sequence of components waiting for maintenance should be optimized with the aim of restoring the system performance within given time, which means the demand of each OD pair can be met in given time.

In this paper the network average traffic objective is established to optimize and arrange maintenance sequence based on two rules: 1) capacity rule and 2) maximum network flow change (MNFC) to assign priority to critical infrastructure. Then the different sequences will be compared with the contribution to the network performance. Eventually this paper will model real infrastructure network and simulate maintenance procedure to verify the feasibility of maintenance scheme.

Keywords: Maintenance, Networked system, Infrastructure, Performance, Multi-objective, Optimization.

Session	[TU4D]—Prognostics and Health Management: From Condition Monitoring to Predictive Maintenance
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Panoramique

TU4D: 380 16:30 hrs

Robust Sensor Fault Detection for Linear Parameter-Varying Systems Using Interval Observer

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This paper proposes a new interval observer for continuous-time linear parameter-varying systems with an unmeasurable parameter vector subject to unknown but bounded disturbances. The parameter-varying matrices are assumed to be elementwise bounded. This observer is used to compute a so-called residual interval used for sensor fault detection by checking if zero is contained in the interval. To attenuate the effect of the system's uncertainties on the detectability of faults, additional weighting matrices and different upper and lower observer gains are introduced, providing more degrees of freedom than the classical interval observer strategies. In addition, a L_∞ procedure is proposed to tune the value of the observer gains, this procedure being easy to modify to introduce additional constraints on the estimation algorithm. Simulations are run to show the efficiency of the proposed fault detection strategy.

Keywords: Fault detection, Robust fault detection, Sensor fault, Linear Parameter-varying system, Interval observer, Continuous-time systems.

TU4D: 421 **16:50 hrs**

Embedded Feature Importance Determination Technique for Deep Neural Networks-Based Prognostics and Health Management

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In the last ten years, deep learning-based models have proven to be suitable for prognostics and health management (PHM) by achieving promising results in both diagnostics and prognostics. However, there is still hesitance by companies to adopt these kinds of models, mainly because there is no straightforward way of interpreting the results a neural network achieves. Besides accurately predicting failure states, models must explain how and/or why these states are reached, in order to determine if there is bias, to build trust, and ultimately learn from the explanations. To address this issue, we propose a technique for feature importance determination embedded in deep neural networks (DNN). The objective is that, after training, the DNN informs not only its performance values but how relevant to its trained task (whether it is diagnostics or prognostics) each of the input features is. To do this, feature importance values are treated as trainable weights within the network. Thus, importance values are adjusted during training with the rest of the network's weights to minimize the loss function. We demonstrate this approach using a dataset with vibrational data from a ball bearing and compare with three other techniques. Results show that the presented technique does not affect performance, that it is able to recognize irrelevant features, and that it reaches high performance with less features than the other evaluated techniques.

Keywords: Feature importance, Model interpretability, Deep neural networks, Deep learning, Prognostics and health management.

Session	[TU4E]—Socio-Technical-Economic Systems
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Amphi Jardin

TU4E: 124 **16:30 hrs**

Risk Management Plan for Technical Facility Operation

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The aim of risk management at the technical facilities operation is the technical facilities integral safety which ensures their coexistence with their vicinity throughout their operation. On the basis of present knowledge and experience, part of risks that threaten technical facilities is coped by preventive measures during their designing and manufacturing. Due to dynamic changes, the limits and conditions of technical facilities operations change. If changes exceed the technical facilities' safety limits which were inserted into their designs, the accidents or failures of technical facilities occur. The presented risk management plan is tool which ensures the correct response to such unaccepted situations and fast ensuring the safety.

Keywords: Technical facility operation, Failure, Risk sources, Safety, Coexistence, Risk management plan.

TU4E: 473 **16:50 hrs**

Challenges of Safety-and Crisis Management Training During Covid19

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Simulation based training is a common way of training for effective learning for high-risk contexts. COVID19 changed large parts of the education and training of safety- and risk management at Nord University in Norway. The training and education have been based on theoretical lectures prior to simulated practical exercises at the university's emergency preparedness laboratory, NORDLAB. Here, academic staff, mentors, facilitators, and the students cooperated prior to, during and after exercises in order to provide an optimal learning context. However, this cooperation required close contact which suddenly ended when COVID19 hit, due to infection control. This resulted in challenges including how to uphold the learning outcome for

the students based on the theoretical foundation of Kolb's (2014) experiential learning, while changing the form of training on a short notice. Kolb's theory is the foundation NORDLAB is based on. The learning context was changed to net-based training and exercises using the software zoom, with all participants geographically spread all over Norway.

Thus, our research question was: *Which challenges in use of simulation and lab exercises in safety management education during COVID19 are central, and how could they be solved*?

The challenges identified were 1) student's lack of ability to actively participate in face to face learning activities 2) mentors' lack of technological flexibility 3) inability to share the lab's simulation technology with zoom 4) novice students difficulties of forming and interacting in digital teams 5) zoom fatigue 6) the need for increased administrative and technological support 7) low body language feedback 8) lack of visualization of injects. Solving the challenges were defiant and elements we used in this case were 1) on-boarding 2) table top exercises 3) video recorded lectures 4) flipped classroom 5) gaming simulated exercises 6) podcasts 7) shorter training sessions

We would like to discuss how and if the solutions matched the challenges for safety training in regard to the expected learning outcome for students who were to enter practical emergency preparedness and safety management.

Keywords: Safety, Training, Simulation, Covid19, Learning, Safety management.

Session	[TU4F]—Probabilistic vulnerability estimation, lifetime assessment and climate change adaptation of existing and new infrastructure
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Espace Grand Angle

TU4F: 654 **16:30 hrs**

Stochastic River Flow Forecasting Using a Markov-Switching Autoregressive Model

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Over time, the climate has changed considerably due to a wide variety of natural processes. During the last century, climate change has impacted infrastructure in different ways. In the particular case of bridges, it modified river flow and bridge scouring patterns, accelerating the deterioration process and reducing their lifetime. Therefore, design and operation require performing predictions that include the variations in river flow due to climate change. This paper represents a stochastic Markov-switching autoregressive model to improve river flow predictions. The proposed model was built based on a historical dataset for the Thames River in the United Kingdom. The dataset was used to predict and estimate the expected shortfall, which is the average amount of river flow lost over the predicted period, assuming that the loss is greater than the 99th and 95th percentile. The results of the model were compared with actual data achieving an estimated R^2 value of 85.45 %. Concerning severe river flow values, the stochastic model provides a R^2 value of 99.8 %. These results indicate that the stochastic Markov-Switching autoregressive model can be used with advantage to forecasting the climate change effects on river flow.

Keywords: Stochastic Markov-Switching autoregressive model, River flow forecasting, Climate change, Infrastructure reliability, Bridges, Scouring phenomenon.

TU4F: 669 **16:50 hrs**

Sensitivity and Reliability Analysis for Reinforced Concrete Structures Subjected to Cyclic Loading Using a Polynomial Chaos

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Fatigue is one of the main causes of failure of reinforced concrete structures subjected to cyclic loading. Several mechanical models based on damage theory have been developed to represent the behavior of reinforced concrete structures subjected to cyclic loading. The use of these models requires knowledge about the model parameters which could be determined from experimental tests. However, there is few information about the more influencing parameters for probabilistic lifetime assessment. In this paper, we propose a methodology based on polynomial chaos expansion (PCE) to propagate uncertainties in a damage mechanical model. The PCE will also be used to perform a sensi-

tivity analysis of the input parameters of the model and to estimate the failure probability of a reinforced concrete component. The methodology is applied to a reinforced concrete beam subjected to cyclic loading. The results obtained were first compared with those of the experimental tests to validate the proposed methodology. Good agreement indicates that our approach is capable of propagating uncertainties. The sensitivity analysis allow us to identify which are the most influencing parameters for lifetime assessment.

Keywords: Reinforced concrete, Cracking, Cyclic loading, Polynomial chaos expansion, Sensitivity analysis, Reliability.

Session	[TU4G]—Maritime and Offshore Technology
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Atrium 3

TU4G: 053 **16:30 hrs**

Empirical Analysis of Ship Anchor Drag Incidents for Cable Burial Risk Assessments

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Subsea cables are critical infrastructure for the global economy but are vulnerable to the risks of anchor strikes from ships, causing significant damage and interrupting global telecommunications or power networks. Whilst methodologies have been proposed to aid decision makers with optimal routeing and mitigation strategies for these cables, such methods require definition of drag probabilities which thus far have not been empirically validated. In this paper, we present a framework through which anchor drag probabilities can be calculated through analysis of historical vessel traffic data and environmental conditions. Drag distances, probabilities and causal influences of conditions are shown through comparison of three million hours of vessel anchoring exposure. We show that the wind speed and wave height are the most significant factors for calculating the likelihood of anchor dragging, but other factors omitted in this study may also be influential. The results show that the method can improve the validity of Cable Burial Risk Assessments, supporting navigation authorities and developers with mitigating the risks to subsea cables.

Keywords: Maritime Risk, Subsea Cables, Automatic Identification System, Ship Anchors, Risk Analysis, Incidents.

TU4G: 078 **16:50 hrs**

Stakeholder Network Analysis for Safe LNG Storage and Bunkering at Ports

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The main purpose of this paper is to present first results of the project entitled "TRiTON", funded by the Greek Ministry of Education, which addresses safety issues of Liquefied Natural Gas (LNG) at ports. A stakeholder network analysis is performed for investigating the safety management during storage, transport, and supply of LNG at ports. The national (Greek) and international regulatory framework for LNG safety has been analysed, so as to identify relevant stakeholders and established relationships between them. Three stakeholder networks have been created for the most widely used methods for LNG storage and bunkering, namely: a) fixed-tank storage and tank to ship bunkering, (b) truck to ship bunkering, and (c) ship to ship bunkering. Statistics and metrics of the networks have been calculated, such as density, betweenness and degree centrality, closeness, clustering coefficient and modularity. Finally, the most important stakeholders for LNG safety at ports have been identified with the help of an open-source software called Gephi.

Keywords: LNG, Bunkering, Ports, Safety, Social network analysis, Stakeholder analysis.

TU4G: 099 **17:10 hrs**

Data Safety, Sources, and Data Flow in the Offshore Industry

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Digitization may provide increased access to and more efficient use of real-time and historical data, internally as well as externally in an organization. However, when information from industrial control systems (ICS) becomes more available in office IT systems and in the "cloud", ICS systems may become more vulnerable and attractive targets

for cyberattacks. We have investigated data safety in ICS in the Norwegian offshore sector when data is processed from ICS to the office network. The work is mainly based on document review and nine interviews with selected oil companies, rig companies and service providers of operational data. The paper addresses strengths and threats related to data safety with emphasis on (1) Data sources and data flow, (2) Safety and security of data, (3) Data cleaning and processing, (4) Contextualization, (5) Validation, and (6) Quality assurance. We also discuss shortcomings for functional safety in current standards such as IEC 61508 and IEC 61511 and standard series for security, IEC 62443. It is a major challenge for the industry that there are no good international standards and guidelines that define the relevant terminology across IT systems and ICS. Future work should address data safety challenges when applying artificial intelligence and machine learning in ICS systems.

Keywords: Data, Safety, Data flow, Data sources, Security.

Session	[TU4H]—Aeronautics and Aerospace
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Cointreau

TU4H: 553 **16:30 hrs**

Reliability Evaluation of a Data Communication System for a Flying Experimental Platform

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CIRA (Italian Aerospace Research Center) has been performing experimental flight test campaigns by means of FLARE platform based on a TECNAM P92 – Echo S. FLARE is equipped with an experimental set-up used for different experimental purposes.

To derive specific reliability figures as requested by the Italian Civil Aviation Authority, CIRA has started investigating the reliability modelling techniques that better suit FLARE configuration made up of hardware, software, homemade and Commercial off the Shelf equipment. CIRA decided to apply an incremental process, starting by Onboard Data Communication System (COMSYS). Based on its configuration, a database has been filled in with reliability data, in terms of Mean Time Between Failure, Mean Time to Repair, failure and repair rates, these data coming from literature research, standards and suppliers' data when available. A first reliability evaluation has been derived by applying Reliability Block Diagram technique. To have a deeper understanding of the potential failure paths leading to the loss of COMSYS functionalities, a second reliability evaluation has been implemented by means of Monte-Carlo simulation. This choice has also been done to easily derive minimal cut sets for identifying the most critical components, the potential mitigations and potential recommendations to design changes.

This paper shows the results of the comparison between the obtained reliability figures, paving the way to enlarge the analyzed system up to include the complete on-board experimental set-up.

Keywords: Reliability evaluation, Monte-carlo simulation, Reliability block diagram, Experimental set-up, Flight trials, Data communication system.

TU4H: 564 **16:50 hrs**

Actuator Load Estimation from Distributed Optical Sensing of Airframe Deformation

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Real-time health monitoring of flight control actuators usually involves the comparison of measured signals either with numerical models or with statistical data. As the external loads experienced by the system influence the operation of most actuators, such loads are a useful quantity to compare with the actuator output and perform onboard fault detection. In common flight controls, the actuator load is not directly available as a measured signal, due to the reliability and complexity penalties often associated to the installation of dedicated sensors and transducers. In this work, we discuss the use of distributed sensing of the airframe strain to infer the aerodynamic loads acting on the flight control actuator. We address a specific sensing technology based on Fiber Bragg Gratings (FBGs) as it combines a good accuracy with minimal invasivity and low complexity. Specifically, we combined a structural and an aerodynamic model to collect a database to train data-driven surrogates intended to map from strain measures to actuator load. Figure 1 displays the information flow of the proposed process.

Keywords: Distributed optical sensing, FBG, Load estimation, On-board fault detection, Prognostics.

TU4H: 634 **17:10 hrs**

Environmental Sensitivity of Fiber Bragg Grating Sensors for Aerospace Prognostics

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Optical sensors have recently gained interest due to the many advantages they offer over traditional electrical sensors commonly used in aerospace applications. In particular, their total insensitivity to electromagnetic interference (EMI), the ease of multiplexing of different signals on a single line, the excellent resilience to hostile environments, the very compact dimensions, and the considerable overall weight savings resulting from the signal cables reduction, make technological solutions based on optical fibers a compelling alternative to traditional sensing elements. In this work, authors consider optical sensors based on Fiber Bragg Gratings (FBGs), which can reflect a very narrow band of wavelengths, called the Bragg wavelength, but are almost transparent for the other signals. This behaviour is obtained by realizing local variations of the refractive index of the FBG core. The Bragg wavelength, nominally defined in the production phase by the grating etching process, can vary as a function of physical changes in the sensor itself or environmental conditions (physical stresses applied to the grating or variations of temperature or humidity). The correlation of the Bragg wavelength variation with the physical variations of the sensor is essential to guarantee satisfactory levels of accuracy and reliability. In particular, using FBGs as mechanical strain sensors, it is crucial to estimate with proper accuracy the disturbance generated by environmental conditions and conceive an effective compensation method. Hence, this work studies the effects of environmental temperature and humidity variations on measurements, examining possible non-linear, time-dependent phenomena arising from the FBGs bonding. For this purpose, the authors developed a dedicated test bench to simultaneously detect the various physical measures (FBG deformation, temperature, humidity, Bragg wavelength variation), analyse their correlations, and formulate the said compensation strategy.

Keywords: Aerospace applications, FBG, Fiber bonding, Environmental factors sensitivity, Mechanical strain, Optical sensors.

Session	[TU4I]—Foundational Issues in Risk Assessment and Management
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Giffard

TU4I: 409 **16:30 hrs**

Eight Years of Collaborative Research on Industrial Safety within SAF∈RA Partnership

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The SAF∈RA project was created to strengthen the link between European researchers working on industrial and allied topics (FP7 ERANET, Grant Agreement no 291812). Between 2012 and 2015, it financed the creation of a mechanism to coordinate the research investment among EU countries. After the end of the ERA-NET in 2015, a formal Partnership has been created which now gathers 16 organizations from 12 European countries. Since 2013, six SAF∈RA calls for projects have been launched, fully funded by the SAF∈RA Partners. To select the topics, SAF∈RA organizes symposia, inviting renowned experts from industry and academia. An independent panel evaluates the proposals and the funding arrangements used involve little bureaucracy. 23 projects have been funded to date, with 4 more projects at the starting line. The projects have involved 68 operating units from 17 European countries, covering many of the topics of "industrial safety", and involving the most renowned European research teams, but also emerging ones. The purpose of the article is to analyse the benefits of this type of collaboration between research funders and present a roadmap for future strategic research. The article will use a series of evaluation indicators, also evaluating the effectiveness of the funds spent from a cost/benefit perspective. After eight years of hard work to promote transnational collaboration, SAF∈RA leadership wants to assess the results obtained and discuss them with the industrial safety research community, to decide the direction to be given to the consortium in the coming years.

Keywords: Research funding, Industrial safety, Research programming, Future research.

TU4I: 448 **16:50 hrs**

A Risk Perspective on Common Operational Pictures: A Case Study of the Swedish Counties' Coordination Office for the Covid-19 Response

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The Covid-19 crisis has led to widespread impacts on society, not only in terms of high death tolls, but also in terms of cascading effects for essentially all societal sectors; especially due to all measures taken to reduce the spread of the disease. A range of actors have become involved in the response to the pandemic and to ensure appropriate actions being taken, these actors need good situational awareness, which can be facilitated by developing and distributing common operational pictures (COPs). This paper presents a case study of the COPs compiled by the Swedish Counties' Coordination Office (SCCO). A point of departure for the paper is that for a COP to become useful, they should not only contain information about the present but also contain description about future potential states and uncertainties. Since this is a perspective that is addressed by the risk science, this paper addresses the question of how risk science can add value to the work with COPs in general and the SCCO's COPs in particular. Our results indicate that SCCO's COPs fulfil the expectations of the Government Office who are the main target organization. But there is room for improvements, where risk science can add value, if the aim is to improve their usefulness as decision basis.

Keywords: Common operational picture, Situational awareness, Covid-19, Risk science, Uncertainty, Prediction.

TU4I: 576 **17:10 hrs**

Information- and Cyber-Security Practices as Inhibitors to Digital Safety

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Every year experience increased focus on cyber -information -security (CIS) from government, official organizations, private industries, and research and academia. As awareness on CIS improves in society, requirements to stakeholders become more numerous and more detailed. The natural response has been to develop CIS as a specialized field, resulting in digital safety and digital security separating into more distinct silos. The paper presents the authors experiences from safety and security analysis and development activities across last 20 years from a range of critical domains with focus on successes and challenges in addressing safety and security. Shared experiences indicate that CIS as a topical area has become both more important, but also more distinct in that it is addressed isolated. The identified challenges are discussed and a set of mitigations to prevent the (self)-alienation of security in safety are provided. The result is a set of best practices to navigate the projects where CIS concerns prohibit safety. To be able to fully integrate the safety way of working, i.e., information sharing and an inclusion culture, a revolt of current practices and ways of working within security is suggested.

Keywords: Safety, Information security, Cyber Security, Critical infrastructures, Critical systems development.

Session	[TU4J]—Seismic reliability assessment
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Botanique 2

TU4J: 660 **16:30 hrs**

State-Dependent Seismic Fragility Functions for Italian Reinforced Concrete Structures: Preliminary Results

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The present paper deals with the analytical assessment of structural vulnerability models for Italian reinforced concrete buildings that constitutes one of the results of the ongoing research project RISE (Real-time earthquake rIsk reduction for a ReSilient Europe). The structures under consideration are taken from the outcomes of the SERA project (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe) and refer to existing reinforced concrete residential Italian buildings.

State-dependent fragility curves are evaluated via back-to-back incremental dynamic analyses using equivalent-single-degree-offreedom systems. The analyses consider

four damage states, identified by transient maximum inelastic displacement thresholds defined on the system's backbone curve, and are performed with the DYANAS software. Such fragilities are required to calculate the seismic structural reliability when it is possible for structural failure to be reached progressively, i.e., due to the cumulative effect of multiple earthquakes.

Keywords: Sequence-based seismic reliability, Back-to-back IDA, Damage accumulation, SDOF systems, Reinforced concrete.

TU4J: 666	16:50 hrs

Predicting Seismic Response of a Tall Building to a Large Earthquake Using Recorded Waveforms from Small Earthquakes

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The Sapphire building located in Istanbul, Turkey is one of the tallest buildings in the country, which has 55 stories above ground level. The structure has been monitored by the Department of Earthquake Engineering of Kandilli Observatory and Earthquake Research Institute, Boğa2ici4 University since 2012. The response of the structure to several earthquakes is recorded by a 37-channel permanent accelerometer network, installed on the basement (9th and 1st), 9th, 14th, 25th, 36th, and 52nd floors. In this study, we determined the dynamic characteristics of the structure using the vibration data recorded by those instruments. The vibration data used in the analysis belong to 5 different earthquakes that occurred between the years 2014 and 2020. The dynamic response of non-instrumented floors isestimated based on the mode shape-based estimation (MSBE) technique. Then the structure is modeled as a cantilever beam based on either Bernoulli-Euler or Timoshenko beam theories. The response of the structure to larger earthquakes is derived using the recursive filter methodology, which uses the corner frequency of the small earthquake and magnitudes for scaling. The maximum inter-story drift ratio (MIDR) is calculated under the effect of various PGV levels.

Keywords: Model calibration, Seismic risk, Earthquake scaling, Mode shape, Timoshenko beam, Bernoulli-Euler beam.

TU4J: 712	17:10 hrs

Practical Issues in Sequential Dynamic Analysis of Simple Inelastic Oscillators

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The analytical evaluation of seismic structural behavior under repeated earthquake shocks, that can potentially cause failure due to damage accumulation, often makes recourse to sequential dynamic analysis of a numerical model. One such dynamic analysis strategy is the so-called, back-to-back incremental dynamic analysis (B2B-IDA), whereupon one accelerogram is scaled in such a way as to bring the structure to a specific conventional damage state and is then followed by a second accelerogram which is scaled in amplitude over a wide range of shaking intensity levels, forcing structural response to span the entire range of possible damage states. The need to effectively capture record-to-record variability of response for seismic reliability analyses, means that B2B-IDA is typically applied using a multitude of ground motions representing both the first damaging shock as well as the second shock in the sequence that affects the damaged structure. The present study uses a variety of such SDOF inelastic structures to explore a series of practical issues that arise in running B2B-IDA and post-processing the results. This investigation uses the DYANAS graphical user interface, which was previously developed with the contribution of the authors as a tool that can be also used for streamlining this type of analysis. The first issue that is addressed in this study is the number of records used to represent both the first and the subsequent seismic shock affecting the structure. Previous research has shown that the statistical inference concept of estimation uncertainty can be used as a tool to quantify the effect of the record sample size, used in single-event dynamic analysis, on the accuracy of the results obtained. The present article picks up on that methodology and seeks to extend it in the context of B2BIDA. A second practical issue considered is the implementation of a hunt-and-fill algorithm in order to minimize the number of runs needed to efficiently represent a single B2B-IDA curve. Such an algorithm can allow the rapid transformation of B2B-IDA curves from one IM to another when combined with appropriate interpolation techniques. Finally, this article briefly addresses updates in the DYANAS software that were explicitly implemented to facilitate the extraction of results from B2B-IDA for the purpose of obtaining so-called statedependent fragility functions, that is models providing the conditional probability of a structure transitioning from

one damage state to another, given shaking intensity.

Keywords: Structural reliability, Non-linear dynamic analysis, Fragility function, Ground motion record selection, Performance-based earthquake engineering, Statistical inference.

Session	[TU4K]—Accelerated Life Testing & Accelerated Degradation Testing
Day/Date/Time	Tuesday, 21 Sep. 2021/16:30–17:30 hrs
Venue	Atrium 1

TU4K: 733 **16:30 hrs**

Accelerated Test Design of Aero Generator Based on Text Mining

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In order to solve the problem of information collection in aero generator accelerated test, this paper proposes a text mining based fault analysis method for Aero generator products. In order to improve the efficiency and accuracy of fault analysis, text mining technology is used to process the weak links and fault modes of complex mechanical and electrical products. Firstly, based on Python software, a text information preprocessing method based on Jieba word segmentation system is developed. Then, aiming at the problem of unstructured information such as faults and weak links in mechanical and electrical products fault analysis literature, TF-IDF and LDA model are used to extract fault information features, which can fully describe the fault information and obtain the feature weight of text information; Finally, a text mining method of fault information based on support vector machine (SVM) is proposed. This method processes the fault information of mechanical and electrical products in the form of classification, and obtains the information of weak links and fault modes, which provides information support for accelerated test. The analysis method proposed in this paper can greatly improve the comprehensiveness of fault analysis. Finally, a typical generator product is taken as an example to verify the method.

Keywords: Text mining, Fault analysis, Jieba word segmentation, TF-IDF SVM.

TU4K: 692 **16:50 hrs**

Design Optimization for the Step-Stress Accelerated Degradation Test under Tweedie Exponential Dispersion Process

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The accelerated degradation test (ADT) is a popular tool for assessing the reliability characteristics of highly reliable products. Henceforth, designing an efficient ADT has been of great interest, and it has been studied under various well-known stochastic degradation processes, including Wiener process, gamma process, and inverse Gaussian process. In this work, Tweedie exponential dispersion process is considered as a unified model for general degradation paths, including the aforementioned processes as special cases. Its flexibility can provide better fits to the degradation data and thereby improve the reliability analyses. For computational tractability, the saddle-point approximation method is applied to approximate its density. Based on this framework, the design optimization for the step-stress ADT is formulated under the *C*-optimality. Under the constraint that the total experimental cost does not exceed a pre-specified budget, the optimal design parameters such as measurement frequency and test termination time are determined via minimizing the approximate variance of the estimated mean time to failure of a product/device under the normal operating condition.

Keywords: Accelerated degradation test, Design optimization, Exponential dispersion process, Step-stress loading.

TU4K: 411 **17:10 hrs**

A New Estimation Method for Automotive Multidimensional Metrics

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In general, failure data is obtained in the automotive industry during the warranty period. If these contain the expression of a service life characteristic for each failure, statements can be made about the reliability and availability of the systems. For this purpose, estimation methods are used to adapt empirical lifetime distributions to theoretical lifetime distributions. By means of the distribution characteristics, a prognosis of the reliability and availability to be expected is also possible beyond the observation time. In addition to the data basis to be investigated, which is available completely in test bench and experimental trials or recensored in the field, various methods can be used for estimation. In the past, several methods have been used, such as the estimators according to ECKEL [1], Kaplan-Meier [2] or the estimators according to Pauli [3]. In general, a field failure is subject to several stresses, which can be described by expressions of several lifetime characteristics. For this application case, which occurs in the automotive industry, the known estimation methods, [1], [2], [3], cannot be used. In this paper, the necessity of multidimensional estimation methods will be introduced first. Then, a new estimation method for multidimensional metrics is presented. In a further step, mathematical proof is given that the new method can provide realistic results. Finally, two example data sets from bench testing and field are presented. Furthermore, some recommendations for the use of the new method are concretized in this context.

Keywords: Failure data, Automotive industry, Warranty, Reliability, Availability, Distribution, Estimation methods, Metrics, Multidimensional estimation methods.

Abstracts — Wednesday, 22 September 2021

Session [WE1A]—System Reliability
Day/Date/Time Wednesday, 22 Sep. 2021 / 08:30–10:10 hrs
Venue Plenary Room

WE1A: 218 **08:30 hrs**

Utilization of Multilevel Flow Modelling to Support Passive Safety System Reliability Assessment

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Many advanced Nuclear Reactor designs deploys passive systems for enhancing safety Passive systems rely on natural driving forces, such as natural circulation, gravity, internal stored energy etc., which do not require external power sources. Substantial efforts are underway towards improving reliability assessment methods for passive system, however, consensus is not yet reached. The existing case studies of various passive safety system reliability assessment methodologies usually consider a single passive safety system, but the reliability of one passive safety system should also dependent on other related systems which operate simultaneously. Thus, this work suggests a framework of passive safety system reliability assessment supported by multilevel flow modelling (MFM) methodology, and a preliminary application is conducted on a small modular reactor station blackout sequence to assess the reliability of Core Makeup Tank (CMT) to remove the decay heat. Also, a causal inference of MFM model and a sensitivity analysis is performed to prove the feasibility of the MFM supported passive safety system reliability assessment methodology. The results show the importance of considering all relevant systems when performing reliability assessment. This MFM supported passive safety system reliability assessment methodology can contribute to the integration of reliability assessment results to the probabilistic risk assessment framework of a whole power plant.

Keywords: Passive safety system, Reliability assessment, Multilevel flow modelling, Sensitivity analysis.

WE1A: 283 **08:50 hrs**

Detection and Localization of Time Shift Failures in Timed Event Graphs: Application to a Remanufacturing Line

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This paper deals with the problem of time shift failure diagnosis in a remanufacturing system when an equipment is late to ensure its functionality. So, the detection and localization of time shift failures must be done as soon as possible to avoid a degraded remanufacturing flow. This paper starts with a description of our modeling methodology of a remanufacturing line as a Timed Event Graph (TEG). Our approach for diagnosis (detection and localization) is an algorithmic approach compared to other related works which use an algebraic approach base on (max,+) algebra. Firstly, we propose an event-driven simulator for TEG which gives us the faultless behavior of the system and allows to simulate the TEG with some time shift failure injection. Secondly, we define several algorithms which take as input timed observations of the functioning of a remanufacturing system and allow to detect and localize time shift failures if there are present. A case study illustrates the feasibility of our approach.

Keywords: Remanufacturing line, Time shift failure, Fault detection, Fault localization, Timed event graph, Discrete event system.

WE1A: 306 **09:10 hrs**

Dynamic Reliability Approach for a Complex Offshore System

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Dynamic reliability is the ability of a system or process to perform a given task on a given mission without failure, and to maintain it over time. Production operations at the onshore liquefied natural gas *LNG* plant and the float-

ing *LNG* plant may be affected by spills stimulated by failures induced by environmental loads and Shuttle tankers present at sea. Our study proposes to develop an assessment of these risks using the dynamic reliability approach based on differential equations. Firstly, we provide an assessment of the offshore operations, such as floating, production, storage and offloading, *FPSO*. Secondly and particularly, we develop a model for assessing the likelihood of leakage in an *FPSO* induced by environmental loads. From the existing methods, we propose to use the dynamic quantitative risk assessment (*DQRA*) method. The main stages of the study conducted are: (i) establishment of failure indicators, (ii) analysis of the interaction between indicators, (iii) risk evolution, consisting on risk evolution monitoring model based in Fault Tree and Event Tree (FT-ET), and (iv) reassessment of the probability of failure. A balance point between the three subsystems is desired for greater system availability resulting from better knowledge of failure mechanisms and risk forecasting.

Keywords: Dynamic reliability, Failure mechanisms, Availability, Corrosion, Leakage, Environmental loads, Failure Indicators.

WE1A: 313 **09:30 hrs**

Sub-Safety Recognition and Reliability Evaluation for Motor Drive System in High Speed Trains

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The concept of sub-safety for high-speed trains is put forward for the first time. As trains run for a long time, train systems constantly age and degrade and enter a state of sub-safety. It is important to recognize the sub-safety state in a timely manner in order to implement safety control measures to prevent the system from entering a faulty state. Firstly, this paper analyzed the main faults of the devices in a high-speed train's motor-drive system and their failure mechanisms. Secondly, a sub-health state was proposed for the main devices of the system. Then a degradation and state transition model for the devices was established based on the Markov theory. Finally, using the reliability model for the system, the reliability was evaluated and the sub-safety state was determined.

Keywords: Sub-safety recognition, Motor-drive system, Sub-health state, Reliability modeling, Reliability evaluation.

WE1A: 317 **09:50 hrs**

Efficient System Reliability Demonstration Tests Using the Probability of Test Success

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In order to demonstrate system reliability, the concept of "Probability of Test Success" is used, and an approach is presented that enables the reliability engineer to identify the most efficient test. Furthermore, general recommendations are given for the most common test types and series and parallel system structures. A case study exemplifies the findings by additionally considering financial aspects of system reliability test planning.

Keywords: System reliability, Reliability demonstration, Probability of test success, System, Test, Efficiency.

Session	[WE1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue	Atrium 2

WE1B: 406 **08:30 hrs**

An Application of Semi-Supervised to Production Data

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Knowledge of the quality of a machine-manufactured product is crucial to its reliability throughout the product's use phase and indispensable if a customer is to be assured of a certain quality standard. However, the quality of not all products can be determined non-destructively. In this case, machine learning methods are increasingly used to predict the quality of the product based on production parameters and non-destructively measurable attributes. Due to the

progress made in recent years, products can be reliably classified if the amount of training data is large enough. However, the generating of such training data is often associated with high effort and high costs. For this reason, the amount of data to be generated should be kept as small as possible while maintaining reliable classification by the machine learning algorithm. We therefore applied a modification of the Yarowsky algorithm, a method from the field of semi-supervised learning, in combination with DNNs. The Algorithm involves a stepwise expansion of the learning dataset. To expand the learning dataset, we used samples that were assigned to a class with high confidence by the neural network. We conducted our experiments on a data set, which contains production parameters of 3600 knives. The dataset features attributes of the surface topography determined by computer vision and gloss values. The gloss values serve as target variables and were divided into 3 classes. For the experiments, we used a neural network architecture that was previously determined to be very performant for the problem. We then conducted a series of runs of our method to determine whether the method could be suitable for real-world applications based on the metrics recorded.

Keywords: Semi-supervised learning, Machine learning, Self-learning algorithm, Neural networks, Production process.

WE1B: 488 08:50 hrs

Reliability Analysis of the On-Board Flight and Navigation Equipment on the Aircraft

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The idea of aviation safety is strongly related to the principle of reliability. To determine this, an aircraft can be considered a complete as well as a complex structure. The current study focused on the reliability of the control and navigation instruments of an M-28 "Bryza" aircraft over the 2011-2019 analysis period. In order to determine the reliability, a measurable parameter should be selected, which changes will allow us to assess whether the defectiveness of the system increases or decreases. In many analysis this parameter is the mean time between failures (*MTBF*), on the basis of which it is possible to determine the intensity of failures and consequently the reliability changes. The selected method is based on the determination of MTBF by means of log-normal, Weibull or normal functions. Consequently, it will be possible to select the function which best describes the data of the maintenance and operation process. The selected function will be the input for the calculation of the reliability. Functions logarithmic-normal function and Weibull function distribution have been fitted to the distribution of the time between failures. In the analysis there are indications the failure distribution is far from being uniform. The MTBF value alone is inadequate to provide information on product reliability over time.

Keywords: Reliability, Airworthiness, Aircraft, Aviation, Mean time between failures, Flight-navigation instruments.

WE1B: 491 09:10 hrs

Optimization-Based Reliability Assessment of Multi-Energy Systems

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Multi-energy systems (MES) connect different energy networks using conversion technologies, leveraging alternative supply paths and redundancy to improve the integration of renewable energy, the reliability and the profitability of energy supply. This paper investigates MES reliability by integrating a pre- and post-failure operational optimization into a reliability assessment based on an alternating renewal process. Expected energy not supplied and uninterrupted supply times are used to quantify the MES' ability to withstand failures of technologies, networks and external grid supply. The method is applied to a Swiss MES that supplies thermal and electrical energy demands of a mixed-use district. A comparison of system configurations with electricity- and gas-based conversion technologies, energy storage and distributed photovoltaic generation shows that both electricity- and gas-based MES are highly reliable due to the high reliability of the Swiss electricity grid. Introducing centralized battery storage and distributed photovoltaic panels further increases the probability of uninterrupted supply and decreases the expected energy not supplied. However, reliability is not always increased by introducing conversion technologies that couple energy carriers. In fact, heat pumps introduce a dependency of the heat supply on electricity, while combined heat and power plants can be less reliable than other technologies, thus increasing the expected energy not supplied.

Keywords: Multi-energy system, Reliability, Optimization, Uninterrupted supply, Alternating renewal process.

WE1B: 497 **09:30 hrs**

Graph Representation of Logic Differential Calculus for Reliability Modeling of Coherent Binary State Systems

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In reliability engineering a large class of models (fault trees, reliability block diagram, event trees, . . .) are founded on the structure function model often written as a Boolean polynomial. Based on the structure function, two approaches were recently proposed to analyze and asses the system reliability: logic differential calculus and graph models based on Hasse diagram. Logic differential calculus is a powerful mathematical methodology that allows the analyze of dynamic properties of Boolean functions by means of Direct Partial Boolean Derivatives. Hasse diagram is a graph representation of the partially order on the values of the state vector. The system states diagram, which is an extension of the Hasse diagram, allows the determination of a minimal disjoint Boolean polynomial as well as a direct computation of the system reliability. In this paper, we propose a new graph to represent Direct Partial Boolean Derivatives that allows us to compare both approaches of logic differential calculus and graph models in order to find correspondences between them. Thereafter these approaches are applied for computation of Birnbaum's importance measure to determine the impact of critical components on the system reliability.

Keywords: System reliability, Structure function, Drect partial boolean derivatives, Hasse diagram, Path/cut vectors, Order relation.

WE1B: 502 **09:50 hrs**

About Bounded Transformations of the Gamma Degradation Process

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Although the degradation processes of technological units are naturally bounded, due to the finiteness of their physical dimensions and/or the nature itself of the degradation mechanism, the models adopted to describe degradation phenomena are typically unbounded. In general, this apparent contradiction does not significantly affect the effectiveness of unbounded degradation models, because degrading units are conventionally considered failed when their degradation level exceeds a threshold value that is quite far from the "natural" bounds. On the other side, however, the effectiveness of an unbounded degradation models can drastically diminish if the physical bound and threshold have comparable values. The aim of this paper is then to investigate the potentiality of the transformed gamma process in modelling bounded degradation phenomena. This idea is not new. Yet, differently than in other existing models, here the upper bound is treated as an unknown parameter and is estimated from the available degradation data. The proposed approach, which led to the definition of a bounded (state-dependent) transformed gamma process, is illustrated starting with a motivating example, which is developed on the basis of a real set of wear data of cylinder liners equipping a diesel engine for marine propulsion. Model parameters are estimated by using the maximum likelihood method. Fitting ability of the innovative proposed bounded process is compared with those of the unbounded gamma process, previously adopted to analyze these wear data. Potentiality of the proposed approach are critically discussed in the paper.

Keywords: Bounded degradation phenomena, Transformed gamma process, Remaining useful life, Residual reliability, Maximum likelihood estimation.

Session	[WE1C]—Digital twin approach in maintenance and safety engineering
Day/Date/Time	Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue	Espace Grand Angle2

WE1C: 070 **08:30 hrs**

Digital Twin-Based Prognostics and Health Management for Subsea systems: Concepts, Classification, Opportunities and Challenges

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Digital Twin (DT) constitutes to be an important pillar for industrial transformation to digitalization. Both academics and industries have recently started the explo-

ration on methodologies and techniques related to DT. A systematic overview on the relationships and differences between DT and traditional approaches, such as simulation, is thus needed. This paper aims to contribute towards better understanding of DT, by reviewing different DT types in an effort for their classification. Subsea production is the focusing industry in this study, where conventional corrective/age-based maintenance is shifting towards condition-based maintenance (CBM) and prognostics and health management (PHM). DT is believed to be meaningful to improve efficiencies and reduce costs of such activities, but technical difficulties of DT-based PHM are existing to impede real-world applications. We outline some of these opportunities and identify challenges of DT-based PHM with an aim of highlighting future research perspectives.

Keywords: Digital twin, Simulations, Prognostics and health management, Condition-based maintenance, Subsea.

WE1C: 246 **08:50 hrs**

A Survey on the Use of Digital Twins for Maintenance and Safety in the Offshore Oil and Gas Industry

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Companies in the oil and gas industry have, since the fall in oil price in 2014, been under pressures to cut costs and improve the effectiveness of their operations. Digitalization is generally considered as an important contributor to achieve this. One barrier to benefit from digitalization that is increasingly being recognized by the industry is data silos. Digital twin is a concept that has been proposed to alleviate this problem, but there is a lack of common understanding of what this concept entails and the potential benefits of this concept. To gain a better understanding of how digital twins are used for maintenance and safety in the offshore oil and gas industry, we have conducted a survey in the form of a web-based questionnaire among practitioners from this industry. 15 responses to the questionnaire was included in the final sample. Nine of these where from respondents that reported to have implemented digital twins in their own organization or in their products or services. Because of the low number of responses, the results cannot be used to draw conclusion on the current state of digital twins for maintenance and safety in the offshore oil and gas industry in general. But the results offer some insights that can be useful for further research.

Keywords: Industry 4.0, Digital Twin (DT), Questionnaire, Survey, Industrial Internet of Things (IIoT), Offshore oil and gas, predictive maintenance, safety, Norwegian Continental Shelf (NCS), Digitalization.

WE1C: 341 **09:10 hrs**

Reliability Digital Twin Approach Based on Bayesian Method for Brake Pad Wear Monitoring

Reliability Digital Twin (RDT) method is regarded as a novel Reliability assessment technology that integrates the characteristics of digital twin implementation and mapping. Based on the real-time data transmitted between physical space and digital space, RDT technology has ability to collect and transmit the parameters data that reflects the braking process of brake pads. Furthermore, the RDT models of the digital space is updated in real time to present the health status of the equipment in the physical space, which is used to guide maintenance-related decision-makings. This paper proposes a reliability digital twin approach based on Bayesian theory to realize the dynamic reliability evaluation and life prediction method for brake pads. Firstly, the wear performance degradation data of brake pads are obtained by accelerated degradation experiments, as well as the amount of wear is selected as its performance parameter to characterize its health state. Secondly, the brake pad wear reliability function and the performance degradation model based on the Wiener process are established, and Bayesian theory is used to update the models' parameters in real time based on the transmission of dynamic sensor data. Finally, the reliability index of brake pad is calculated in real time, and the remaining wear life prediction of brake pad is realized under different degradation degrees. Numerical examples verify the effectiveness and accuracy of the proposed method. The proposed RDT approach can provide a more efficient and economical way to realize brake pad health assessment and maintenance activities.

Keywords: Reliability digital twin, Wiener process, Bayesian estimation, Reliability assessment, Remaining Useful Life (RUL).

WE1C: 365 09:30 hrs

Application of Digital Twins in Condition-Based Maintenance

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Condition-based Maintenance (CBM) is a combination of fault diagnosis, fault prognosis, and maintenance decisions. The diagnostic results can be used to predict the remaining life and maintenance plans are made based on current state and future state. Digital Twins (DTs) allows CBM to be carried out in a more efficient way. It simulates the operation of the system and realizes real-time interaction with the system. For this, the CBM model can get more data from the DTs and display the results through DTs. Compared with the traditional CBM, DT-based CBM is more intelligent, and thus, DTs-based CBM is widely studied in recent years. This paper presents the changes that DTs brings to CBM and the focus is the changes that DTs brings to fault diagnosis, fault prognoses, and maintenance decisions. The work divides the changes into three aspects, that is, DTs provides a new CBM framework, DTs provides data for CBM modeling and DTs provides good visualization tools. The future direction of DTs for CBM is also discussed in this paper.

Keywords: Digital twins, Condition-based maintenance, Fault diagnosis, Fault prognosis, Maintenance decisions.

WE1C: 373 09:50 hrs

A Usage-driven Approach to Characterize and Implement Industrial Digital Twins

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The Digital Twin is a new concept with various definitions, shapes and applications. In recent years, publications on this subject have been increasing sharply without any real coherence, representing very different realities and including a wide variety of models. In order to clarify such a complex representation, we propose not only a global definition, but also a complete, usage-driven classification methodology. Our generic overview relies on three axes as the Digital Twin is not just a set of data or models but a data organization in information and meta-information allowing to combine models in order to provide usages required for its application. As the required services are evolving throughout the object lifecycle, the Digital Twin properties must also evolve, making it a 'living model'. Seven different usages can be combined to respond to a wide range of industrial applications. We give different examples of this classification to support the deployment of the Digital Twin in predictive maintenance, line reconfiguration, operator training... Moreover, such a usage-driven approach also ensures to be user-centric, in order to foster acceptance and facilitate risk management.

Keywords: Digital twin, Agile manufacturing, Predictive maintenance, Smart manufacturing systems.

Session	[WE1D]—Flexible Tolerancing Analysis of Complex Structures and Assemblies
Day/Date/Time	Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue	Panoramique

WE1D: 722 08:30 hrs

Fastening Process Simulation of Structural Parts with Shape Defects

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The design of fastened joints consists in choosing adequate geometric, material and joining parameters, such as the ratio of fastener diameter to adherent thickness or clamping force in order to ensure target mechanical performances of the assembly. Deviations of nominal values of design parameters as geometric errors involve in most cases a decrease in the mechanical performance and reliability of the assembly[1,2].

This paper proposes a method to analyse the fastening process of parts that include geometric form defects. The structural behaviour of the joint is simulated using a finite element model combining connectors and rigid surfaces to represent fasteners[3,4]. With this approach, the calculation time can be drastically reduced while frictional contact is maintained between fasteners and parts. Shape defects are generated by translating parts mesh nodes. The method is

applied to a case study and its efficiency is evaluated by analysing the evolution of axial bolt preloads and transverse bolt forces during the assembly process as shown in Fig. 1. Results demonstrate the ability of the method to simulate different clamping sequences and to capture the interaction between shape defects, bolt-hole clearance and target axial preload.

Keywords: Bolted joint, Fastening process, Clamping sequence, Shape defect, Finite elements.

WE1D: 724 **08:50 hrs**

Statistical Tolerance Analysis of Over-Constrained Mechanical Systems Using Tolsis Software

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All manufactured product has geometrical variations which may impact its functional behavior. Tolerance analysis aims at analyzing the influence of these variations on the product behavior, the goal is to evaluate the quality level of the product during its design stage. Analysis methods must check if specified tolerances enable the assembly and functional requirements. The technique consists in computing the non conformity rate of the mechanism for both requirements, expressed in parts per million (ppm), by mixing the resolution of an optimization problem and reliability analysis techniques such as Monte Carlo simulation or FORM system approximation.

Analysis methods must consider geometrical deviations as realizations of random variables (resulting from the manufacturing process) and the worst admissible configurations of gaps. As the geometrical behavior is formalized by an implicit assembly response function, these configurations change depending on the deviations. Hence contacts between the different parts of the mechanism may change according to the considered configuration. These configurations must be found using an optimization scheme. For simple mechanism, it is conceivable to build the mathematical behavior model manually but for complex system it is needed to build it automatically using a dedicated tool.

The presentation proposes to illustrate how the Tolsis software, integrated in Catia or in SpaceClaim, can deal with such tolerance analysis problem. First a brief reminder on the behavior model1 will be presented. Then the characteristics of the software will be described using a mechanical system as example, from the initial definition of the surfaces and linkages to the evaluation of the non conformity rates.

Keywords: Tolerance analysis, Over-constrained mechanism, Reliability analysis, Optimization, Non conformity rate, Tolsis software.

WE1D: 726 **09:10 hrs**

Tolerancing Analysis of Complex Assemblies with Surrogate Chaos and Kriging Meta-Models

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In industry, the modelling of product / process assemblies is based on the theory of Geometrical Product Specification and tolerancing analysis. This industrial approach follows several international standards to specify the parts and to build stack-ups models of tolerances of an assembly. The main hypothesis of these standards is the rigid workpiece principle. However, for large dimensions thin parts and assemblies as example, under the effects of gravity and of the forces and/or displacements imposed by the tools, this rigid bodies assumption is not acceptable and "classic rigid stack-ups" can lead to non-representative results on functional requirements. Thus, this paper proposes an approach to take into account the flexibility of the parts and assemblies in the 3D tolerancing stack-ups. Coupling the tolerancing theory, the structural reliability approaches and FEA simulation, an original approach based on the stochastic polynomial chaos development, the Kriging meta-model and the Sobol' indices is developed to build 3D flexible stack-ups and to estimate the main tolerancing results.

Keywords: Tolerance analysis, Flexibles parts and assemblies, Finite elements, Chaos development, Adaptative Kriging, Sobol' indices.

WE1D: 751 **09:30 hrs**

Toward a Normalized Method to Evaluate the Quality and the Relevance of a Linear Approximation for Tolerance Analysis and Synthesis

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In tolerance analysis and synthesis field, specified tolerances generally allow to expect small variations on parameters, justifying the use of a linear approximation for the transfer function between these identified parameters and studied resulting criteria.

With 1D textbook stack-ups, there is no doubt about this linearity, but in real world, geometrical, kinematical and mechanical effects are common, in 2D and 3D, and the relevance of linear approximation is not obvious. Strangely, existing Tolerance Analysis Tools on the market never provides metric to evaluate the relevance of their linear approximations.

Today, technical enhancements allow to hope for the integration of parts flexibility in our stack-ups, and the question of the validity of the linearization reappears as legitimate. This question is not to determine if the cause-effect relationship to deal with is linear or not, but to validate if the use of a linear approximation is reasonable to deal with tolerances allocation and reliability assessment. Appropriate mathematical methods are known, usually named "regression analysis methods" and the problem is not theory, but about its implementation in tolerance analysis software.

The objective of this paper is to motive tolerancing scientific community to build a normative frame guiding Tolerance Analysis Tools to integrate the relevant routines to evaluate the quality of their linear approximations. the question is finally about the confidence we can have in provided results.

Keywords: Tolerance analysis & synthesis – linear approximation -regression analysis- computer aided tolerancing.

WE1D: 754 **09:50 hrs**

Tolerance Analysis of a Wiper Blade Using the Probabilistic Approach

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Engineers are aware that uncertainties in the dimension of manufactured products cannot be avoided, i.e. mechanical components manufactured using the same tools and the same raw materials have slightly different shapes; and their dimensions are also different from the designer's request. Tolerance analysis offers a rational framework to study such uncertainties, and allows guaranteeing that the quality associated with the production remains acceptable. This quality is quantified by estimating the defect probability, which is often expressed in parts per million. In this contribution, the probabilistic approach is used, and the dimensions of the components are modeled using random variables. A reliability analysis is then performed to estimate the probability of manufacturing a component which does not meet its functional requirement. The procedure described previously is applied to an industrial problem; the method is developed in collaboration with Valeo Wiper Systems. Components of the wiping systems have been periodically collected from the production lines and their dimensions have been measured. These results are then used to identify the distributions of the random variables associated with the geometry of the components. It is assumed that the model of uncertainty can be fully represented using the marginal distributions and the linear coefficient of correlation. For each random variable, several distributions are considered, and the most suitable one is select using the Akaike information criterion [1]. The performance of the wiping systems can be estimated using Finite Element (FE) simulations. The FE model is parameterized, which allows investigating the consequences of the shape imperfections. A meta-model is subsequently calibrated in order to reduce the numerical efforts. The formulation of the probabilistic model is similar to the one introduced in [2], the quantifiers for all and there exists are introduced and the problem is expressed using system reliability.

Keywords: Tolerance analysis, System reliability, Meta-model, Wiping system.

Session	[WE1E]—Organizational Factors and Safety Culture
Day/Date/Time	Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue	Amphi Jardin

WE1E: 092 **08:30 hrs**

Preconditions for Learning from Fires in Norway – Structural, Cultural, Technological, Interactional and Relational Aspects

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Learning from incidents is widely accepted as a core part of safety management. This is also true for fires – however few fires in Norway are investigated. Fires are interesting incidents conceptually due to their potential of devastating outcomes on material and human lives and because they happen across all sectors and industries, businesses, and homes. In Norway, several different actors play a role in investigating and learning from fires, from the fire rescue services to directorates and Non-Governmental Organisations. The present study seeks to understand the preconditions for learning from fires in Norway, with emphasis on the formal actors that play a role in preventing and mitigating fires. Methodologically, the study is based on qualitative interviews conducted with relevant actors from first responders, authorities, and other sectors. We found that

there are structural, cultural, technological, and relational aspects that seem to influence learning from fires in Norway. The results were analyzed using thematic analysis and the Pentagon model framework. The findings are discussed in relation to theories from organisational learning and learning from incidents.

Keywords: Organisational learning, Fire safety, Fire and rescue services, Pentagon model.

WE1E: 159 08:50 hrs

Innovative Road Safety Education Program

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The Norwegian Council for road safety, Trygg Trafikk with SINTEF and Nord University developed a new road safety education program based on the last findings in Neuro-Education. Whereas traffic rules are essential and part of the school road safety education program, learning how to properly use attention in complex traffic situations was never taught before. This paper presents the method developed for stimulating schoolchildren' reflection on traffic safety issues and three concepts: risk, orientation, and attention. SINTEF compared the new education program with the one currently in place in Norway at its Virtual Reality laboratory. The program was evaluated with two groups of 5th grade pupils. A bicycle simulator and a Head Mounted Display (HMD) with an integrated Tobii eye tracking system, were connected to the Virtual Reality. The virtual environment was identical to the traffic center facility (a miniature traffic system with intersections. Traffic lights and signs) used for the school road safety education program. The results showed that the experiment group who participated in the new education program orientated themselves and used their attention better than their counterparts in the control group who followed the traditional program.

Keywords: Road safety, Neuroeducation, Schoolchildren, Cyclist, Virtual reality, Eye tracking system.

WE1E: 284 09:10 hrs

Security of Electricity Supply in the Transition Toward Smarter Grids

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The paper presents the results of an exploratory study of the way digital transformation processes can involve challenges for the security of electricity supply. The case for the study was the development of digital substations in a European electricity grid operator. By means of a sociotechnical approach, we studied digitalization as a process, focusing on transition risks related to the process itself. Six categories of challenges are described: 1) The role of risk assessment and risk management in procurement processes, 2) issues related to language, culture and competence, 3) the management of emergencies and crisis situations, 4) technological aspects of redundancy and oversight, 5) formal organization and responsibility, and 6) changes in regulation, regulatory roles and threat landscape. Common themes cutting across the six categories are discussed and the paper is concluded with a delineation of strategies that can serve to mitigate the risks involved.

Keywords: Security of electricity supply, Sociotechnical systems, Organizational factors, Risk governance, Societal security.

WE1E: 288 09:30 hrs

Prevention and Management of Industrial Risk Through Effective Citizen-Facing Communication from Authorities: The Experience of Regione Lombardia in Italy

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The paper presents the experience of Regione Lombardia in Italy in promoting at regional level the activity of industrial risk communication from Authorities to citizens. After an

overview and a territorial analysis of the region carried out with GIS tools, the adopted approach is described: i) the organization of technical meetings with the municipalities of Regione Lombardia to collect best practices of risk communication, ii) the preparation of a survey for the knowledge of the state of implementation of communication tools in Regione Lombardia and for highlight the most suitable tool on which provide support by Regione Lombardia, iii) the development of an industrial risk communication tool represented by a brochure that can be filled and customized by different municipalities.

Keywords: Risk management, Safety culture, Risk communication, Societal risk, Dangerous goods industry, Emergency plan, Public engagement, Major accident Hazard, Major Hazard installation.

WE1E: 295 **09:50 hrs**

Getting Realism Into a Participative Framework for Operational Risk Analysis

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The risk analysis is a systematic use of available information to identify hazards (potential sources of harm) and to estimate the risk (probability of occurrence and severity of the harms). Based on the risk analysis, the risk evaluation is used to determine whether the tolerable risk is achieved. The resulting risk assessment is a fundamental step for managing risk with the appropriate protective measures in order to obtain safety (freedom from unacceptable risk). It is suitable to make a risk analysis in an early phase of a project for anticipating the management and reducing both risks and costs. However, the risk analysis should also be updated once a feedback is observed. The reality of the operations may differ significantly from the procedures in mind during the design phase. It is therefore also very important to make a risk analysis during the operational phase. The main challenge is then to get the reality of the operations.

To get realism into the operational risk analysis, a framework has been developed in order to stimulate the participation of the operators. The guideline consists in creating a discussion forum suitable for: providing detailed explanations on the actual sequences of operations; discussing on the different practices; identifying the "weaknesses" and "strengths"; proposing "good practices" to integrate into the procedures and the trainings. The proposed framework includes several workshops under specific stimulating conditions, allowing to draft dedicated risk analysis sheets while avoiding tedious exercises and cognitive biases.

The participative framework has been applied to the drilling in-charge operations on the pipelines of the main high-pressure natural gas network in Europe. About twenty proposals have emerged from this operational risk analysis, in terms of: competences and professionalism (minimal practice), tools and procurement (standard, verification), risk and guidelines (realism of the rules, risk reduction measures), operation management (validation procedures), and feedback (traceability, trainings). Additional concepts have been also proposed, such as the safety criteria (acceptable risk level in operation), the yellow lines (rules that can be derogated under conditions) and the red lines (inescapable rules, i.e. compulsory). Several updates of the guidelines have then been performed thanks to this approach, reducing the actual operational risks under realistic conditions.

Keywords: Operational risks, Risk analysis, Risk assessment, Risk management, Occupational safety, Human and organizational factors, Gas network, Gas pipeline.

Session	[WE1F]—Civil Engineering
Day/Date/Time	Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue	Espace Grand Angle

WE1F: 010 **08:30 hrs**

Probabilistic Determination of the Phreatic Line in River Levees Under Steady-State Conditions and Its Effect on the Stability Statement

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Seepage is a sub-process of high relevance for a stability statement, because the phreatic line separates the cross-section into the watersaturated and the unsaturated cross-sectional part. In stationary cases, the phreatic line is imprinted into homogeneous systems by the outer cubature. In transient cases and the analysis of structured designs, its position depends on the material's saturated permeability. However, the saturated permeability is a spatially scattering and therefore uncertain quantity which should be considered as such.

This paper presents a methodology to incorporate the phreatic lines probabilistically in river levee cross sections and applies to standard designs. Using input distributions, the position of the seepage line is analytically determined as an uncertain quantity. By means of a Monte-Carlo simu-

lation it is then evaluated in the form of undercutting probabilities of discrete phreatic lines. Subsequently, the effect of uncertain phreatic lines on the stability of levees is illustrated by the results of a reliability analysis. The results show a variability in the stability statement which is quantified by the failure probability.

In the end, not only the input distributions of the saturated permeability are decisive for the quality of the results, but also the distributions of further soil mechanical parameters. Therefore, it is recommended to summarize experiences with soil mechanical parameters in an (inter)national database to feed probabilistic parameter studies.

Keywords: Probabilistic analysis, River levees, Seepage, Permeability, Soil parameters, Reliability, Probability of failure.

WE1F: 160 **08:50 hrs**

Fire in Railway Tunnels Dynamic Simulation: Structural Assessment and Effects Mitigation

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Fire safety in tunnels is a key issue for railway safety. Various approaches are usable to assess the concerned risks and to assess how to manage them. Large-scale experiments are not economically affordable to recreate a significant variety of configurations, reason why Computational Fluid Dynamic (CFD) is nowadays the prevalent method to address such topics. This paper discusses the simulation of a very typical fire-scenario for lines with relevant freight traffic carried out with the Fire Dynamics Simulator (FDS). The scenario includes a 150 MW fire caused by an accidental spillage of liquid octane from a tanker inside an artificial railway tunnel. The main goal is to study how the geometric peculiarities of the tunnel can significantly influence the temperature field within the tunnel, to an extent that is not easy to predict through simplified conventional methods. The applied method bases on a sensitivity analysis on obtained results to the variation of specific parameters. The structural checks performed in this scenario show that prolonged exposure to fire plays a key role in reducing the load bearing capacity of the system. This result is more relevant for the structural elements inherently sensitive to spalling phenomena, triggered by high temperatures (e.g. beams or columns characterized by low concrete cover).

These elements need appropriate mitigation measures to prevent the onset of spalling phenomena. In particular, the case study shows how the installation of insulating plaster is able to protect the pre-stressed concrete roof beams and to safeguard the required safety level for the structure.

Keywords: CFD Modelling, FDS, Fire simulation, Railway tunnel, Fire safety, HRRPA, Thermocouple, Spalling, Insulating plaster, Damage mitigation, Structural thermal analysis.

WE1F: 242 **09:10 hrs**

The Importance of Implementing Buliding Information Modeling, Risk Analysis and its Impacts on a Real Estate Development: A Case Study

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This study aims to show the importance of developing and making compatible complementary projects using BIM (Building Information Modeling) and to analyze the risks on the costs and schedule during the execution of a real estate development. The study also shows that advanced response to risks improves performance, increases assertiveness in the work, minimize waste of material, rework and unnecessary wear and tear. Construction work is complex, teams from various disciplines are involved, and a compatibility of projects is necessary to minimize execution errors and risks during the construction. The performance of a real estate project is affected by the lack of compatibility of complementary projects using the BIM (Building Information Modeling) methodology, generating conflicts between the disciplines, rework, cost, and time overflows. As a methodological approach, an in-depth literature review and a case study was conducted. The first step in the case study was to map out the whole construction process, then analyse the risks present in each step. The probability of existing risks at each stage was combined using Bayesian Belief Networks (BBN) and the impact were analyzed Analytic Hierarchy Process (AHP). This study is a source of information for professionals and companies planning to invest in BIM as support for decision making and shows the benefits in the practice.

Keywords: Building information modelling, Risk assessment, Analytic hierarchy process, Bayesian belief networks.

WE1F: 249 **09:30 hrs**

A Stochastic Simulation Scheme for the Estimation of Small Failure Probabilities in Wind Engineering Applications

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To ensure the feasibility of performance-based wind engineering (PBWE) frameworks, particularly when it involves computationally expensive nonlinear dynamic analyses and estimation of small failure probabilities, there is a need for efficient stochastic simulation schemes. To this end, an optimal stratified sampling-based Monte Carlo simulation (OSMCS) scheme is proposed to simultaneously estimate failure probabilities associated with multiple limit states including those which are implicitly defined. The scheme is based on the optimal allocation of Monte Carlo simulation (MCS) samples among the strata which are partitions of the uncertain parameter space, defined using one or more input random variables. The partitions enable simulation of rare events and the optimality guarantees minimum estimator variance for a target failure probability. The optimality criterion is derived and some theoretical aspects of the OSMCS estimator are discussed. To demonstrate the applicability and efficiency of the scheme a case study is presented and the implementation issues are also critically discussed.

Keywords: Structural safety, Monte Carlo methods, Wind engineering, Stratified sampling, Variance reduction, Nonlinear modeling.

WE1F: 255 **09:50 hrs**

The Importance of Maintaining the Brazilian Habitat Quality and Productivity Program (PBQP-H), Risk Analysis and the Impact on the Maintenance of Civil Construction Companies Certification. A Case Study

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Brazilian Federal Government created the Brazilian Habitat Quality and Productivity Program (PBQP-H), with the aim of organizing the construction sector around two main elements: habitat quality improvement and productive modernization. The program provides alignment of management requirements to the requirements and concepts of ISO 9001:2015 and the compliance with the program is now required in all construction works, not only in the works of buildings. This study discusses the importance of meeting quality requirements in construction work and the challenge of maintaining the PBQP-H certification. The study also shows the critical risk factors in meeting the requirements, maintaining the certification and if it is worth keeping it in a construction company. As a methodological approach an indepth literature review was made to obtain the critical factors in the compliance with quality requirements used on construction work all over the world. The critical factors obtained in the literature supported the case study, which was conducted in a specific company that adopted the program. The performance of the construction company against the requirements of PBQP-H was evaluated by a quality audit and based on the quality audit result and the information obtained in the literature review the critical factors were listed and the respective actions proposed. Such program brings a positive standardization of the quality requirements in construction companies. As a result of the study, some of the critical factors identified are the lack of inspections on the materials used; material not stored correctly in accordance with the manufacturers and technical standards; services not undergoing checks based on standard procedures and based on technical standards and PBQP-H requirements. The study is important for several reasons. First, risk assessment is gaining importance in all fields and the evaluation of risk factors in meeting PBQP-H has not been reported yet. The study succeeded in identifying the critical risk factors in maintaining a certification and the required responses. Second, the paper shows that the risk factors identified in this study must be controlled to avoid waste and unnecessary costs and preventive actions can be planned to minimize the downtime of the construction work and delays. As a conclusion, maintaining the certification and compliance is a challenge for construction companies all over the world. However, when the risk factors are known and risk responses correctly incorporated in the company's daily routine, they bring significant improvements and waste /cost avoidance. This study is important for engineers, professionals and companies working in construction field.

Keywords: Quality management system, Quality, Quality system certification, Construction sector, pbqp-h, Civil engineering.

Session [WE1G]—Asset management
Day/Date/Time Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue Atrium 3

WE1G: 127 **08:30 hrs**

An Integrated Functional Modelling Framework Applied for Operations and Maintenance

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Safe operations and adequate maintenance are two main means to achieve reliable production and reduce downtime of a plant. In a good manner, operations are the customer of maintenance, and maintenance is the service provider. However, in reality, the tasks of operations and maintenance are carried out by two different groups so that the close relationship between the two tasks is split.

In this paper, this challenge is handled by a proposed integrated functional modelling framework. In this framework, the Multilevel Flow Modelling (MFM) method with its cause-consequence reasoning rules is used. The qualitative relationship distribution between operations and maintenance can be established by using a distributed qualitative evaluation method based on the function states of the system. In addition, these relationships are visible for both groups and utilize the detected information in the early stage of the development of the unpleasant scenarios to improve the situation awareness, and prevent the undesired emergency shutdown from both perspectives of operations and maintenance. Consequently, it can reduce production loss.

A case study of operations and maintenance of a seawater injection system is carried out and shows the industrial applicability of the proposed framework. The case study strongly reveals that there is a highly close relation between operation and maintenance for ensuring the system working properly. It demonstrates that the proposed integrated framework is not only able to support operational tasks but also for the maintenance tasks by including relevant maintenance information of the system. The results show that it can potentially help with decreasing downtime of the system.

Keywords: Maintenance, Operation, Safety, Functional modelling, Decision-making, Process systems.

WE1G: 225 **08:50 hrs**

A Look at the Influence of Hydraulic Power Generator Operation on Hydraulic Passages

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A Hydraulic Power Generator unit can be designed to provide base load or to be used in peaking mode. Operation in peaking mode is more demanding and will influence not only the Generator and turbine but also the Hydraulic Passages. A unit operating in peaking mode but not designed for it might need supplementary maintenance that will influence both its profitability and the portfolio business case. For an existing unit designed for base load but submitted to peaking mode, the impact of increased maintenance costs on the project profit and production price was studied. The techno-economic analysis reveals that there is a critical point beyond which the supplementary load generated will make operation in peaking mode unprofitable. The results indicate that to build a profitable portfolio, it is crucial to make an informed decision concerning the supplementary load imposed on a Hydraulic Power Generator.

Keywords: Peaking, Balancing, Critical point, Renewable, Hydraulic passages, Maintenance costs, Profitability.

WE1G: 340 **09:10 hrs**

Comprehensive Method for Improving Asset Integrity Management

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Asset Integrity Management (AIM) plays a significant role in keeping complex ageing assets, such as oil and gas plants, power stations, manufacturing plants operating safely and productively. Many assets are now in a critical stage of life and new approaches to monitor and improve assets' performance are required. We present a systematic monitoring method for improved efficiency and effectiveness of the plants' assets; through a comprehensive data analysis based on 12 factors related to 5 underlying pillars as illustrated in Figure 1. These pillars and factors have been identified from an extensive review of academic literature and organizations' publications which focus on AIM programs. We

integrate the pillars within one monitoring model such that asset owners can measure AIM performance through key performance indicators (KPI) and identify pitfalls/gaps in each pillar for improvement and enhancement opportunities. The core idea is integrating all AIM's pillars in one method and measuring the performance as one indicator, as well as each individual pillar's performance. To measure each pillar performance, its each element's performance has to be computed first. We propose using a Multi Attribute Value Analysis (MAVA) approach to scoring and weighting the individual pillars and overall performance. We propose that the method is regularly applied to ageing assets to identify weaknesses early. We expect that asset owners or operators will oversee the proposed approach in order to gain a bigger picture view of the asset performance, identify poor performers and develop a remedy to close gaps before getting poorest. which can draw more attention to improve assets from several aspects.

Keywords: AIM, MCDA, Asset integrity management, KPI, Key performance indicator, Equipment lifecycle, preventive maintenance, MAVA, Attribute value analysis.

WE1G: 342 **09:30 hrs**

Techniques for Assets' Criticality Judgement

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Critical infrastructure is composed of systems of various natures (technical, organizational, cybernetical, social, etc.). The critical infrastructure is important for human security, the economics and functionality of cities and States, especially under emergency and critical conditions. Its integral safety is predetermined not only by criticality of its assets but also by criticality of its interdependences. The subject of research is safety of Praha metro. The metro critical assets were determined by expert judgement of disaster scenarios in the first part of the research. In further part, which is the object of this paper, it is determined their criticality by application of the Sensitivity theory. For presentation of cited theory results and their judgement the Graph theory is used. The target of this research was to improve integral safety by decreasing the criticality, which is connected with interfaces that are uncomfortable and originated at special conditions induced by beyond design disasters. The paper shows the supplement of critical assets from the domain of both interfaces, required and unrequired that occurring at conditions induced by beyond design conditions and proposal of measures for metro safety improvement.

Keywords: Critical infrastructure, System of systems, Interdependences, Risk management, Criticality, Safety, Integral safety, Security, Sensitivity theory, Graph theory.

WE1G: 344 **09:50 hrs**

Applying Cluster Analysis to Support Failure Management Policy Selection in Asset Management: A Hydropower Plant Case Study

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Maximizing the realization of value from physical assets through asset management is a contemporary approach to support the achievement of organizational goals. As consequence, organizations have placed maintenance as a strategic function to deliver business outcomes. The development of appropriate failure management policies for failure prevention is essential but also a challenge for maintenance planning. In this context, this paper proposes a method to support the failure management policy selection in asset management based on the exploratory cluster analysis technique. The proposed method comprised three sections: acquisition of the physical asset performance data, cluster analysis, and selection of the failure management policies. Criticality aspects supported the definition of the criteria and scales for evaluating the performance of physical assets and the composition of the dataset. Then, the distance measure and agglomeration schedule were defined for the application of the cluster analysis. From the set of formed clusters of physical assets, it was assigned an overall failure management policy to each cluster based on their internal homogeneity assessment and the context of the organization. The proposed method is demonstrated through a case study in a maintenance management context of a Brazilian hydroelectric power plant. The results obtained show that the method can support organizations in the selection of appropriate failure management policies according to determined groups of physical assets.

Keywords: Asset management, Maintenance, Failure management, Cluster analysis, Machine learning, Hydropower plant.

Session [WE1H]—Case Studies on Predictive Reliability: an Industrial Perspective
Day/Date/Time Wednesday, 22 Sep. 2021 / 08:30–10:10 hrs
Venue Cointreau

WE1H: 226 08:30 hrs

Fail-Aware Concept for Autonomous Driving Cars

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Condition monitoring is getting increased attention in the automotive industry. Especially the development of autonomous driving cars requires information about the health status of a vehicle. Not a driver but the car itself has to react on a fault autonomously. Cars have to be built in a way that they are fail-safe, fail-operational, and fail-aware. This affects their architectures, the modules and subsystems used, and the semiconductors that are selected.

The idea of the fail-aware concept is to detect degeneration of a device and act before a failure occurs. This turns a potential failure into a maintenance action. Fail-aware reflects the health status of a device and is part of a prognostics and health management (PHM) system.

In order to detect drift of electrical parameters of semiconductor devices, we use data from stress tests, like the high temperature operating life test[1] (HTOL). At the HTOL test devices are electrically tested, then put to stress, tested again, and put to stress again. This is repeated until the required stress time is completed. We use the data from these electrical tests and correct them for tester offsets and for the measurement uncertainty[2]. The drift is calculated for each device individually. We model the drift itself as a normally distributed random variable. In that way we are able to calculate the likelihood of a device to drift outside the specification limits during operation and the remaining useful life (RUL).

As a example, an angle sensor may show some drift. This drift can be tracked in the autonomous driving car and the RUL can be calculated. On higher system levels data driven tools are used, like the weakness monitor[3]. Such health status information can be made available via the onboard diagnostics system of an autonomous driving vehicle.

Keywords: Condition monitoring, Fail-aware, Lifetime drift, Prognostics and health management, Remaining useful life, Semiconductors.

WE1H: 538 08:50 hrs

Probabilistic Fatigue and Reliability Simulation

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The fatigue design of mechanical systems has historically followed a ‘deterministic’ process, therefore for a given set of inputs it will return a consistent set of fatigue life results with no scatter. In practice, the designer applies a safety factor to each input parameter to account for the uncertainty. In comparison, a ‘Probabilistic Fatigue Simulation’ method is ‘stochastic’ in nature.

The inputs parameters are expressed as an expected average and its scatter, according to a give a probability distribution. This design process helps to avoid poor in-service reliability whilst reducing over-design. This paper address in detail the three stages of Probabilistic Fatigue and Reliability Simulation:

(1) Uncertainty Quantification (UQ) of input parameters
(2) Stochastic fatigue simulation of individual components
(3) Reliability simulation of the entire system

In order to take advantage of Probabilistic Fatigue Simulation, uncertainties in the input and in the analytical model must be properly calculated. Two types of input uncertainties are considered:

(1) Reducible uncertainties (or epistemic uncertainties)
(2) Irreducible uncertainties (or aleatoric uncertainties)

Stochastic simulations are performed using the ‘Monte Carlo’ method. A statistical sampling technique known as ‘Design of Experiments (DOE)’ is discussed for optimizing the size of the design space matrix. Two broad areas are explored: i) the extremities of design space and ii) the statistical variability of design space. Reliability analysis of the simulated failures is performed using a Weibull analysis. A case study will demonstrate how reliability analysis is used to:

(1) Optimize the design to achieve the target reliability
(2) Identify potential cost savings by identifying the most influential uncertainties
(3) Provide an optimized maintenance schedule

The objective of the industrial case study is to assess the existence of a location parameter as “minimum resistance threshold”. Indeed, a minimum resistance threshold would represent the minimum value of the in-service duration before any fatigue failure can appear. The consideration of such threshold would be very convenient in case of exten-

sion of the warranty period, because below the threshold no wear out fatigue failures would be expected, therefore a longer warranty can be contemplated. Moreover, the predictions performed according to this stochastic model would help the control of the manufacturing process: by considering the change of the uncertainty parameters (thickness, material, etc. . .) it would be possible to predict any production shift influencing the "minimum threshold resistance" of the product.

Keywords: Fatigue, Reliability, Uncertainty Quantification (UQ), Probabilistic design, Design Of Experiments (DOE), Weibull analysis.

WE1H: 708 **09:10 hrs**

Outliers Detection at the Lower Tail of A Small Statistical Sample Originated from Test Results of Strength

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In the automotive sector the stress-strength interference approach is commonly used to ensure the reliability of the components during the design validation. In this framework, during the development process, only a limited number of prototypes are tested to estimate their minimum resistance threshold. In order to meet ever-increasing technical and economical requirements (cost and timing), destructive tests are carried out on the smallest number as possible prototypes units, which are assumed to be representative of the overall serial population. The minimum resistance threshold is estimated as a random variable resulting from experimental sampling. Its mean value and the coefficient of variation are affected both by the small number of devices tested (3 ¡N¡10) and by the possible appearance of values considered abnormal (outliers). Indeed premature failures may occur as the result of the not yet optimized manufacturing process. Under these conditions, a classical statistical treatment of the results encounters serious limitations, because any outlier within the small sample size must first be detected. Then, the further reduction of the samples available for such analysis must be considered. We have therefore developed a specific methodology, based on order statistics, for the treatment and elimination of these outliers. Because of the statistically low sample size, its interpolation according to a particular distribution would be affected by a significant level of uncertainty. For this reason, a bounded distribution of maximum entropy has been chosen as a prior assumption that can reasonably justify the dataset distribution. As for the statistical criteria usually applied for outliers detection (statistical tests for a chosen confidence level), they are not appropriate because the datasets are fitted according to the normal distribution an assumption which is not suitable in this particular context. We have overcome this difficulty by replacing the classical approach with one based on the sequential combination of two deterministic criteria, which leads to a simpler decision-making process and reduces the zone of ambiguity. Several examples of the method are presented , both in the technical domain (ie. rupturing tests of mechanical devices) and in the biological domain (ie. survival data of living beings).

Keywords: Stress-Strength Method, Resistance Distribution, Statistical Sample, Discrete Distribution, Order Statistics, Outliers Values, Detection Process, Analytical Approach, Ball Bearings.

WE1H: 711 **09:30 hrs**

Faster and More Accurate Industrial Relibility Predications from Data Mining Using AI Methods

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Contributions to 31th European Safety and Reliability Conference, Angers, France, 19 – 23 September 2021 are to be in American English.

The predictive reliability estimation of industrial components is a key for many projects into an accelerated and quicker industrial process. The main goal of this presentation is to show by real examples how data mining strategy can support, improve and accelerate this predictive reliability approach. Agility of such approach will be demonstrated through new and complementary competences needed for implementing such modern techniques. Data mining is the process of generating insights in large data sets involving methods at the intersection of data science (meaning artificial intelligence), statistics, and database systems. This trend has become unavoidable and touchable tendency in the framework of big data and Artificial Intelligence. The presentation will highlight several examples of use cases in the automotive industry dealing with data mining and predictive reliability. Machine Learning or Deep Learning algorithms or models will be used in order to manage high volume of data in short time. Natural Language Processing can be used in order to extract knowledge from unstructured database. It means that even a weird or complex document or record can become an asset and will contribute to predictive reliability assessment. By the way, the presentation will show how these complex and mathematical approaches can be shared within a worldwide company and distributed to

all contributors to project development. The way to make such approach popular and "easy to use" has a wide contribution to such deployment and success.

Keywords: Data Mining, Art ificial Intelligence, Machine learning, Reliability.

WE1H: 741 **09:50 hrs**

Stratégie Et Analyses : Comment Anticiper L'augmentation de La Durée Des Périodes Garantie?

Caroline Ramus[1] and Lavanya Bonvin[2]

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Garantir la durabilité des composants d'un système est une activité stratégique pour les entreprises des secteurs industriels clés, comme celui des transports. Les enjeux sont doubles : impact économique et image de marque. En effet, un manque de maîtrise de la fiabilité d'un produit peut entraîner des coûts importants.

Session	[WE1I]—Electromagnetic Risk Management
Day/Date/Time	Wednesday, 22 Sep. 2021 / 08:30–10:10 hrs
Venue	Giffard

WE1I: 154 **08:30 hrs**

A State-of-the-Art Review on IC EMC Reliability

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Electromagnetic compatibility (EMC) of integrated circuits (IC) should be within the desirable level for maintaining the functional safety and reliability of electronic systems in different complex automotive and aeronautical applications. Throughout the operational lifetime of ICs, harsh environmental conditions including extreme high or low temperature, humidity, shock, and stress tend to cause intrinsic physical degradations, which results in significant variations of long-life EMC performance of IC device. Consequently, ensuring along with maintaining electromagnetic robustness (EMR) and integrating IC reliability throughout their whole lifetime period is a key challenge that needs to be addressed. The purpose of this paper is to conduct a comprehensive state-of-the-art study on developing accurate immunity and emission models of ICs focusing on quantitative evaluation of experimental characterization based on various IC EMC measurement methods under various ageing accelerated life tests. Producing accurate transient EMC models help not only estimate EMC immunity and emission levels of ICs but also allows determining different failure types and mechanisms due to radio frequency disturbance when applied to IC model structures. This paper presents a few recent researches on the conducted pulse immunity as well as emission models for ICs based on the IEC standard models, showcasing the electric fast transient (EFT) simulations and measurements applied on different IC pins considering the ageing impact. Previous studies demonstrated the importance of the ageing on the EMC performance of ICs depending on the ageing stress parameters. Future perspective of the current study would involve proposing and implementing predictive reliability model for the IC during its entire lifetime under accelerated life tests.

Keywords: EMC, Electromagnetic robustness, Reliability, Integrated circuits, Conducted immunity and emission model, EFT.

WE1I: 428 **08:50 hrs**

Peter – A Pan-European Training, Research and Education Network on Electromagnetic Risk Management

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Sophisticated electronic technologies are increasingly used in mission- and safety-critical systems where electromagnetic interference (EMI) can result in substantial risks to people and the environment. Currently, EMI engineering follows a rule-based approach, which is unable to cope with complex modern situations. With this rule-based approach, during the design stage, guidelines are used, which result in the application of a set of mitigation techniques, which are verified in the finished product against standards. This rule-based approach is costly, but with no guarantee of the required performance. This is particularly so for sensitive medical applications or the fully autonomous systems that are becoming ever-more common in our society. What we need is a risk-based approach, which is what PETER[1], the Pan-European Training, Research & Education Network on Electromagnetic Risk Management, will provide. PETER is training 15 young engineers in topics related to the development of high-tech systems that maintain reliability and safety over their full life-cycle, despite complex EMI, such as in hospitals or transport systems. This is achieved using best practices and state-of-the-art EM engineering, reliability engineering, functional safety, risk management and system engineering, to create the risk-based EMC approach.

Keywords: Electromagnetic interference, Electromagnetic disturbances, Functional safety, Risk management, Electromagnetic resilience, Risk-based approach.

WE1I: 263 **09:10 hrs**

Assuring Shielded Cables as EMI Mitigation in Automotive ADAS

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Shielded cables are an important mitigation for electromagnetic interference (EMI) in high-speed data systems. In the automotive domain, one use for them is to transmit image data from a front camera to an advanced driver assistance system (ADAS) controller. Some ADAS functions have implication for human safety and thus place extra requirements for the design of the transmission path including its resilience to EMI.

This paper presents a case study of an automated lane centering (ALC) system with the above-mentioned shielded cable use case. The study starts from a National Highway Traffic Safety Administration (NHTSA) concept level assessment. Subsystem components are then separated and a physical realization derived. Goal Structuring Notation (GSN) is used to present EMI assurance scenarios over the safety requirements. First, the ability of a shielded cable reliability argument to cover the derived safety requirements during different operating scenarios is studied. It is found that relying on reliability alone, it is challenging to fulfil all the safety requirements. To overcome this challenge, an alternative systems safety based method is studied.

Keywords: EMI, Shielded cable, Functional safety, Automotive, Lane centering system, ADAS.

WE1I: 203 **09:30 hrs**

Knowledge-Based Approach for System Level Electromagnetic Safety Analysis

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Road vehicles and similarly complex systems are constructed by integrating many subsystems and components that are sourced from a large number of suppliers. This process may lead to the emergence of possible system-level safety issues, some of which could be caused by external or internal electromagnetic interference. Demonstrating compliance with standard tests is not sufficient for safety assurance in complex systems. Hence, there is a need for additional methods to help estimate the likelihood of electromagnetic interference risks associated with such systems. Probabilistic graphical models, such as Bayesian and Markov networks, are able to provide a better visualization of various features and their relationships in a single graphical structure. Moreover, using template models, a generalpurpose representation for various integrated components of a system can be developed for collective inference. Using such methods, this paper proposes a knowledge-based approach to assist risk management in system-level electromagnetic engineering. The purpose of using a knowledge-based approach is to be able to undertake safety risk analyses during the early stages of design, when many factors (e.g. internal, and external electromagnetic interference levels, physical location of the component) remain uncertain.

Keywords: Safety, Bayesian networks, Risk analysis, Template models, Knowledge-based methods, EMC.

WE1I: 701 **09:50 hrs**

Evaluation of EMI Risks

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The Electromagnetic Interference (EMI) Risk is defined as a possible EMI scenario with the possibility that an EMI event causes an effect which has a negative consequence on the functional safety and/or the main functionality of an electronic system. The main task of risk assessment is to classify identified risks (including their impact and probabilities of occurrence) in: (1) risks that can be tolerated and do not require risk mitigation, (2) significant risk which cannot be taken easily and therefore require further analysis and tailored mitigation measures and (3) risks that are not tolerable and must be subjected to risk mitigation (avoidance, mitigation,. . .). In addition, the risk assessment should provide the basis for prioritizing necessary risk management measures.

Regarding the nature of EMI risks they are usually evaluated by the three risk indicators: (1) extent of the impact or severity of the caused consequences, (2) probability of occurrence and (3) chance of detection. Due to the lack of historical experience with deliberately induced electromagnetic influences in the case of EMI risk analysis, the probability of occurrence of the considered hazards (EMI environments) can only be limited or not quantified at all in the form of a decidedly determined percentage number. In most cases it is therefore more practicable to indicate the probability of occurrence employing probability categories. These are the result of subjective evaluation by experts and are less suitable for pure product format ion. In many cases it is difficult to express the caused damage of and the negative impact on the main functionality in a monetary value. Thus, the monetary value does not always reflect the severity of the damage. Therefore, the severity of EMI caused consequences is evaluated using severity categories ranging from undisturbed over severe (reduced efficiency) to catastrophic (loss of system).

This contribution explains how an EMI risk that is characterized by the three risk indicators can be mapped to five risk categories by the risk cube method and the risk graph method. The application of those evaluation methods on EMI risks as well as the discussion of their strength and limitations results into the recommendation that the risk graph method is best suited for evaluating EMI risks.

Keywords: Electromagnetic Interference (EMI), Risk evaluation, Risk matrix, Risk graph, Risk priority index.

Session	[WE1J]—Advancements in Resilience Engineering of Critical Infrastructures
Day/Date/Time	Wednesday, 22 Sep. 2021/08:30–10:10 hrs
Venue	Botanique 2

WE1J: 056 **08:30 hrs**

Evaluation of the Resilience of the Baltic Power System When Operating in Island Mode

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The power system of Baltic States is undergoing a radical transformation. An intention to achieve a substantially higher share for renewable energy sources, going along with displacement of traditional generation sources that no longer conform to environmental requirements, will lead to a major structural changes of the power grid. These changes will take place simultaneously with desynchronization of the Baltic power grid from the Unified Power System of Russia and synchronization with the European Network of Transmission System Operators power system. It is expected that existing and future planned transformations may pose additional challenges to system operation, particularly, when system is exposed to extreme events. In this paper we evaluate an effect, the future planned configuration of the Baltic power grid has on system resilience. A practical method of evaluation of the system resilience when transiting from undisturbed state to a degraded one presented in the paper.

Keywords: Resilience, Power grid, Natural gas grid, Frequency response, Synchronous condenser.

WE1J: 115 **08:50 hrs**

Comparative Evaluation of the Reliability and Vulnerability of Electrical Networks with a High Share of Renewable Generation

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The uncertainties associated with renewable energies can have a significant impact on the security of power systems. To address this problem, this article studies the effect of renewable sources on the reliability and vulnerability of systems with a high share of renewable generation and compares the results obtained with those measured in electrical grids mainly composed of thermal power plants. This comparison aims to quantify the influence of renewable generation on the performance and operational behavior of infrastructure under severe contingencies. Both reliability and vulnerability are assessed in parallel in two case studies: one based on the IEEE RTS-96 test system with thermal generation and the other on the IEEE RTS-GMLC test system with a high share of renewable generation. Different reliability indices are calculated using the sequential Monte Carlo method, and a vulnerability index is measured using a cascading failure approach. The simulations show that the integrated system with renewables is less reliable and more vulnerable than its purely thermal counterpart. These conclusions highlight the importance of analyzing the operational security of infrastructure from both perspectives.

Keywords: Cascading failures, Critical infrastructures, Power systems, Reliability, Renewable energies, Robustness, Vulnerability.

WE1J: 143 **09:10 hrs**

Modeling Environment Dependency in Partially Observable Markov Decision Processes for Maintenance Optimization

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Partially Observable Markov Decision Processes (POMDPs) are studied in the maintenance literature because they can take uncertainty of information into account [1–4]. This uncertainty may, for instance, arise from imperfect information from a sensor placed on the equipment to be maintained. Examples of such system-sensor pairs are an engine with a temperature sensor, ball bearings with a vibration sensor or a heating, ventilation, and air conditioning (HVAC) system with a temperature sensor. Our research into environment dependent POMDPs is motivated by HVAC systems used in trains. Their functioning is crucial during hot summer months, as carriages with failed HVAC systems cannot be used during this period. Hence, from a resilience standpoint it is important that HVACs are maintained effectively to ensure mobility around the country. Failures of an HVAC system are obvious in the summer and winter when its functionality is needed to keep the temperature stable. However, failures also occur in the fall and spring, but these failures are not as obvious from the temperature read-outs as the failures in summer and winter. This setting can well be modeled as a POMDP since the temperature read-out does not give complete information on the current state of the system. We model the following three actions: an inspection with incomplete information, a perfect inspection, and a maintenance intervention. To this model, we add a Markovian environment, giving rise to a model in which environment dependent partial observations, degradation and costs are included. For this model we show that an environment dependent 4-region policy is optimal. In other words, adding the environment preserves most of the properties of the original model. This contributes to the literature, as the preservation of properties will also hold when adding an environment to other POMDP models. We further perform numerical experiments that lead to interesting insights.

Keywords: Condition-based maintenance, Incomplete information, Environment dependence, Markov decision process, Partial observability, Inspection planning.

WE1J: 170 **09:30 hrs**

Interactive Method of Knowledge Elicitation and Simulation: Heuristic-Based Restoration Planning of Water Supply Systems

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Water supply systems are considered critical infrastructure, and the effectiveness and efficiency of their post-disaster restoration vastly contribute to the resilience of society. Simulation-based optimization using the genetic algorithm (GA) and machine learning (ML) has been widely applied to optimize the restoration planning of such critical infrastructure. However, these methods face challenges of interpretation and explainability. A heuristicbased algorithm reflecting the empirical rules of experts in restoration planning is a promising alternative because the result can be explained and justified in terms of these rules. In addition, the compu-

tational cost is lower than that of the GA and ML, both of which require iterative simulations. However, it is not easy to precisely and comprehensively elicit such empirical rules. In addition, the result obtained by the algorithm does not necessarily ensure optimality and validity. To solve these problems, we designed a workshop to elicit knowledge from experts by comparing restoration plans created by experts, plans created by a heuristic-based algorithm prototype, and optimal plans obtained by a GA. In the workshop, the participants were first asked to create a restoration plan for a disaster scenario that contained the locations and specifications of damaged water pipes, as well as the geographic and demographic data of the target city. After the session, we revealed the performance evaluation of these restoration plans performed by the restoration process simulation developed in our previous study and asked the experts to discuss the results, particularly the differences in their plans. We recorded the observations expressed in the workshop and analyzed them to extract the empirical rules. This workshop was conducted thrice, and it was confirmed that the interactive approach was effective for knowledge elicitation. We also confirmed that the heuristics are dynamic and contextdependent. We observed that different rules were applied depending on the severity of the disaster scenarios and phase of recovery. Further, we confirmed that in many cases, the GA optimization was superior to the others within the tested scenario, but the difference was not significant. This suggested that quasi-optimality was assured in the heuristic-based algorithm.

Keywords: Water supply system, Restoration planning, Genetic algorithm, Heuristics, Knowledge elicitation.

WE1J: 239 **09:50 hrs**

Strengthening Resilience in Critical Infrastructure Systems: A Deep Learning Approach for Smart Early Warning of Critical States

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Systems of critical infrastructures are characterized by strong interdependencies and the developments of urban areas towards Smart Cities even increase the underlying complexity due to growing automation and interconnectedness. A system of highly cross-linked components is especially prone to systemic risks making concepts of resilience accordingly important. One way for being able to withstand in times of stress, maintain security of supply, and promote adaptive and anticipative capabilities, is to establish early warning capabilities. As cities are complex and rather chaotic socio-technical systems reigned by randomness, the caused parametric uncertainties challenge modeling approaches that are intended to support robust decision-making. Sophisticated methods based on artificial intelligence can play an essential role in this case, as they perform well on highly complex environments and large data set. To study resilience, the urban area is split into zones where the city's state is determined by the states of these zones and the state of a zone is characterized by the criticalities of infrastructures accommodated there. Considering criticality as an atomic building block for urban performance assessments, this paper proposes a zone-based state forecast methodology by applying deep convolutional neural networks for learning state evolution that is influenced by non-linear demand dynamics. Furthermore, a case study is presented that applies agent-based simulations and underlines the relevance of deep learning approaches for Smart City early warning systems.

Keywords: Smart crisis management, Resilience, Security of supply, Forecasting, Agent-based modeling, Performance metrics, Deep learning.

Session	[WE1K]—Occupational Safety
Day/Date/Time	Wednesday, 22 Sep. 2021 / 08:30–10:10 hrs
Venue	Atrium 1

WE1K: 346 **08:30 hrs**

A Scientific Approach to Get a GRIP on Practical Robot Safety

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This work provides insight into the scientific-ground work for the development of digital safety tools for human-robot interactions; GRIP - Guarding Robot Interaction Performance. GRIP is a digital safety management system under development for human-robot interactions (HRI) in an Industry 4.0 setting. GRIP draws knowledge from different sources to utilize practical, scientific and legal information in a single tool; Storybuilder, HRI-GRIP, and the Machine Directive. Storybuilder deals with the structured recording and analysis of occupational accidents. HRI-GRIP provides a structured ontology of relevant characteristics that affect the outcomes of HRI. The machine directive col-

lates all legal safety requirements for machines and working safely with machines Each of the parts provides a relevant viewpoint for robot-safety and together they provide the basis for a holistic analysis of safe working with robots. With this scientific framework GRIP can operate as a 360° diagnosis tool for the safety assessment of HRI applications on the work floor.

Keywords: HRI, Occupational safety, Robots, Machine directive, Storybuilder, Risk analysis.

WE1K: 393 **08:50 hrs**

A Review of Risk Control Regulations and Practices on BPA in the EU and China

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BPA is one of the most widely used chemical compounds in the world. However, it has reproductive toxicity and is similar to natural and synthetic estrogens, which may damage fertility. This paper introduces the main regulations dealing with risk management of BPA in EU and China, and compares the protection requirements of workers and users who may be exposed to BPA. It is found that for protecting workers, both EU and China have posed requirements for risk prevention, evaluation, control, notification, and health surveillance, and have stipulated the Occupational Exposure Limit of BPA. For protecting product users, controlling the content of BPA in materials in contact with food and thermal paper is the key requirement of EU regulations. China also restricts the use of BPA in materials in contact with food, but BPA exposure to people exposed to thermal paper is not given enough attention. Currently, the regulation of BPA risk control in the EU is more advanced than in China. The EU has more extensive restrictions and stricter control requirements. In contrast, China's control of BPA risks needs further development. Thanks to the International Joint Laboratory on for Risk Management and Sustainability, which created by INERIS and BJAST, the BMILP (belonging to BJAST) is learning experience and practices from INERIS to promote good practices and reduce people's exposure.

Keywords: BPA, Risk control, Occupational safety, Comparison between china and europe.

WE1K: 401 **09:10 hrs**

The Emergence of Netcentric Principles in Dutch Safety-Experts Networks During the Covid Crisis

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The paper reports how an investigation into the experiences of safety experts and -practitioners in the Covid crisis led to discussions about netcentric working systems. As experts struggled with a wide spectrum of counter-measures they became heavily dependent on personal, professional and digital networks. The information gathered from networks was combined with their personal training and experience to design local measures for combatting Covid. The method of working echoes an earlier observation that netcentric working methods are becoming the norm in Dutch expertise-networks. However, current networks are as yet not optimised for rapid information sharing and, it makes sense to consider more professional ways of utilizing networks. This work reports about the initial investigations and provides a conceptual design for a netcentric approach to in safety networks.

Keywords: Covid, Safety experts, Netcentric working, Conceptual architecture, Safety enterprise architectre.

WE1K: 578 **09:30 hrs**

Smart System for Worker Safety: Scenarios and Risk

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The introduction of IoT (Internet of Things) in work environments has the potential to revolutionise the industrial scenario. Among others, IoT technologies have the capability to innovate the customer experience, to improve the effectiveness and accuracy of the process, to identify in the early stages possible problems and/or defects, to enhance the efficiency and the sustainability of the activities. Moreover, IoT can dramatically improve the safety of workers, allowing to assess the psycho-physical state of the workers, the effectiveness and the correct use of the safety devices and the status of the environment, with the capability to

provide on-line and in the field assessment in order to improve the situational awareness. In this paper, we will illustrate the main uses of such technologies in the OSH framework providing a taxonomy in terms of purpose and typology of sensors (either worn or environmental), type of measurements collected and information processing. A specific attention will be posed on the privacy, since the risk of potential remote control of the worker is an aspect that can negatively impact on the adoption of these solutions. Moreover, we will carry out an analysis of the problems related to the use of smart systems at large in the safety framework. Specifically, the paper will analyse the negative consequences that can be induced in the consequence of the employee de-responsibilities and due to the systemic fragility introduced by the cyber security aspects. Finally, using a specific case study, we will provide some recommendations to design an effective and "safe" smart safety environment. In this way the paper provides an overview on the technological solutions that enable cutting-edge applications in the OSH framework.

Keywords: Smart environment, Privacy, OSH, Cyber risk, IIoT, Wearable devices.

WE1K: 614 **09:50 hrs**

The Use of Proporational (Flow) Control Valves in Operating Machines: Energy Efficiency and Safety

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Proportional flow control valves can control flow and they are sometimes pressure compensated and temperature compensated. Proportional valves are particularly suitable for applications where it is necessary to vary the output flow, both during the same process and moving from a process to another. The control of these valves can be obtained by many coils (solenoids), this allows a more accurate regulation of flow. Another advantage is that they allow various speeds achievable by changing the electrical signal without any additional hydraulic components. Proportional controls, used with their respective electronic controls, add a variety of machine cycles, operated at higher speeds, in conjunction with controlled start and stop. The regulation of acceleration and deceleration allows improved cycle times, production speeds of the machine and a stable flow is also obtained. These features make proportional valves particularly suitable also for the design of Industry 4.0 systems. Therefore, Inail and the University of Perugia have begun a research activity aimed at studying the main safety and energy efficiency aspects that must be considered in the utilization of proportional valves within hydraulic systems. In this paper relevant application of those components, first for lifting and operating machines and then for machinery tool sector, has been investigated. Main failure modes and safety issues are presented. The complete risk assessment necessary for possible application in the field of machinery will be carried out in future research activities.

Keywords: Control valves, Safety of machinery, Energy efficiency, Industry 4.0, Component reliability.

Session	[WE2A]—Risk Management
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Plenary Room

WE2A: 037 **10:25 hrs**

Multicriteria Risk Visualization Tools in Networks of Natural Gas Pipelines

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The expansion, maintenance, and optimization of pipeline systems that distribute natural gas are all essential to meet commercialization demands for various uses of natural gas. Therefore, these are some of the key-factors for this sector that must be attended in order to stimulate growth in investments and to enhance current activities. However, understanding how risk is managed in the decision context must be a focus of particular attention. Thus, recent studies involve multidimensional risk analysis, and this approach deals with physical and operational aspects of natural gas pipeline systems that can lead to accidents with potential for human, financial and environmental losses. In this context, a consistent decision-making process is needed to manage risks in this complex system, and the decision maker's perception of risk by applying decision models may contribute to prioritizing maintenance actions and improving resource allocation. Therefore, this paper seeks to contribute

to the decision-making processes by analyzing risk in natural gas pipelines, for which multidimensional risk visualization tools are explored. To this end, this paper uses a multicriteria model and applies it to a case study from the literature to assess risk and evaluate uncertainty aspects. In addition, potential contributions of this approach using a graphical visualization analysis are suggested. Finally, it is shown that categorizing risk in natural gas pipeline sections in different hazard scenarios by using graphics and visual information is the main innovative feature this paper introduces to aid the decision-maker reach a more assertive recommendation.

Keywords: Multicriteria, Natural gas pipelines, Multidimensional risk analysis, Risk visualization, Graphical information, Decision-making.

WE2A: 072 **10:45 hrs**

Risk Register Database to Improve Organizational Resilience and Knowledge Management

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Risk monitoring is a fundamental part of risk management that allows detecting changes that might affect the risk consequences and their likelihood. To be effective, the process requires storing the risk information into a so-called risk register. This paper presents an implementation that is realized in form of a relational database. We present the complete table schema of the database and discuss what motivated the different features. We believe that certain aspects of our schema improve its application in comparison to related works. A noteworthy characteristic is the separation of the risk scenarios and risk analyses in different tables. This feature relates to the fact that the same scenario can be assessed within multiple analyses, in which individual circumstances may result in different risk levels. Moreover, different analyses can apply distinct risk criteria. Thus, the analysis-specific criterion must be stored in the database as a risk matrix. A risk scenario includes an entity or item that is the subject being considered in that scenario. This subject can be a system or organization or a subpart of a system or organization. Due to this reason, the schema allows a hierarchical categorization of entities. The developed schema also employs ideas from the object-oriented programming approach, which allows entities to inherit already defined risk scenarios. This paper further presents a browser based user interface to access the database.

Keywords: Risk register, Relational database, Table schema, Knowledge management, Web application.

WE2A: 137 **11:05 hrs**

Cyber Security for Medical Devices from a Risk Management Perspective: A Case Study

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Today, medical devices are characterized by a significant use of software technologies and increasingly sophisticated interfaces for supervision and control. On the one hand, this broadens the range of applications of medical devices in medicine, while on the other hand, it introduces new failure scenarios, which pose new risks for the patient. A relevant contribution in this respect is attributed to cyber security threats, which may potentially become a risk higher than that of human errors. As it is often the case, any technological advance brings non trivial shortcomings, which shall be weighed against the benefits. Because of this, the review of the safe and effective use of the medical device versus cyber security has been performed. The outcomes of this review are reflected in the Medical Device Regulation MDR 2017/745 and in the latest issues of medical device standards, including the risk management standard ISO 14971. This paper aims at addressing the cyber security from the point of view of risk management and its impact on the secure and safe design of the medical device. The concepts will be presented using the MedAustron Particle Therapy Accelerator (MAPTA) of Wiener Neustadt, in Lower Austria.

Keywords: Cyber security, Medical devices, Risk analysis, Risk management, Safety, Secure design.

WE2A: 198 **11:25 hrs**

The Aftermath of 26 September 2019 Accident: A Focus on Risk-Related Policy Analysis

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The 26 September 2019 industrial accident, at the "Lubrizol" chemical plant and "Normandie Logistique" warehouse in Rouen (France), has urged the authorities to investigate/reconsider the efficiency of some policy assumptions and safety management measures. This study aims to analyze organizational and policy gaps by examining the published official documents and inquiries of this accident. Its method relies on (i) historical review of Lubrizol's

past accidents; (ii) stakeholder review through the examination of the Law of 30 July 2003 (theoretical) and the accident's Learning from Experience (LFE) Report (practical); (iii) organizational analysis through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) model to examine the means used to manage the crisis and prevent risks; and (iv) a policy analysis of the Law of 30 July 2003 to compare the desired practices (in theory) with those adopted (in practice) affecting the involved stakeholders. Results show that repetitive practices and LFEs highlight a poor change management and risk culture; this is coupled with significantly complex stakeholder network; which is hindering an effective crisis management despite several policy evolutions. Further investigations aim to tackle the encountered stakeholder mapping complexity proving a lack of performance efficiency.

Keywords: Policy analysis, Industrial accident, Risk management, Lubrizol fire, SWOT analysis, Chemical industry.

Session	[WE2B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Atrium 2

WE2B: 558 **10:25 hrs**

Detailed Repair Modeling in a Scalable Dynamic Analysis

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Boolean combinations of basic failures leading to an undesired consequence which one can specify by fault trees allow for a very efficient analysis even for large industrial safety studies, such as nuclear Probabilistic Safety Assessment (PSA). This efficiency comes for a price of approximating possibly complex dependencies, failure behaviors and accident mitigation strategies by Boolean structures with basic events. Often, these approximations are acceptable and give valuable insights about system risks, making fault trees (and event trees) an industrial standard. Two aspects of typical safety systems might lead to skewed, typically overly conservative, results in fault tree models especially when considering prolonged accident durations cold standby systems and repairs. Including cold standby systems and a possibility to repair failed components in exponentially distributed repair times implies solving Continuous Time Markov Chains (CTMC) in the model quantification. General analysis methods for CTMCs hit the computational limits of current computers even for medium size models with ca 300 basic events. Approximative algorithms help to overcome these computational costs. One such approach restricts the number of repairs of each component by a fixed number. We adopt this restriction and investigate which possibilities it brings for modeling repairs in a more detailed way.

Keywords: Dynamic analysis, Detailed repair modeling, Stand-by dependencies, Probabilistic safety assessment, Industrial scalability.

WE2B: 568 **10:45 hrs**

Reliability of Noisy Intermediate Scale Quantum Computers: A Network Reliability Approach

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Quantum physics applications in secure communications and high-performance computing are currently receiving a lot of attention worldwide. Huge investments are being made in the field of quantum computing, with major players such as Google, IBM, Intel, Microsoft, etc. competing for commercial solutions. Quantum supremacy[1] or advantage[2] have made the headlines, and are hotly debated.

While the operational number of qubits is not yet sufficient to implement a general-purpose quantum computer, it has been suggested by Preskill3 that systems with a few tens of qubits, called Noisy Intermediate Scale Quantum (NISQ) computers, could be very useful for specific problems/quantum algorithms. They are termed noisy because the qubits are very sensitive to their environment, so that the error rate of qubit operations is still important. A relatively simple meshed architecture is also required in order to be able to address all qubits properly. In this context, Tannu and Qureshi4 first assessed the reliability of NISQ computers, defining two figures of merit. Because of the significant variations in the errors rates of qubits and links, they proposed a variation-awareness to qubit-movement policy in order to improve the overall system reliability. Their approach is based on a shortest-path routing algorithm to transfer information from one qubit to another.

We propose here to apply the formalism of network two-terminal, and more generally kterminal reliability to the calculation of the probability of qubits association, so that the result is not path-dependent anymore. This calculation can rely on analytical results for already solved generic network configurations, to which the IBM Q architectures have the good taste to belong. We shall apply our methodology to a few such cases. The variability of the error rates can also be included very simply in our approach, in which node and link availabilities may be defined individually. Finally, we shall provide directions for the inclusion of correlations in the error rates.

Keywords: Quantum computers, Noisy intermediate scale quantum computers, Qubits, Error rates, Network reliability, Two-terminal reliability, Availability.

WE2B: 579 **11:05 hrs**

City Bus Reliability Assessment Based on State Space Models

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The city bus reliability and safety are crucial aspects of their frequent operation. Reliable and safe operation has, apart from others, one important aspect—it does not increase ownership and entrepreneur costs.

We had been part of the assessment team, which was supposed to observe bus operations in a medium size town.

We collected records of bus operation, maintenance, failures occurrences, etc. The buses failures were identified up to a subsystem level; therefore, we know which subsystem in a bus had failed. This project lasted for more than six years. Thanks to this, we possess a significant statistical data set, which is very rich in information. As we have records of each event occurrence in terms of date, mileage, fuel consumption, subsystem affected, etc., we do have a vector of more than 20 variables while some are dependent and some independent.

In this paper, we present the data elaboration. There are various approaches possible to model empirical data.

However, thanks to the data form and structure, a suitable approach is time series modeling. Our effort is aimed at initial data mining, basic characteristics modeling, reliability measures estimation, course plotting, and finding correlation amongst respective variables. The data create interesting courses and dependencies, which we would like to develop further. Modeling approach such as time series state space models based on backpropagation Kalman recursor is a suitable tool, which is applied on the data here. The modeling approach has been chosen due to relevance and ideal applicability.We would like to present essential reliability measures, their courses, and developments with potential to their predictions.

Keywords: Reliability assessment, Safety assessment, ROCOF modeling, State space models.

Session	[WE2C]—Bayesian network for reliability modeling and maintenance optimisation
Day/Date/Time	Wednesday, 22 Sep. 2021 / 10:25–11:45 hrs
Venue	Espace Grand Angle2

WE2C: 128 **10:25 hrs**

Development of a Bayesian Updating Model for O&M Planning of Offshore Wind Structures

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Offshore wind structures are generally more complex than their onshore counterparts due to requirements to overcome challenges associated with severe marine environments and impact under substantial wave loading. There are difficulties associated with the accurate analysis of fatigue damage in offshore wind structures as a result of uncertainty within the crack growth models. To overcome such difficulties, this study proposes a model called Bayesian updating for predicting fatigue crack growth based on hourly observations from remote condition monitoring sensors. The Bayesian updating is applied to the Paris law, which is commonly used to represent the growth of fatigue-induced cracks in structures. The research method employed in this study also involves the use of influence diagrams to show the effects of condition monitoring decisions on fatigue crack growth. The model is applied to predict fatigue crack growth in an offshore wind turbine monopile over a 24-hour period. The results demonstrate a theoretical proof-of-concept of how ‘real-time’ condition monitoring technologies can be utilised to predict different damage modes in offshore wind turbine structures.

Keywords: Offshore wind structures, Bayesian updating, Condition monitoring, Fatigue, Operation and maintenance (O&M).

WE2C: 598 10:45 hrs

Unsupervised Co-Training of Bayesian Networks for the Diagnosis of Machining Spindle

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The objective of Smart Manufacturing is to improve productivity and competitiveness in industry, based on in-process data. Indeed, failures can stop the production for a couple of days and generate costs of non-quality. Failures in industry can either damage the machine or the product being produced. In both cases, the earlier the failure is detected, the lower the impact on production. Thus, monitoring both the process and the machine condition is interesting, due to their potential interactions. Besides, the diagnosis of the nature of the incident is also important, in order to react adequately as fast as possible.

It requires reliable, explainable and understandable models such as Bayesian networks for performing tasks like condition prediction. Bayesian networks can be learned with incomplete data and in a supervised or unsupervised way, which is very useful because the collect of labelled data is costly and sometimes impossible, especially in industry where problems are, moreover, very rare.

In this paper, we propose a generic architecture based on two Bayesian networks and a collaborative learning strategy that improves the condition monitoring of rotating machines in unsupervised context by using information gathered from process monitoring.

Keywords: Industry 4.0, Condition-based maintenance, Process monitoring manufacturing, Machining, Tool breakage, Bayesian networks, Unsupervised learning, Co-training.

WE2C: 705 11:05 hrs

Quantitative System Risk Assessment from Incomplete Data

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In this work we focus on the use of belief networks as a generalization of a fault tree analysis, where the main interest is in learning about the probability of the top event, and where a fault tree has been constructed that relates it to the occurrence of one or more primary or intermediate causal events. Furthermore, we focus on a common situation where:

(1) There is substantial expert opinion, but that constraints on the availability of the experts, or their experience of an elicitation process, means that the elicitation process must be kept simple;
(2) There are limited data from past instances of the risky event, meaning that this information must be used to the full but that also there is uncertainty in the risk assessment that must be properly quantified. In other words, typically some of the events in the fault tree are not observed, and which are observed may change from one observation to the next.

The advantages of this approach, in terms of the use of a fault tree and as a way to facilitate a probabilistic risk assessment, are discussed.

The motivating example for this work comes from an application in the space industry. To reduce the creation of space debris, operators are increasingly resorting to a controlled re-entry of satellites and spacecraft once they are no longer needed, with the objective that they will largely burn up in the atmosphere. The re-entry trajectory is designed so that any components that do reach the surface will land in areas of remote ocean, such as the South Pacific. A recent example, and the motivation for this work, is the European Space Agency's Automated Transfer Vehicle (ATV), built to supply the International Space Station. Other examples of situations where the approach of this paper may be relevant are nuclear power, maritime safety or counter-terrorism.

A panel of experts approach is used to elicit prior distributions on primary event probabilities, which are then updated from data with the usual belief network methodology. We illustrate the approach with the space debris example, and discuss the use of the method in deciding whether it is worth collecting more detailed data from the fault tree.

Keywords: Bayesian methods, Belief network, Fault tree analysis, Pairwise comparison, Prior elicitation, Risk analysis, Spacecraft re-entry, Space debris.

Session	[WE2D]—Prognostics and System Health Management
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Panoramique

WE2D: 396 **10:25 hrs**

New Mixture Distribution Model For Mapping And Analyzing Different Failure Mechanism Caused By Different Stresses

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Failure symptoms of technical complex products are often caused by mixed failure root causes. In reliability engineering, the use of a single Weibull-distribution is the state of the art regarding the description of a single failure mode. In terms of a mixed failure root cause, a mixture of distributions models has to be considered. The subsequently following failure models are state of the art: Compete failure model, Mixed population failure model, Partial population failure model, General failure model. Only the first two models are fundamentally different. The third model is a special case of the second, and the fourth is a mixture of the others. In many cases resulting curve plots of the mixture distributions have been observed, which differ to the just described by a clearly sharper bend between two straight lines. Thus the “compete failure model” does not explain this phenomenon. In some cases, an explanation by the “mixed population model” could be possible, if there are assumptions for inhomogeneous populations. This paper shows the development of a new failure model with respect to a mixed failure root cause. The model considers especially a distribution of different stress levels affecting the components in field. It is based on the “inverse power law” and the “damage accumulation hypothesis”. Furthermore, an application case study for the evaluation of the new failure model is shown.

Keywords: Mixed distribution model, Mixed failure root cause, Weibull distribution model, Wöhler lines, Damage accumulation hypothesis, Gradient method.

WE2D: 426 **10:45 hrs**

Prediction of Remaining Useful Life Via Self-Attention Mechanism-Based Convolutional Long Short-Term Memory Network

Jiusi Zhang, Shen Yin, Hao Luo and Muhammad Gibran Alfariz

With the increasing complexity of the various large-scale equipments, prognostics health management (PHM) technology has attracted more and more attention1. Prediction of remaining useful life (RUL) is of vital significance in the PHM technology. Deep learning approaches can achieve great performance in predicting RUL2. However, conventional deep neural networks, such as convolutional neural network (CNN), recurrent neural network (RNN), and long short-term memory network (LSTM), do not consider the impact of the various features on RUL at different times. To solve the limitation, we propose a novel self-attention mechanism-based convolutional long short-term memory network (AM-CNNLSTM) for RUL prediction, whose framework is shown in Fig.1.

The main contributions of the proposed approach lie in extracting the spatial and temporal feature information of historical data with the aid of the CNN and the LSTM, meanwhile, the self-attention mechanism is able to learn the significance of the different features and times, and assign larger weights for more significant ones. Feature selection is employed to eliminate the features that are not useful for RUL. In addition, the data are smoothed, and combined into the time window to construct the relationship between input and output. The AM-CNN-LSTM is trained by the time window data. Finally, the trained neural network is used for online RUL prediction. The aircraft turbofan engine dataset provided by NASA is applied to verify the effectiveness of the proposed RUL prediction approach.

Keywords: Prognostics health management, Remaining useful life, Self-attention mechanism, Convolutional neural network, Long short-term memory network.

WE2D: 475 **11:05 hrs**

RUL Prediction of Bearings using Empirical Wavelet Transform and Bayesian Approach

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Remaining useful life (RUL) is an important requirement for condition-based maintenance specially for critical components whose failures can cause a long unplanned shutdown. Almost 30% of the abnormalities of the rotating machinery are initiated by the bearings’ failures. Thus, bear-

ing is considered as one of the most critical components in rotating machinery and it is important to monitor its health condition to be able to avoid the upcoming failures, increase reliability, reduce unplanned shutdowns and maintenance costs. Since the vibration signals in bearings have both nonlinear and nonstationary characteristics, neither of time and frequency-domain approaches can provide reliable and accurate RUL prediction results. For this purpose, most research is based on time-frequency representation techniques such as wavelet transform, Hilbert-Huang transform and Short-time Fourier transform. However, these approaches are more popular within fault detection field, while the combination of these methods as an input for health indicator (HI) construction together with RUL estimation approaches for failure prediction have not been studied thoroughly before. In addition, most research are based on online datasets in which the bearings are only degraded by loading factor. This paper presents a framework using empirical wavelet transform (EWT) for fault detection and HI construction combining with Bayesian inference approach to predict RUL of the bearings. The datasets in this paper are collected by performing several accelerated life tests at NTNU. EWT as an adaptive approach has been employed to decompose the signals into sub-bands to extract different features. The features extracted from the sensitive sub-band are then comparedusing several performance measures. Afterwards, the Bayesian approach together with Wiener process has been applied on the degradation trajectories to predict RUL efficiently and the framework is validated using the collected experimental datasets.

Keywords: Remaining useful life, Empirical wavelet transform, Condition-based maintenance, Bearing, Bayesian inference.

WE2D: 521 **11:25 hrs**

A Comprehensive Parameter Study Regarding the Neural Networks Based Monitoring of Grinded Surfaces

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The optical perception of high precision, fine grinded surfaces is an important quality feature for these products. Its manufacturing process is rather complex and depends on a variety of process parameters (e.g. feed rate, cutting speed) which have a direct impact on the surface topography. Therefore, the durable quality of a product can be improved by an optimized configuration of the process parameters. By varying some process parameters of the high precision fine grinding process, a variety of cutlery samples with different surface topographies are manufactured. Surface topographies and colorings of grinded surfaces are measured by the use of classical methods (roughness measuring device, gloss measuring device, spectrophotometer).

To improve the conventional methods of condition monitoring, a new image processing analysis approach is needed to get a faster and more cost-effective analysis of produced surfaces. For this reason, different optical techniques based on image analysis have been developed over the past years. Fine grinded surface images have been generated under constant boundary conditions in a test rig built up in a lab. The gathered image material in combination with the classical measured surface topography values is used as the training data for machine learning analyses.

Within this study the image of each grinded surface is analyzed regarding its measured arithmetic average roughness value (Ra) by the use of feedforward Neural Networks (NN). NNs are a type of machine learning algorithms which can be particularly applied for any kind of analysis based on extracted features. For the determination of an appropriate model, a comprehensive parameter study is performed. The approach for the search of the best algorithm results and identification of a reliable and reproducible NN model which operates well independent of the choice of the random sampled training data is presented in this study.

Keywords: Neural networks, Machine learning, Condition monitoring, Surface analysis, Computer vision.

Session	[WE2E]—Autonomous system safety, risk, and security
Day/Date/Time	Wednesday, 22 Sep. 2021 / 10:25–11:45 hrs
Venue	Amphi Jardin

WE2E: 113 **10:25 hrs**

Operational Design Domain for Cars versus Operational Envelope for Ships: Handling Human Capabilities and Fallbacks

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Autonomous cars have been researched since the 1980s and has created significant interest in both the research and commercial communities. Terminology is in the process of being standardized and the concept of the operational design domain has been proposed to define the capabili-

ties of the car's driving automation system. Autonomous and unmanned ships have similarly been a research item, also since the 1980s, but with a much lower public profile. A main difference between the two types of vehicles is that autonomous ships in most cases will have human supervision and backup control responsibilities. This has led us to suggest the term operational envelope for the ship, instead of operational design domain, and to include the human capabilities in the operational envelope. This paper describes these concepts and the benefits of the operational envelope when dealing with ships.

Keywords: Autonomous cars, Autonomous ships, MASS, Operational design domain, Operational envelope.

WE2E: 193 **10:45 hrs**

Road Marking Characterization for ADAS Machine Vision Reliability

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The evaluation of the road markings visibility has been defined according to human needs, but shall now be extended to the needs of vision-based Advanced Assistance Driving Systems (ADAS). Several publications propose minimum levels of daytime or night-time visibility of the road marking and their contrast with the surrounding pavement, to ensure optimum detectability of Machine Vision systems. However, the calculation methodology is rarely indicated (the heterogeneity of the markings is not always taken into account) and very little information about the Machine Vision system is provided. In this study, a daily experiment was conducted on a small dry road section using a mobile retroreflectometer and a vehicle equipped with a Machine Vision system. Several statistical analyses are performed on the collected data at different study scales (punctual or global scale). They show that despite very low levels of marking retroreflection values and visibility contrast ratios, the road marking lines are almost always very well detected by the camera's algorithm. That demonstrates that the current indicators characterizing the marking visibility according to standards are not enough to fully understand the behaviour of Autonomous Vehicle cameras.

Keywords: Road marking, ADAS vision reliability, Photometry, Detection level, Retroreflection.

WE2E: 412 **11:05 hrs**

Cybersecurity Assurance Challenges for Future Connected and Automated Vehicles

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Increases in the connectivity of vehicles and automation of driving functions, with the goal of fully automated driving, are expected to bring many benefits to individuals and wider society. However, these technologies may also create new cybersecurity threats to vehicle user privacy, the finances of vehicle users and mobility service operators, and even the physical safety of vehicle occupants and other road users. Assuring the cybersecurity of future vehicles will therefore be key to achieving the acceptability of these new automotive technologies to society. However, traditional prescriptive assurance methods will not work for vehicle cybersecurity, due to the evolving threats, through-life software updates, and the deployment of artificial intelligence techniques. Cybersecurity regulations that are goal-oriented and risk-based, like those increasingly used in safety engineering for complex systems, are now mandated in recent vehicle type approval regulations. This results in many new assurance challenges, which will not be limited purely to cybersecurity. In particular, emerging standards have proposed that an assurance case approach should be adopted in relation to cybersecurity. This paper therefore proposes a novel cybersecurity case framework that adapts existing approaches from safety engineering, emphasizes the limitations of the analysis through eliminative argumentation, and merges in the attack-defence tree techniques used in cybersecurity engineering, with the aim of providing a better reflection of the some of the uncertainties in the cybersecurity risk analysis.

Keywords: Assurance, Automated driving, Connected vehicles, Cybersecurity, Risk, Safety, Software updates.

WE2E: 470 **11:25 hrs**

Resilience in Autonomous Shipping

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In this article, we will look at some of the potentials within autonomous shipping and discuss how we can ensure resilience. The term resilience is widely used, Woods (2015) discusses four different common usages: (1) resilience as rebound from trauma and return to equilibrium; (2) resilience as a synonym for robustness; (3) resilience as the opposite of brittleness, i.e., as graceful extensibility when surprise challenges boundaries; (4) resilience as network architectures that can sustain the ability to adapt to future surprises as conditions evolve (sustained adaptability). Many factors affect the resilience approaches of the autonomous system, including communication and collaboration between technology and humans. This paper will give an understanding of technological limitations, as well as understanding of operational knowledge applied within shipping today that might be addressed to the autonomous sector. Will the knowledge at a Remote Control Centre be sufficient to recover from an unwanted situation? Will the autonomous system be capable to perform without human interactions? A bowtie methodology will be applied to identify and describe preventive and reactive barriers, which can be used to understand the resilience mechanisms. This paper will point to known operational challenges, focus on the interaction between technology and humans, and elaborate on issues which will be important drivers for increased resilience and a successful implementation of autonomous maritime transportation systems.

Keywords: Autonomy, Automation, Transport systems, Remote Control Centre, Safety, Resilience.

Session	[WE2F]—Risk and Resilience Analysis of Interdependent Infrastructures
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Espace Grand Angle

WE2F: 210 **10:25 hrs**

Energy and Telecommunications Networks Interdependency: Resilience Challenges

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This paper focuses on interdependency between telecommunication and energy distribution networks, both belonging to critical infrastructures as described in [1].

Energy distribution is always behind every single telecommunication network and related equipment. To anticipate power cut or frequency issues, different solutions have been deployed depending on the sites size and importance in terms of hosted network functions: batteries, inverters to generators. From Distribution Service Operator (DSO) perspective, energy distribution networks depend more and more on telecommunication services provided by Telecommunication Operators (Telco) to supervise, monitor and automate processes.

With the digital transformation, the economy across all industry sectors will continue to develop a critical dependency upon telecommunication networks. DSOs have new requirements linked to their deployed networks, but also requirements for new services relying on telecommunication networks capabilities [2]: massive deployment of electric mobility, smart grid, augmented technicians… with a will to manage these services and associated networks. Telecommunication networks are also evolving, new enhanced functions (like Mobile Edge Computing, MEC) are to be deployed closer to customers. Smaller sites will require a better resilience against power cuts than today. In addition, evolution to 5G will draw new challenges as well, because of the inherent complexity of 5G architecture and softwarization paradigms [3].

This paper is the result of a collaboration between energy and telecommunication companies and has as purpose to provide some answers to face these new challenges. The proposed solutions cover both technical and organizational approaches. The technical solutions will rely on new technological paradigms (5G, Artificial Intelligence [4]) to ensure and improve the resilience of each type of networks and will depend on some proposals of information exchange modes. To put in place these technical solutions, a task force with delegates from DSO and Telco should be built to select the best way to proceed depending on local constraints.

Keywords: Resilience, Systems interdependency, Telecommunication network, Energy distribution network, 5G, Smart grid.

WE2F: 219 **10:45 hrs**

Dynamic Orchestration of Communication Resources Deployment for Resilient Coordination in Critical Infrastructures Network

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In modern Critical Infrastructures (CIs) network, Smart Grid (SG) and Information & Communication Technology (ICT) infrastructures ensure security, as well as economic and societal well-being through a variety of services. Modern CIs rely on the fifth generation of mobile communication (5G) paradigm to incorporate new technologies, deliver new sophisticated services and adopt new business models. These models will shift the CI interdependencies towards a new dynamic paradigm where communication resources are deployed within the CIs operational scheme to reach performance and quality of service (QoS) objectives. Network Function Virtualization (NFV), Network Slicing (NS) and Software Defined Networking (SDN) are examples of 5G-enabling technologies used to reach the aforementioned objectives. However, due to the complex nature of CIs and the interdependencies between their components, the shift toward a dynamic operational scheme will increase the vulnerability and exposure to risks, impacting the network resilience. This requires the design of new resilience frameworks that consider the heterogeneity, privacy and self-interest nature of CIs and guarantee reliability and QoS objectives in such a constrained and dynamic environment. To tackle the resilience problem, we propose a framework to dynamically coordinate and manage the deployment of communications resources, based on NFV. This framework will ensure the availability of services, meet performance objectives during disruptive events and overcome constraints of interdependencies and heterogeneity. To illustrate our approach, we formulate the case of maintenance operations as a disruptive event in ICT hosting SG services.

Keywords: Critical infrastructure, Resilience, ICT, Smart Grid, QoS, 5G, NFV, Optimization.

WE2F: 356 **11:05 hrs**

Towards a Realistic Topological and Functional Modeling for Vulnerability Analysis of Interdependent Railway and Power Networks

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Railway systems and power grids are recognized as two of the most important critical infrastructures. The majority of European railway networks are electrified, and power transmission networks represent usually the main power supplier. Railway and power networks share thus a unidirectional interdependency, as the railway network functionality depends on the power network. Due to this interdependency, failures in power networks have the potential of causing vast disruption in the dependent railway networks. Despite this, the issue of modeling interdependent railway and power networks has not been addressed sufficiently carefully in the existing literature. Furthermore, the treatment of cascading failures in power networks and their consequences in railway networks is limited and approximative. In this work, we propose a modeling framework which accounts for more realistic assumptions on the interconnections topology and the cascading failures dynamics. Firstly, we model the interconnections between the railway and external power network by introducing the traction power network, which acts as a bridge between the external power grid and the railway network. Secondly, we model cascading failures in the external and traction power networks with an approach based on the DC power flow model. Thirdly, we suggest a simple approach to estimate the negative consequences on the railway network due to load shedding in the traction power network. Vulnerability analysis is performed to estimate the negative consequences in the railway network due to different failure scenarios in the external power network. Sensitivity analysis on the initial assumptions is also performed.

Keywords: Critical infrastructures, Interdependent networks, Power network, Railway network, Cascading failures, Vulnerability.

WE2F: 402 11:25 hrs

A Risk and Resilience Assessment Approach for Railway Networks

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Railway transportation dynamically performs under complex coherent systems and fail-safe interlocking conditions. Security and safety are the first priorities of this massive intermodal transportation. However, railway systems, like any other critical infrastructure, face many threats that can take not only the form of physical, but may also be cyber or combined cyber-physical threats, since the automatedand digital-based technologies in the rail operation may be vulnerable. Therefore, SAFETY4RAILS (S4R), a H2020 EU project, was initiated to strengthen the EU rail operations by increasing the resilience and improving the safety and security of railway and metro networks against these threat types through the further development and combination of a variety of state-of-the-art tools, most of which start with a Technology Readiness Level (TRL) of around 5. Within S4R, many tools will be utilized including a predictive risk and resilience assessment tool, an anomaly detection tool and an asset management tool. To achieve effective tool development and integration, the project requires huge collaboration from different expert and informative sources. This paper will include a discussion on risk and resilience assessment specific to rail systems, including a section on hardware-based countermeasures, before focusing on the risk assessment tool and how it will be implemented. The paper will also introduce a few other tools within the project and discuss the expected interactions the predictive risk assessment tool will have.

Keywords: Risk, Resilience, Risk and resilience assessment, Railway, Safety, Security, Critical infrastructure.

Session	[WE2G]—Mechanical and Structural Reliability
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Atrium 3

WE2G: 033 10:25 hrs

Reliability of Spur Gears - Determination of Stress-Dependent Weibull Shape Parameters for Tooth Root Fracture

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For fatigue and wear failures, a stress-based determination of the Weibull shape parameter is of importance and thus ultimately a stressbased reliability prognosis. The failure behavior of a spur gear at different load levels with torsional vibration excitation is examined and analyzed with the three-parametric Weibull distribution. The distribution parameters are shown for all tested load levels and a 90confidence interval is given. The failure-free time is another parameter of the Weibull distribution. It is the most important parameter in the context of fatigue failures. The level of the shape parameters depends on the failure-free time. The shape parameters on different load levels are stress-dependent. The shape parameter decreases with increasing load levels in high cycle fatigue (HCF) area without vibration excitation. The shape parameter remains constant or increases with increasing load levels in low cycle fatigue (LCF) area with vibration excitation. For the failure of tooth fracture, a typical value range of the shape parameter from 1.2 to 2.2 is well-known in literature. The given mean value range for the stress-dependent shape parameter largely coincides with the test results.

Keywords: Accelerated life test, Gearbox, Failure probability, Weibull distribution, Failure free time, Stress-

dependent weibull parameters, Non-constant shape parameter, Fatigue, Rotational irregularity, Vibration.

WE2G: 272 **10:45 hrs**

Bending Fatigue Analysis of a Steel Cable on the UCP MEA1000 Machine – A Reliability Case Study

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This paper discusses the operation of the fatigue testing machine for cables and moorings, named MEA1000, which performs fatigue tests by bending of high-gauge steel cables under moderate tension. This machine has an exclusive and pioneering project in Latin America as it is the only one capable of conducting tests with cables up to 76 mm thickness. The machine is installed at the Petropolis Catholic University, in the Steel Cable Fatigue Testing Laboratory (LEMOC), as the result of an agreement between Petrobras (National Petroleum Agency), Dom Cintra Foundation, and Petropolis Catholic University. This study analyzes the results obtained in the commissioning test of the MEA1000 machine to obtain information about its functioning, and presenting observations on the steel cable behavior providing a critical analysis of the results about cable performance and its reliability. As a result, obtained through the commissioning test, under detailed observation of the graphs generated from the data, the behavior of the cable on the machine, regarding its resistance to fatigue due to bending force and the contact with the tie components such as pulleys and lever hoist could be evaluated. The behavior of the rope during the cycles is checked.

Keywords: Steel cable, Steel cable fatigue, Fatigue test, Bending fatigue, Fretting, MEA1000 UCP.

WE2G: 362 **11:05 hrs**

Analysis of the Reliability of Training Helicopters

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Providing safe and on-time flight training is one of the most important activities of a university for educating future pilots. It therefore follows that the unreliability of the aircraft participating in the training program is resulted in delays and may also be the trigger for catastrophe. The main aim of the research was the identification of the main caused of failures. It was assumed that the concept of reliability is understood as the probability of the aircraft to fulfil the functionalities as intended. It is also assumed that the object is reparable. As a part of the research, data from the process of operation of the aircraft used in the Military University of Aviation were investigated. The reliability of two types of helicopters Guimbal Cabri G2 and Robinsson R44 has been subject of studies. In this publication the intensity of damage, unreliability and reliability of the helicopters in question as a function of time have been calculated. On the basis of the operating and maintenance data, it was concluded that the majority of the incidents were caused by technical failures in the cooling system, fuel system, impossibility to start the engine and damage to the clutch. In helicopters, the airframe itself was also characterized by high failure rate, i.e. problems with the landing gear and damage to the outside of the helicopter fuselage.

Keywords: Reliability of aircraft, Failure rate, Aviation, Human factor, Technical failures, Helicopters.

WE2G: 442 **11:25 hrs**

Probabilistic Mixed Mode Fatigue Crack Growth Analysis Considering Spatially Varying Uncertainties

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The fatigue crack growth process is characterized by uncertainties inherent to the variations in geometrical properties, material properties and loading conditions. These variations are often considered in the mechanical computations through a simple probabilistic models namely random variables, which are unable to model a spatially varying uncertainties such those related to the material properties. Indeed, in some structural materials like timber, composite and graded materials this behavior is very pronounced. Then it become trivial to be considered to design safe structures. This necessitates to handle intricate probabilistic models such as random fields. In the practice, a random field $F(\boldsymbol{x}, \theta)$ with mean μ and standard deviation σ is represented through an M^{th} order truncated expansion based on a set of standard normal variables $\{u_i(\theta)\}_{i=1}^{M}$, the eigenvalues λ_i and eigenfunctions of the covariance func-

tion $c(\boldsymbol{x}_1, \boldsymbol{x}_2)$.

$$F(\boldsymbol{x}, \theta) \approx \mu + \sigma \sum_{i=1}^{M} \sqrt{\lambda_i} u_i(\theta) f_i(\boldsymbol{x})$$

Higher is the truncation order M, better is the accuracy of the expansion to reproduce the true variability of the random field. Unfortunately, this contributes to a significant increase of the probabilistic dimension of the problem, and consequently classical uncertainty propagation methods become inefficient, since all of them suffer from the problem of the curse of dimensionality. This problem is amplified if the mechanical model it-self is time consuming such in the case of fatigue crack growth. To overcome this problem, an efficient probabilistic method is developed, having as backbone the well-known dimension decomposition technique. The s^{th} variate approximation of the mechanical responses, constructed in the standard random space, is obtained through a projection on Hermite polynomials $\{H_i\}_{i=1}^{m}$.

$$\tilde{y}_s = y_0 + \sum_{i=1}^{N} \sum_{j=1}^{m} \alpha_{ij} H_{ij}(u_j) + \cdots + \sum_{i_1, i_s=1; i_1<\cdots<i_s}^{N} \sum_{j_1=1}^{m} \cdots \sum_{j_s=1}^{m} C_{i_1,\ldots i_s j_1,\ldots j_s} \prod_{k=1}^{S} H_{i_k j_k}(u_{i_k})$$

The unknown coefficients y_0, α_{ij} and $C_{i_1,\ldots i_s j_1,\ldots j_s}$ defined as multidimensional integrals, are computed by convenient monomial cubature rules in order to reduce again the number of mechanical model evaluations. A mixed mode fatigue crack growth problem, where some of material properties are spatially varying uncertain parameters, is addressed using the proposed approach. The spatial variability of the mechanical responses defined by the fracture parameters as the stress intensity factors and the bifurcation angle is well established with high accuracy level and a reduced computation cost compared to most existent approaches.

Keywords: Uncertainty propagation, Random field, Dimension decomposition, Monomial cubature, Fatigue crack growth.

Session	[WE2H]—Railway Industry
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Cointreau

WE2H: 391 **10:25 hrs**

Prognostic Expert System for Railway Fleet Maintenance

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To realize maintenance of a large rolling fleet, with operational constraints due to mass transit, a mixed maintenance solution based on real-time data analysis and condition-based maintenance has been integrated into the SNCF maintenance process in 2017. Based on a prognostic expert system, this solution relies on constant signalling thresholds defined using technical knowledge and physical models in order to assess the health state of a system. As the health of a system differs from one train to another and independently evolves in time, constant signalling thresholds does not always match maintenance load and infrastructure availabilities in the workshop. To overtake these limitations and enhance the current maintenance solution, an upgrade of the existing expert system is under development, using dynamic signalling threshold based on the distribution of health indicators across the whole fleet. The article describes the concept of this new expert system, showing how dynamic thresholds are computed and how they are combined with failure thresholds to manage maintenance load and aging effects.

Keywords: Railways, Predictive maintenance, Expert system, Fleet monitoring, Dynamic threshold.

WE2H: 400 **10:45 hrs**

A Complete Streaming Pipeline for Real-time Monitoring and Predictive Maintenance

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Railway maintenance is changing as predictive maintenance (PdM) comes to prominence. In particular, the rapid progress of learning algorithms, commonly known as Machine learning (ML), strongly motivates data-driven PdM applications. However, traditional ML struggles with the large amount of data that arrive at high velocity in real-time streams. Facing big data-related issues, Stream learning (SL) is a new learning paradigm that adapts ML to the handling of fast, unbounded, and dynamic data streams. We deem SL suitable for online monitoring and relevant to our need of having incremental, drift-aware algorithms that quickly detect and predict anomalies. Aiming to enhance railway PdM with SL, we propose a complete streaming pipeline for real-time monitoring, anomaly detection, and anomaly prediction. A partial implementation of this pipeline has resulted in an interactive application named InterCE. Preliminary results on two real-world datasets supplied by a French railway company show that InterCE helps to improve the accuracy of the learning process.

Keywords: Predictive maintenance, Monitoring, Stream learning, Machine learning, railway, Human-in-the-loop.

WE2H: 486 **11:05 hrs**

Implications of Cyber Security to Safety Approval in Railway

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The railway domain has a justifiable preoccupation with safety, but less of a focus on cyber security. This could result in the risk of cyber security flaws in current railway systems being unacceptably high. However, in recent years the railway industry has realized the importance of cyber security, and the possible effects cyber security could have on safety functions, necessitating these aspects to also be considered as part of the safety approval. This trend can be seen from the fact that later updates of the railway standards from CENELEC to a larger degree include cyber security. This is also a consequence of the increasing digitalisation trend in the railway sector, as elsewhere in society (e.g., the ERTMS national implementation project in Norway). This paper presents findings from a brief literature study on how railway systems are vulnerable to cyber security threats and discusses how cyber security issues are covered by current railway legislation. Challenges related to the handling of cyber security threats as part of the railway approval processes is then elaborated. The fact that cyber security threats change faster than the pure safety threats must be taken into account. The problem is viewed from an independent safety assessor's point of view. Some major findings of the study are elaborated, and conclusions on how to deal with cyber security as part of the railway approval process are outlined with pros and cons.

Keywords: Railway, Cyber security, Safety, Approval, Legislation, Standardization.

WE2H: 504 **11:25 hrs**

Towards a Specified Operational Design Domain for a Safe Remote Driving of Trains

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In this paper, we extend the concept of the Operational Design Domain (ODD) to the context of railway remote driving in order to guide the safety demonstration process. Mainly, we propose an iterative process to define and to specify an ODD for the railway remote driving based on the operational risk assessment process. The main idea consists in, starting from an initial high-level ODD, including the overall operational environment of conventional in cab driving, iteratively restrict and refine the ODD by exploiting the risk assessment steps (particularly, the risk evaluation and the risk reduction) through feedback loops to the ODD.

Keywords: Autonomous transportation, Train remote driving, Railway safety, Safety demonstration, Operational design domain.

Session	[WE2I]—Artificial intelligence for reliability assessment and maintenance decision-making
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Giffard

WE2I: 006 **10:25 hrs**

A Network Connectivity Reliability Estimation Model Based on Light Gradient Boosting Machine

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IoE (Internet of Everything) has become an inexorable trend of modern society development, which makes the network systems more and more complex. This also puts forward higher requirements for the security and reliability of complex network systems. Network connectivity reliability is a key index to evaluate network reliability. However, the computation complexity of the traditional exact algorithms increases exponentially with the expansion of network structure. Therefore, a network connectivity reliability estimation model based on LightGBM (Light Gradient Boosting Machine) is developed in this paper. The model takes the network structure sequence, link reliability, source node and target node as input and network connectivity reliability as output, which can realize the fast estimation of network connectivity reliability. A verification experiment is carried out on a data set of 81920 samples, which is obtain by the node traversal method and the inclusion-exclusion principle. The final experimental results also verify the effectiveness of the proposed model.

Keywords: Network connectivity reliability, Approximation algorithms, Machine learning, LightGBM.

WE2I: 252 **10:45 hrs**

Artifical Neural Networks and Differential Evolution for Optimal Maintenance Planning

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More and more complex models are being developed for Engineering Asset Management (EAM) and the current challenge is to develop optimization methods that would help engineers define the optimal maintenance planning. The difficulty has several origins:

(1) Time-consuming computations: realistic asset management models evaluation are usually based on Monte-Carlo simulation that may be long to run.
(2) Stochastic process: the underlying objects in an asset management model are failures dates described as stochastic variables, the goal function is then also probabilistic.
(3) Dimensionality: maintenance optimization may be done on large systems, the controls (dates) are then defined on a large multidimensional space. Therefore, it is likely that the optimization problem meets the curse of dimensionality.

Several methods have been proposed in the past to tackle such maintenance optimization problems. Some proposed methods are based on decomposition algorithms [1] that aim at transforming large problems into several small problems that can be solved easily and exactly. Although very efficient this type of algorithms is based on strong assumptions regarding the dynamic of the studied systems that could be too restrictive. In this contribution we will present a method that uses Artificial Neural Network as a surrogate model of the stochastic code [2] simulating maintenance planning. The goal is to tackle the two first difficulties identified, that is to say reducing the number of code calculations and also capture the stochasticity of the output. The network is then linked to a Differential Evolution algorithm [3] that is a powerful meta-heuristic for continuous optimization in large dimension, the training data of the NN being expanded throughout the exploration performed by the DE algorithm. Application to several test cases will be presented, from reference analytical problems (Rosenbrock, Sphere or Rastrigin functions) to cases using real EAM models. These tests will show that if the proposed method has some limitations when it comes to solutions in flat or narrow domains (Rosenbrock) its performance is very good on more usual problems (Sphere) even ones with multiple local optima (Rastrigin). This good performance being well translated to real EAM problems.

Keywords: Artificial neural network, Differential evolution, Maintenance, Stochastic optimization.

WE2I: 304 **11:05 hrs**

Reinforcement Learning for Maintenance Decision-Making of Multi-State Component Systems with Imperfect Maintenance

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In this paper we propose an artificial intelligence (AI) based framework for maintenance decision-making and optimization of multi-state component systems with imperfect maintenance. Our proposed framework consists of two main phases. The first aims at constructing artificial neural network (ANN) based predictors to forecast system's reliability and maintenance cost. The second refers to the use of deep reinforcement learning (DRL) algorithms to optimize maintenance policy which can deal with large scale applications. Numerical results show that ANN is suitable to reliability, maintenance cost forecasting and DRL is a potentially powerful tool for maintenance decisionmaking and optimization.

Keywords: Deep reinforcement learning, Maintenance decision-making, Multi-state component system, Imperfect maintenance, Optimization.

WE2I: 387 11:25 hrs

Predictive Maintenance of Natural Gas Regulators by Forecasting Output Pressure with Artificial Intelligence Algorithms

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With the emergence of Industry 4.0, smart systems, machine learning (ML) within artificial intelligence (AI), predictive maintenance approaches have been extensively applied in industries for handling the health status of industrial assets. Due to digital transformation towards Industry 4.0, computerized control, and communication networks, it is possible to collect massive amounts of operational and processes conditions data generated from several pieces of equipment and harvest data for making an automated fault detection and diagnosis with the aim to minimize downtime and increase utilization rate of the components and increase their remaining useful lives. Machine learning (ML) techniques have emerged as a promising tool in Predictive Maintenance applications for smart manufacturing.

In the proposed work, we test the recent advancements of ML techniques widely applied to predictive maintenance to forecast natural gas regulators pressure deviations and to predict failures. The data represents about a hundred of gas regulators with monitored output pressure, temperature and flow, plus the observed failure mode "pressure regulation out of specification" (too high or too low), dates and durations of preventive maintenance over the last three years. ML and neural networks models are tested to forecast the output pressure of the regulators and to predict the passing over the failure thresholds. Defining the parameters that optimize the prediction of failure while limiting the spurious detections is a challenge that is investigated in the proposed paper.

The deployment of such methods is expected to reduce the preventive and field maintenance operations costs by providing early warning notification and diagnosis of gas regulators issues.

Keywords: Artificial intelligence, Neural networks, Machine learning, Predictive maintenance, Gas transmission.

Session	[WE2J]—Advancements in Resilience Engineering of Critical Infrastructures
Day/Date/Time	Wednesday, 22 Sep. 2021/10:25–11:45 hrs
Venue	Botanique 2

WE2J: 357 10:25 hrs

A Resilience Evaluation Framework for Complex and Critical Systems

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Critical systems pose serious safety and reliability challenges for the researchers and practitioners when subjected to disruptive events. The complexity and uncertainty of threat prompts for consideration of resilience in system design and performance evaluation. Consequently, researchers have proposed several definitions and evaluation methodologies to assess resilience of potentially complex infrastructure systems. However, methods to quantify resilience of a specific infrastructure from multiple recovery paths, and their applicability to a large-scale system are limited. This paper presents a novel resilience evaluation framework to model critical infrastructure systems and to quantify net resilience by focusing on key characteristics of resilience. The proposed approach extends the framework proposed previously by the authors which explicitly models the temporal aspects of system response to disruptive event towards effective recovery from various recovery measures. This extended framework also proposes a global resilience model to quantify net resilience from multiple restoration paths based on the weighted geometric mean of area under multiple restoration curves. The proposed framework is illustrated with a case study on regulating function of nuclear reactor modelled using Petri nets. The model of the reactor system comprising regulating function, setback function, and human and organizational aspects is developed and simulated starting from an initial steady state until complete recovery state after a disruptive event on regulating rods. The net resilience of regulation system is computed from the performance parameter over various recovery sequences with their associated weights. This novel approach demonstrates its capability to be applicable to various critical infrastructure systems by considering temporal aspects of system with human and organizational factors for quantitative resilience evaluation.

Keywords: Resilience, Human factors, Critical infrastructure, Nuclear power plant, Petri net.

WE2J: 367 **10:45 hrs**

Cascading Failure Analysis for Power System Vulnerability Assessment

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Power systems as a critical infrastructure are an integral part of human society and are therefore of paramount importance to modern life. Vulnerabilities in the system, that are reviled either by accidental or deliberate events, can cause large losses of power supply with sever social and economic consequences. A tool that identifies the vulnerabilities in a power system can provide the operators the means to support a more reliable power system operation. This paper presents a methodology for power system vulnerability assessment that couples an AC based cascading failure simulation model and a meta-heuristic optimization procedure. The objectives of the assessment is to (1) rank the most important branches in the transmission grid, and (2) identify sets of branches if simultaneously tripped will cause the cascade with highest intensity. The first objective is achieved by ranking the criticality of the branches using two criteria (i) the impact that each branch failure has on the DNS and (ii) the frequency of line overload. The second objective is achieved by hard linking an AC based cascading failure simulation model and a meta-heurist based optimization procedure. The algorithm developed for the purpose of this study is applied to the IEEE 118-bus test system. The results demonstrate the capability of the proposed methodology to identify vulnerabilities in a power system.

Keywords: Power system, Vulnerability, Cascading failures, Power flow, Optimization.

WE2J: 554 **11:05 hrs**

Gas Network Resilience Enhancement by Quantitative Prioritization of Main Valves for Scada Connection

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The study aims to develop a priority list of main valves of the gas transmission network that should be connected to SCADA for remote monitoring and control. Remotely controlled valves are necessary to quickly localize accidents, minimize methane release into atmosphere and enable rerouting of the gas flow to ensure security of supply. Although the highest system resilience is achieved when connecting all main valves, this process is long and therefore must be prioritized as not all valves have the same importance for the system operation.

The priority list involved development of a multi-criteria decision tool [1] as many different parameters should be considered for connection of a valve to SCADA. Each parameter was quantified on a unified scale and then the total priority score was obtained by applying a specific weighting scheme. The following quantitative and qualitative criteria were used for the ranking: pipeline importance in terms of security of supply [2]; pipeline diameter; type of customers served and demand volumes (protected, industrial); valve accessibility (distance to the roads); land use parameters and hazard zones (forest areas, flood areas, swamps); costs of installation and maintenance; networks topology (number of valves in close vicinity, within 300 meters). These criteria were further developed and applied for the valve topology in QGIS software, obtaining individual scores of some indicators directly from QGIS computational routines.

The final priority list of over 500 valves strongly depends on weights that individual indicators are assigned. The weights were assigned by experts applying expert judgment techniques.

The work presented was co-funded under Horizon 2020 framework by SecureGas project.

Keywords: Gas network, Resilience, Quantitative indicators, Valves, SCADA.

WE2J: 584 **11:25 hrs**

Conceptual Approach Towards a Combined Risk and Resilience Framework for Interdependent Infrastructures

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We describe a combined risk and resilience framework, developed based on a standard risk management process (as proposed for example in ISO 31000) integrating core aspects from resilience management. Furthermore, it focuses on interdependencies among critical infrastructures (CI) in a city and aims at capturing potential cascading effects among CIs caused by a local incident (intentional or random). The application of a stochastic simulation model in this context provides an elegant description of these cascading effects of an incident and enables the overall risk assessment (of that incident) for the entire CI network. To get from incident propagation to the evolution of the resilience, we complement the simulation model by an additional resilience model. For this simulation-aided management of risks and resilience, our framework utilizes game-theoretic optimization to identify the most effective mitigation strategies against the worst-case incident implications. This quantitative decision support for the choice of best actions is made possible by the simulation model, allowing to evaluate the efficacy of different actions for risk and resilience control in a planning phase for an optimal time- and resource investment. Specifically, the use of simulation allows for arbitrarily chosen actions, ensuring that the planning is consistent with feasibility constraints (budget, cooperation of actors, etc.), and leads to understandable and effective preventive and reactive actions. In this way, the developed framework supports municipalities' decision makers and individual CI operators in assessing their preparedness against specific incidents as well as evaluating novel strategies to improve a city's risk and resilience management.

Keywords: Risk and resilience framework, Critical infrastructures, Interdependencies, Stochastic simulation, Game-theoretic optimization.

Session	[WE2K]—Autonomous Driving Safety
Day/Date/Time	Wednesday, 22 Sep. 2021 / 10:25–11:45 hrs
Venue	Atrium 1

WE2K: 052 **10:25 hrs**

Clarification of Discrepancies in the Classification of 1oo2 and 2oo2 Architectures Used for Safety Integrity in Land Transport

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Automated car driving or advanced railway signaling systems are based on the safe vehicle position determination. The required safety integrity of the positioning function cannot be achieved using a single element, and therefore a combination of information from several diverse sensors should be used – e.g. within the 1oo2 (one-out-of-two) or 2oo2 (two-out-of-two) architecture. The standard IEC 61508 says that the 1oo2 architecture is intended for safety integrity and 2oo2 for availability. On the other hand, the railway standard EN 50129 says that 2oo2 is used for integrity – quite the opposite. So where is the truth? The purpose of the contribution is to clarify the above discrepancies. The paper begins with the classification of safety systems as 'safety-critical' and 'safety-related' and examines the possible impact of system classification on system properties depending on the area of application. Then, the basic safety parameters of dualchannel architectures for safety integrity are presented using two examples with Markov modelling. The main differences between 1oo2 and 2oo2 architectures used for safety integrity are explained. Finally, the equations concerning the safety parameters contained in the automotive standard ISO 26262-10 for a dual-channel architecture are verified using rail safety experience. Recommendations for the safety architecture design for self-driving cars are given, which are based on the numerical results obtained in the examples.

Keywords: 1oo2, 2oo2, ASIL, PMHF, SIL, Automated car driving, Fail-operational, Fail-safe, Railway signaling, Safety integrity.

WE2K: 087 **10:45 hrs**

Trust Me, We Have a Safety Case for the Public

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Road traffic will change dramatically, triggered by the development of new technologies and a focus on accident-free driving. It is a race among the car manufacturers to be among the first to develop autonomous vehicles.

Several standards for road vehicles require a safety case. A safety case is developed to convince a third party that the vehicle is safe. We suggest that also a "safety case for the public" should be issued to ensure (1) that the public are aware that safety evidence exists, (2) that they are aware of relevant safety aspects when they are passengers and (3) that limitations are transparent and described.

A safety case is too technical for the public, is lengthy and includes confidential information. As a result, the safety case cannot be presented to the public. Trust in this technology is a vital precondition for this adoption. In an earlier paper we have addresses the safety topics of the safety case for the public. These aspects were based on safety standards and a survey including only safety experts. We have made a new survey of 311 passengers and interviewed 18 autonomous bus passengers. Based on this information we have proposed a template for the "safety case for the public". Using such a safety case will help manufacturers of autonomous vehicles and operators to gain public trust.

Keywords: Trust, Safety, Standards, Safety case, Autonomous vehicles.

WE2K: 106 **11:05 hrs**

Traffic Psychology in Digital Drive: Deceptive Safety by Corrosion of Agency

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Traffic psychology is context-specific. The context however, is changing. This change is digital. A forceful momentum, fueled by opportunity and enthusiasm. It is a 'digital drive.' In the traffic context, this drive concerns computer automation spanning from digital support systems, to the future ambition of the fully automated machine. As vehicles changes, so does driving, and the traffic context. In traffic psychology, concepts were developed within old pre-digital contexts. The divergence (between old and new contexts) must be addressed; to ensure that it does not develop into a schism, a deep split that irreversibly separates old from new. Although the extent of automation varies, a tendency is corrosion of agency (i.e., involvement, action). Considering risk perception, this problem is acutely accentuated. The premise being that risk awareness is developed by exposure, involvement and action. Paper aim: Examine the Corrosion of Agency Thesis by exploring digitally 'produced' gaps for risk perception and risk-taking behavior. To connect traffic psychology to 'the digital,' the paper is inspired by Carr's (2014, 2016) reflections on digital transformation and its unnerving repercussions for us as human beings. Elements from Trimpop's (1994) Risk Motivation Theory is used as theoretical framework. If driver agency deteriorates, this ricochets straight back into a fundamental principle in traffic psychology: That experience is built by agency. How is experience built without agency? And, fundamentally: What about safety?

Keywords: Digital transformation, vehicle digitalization, traffic psychology, risk perception, risk-taking behavior, safety.

WE2K: 147 **11:25 hrs**

Trust and Acceptance of Self-Driving Busses

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The work is done as part of the TrustMe project – a project about public trust to self-driving busses, sponsored by the Norwegian Research Council. Trust is both a technical and psychological problem and these two areas use different terms and in some cases uses the same word with different meaning. Thus, the paper starts with a discussion of terms. Since the acceptance of selfdriving vehicles partly is a psychological problem and partly an engineering problem we need to look at it from both angels. Next, we discuss some of the relevant models – Ajzen and Fishbein's model for planned behavior – a psychological model – and the TAM model – a technical model. The TAM model will include the extensions added by Venkatesch et al. The first part ends with a short discussion on risk acceptance.

The second part of the paper introduces the results from two focus groups plus a SMS-based survey that have been run by the bus operator AtB AS together with TrustMe project personnel and discuss how the problems raised in

these focus groups can be handled in a self-driving vehicle. Since risk and risk acceptance is an important part of acceptance of self-driving vehicles, we end the paper with a short discussion on how to talk risk with the general public and some preliminary conclusions.

Important conclusions are that the extended TAM model of Venkatesh and Davis is well suited for the TrustMe project. Using this model will help us to categorize and analyses our observations. In addition, it will help us to find new questions and problems to consider. We need to consider both technical and societal risks when construction safe and trustworthy / reliable self-driving busses for public transport.

Keywords: Self-driving busses, Technology acceptance, Trust, Safety.

Session [WE3A]—Risk Assessment
Day/Date/Time Wednesday, 22 Sep. 2021/14:00–15:00 hrs
Venue Plenary Room

WE3A: 397 **14:00 hrs**

Covid-19 Pandemic: Analyzing Of Different Pandemic Control Strategies Using Saturation Models

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Since December 2019, the world is confronted with the outbreak of the respiratory disease COVID-19. At the beginning of 2020, the COVID-19 epidemic evolved into a pandemic, which continues to this day. Within many countries, several control strategies or combinations of them, like restrictions (e.g. lockdown actions), medical care (e.g. development of vaccine or medicaments) and medical prevention (e.g. hygiene concept), were established with the goal to control the pandemic. Depending on the chosen control strategy, the COVID-19 spreading behavior slowed down or approximately stopped for a defined time range. This phenomenon is called saturation effect and can be described by saturation models: E.g. a fundamental approach is Verhulst (1838). The model parameter allows the interpretation of the spreading speed (growth) and the saturation effect in a sound way. This paper shows results of a research study of the COVID-19 spreading behavior and saturation effects depending on different pandemic control strategies in different countries and time phases based on Johns Hopkins University data base (2020). The study contains the analyzing of saturation effects related to short time periods, e.g. possible caused by lockdown strategies, geographical influences and medical prevention activities. The research study is focusing on reference countries like Germany, Japan, Denmark, Iceland, Ireland and Israel.

Keywords: COVID-19 pandemic, Data analytics, Saturation model, Pandemic growth, Pandemic control.

WE3A: 423 **14:20 hrs**

A Systemic Approach for Preliminary Risk Analysis of Cybersecurity of Industrial Control Systems

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The objective of this communication is to describe a systemic analysis method for carrying out the analysis of cybersecurity risks of installations made up of computer elements and industrial systems control systems. We first recall the principle of systemic risk approaches, specify the context and then detail the proposed method. It is based on a decomposition into interacting systems. For each system, a risk model is produced from a knowledge base. The scenarios are obtained by composition. This approach is illustrated on an example installation. We end by suggesting areas for improvement.

Keywords: Cybersecurity, Systemic, Risk analysis, MITRE ATT&CK.

WE3A: 425 **14:40 hrs**

Risk Analysis of Emergency Operations in Presence of Limited Prior Knowledge

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The risk of emergency operations can lead to the expansion of accident losses. The emergency process can introduce uncertain factors, and the resulting risk can threaten the safety realization of the emergency goal. By considering the characteristics of emergency operations, we proposed a methodology to assess the risk of emergency operations. In the methodology, Bayesian network is applied to capture the risk characteristics in the emergency process. Fault tree is utilized to depict the reason for emergency failure. Fuzzy set theory is employed to determine the prior probabilities of the root nodes in presence of limited prior knowledge. The methodology was applied to the emergency operations in the deepwater blowout accident. The risk-influencing factors of emergency operations and their correlations were identified. In emergency operations, fault tree is used to assess the risk of the lower process.

A Bayesian network-based emergency operation model for the deepwater blowout is developed. The model captures the variability of parameters and simulates the evolution of emergency operations over time, with probabilistic updates based on field observations. The mutual information is also utilized to conduct sensitivity analysis and diagnostic reasoning on the model.

Keywords: Emergency operation, Risk analysis, Fuzzy set theory, Bayesian network.

Session	[WE3B]—System Reliability
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Atrium 2

WE3B: 330 14:00 hrs

RAM and Importance Measures Analysis of Offshore Drilling Rigs' Cuttings Dryer

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This paper presents a Reliability, Availability, and Maintainability (RAM) Analysis and an Importance Measure Analysis of an actual cuttings-dryer system of a drillship operating in the Brazilian Pre-Salt region. The methodology used consists in the development of a functional analysis, in which the technical and operational characteristics of the system were identified, followed by the modelling of the system using the Reliability Block Diagram (RBD) technique. Since traditional RBD's do not permit the failure-repair transitions analysis, it was necessary to additionally apply the Monte Carlo Simulation (MCS) technique to assess availability and maintainability. Finally, a multicriteria Importance Measures analysis was performed, considering five different approaches: Birnbaum, Criticality, RRW (Risk Reduction Worth), RAW (Risk Achievement Worth), and Fussell-Vesely. The analysis shows that the fluid cleaner, centrifuge, and catch tank are the most critical components of the system in analysis. It also indicates that a monthly preventive maintenance should be performed in order to lessen the likelihood of the cuttings-dryer system failing.

Keywords: Reliability, Availability and Maintainability (RAM) analysis, Reliability Block Diagram (RBD), Monte Carlo Simulation (SMC), Importance measures analysis, Offshore drilling, Cuttings dryer system.

WE3B: 378 14:20 hrs

Knowledge-Based System Modelling to Enhance Design for Reliability Process: An Application to LNG Industry

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Modern vessels require integration and interaction of many on-board systems. Adoption of fuel-saving technologies and more demanding environmental regulations are pushing towards increasingly complex and expensive design solutions. This poses several challenges in terms of safety and reliability. In this scenario, modern simulation capabilities play a pivotal role for the analysis and optimization of innovative vessels. Furthermore, a digital environment allows the investigation of failure modes and hazardous situations in place of expensive and time-consuming laboratory tests as well as whenever field data do not ensure proper faults investigation. These aspects make knowledge-based simulation models a supportive tool for Reliability Engineering Experts. This paper describes a proposal to enhance the Design for Reliability (DFR) methodology within product development process relying on system simulation capabilities.

Keywords: System reliability, LNG hybrid vessel, De-carbonization, Smart technology, System integration, Knowledge-based model, System simulation.

WE3B: 482 14:40 hrs

Bayesian Cross Entropy Method for Network Reliability Assessment

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We propose a modification of the improved cross entropy (iCE) method to enhance its performance for network reliability assessment. The iCE method is an adaptive sampling approach that employs a smooth transition from the nominal density to the optimal importance sampling (IS) density and updates a chosen parametric distribution model through cross entropy minimization (Papaioannou et. al., 2019). The efficiency and the accuracy of the iCE method are largely influenced by the choice of the parametric model. In the context of reliability of systems with binary component states, The obvious choice of the parametric model is the multivariate Bernoulli distribution. In systems with highly reliable components, the parameters of the Bernoulli model often converge to 0 due to lack of occurrence of failure data/samples. The problem is known as “zero count problem” or “sparse data problem” in the context of maximum likelihood estimation (Murphy, 2012). To circumvent this problem, an accurate yet efficient algorithm termed Bayesian cross entropy (BCE) method is proposed. In this approach, instead of employing a weighted maximum likelihood estimator to update the distribution model, the posterior predictive distribution is derived. The information from the samples generated at the previous levels can be further exploited in BCE through introducing a mixed prior. A set of examples are used to illustrate the efficiency and the accuracy of the proposed method.

Keywords: Network reliability assessment, Importance sampling, Improved cross entropy method, Bayesian analysis.

Session	[WE3C]—Maintenance Modeling and Applications
Day/Date/Time	Wednesday, 22 Sep. 2021/14:00–15:00 hrs
Venue	Espace Grand Angle2

WE3C: 480 **14:00 hrs**

Condition-Based Maintenance with Functional Modeling: Challenges and Opportunities

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Practices in the process industry have shown benefits from functional modeling in particular a methodology called Multilevel Flow Modeling (MFM) for corrective maintenance by quickly reasoning out the root-cause of failure and suggesting plausible counteractions to maintain the normal operation. In order to decrease the downtime and reduce the costs, condition-based maintenance (CBM) has also been advocated. With the robust capability of knowledge representation and automated reasoning for complex process systems, MFM has the potential for CBM by representing relevant functions and processing data from condition monitoring, but may need a revolutionary methodology extension from the process level to the perspective of mechanical equipment. This paper goes over the key CBM steps and prevailing CBM approaches, from which the possible opportunities and challenges of applying MFM as the unified knowledge base for CBM are defined. The authors aim to develop a computerized maintenance management system, which will interact with the existing MFM-based reasoning platforms to provide operators an integrative decision support for operation and maintenance.

Keywords: Decision support system, Condition-based maintenance, Functional modeling, Multilevel flow modeling, Condition monitoring, Computerized maintenance management system.

WE3C: 594 **14:20 hrs**

Energy Footprint of a Refractory Lining

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In foundry processes, and more in general in the metallurgy industry, refractory materials are used for lining the furnaces: they serve as a thermal barrier between the melting metal and the containing vessel and protect the furnace’s coils of copper wire during the fusion phase.

Refractory materials are subject to wear as they deteriorate by reducing their thickness during the furnace functioning and need to be replaced on a regular basis when a “limit thickness” is reached. The procedure of replacement is economically demanding because it requires a long downtime in other to allow the substitution of the lining and the re-heating of the furnace before it can start melting again. At the same time, an excessive delay in the replacement may bring safety issues: as the material deteriorates, cracks due to the extreme wear of the lining may form and a break in the coating could allow the melting metal to reach the copper coils putting the furnace at the risk of explosion.

In some cases, no monitoring system for measuring the thickness of the refractory lining is in place and the decision of changing the coating is left to the expertise of an operator who, based on his experience, decides the right time for the substitution.

In this paper we propose a method for the detection of refractory lining wear based on the signal in the energy profile of a furnace. A time series analysis is conducted by training a dataadapted classifier consisting in convolutional neural networks performing phase classification to unveil the energy footprint of the degradation process in the refractory layer. The proposed method is evaluated on a real industrial case.

Keywords: Refractory wear, Predictive maintenance convolutional neural networks, Phase classification, Time series analysis, Energy footprint.

WE3C: 642 14:40 hrs

A Planning Strategy for Maintenance Interventions Under Complex Systems

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This research presents the elaboration and computational implementation of a framework for optimizing planning strategies on maintenance interventions. Our model comprehends a novel integrated approach for the opportunistic grouping strategy of preventive maintenance activities originally presented in Viveros et al. (2020), incorporating through this extension new criteria to improve applicability in real industrial environments, i.e., a technical feasibility criterion for grouping, whereas a non-negligible repair time for preventive maintenance activities, and the application of time-window tolerances in order to facilitate opportunistic maintenance grouping schemes.

This work also develops an optimization model based on the mixed-integer linear programming (MILP) paradigm for the implementation of the present framework. Our numerical experiments show a 39% downtime reduction in the system under analysis, considering a maximum tolerance factor of 10% for six preventive maintenance activities, demonstrating the framework's effectiveness to improve productivity and reduce fixed maintenance costs. This research aims to formulate a new proposal for efficient maintenance planning, which considers realistic applicability criteria to facilitate the transfer of knowledge and its industrial application, with an approach oriented to the simulation and risk quantification of failure events in complex systems.

Keywords: Preventive maintenance, Opportunistic maintenance grouping, Maintenance planning, Mixed-integer linear programming, Complex system.

Session	[WE3D]—Uncertainty Analysis
Day/Date/Time	Wednesday, 22 Sep. 2021/14:00–15:00 hrs
Venue	Panoramique

WE3D: 235 14:00 hrs

Interrval Uncertainty in Logistic Regression

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Logistic regression models the probablility of a binary outcome given some predicting features or risk factors. As many decisions and events are binary in nature (yes/no, failed/passed, sick/well), logistic regression has many practical applications, and thus it is considered an important machine learning algorithm. Logistic regression algorithms can be used to make predictions across many different fields, from predicting whether a sports team will win a particular match [1] to the probability of lightning strikes at the Kennedy Space Center [2]. Traditionally it has been assumed that all the values of the risk factors and outcome statuses used in logistic regression are precisely known. This assumption is valid when the sampling uncertainty or natural variability in the data is large compared to the incertitude (lack of knowledge or epistemic uncertainty). However, in practice there can be considerable incertitude in both the independent and dependent variables used in the regression analysis as well as incertitude in the application of the regression model. Measurement uncertainty is a common cause of epistemic uncertainty in the risk factors and is often expressed as plus-or-minusintervals. Analysis using data from combined studies with inconsistent measurement methods can even result in data sets with varying degrees of incertitude. Likewise, the outcome data can be uncertain if there is ambiguity in the classification scheme (e.g., diseased/healthy) or if the outcomes are lost or otherwise censored. In the case of the classifications being uncertain the data points can be expressed as vacuous [0; 1] intervals.

The purpose of this paper is to show why analysts should account for these sources of uncertainty. We show that considering the interval uncertainties introduces upper and lower bounds on the logistic function. We suggest that uncertainty added to the logistic regression caused by uncertain data points leads to values for which classifications cannot be made, as the interval probabilities straddle decision thresholds. Such a sample would require further analysis to make a prediction; in a safety-critical or high-cost situation this could be of benefit. In general, excluding uncertain predictions from the analysis leads to improve-

ments in the sensitivity and specificity of the predicted values.

Keywords: Logistic regression, Uncertainty analysis, Interval analysis.

WE3D: 450	14:20 hrs

Optimal Sensor Location in Smart Building to Estimate Occupancy While Addressing Model Uncertainties

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Nowadays, buildings are responsible for over 30% of society's energy consumption and half of the global electricity demand [1]. In order to build a sustainable and integrated energy system, it's crucial to make the buildings more intelligent not only to minimize the energy consumption while ensuring comfort but also to provide ancillary services to the energy market in the future smart energy system for the system operators and balancing party.

The prerequisite for achieving the goal of the intelligent building is data collection. The accuracy, diversity, and non-repeatability of data become the key to this problem, so finding an optimization method to locate different kinds of sensors so as to obtain good data quality and to minimize the sensors number played a prominent role in data collection. This presentation first provide a short state-of-art review for various optimal sensor placement techniques. Based on the literature review, a greedy algorithm relying on the condition number of a Fisher information matrix [2] is presented in the methodology section. It is applied to find the M optimal temperature sensors placement for a typical university lecture room in west of France, for which temperature was computed at several points through energy (EnergyPlus tool) and CFD simulations. In the results section of the presentation, the set of M indoor temperature sensors that bests fit the temperature at T target points is identified. Then, an implicit model linking estimated and real temperature at some target points is designed for N occupancy scenarios. The model related error is estimated between each N cases. Then, using these model uncertainties as well as the estimated temperature at the target points, an artificial neural network is applied to predict the occupancy status (absence or presence of occupants) with a certain level of confidence. Furthermore, a more profound study of variational number (M) of sensors will be addressed to gain insight for prediction accuracy

Keywords: Intelligent building, Optimal sensor placement, Fisher information matrix, EnergyPlus, effective independence method, Uncertainty analysis.

Session	[WE3E]—Autonomous system safety, risk, and security
Day/Date/Time	Wednesday, 22 Sep. 2021/14:00–15:00 hrs
Venue	Amphi Jardin

WE3E: 499	14:00 hrs

Mind the Gap Between Automation and Meaningful Human Control, Through Standards

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Automation is increasing to improve efficiency, cost/benefit and safety. Human interventions are often needed and must be designed. The need for standards is critical to handle the challenges of automation and support meaningful human control. This need for standards in the petroleum industry is based on: (i) a literature review including study of accidents involving automation from shipping, aviation, transport and petroleum; (ii) interviews of industry experts and users of drilling automation; (iii) a discussion of standards with human factors (HF) experts and key stakeholders in Norway. The study shows the need to prioritize HF in the development of automation. Exploration of accidents identified gaps in meaningful human control and learning. This gap is due to technology optimism, poor design of HF and poor learning from human factors. User centred design based on the experience of operators is necessary to get systems with meaningful human control. Experiences indicates stepwise automation in collaboration with users has improved user satisfaction, efficiency and safety. Automation, poor human machine interfaces and poor sensemaking may create additional gaps between work as done vs imagined, that must be addressed. This paper highlights three main issues: -Successful automation has benefited from user centred design; - Learning from accidents must include the gap in human factors knowledge and poor design; - Human Factors principles and standards are needed from regulators and industry.

Keywords: Human factors, Automation, User centered design, Sensemaking.

WE3E: 508 14:20 hrs

A Modeling Approach to Consider the Effects of Security Attacks on the Safety Assessment of Autonomous Vehicles – An AT-CARS Extension and Use Case

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Researchers and developers of autonomous vehicles are facing various challenges ranging from establishing public acceptance to meeting high reliability requirements. These challenges are often faced individually in specific areas, e.g., safety and security, or are addressed separately for each software and hardware component. The applied approaches are delivering single solutions that might not consider the interdependencies between the different areas. Some common interdependencies include, for instance, the safety failure of an element that provides security measures or the safety failure of the system due to a security attack of a safety-related component. Therefore, in this paper, we integrate these ideas based on our previous research into a safety analysis to consider the interdependencies between safety failures and security attacks. In particular, we implement security attack rates into our safety analysis tool, called AT-CARS, and develop failure management strategies to handle these security attacks. Furthermore, we introduce a new component to our modeling approach, the so-called *security protection component*, which provides security protections for specific components. Besides, a show-case demonstrator visualizes the developed methods and tools.

Keywords: Safety, Security, Analysis tool, Failure management process, Autonomous vehicles.

WE3E: 518 14:40 hrs

Analyzing Influence of Robustness of Neural Networks on the Safety of Autonomous Vehicles

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Neural networks (NNs) have shown remarkable performance of perception in their application in autonomous vehicles (AVs). However, NNs are intrinsically vulnerable to perturbations, such as occurrences outside of the training sets, scene noise, instrument noise, image translation, and rotation, or small changes intentionally added to the original image (called adversarial perturbations). Incorrect conclusions from the perception systems (e.g., missing objects, wrong classification, and traffic sign misdetection or misreading) have been a major cause of disengagement incidents in AVs. In order to explore the dynamic nature of hazardous events in AVs, we develop a range of methods to analyze AV safety and security. This work is part of the project and is devoted to analyzing the influence of robustness in the NN-based perception system by using fault tree analysis (FTA). We extend the traditional FTA to represent combinations of failure causes in the multi-dimensional space, i.e., two variables that influence whether the image is classified correctly. The extended FTA is demonstrated on the traffic sign recognition module of AV theoretically and in practice.

Keywords: Safety, Neural network, Autonomous vehicles, Robustness, Failure mode, Hazard identification.

Session	[WE3F]—Critical Infrastructures
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Espace Grand Angle

WE3F: 140 **14:00 hrs**

Risks in the Operation of Gas Installations in Commercial and Residential Buildings

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Gas installations in commercial and residential buildings are important equipment that rise quality human lives in residential buildings and enhance production in commercial buildings. However, gas installations using the natural gas or propane-butane in commercial and residential buildings are often the sources of accidents. These accidents are accompanied by human losses, damages on properties and harms on environment. The paper shows the examples of selected accidents, proposes countermeasures for prevention and summarizes demands on response to accidents.

Keywords: Gas installations, Commercial and residential buildings, Accidents, Prevention, Risk, Safety.

WE3F: 191 **14:20 hrs**

Perception Shift Between the Classical Physical and Modern Digital Notion of Critical Infrastructures of a State: Elements of Diagnosis based on a Qualitative Study

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Over the last two decades, society has been radically transformed by digitalization, moving to a more globalized model with transnational interdependencies on multiple aspects allowing the massive and wide transportation and distribution of people, materials, products, services as shown by Aven and Zio (2020). But this globalization of society is creating new risks that current risk management practices sometimes have difficulty identifying and managing, such as cyber-risks, social engineering, social exclusion or reduced commitment to work, where the human factor is always underlying.

We notice a shift between the classical physical and modern digital notion of critical infrastructures of a state. This is the case for example for the broadband network or the cyberspace. The shift of some critical infrastructures creates new risks that should not be ignored. When a major incident hits a modern digital critical infrastructure, the handling of the crisis cannot rely on the standard approaches and new ones need to be developed to protect the essential functions of a government, the national security, the national economy or public health as described by Hull et al. (2006). The event could have a negative impact on other infrastructures as well as explained by Löschel et al. (2010).

In this paper, we have taken an interest in the role that the governments should play in the identification and the management of the risks of its critical digital infrastructures in particular with the increased interdependencies of the GAFAM. We have conducted semi-directive interviews of different people from the public or private sectors with a direct or indirect experience with crisis management. The findings of this research have enabled us to develop a diagnosis template to better assess and respond to the risks of new digitalized critical infrastructures.

Keywords: Critical infrastructure, Digitalization, Global risk, Crisis management, Interdependency, Resilience.

WE3F: 280 **14:40 hrs**

Functional Impact Analysis for Complex Critical Infrastructure Systems

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The well-being of the population depends to a large extent on services of critical infrastructures (CIs). It is a well-known fact that the dependencies between CIs lead to even greater impacts on society in the case of malfunctions. To assess these impacts, understand and mitigate them, it is essential to determine and possibly quantify the dependencies. The approach described here consists of three steps. First, the disruptive event for which the impacts should be analyzed is defined (e.g. a blackout). In a second step, the

infrastructure system is modeled. For this purpose, the system is divided into its entities according to common CI definition. Then, the possible service levels of each entity are assessed and quantified, such as standard operation mode, emergency operation mode or breakdown. Logically linked requirements for reaching those levels are defined, either autonomously or as an external dependency (e.g. a power generator), forming a system of dependent services. In a third step, impacts of events are analyzed by degrading selected services and calculating the effects on other services according to the logically linked requirements. Uncertainties can be described by specifying probabilities for service levels. The development over time can be examined by evaluating the impacts of sequential time intervals, e.g. for a regional blackout, where more CIs will face difficulties over time.

Keywords: Critical infrastructures, Modeling, Cascading effects, Boolean logic, Functional impact analysis, Uncertainty, Uncertainty propagation.

Session	[WE3G]—Oil and Gas Industry
Day/Date/Time	Wednesday, 22 Sep. 2021/14:00–15:00 hrs
Venue	Atrium 3

WE3G: 649 **14:00 hrs**

Environmental Monitoring in a Cuban Oil Storage Plant to Characterize the Hydrocarbons Pollution Exposure in the Fence-Line Community

David Javier Castro Rodríguez[1,a], Omar Gutiérrez Benítez[2,c], José Reinol Poma Rodríguez[2,d], Jelvys Bermúdez Acosta[3] and Micaela Demichela[1,b]

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Due to the wide application of oil in industry, large amounts of petroleum hydrocarbons have been annually released into the environment. Legacy contamination and its interaction with other risks, continue impacting a new generation of residents in the fence-line communities. The goal was to characterize the hydrocarbon pollution which could impact on the community living near to an oil plant. A Cuban oil storage plant was analyzed as a case study, in order to address the environmental monitoring of physic-chemical parameters from process industry, as factors which may be used in the spatial modelling of local vulnerability and communities resilience analysis. Firstly, the engineering research on the interest area were reviewed, from which, four comprehensively geographical strata were established. Furthermore, 19 wells were identified around the industry, which were almost exclusively used for human being consumption water. Subsequently, a monitoring program upstream, downstream and inside the plant was design. The lab results regarding hydrocarbons, fats and oils, and organic load frequently trespassed the standard requirements. The causal analysis suggested that the contamination with hydrocarbons in the aquifer was produced by infiltration in the unsaturated area, derived from the poor management of oily residuals in the plant. The results highlighted the negative impacts linked to the plant operations, which have acted as a dynamic stressor against the territory, increasing the vulnerability on the local community. The case study results not only contributed to raise the vulnerability awareness in the decision-making process, but also, have supported the effectiveness of the framework adopted.

Keywords: Aquifer, Local vulnerability, Hydrocarbons pollution, Oil storage plant, Monitoring, Spatial modeling, Resilience analyses.

WE3G: 656 **14:20 hrs**

Physics-Based Accelerated RDT Testing for High Reliable Equipment

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Reliability Demonstration Testing (RDT) is a reliability evaluation methodology focused on experimentally simulating system lifetime and using the test results to conclude if a pre-specified reliability threshold for the desired confidence level is reached. At first, RDT planning entails analyzing specific failure modes and mechanisms that may cause system failure so that the test design adequately addresses them. Then, the test time for a given number of specimens is estimated, or the required number of units to be tested over the available test time is established. However, for high reliable equipment, the amount of time or the number of items necessary to be tested to simulate actual field conditions are rather long and even unfeasible, given budget

and time constraints. An alternative solution for applying RDT in these situations involves using physics modeling of the failure mechanism to reduce the test time by accelerating test variables according to the subjacent physical law. In this paper, we design an RDT for highly reliable equipment used in the O&G industry considering fatigue failure induced by vibration as the main failure mechanism. The physics-based RDT includes the fatigue S-N Curve in its planning, which permits test time acceleration and test costs reduction. A sensitivity analysis is carried out to assess the impact of RDT inputs, such as the acceleration level and the number of specimens tested, on the test time. The obtained results show that the proposed physics-based RDT is an effective method to support the design of efficient physical tests for equipment under development that must comply with high-reliability targets. Keywords: RDT; Numerical Simulations; Reliability Analysis; Fatigue failure; acceleration factors.

Keywords: Reliability demonstration tests, Accelerated life tests, Fatigue life, Physics-of-failure, O&G industry.

WE3G: 703 **14:40 hrs**

A Bayesian Regularized Artificial Neural Network for the Estimation of the Ignition Probability in Accidents in Oil & Gas Plants

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Within the Quantitative Risk Assessment (QRA) of Oil & Gas (O&G) plants, the estimation of the Ignition Probability (IP) following the release of flammable material in an accident (e.g., a Loss of Primary Containment (LOPC)) is commonly conducted by timeconsuming and computationally demanding Computational Fluid Dynamics (CFD) simulations, for only a limited number of operational configurations and accident scenarios. In this work, we propose an Artificial Neural Network (ANN) to overcome these limitations. Specifically, a Bayesian Regularized ANN (BRANN) is developed from a limited set of operational configurations and LOPC characteristics relative to a representative onshore O&G plant, then benchmarked and shown to outperform a traditional polynomial regression approach often adopted in O&G industry.

Keywords: Quantitative risk assessment, Ignition probability, Computational fluid dynamics, Linear regression, Bayesian regularization, Bayesian regularized artificial neural networks.

Session	[WE3H]—Maritime and Offshore Technology
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Cointreau

WE3H: 513 **14:00 hrs**

Towards Safe and Efficient Operation of Autonomous Ships from a Land Based Center

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Through maritime digitalization, there is a possibility of operating ships from a land-based center. The objectives are to reduce cost, risk to personnel and environmental emissions. This paper's contribution is research for safe and efficient supervision of unmanned, autonomous cargo-ships from a land-based center. Based on the need to maintain a high level of situational awareness, we ask: i) Which information is needed, and how should the information be presented to the land-based operation center? ii) Which situations are particularly challenging for autonomous ships? Semi-structured interviews with experienced navigators were performed. The results suggest that the land-based operational centers should present the "larger situational picture", combining information from the ship's technical systems with the "out of the windows" bridge view. Information from radar systems and electronic maps seem important for building a picture of the situation. In addition, a land-based center should also provide support for planning ahead, before unberthing. Identified concerns of unmanned, autonomous cargo-ships were particularly related to safety and competence aspects. One example of the latter was that the "feeling for the ship" could be lost during challenging weather conditions if a crew is not onboard. Further work should focus on a usercentered integration of systems, presenting the "whole picture", avoiding too many standalone systems. We suggest continuing this research through simulator-based studies with maritime scenarios to further explore possible challenging situations.

Keywords: Autonomous ships, Land based operational centre, Situation awareness, Risk, Interview study.

WE3H: 527 **14:20 hrs**

Autonomous Ships: Challenges, Opportunities, and Trust, As Seen From the Perspective of Current and Future Navigators

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This paper presents a small-scale study that was performed in an early phase of a research project focusing on developing interaction solutions for the concept of unmanned, autonomous cargo-ships. This research project is funded by the Research Council of Norway. There is a need to gain more knowledge about the interaction between human and automation in this new operational concept. This paper focus on how the concept of unmanned, autonomous cargo-ships is perceived by navigators. Open and structured questions regarding challenges, opportunities and trust were distributed to two groups, i) experienced and, ii) future navigators. Answers regarding possibilities and challenges seem to be influenced by the participants' previous sailing experience. Regarding trust, our findings indicate that experienced navigators evaluate their trust in unmanned, autonomous cargo-ships lower than future navigators, and it also seems like experienced navigators show a larger variation in their general attitude towards the concept. This suggest that affective factors may impact trust towards the concept. Furthermore, in our study, experienced navigators seem to be particularly concerned about complex traffic situations for unmanned, autonomous cargo-ships. The paper outlines several areas for further research and development. The next phase of this project will be to start developing prototype interaction solutions for a remote operation center and test these solutions iteratively with navigators in a simulator.

Keywords: Autonomous cargo-ships, Remote supervision, Challenges, Opportunities, Trust, Current navigators, Future navigators.

WE3H: 543 **14:40 hrs**

Human-Automation Interaction for a Small Autonomous Urban Ferry: A Concept Sketch

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At the NTNU in Trondheim, a new Centre for Research and Innovation started in 2021 with the aim of supporting the Norwegian industry's attempts to realize autonomous shipping. One of its use cases is AutoFerry, a small autonomous urban passenger ferry crossing the harbour canal in Trondheim. This research area is usually technology cantered and there is a lack of Human Factors (HF) research. This concept paper is presenting some design sketches of Human-Automation Interaction for this ferry. The ferry's operating concept is simple but includes some difficult problems regarding HF and interaction design implementations. First, the design of interaction between the autonomous ferry and other, manned vessels in the canal: How to signal intentions using different interfaces? Second, the design of the control room: Situation Awareness by different sensors, automation transparency, and how do the operator understand and interact with automation? And thirdly, the interaction between the crew-less ferry and passengers: How to promote trust and safety, and how to handle emergencies? The paper discusses safety and security issues and presents some possible solutions and sketches of prototype interfaces for testing.

Keywords: Maritime autonomous surface ships, Urban ferry, Human-automation interaction, AutoFerry, human-machine interface, Human Factors, SFI AutoShip.

Session	[WE3I]—Artificial intelligence for reliability assessment and maintenance decision-making
Day/Date/Time	Wednesday, 22 Sep. 2021/14:00–15:00 hrs
Venue	Giffard

WE3I: 434 **14:00 hrs**

Big Data Analytics for Reputational Reliability Assessment Using Customer Review Data

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Traditionally, reliability assessment is done based on lifetime testing data. Such assessment methods suffered from a lot of limitations. For example, it is in general difficult to collect enough life testing data to support an accurate reliability assessment. Further, the experimental conditions can hardly reproduce the way a consumer will use a product in practice. In the meantime, with the expansion of the Internet, a lot of customers give their feedbacks on the products by posting reviews on websites. This constitutes a huge, easily accessible, and more realistic database that can be used to assess reliability.

In this work, we scraped reviews from a famous e-commerce website. Machine learning models are developed to extract failure-related information from these reviews. Two kinds of information are examined in this study : (1) whether a review reports a failure and, in such a case, (2) the severity of the failure. We used natural language processing tools to process text and we developed different classification models for information extraction. The developed methods were tested on customer review data from 11 different tablets of several brands. The results we obtained were around 85% accuracy when training and testing our models with our dataset. Hence, the machine learning-based approach we developed is demonstrated to be a promising first step to assess reliability thanks to web-based data. However, with a corpus containing only a few thousand reviews and more than 100,000 words, using text to train classification models remains a complicated task. Especially, the models developed in this paper strongly overfit despite the use of several methods designed to prevent overfitting.

Keywords: Internet, Scraping, Logistic regression, Classification, Natural language processing, Ensemble learning.

WE3I: 467 **14:20 hrs**

Efficient Deep Learning Scheme to Evaluate the Reliability of a Passive Safety System

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Passive safety systems are introduced to mitigate accidents in nuclear power plants (NPPs) even under extremely harsh conditions. The one way to estimate the reliability of this passive system is to employ the Monte Carlo simulation (MCS) with the thermal-hydraulic (T-H) simulation code. Due to the fact that the failure probability of a passive safety system is extremely low, a number of simulations are essential to obtain reliable results; the long computation time of a T-H code makes it difficult to perform a large amount of analysis. In order to reduce this computational burden, previous researches have proposed the framework using the advanced sampling techniques for MCS combined with a surrogate regression/classification model instead of the running T-H code.

This paper also employs a deep learning (DL) scheme as a surrogate model to minimize the running of T-H code when evaluating the reliability assessment of a passive system. In addition, this paper also suggests the efficient scheme for the generation of training data to make data sets include more failure cases that rarely occur during MCS. With this motivation, at first, distributions of input parameters are updated by constructing empirical distributions based on specific combinations contributing to the system failure. In the next step, the semi-supervised learning is carried out to obtain more training data without the T-H code. Using this concept, it can be found that the performance of the surrogate DL model describing the decision boundary can be enhanced.

Keywords: Passive safety system, Failure probability, Deep learning, Monte Carlo simulation, Sampling, Semi-supervised learning.

Session	[WE3J]—Effectiveness, Management and Reliability of Natural Risks Reduction Measures and Strategies
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Botanique 2

WE3J: 134 **14:00 hrs**

On Communicating Cost-Effectiveness of Flood-Mitigation Schemes

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Flood risk protection measures are designed to reduce intensity, frequency and extent of feared events. For any category of measures ranging from classical civil engineered measures to Nature-Based Solutions (NBS), being able to assess their physical and technical capacity remains a starting key issue and requirement. It is essential both to design effective solutions and also to analyze their reliability during their lifetime. For hydraulic applications, the analysis of this capacity consists in checking that proposed solutions are able to evacuate flood water discharge or to store water volume. The protocol described in this paper provides an easy-to-understand framework to assess and represent the effect of measures on the considered flood event and to compare it with their relative costs. It can therefore be considered as a basis to help decision-making within the risk management process and also as a contribution to the analysis of the safety and reliability of planned measures. The protocol enables rapid a priori, as well as thorough *a posteriori*, comparisons to be made of the efficacy of various flood-mitigation options and scenarios. We have considered a concept called "dynamic flood-excess volume" (dFEV or FEV) and revisited it in a three-panel graph comprised of the (measured) in-situ river-level as function of time, the rating curve and the hydrograph, including critical flooding thresholds and error estimates. FEV is the amount of water in a river system that cannot be contained by existing flood defences. The new tool deliberately eschews equations and scientific jargon and instead uses a graphical display with FEV displayed as a (dynamic) hypothetical square lake two metres deep. This square-lake graphic is overlaid with the various mitigation measures necessary to capture the floodwaters and how much each option will cost. The tool is designed to help both the public and policymakers grasp the headline options and trade-offs inherent in flood-mitigation schemes. It has already led to better understanding and decisionmaking regarding flood defences in the UK, Slovenia and France, particularly where a number of alternatives are being considered. Three realistic cases –from the UK, Slovenia and France– will be reviewed, including insights on dealing with uncertainty and on the communication of multiple benefits of Nature-Based Solutions, followed by a Socratic-method dialogue.

Keywords: flood-mitigation assessment, Cost-effectiveness analysis, Decision-making, Flood-excess volume.

WE3J: 151 **14:20 hrs**

Improvement of Proportional Conflict Redistribution Fusion Rules for Levee Characterization

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Levee security assessment is a complex expert assessment process based on several heterogeneous data. In our previous research works, we applied information fusion techniques to characterize flood protection levees. We used the proportional conflict redistribution rule no.6 (PCR6) proposed in DSmT (Dezert Smarandache Theory) framework to combine data from geotechnical and geophysical investigation methods. However, in some cases, this rule can generate non satisfactory results. Indeed, the uncertainty between several hypotheses (lithological materials) is overestimated after the fusion process, which is detrimental to decision making in the end. This result occurs because the PCR6 rule does not preserve the neutrality of the vacuous belief assignment, which can be judged as being a counter-intuitive behavior. To overcome this problem we present an improved rule that preserves the neutrality of vacuous belief assignments in the fusion process. Hence, the redistribution of the partial conflict masses using this new rule does not overestimate the masses associated with partial uncertainties. To illustrate the use of this new fusion rule in a levee characterization problematic, we simulate data acquisition. Two geophysical investigation campaigns (electrical resistivity tomography and multi-channel analysis of surface waves methods) and a geotechnical acquisition campaign (core drillings with particle size analysis) are numerically simulated on an earthen structure. The objective is to compare and discuss the fusion results obtained using this new rule with respect to the methodology based on the original PCR6 rule as well as to demonstrate the enhancement of the levee characterization.

Keywords: Belief functions, Levee, Cross-disciplinary approach, Natural hazards, Fusion rules, Risk management, Proportional conflict redistribution rule.

WE3J: 230 14:40 hrs

Prediction of Runoff Sediment Volume Using Stochastic Analysis of Debris Flows Peak Discharge

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Recently, large-scale disasters have occurred all over the world including Japan due to climate change. Hereby, debris flows which have exceeded their associated initial structural design hypothesis have been recorded in disaster report. Protection works failures linked to those debris flows exceeding their design assumptions may lead to disasters. In Japan, Sabo works are based on hypothesis about structural stability including loading scenarios defined in the Sabo plan. It depends on the debris flow peak discharge and planned sediment amount (movable sediment volume) from the estimated rainfall that mean 100-year excess probability rainfall[1]). Predicting debris flows' run off sediment volume and peak discharge is necessary to design active and passive protection measures in torrential streams. This study proposes a method to estimate both debris flows runoff sediment volume and peak discharge using a probabilistic safety assessment based on about 450 debris flows data recorded in Japanese survey database[2]. On one hand, statistical analysis showed relative correlations between drainage basin area and both runoff sediment volume and peak discharge. On the other hand, there were no significant correlation between runoff sediment volume and the peak discharge. An estimation method for choosing the design value of runoff sediment volume and peak discharge using the drainage basin area is proposed: it uses a 95% prediction threshold based on data provided by the survey.

Keywords: Debris flows, Runoff sediment volume, Debris flow peak discharge, In-situ survey data, Basin area.

Session	[WE3K]—Autonomous Driving Safety
Day/Date/Time	Wednesday, 22 Sep. 2021 / 14:00–15:00 hrs
Venue	Atrium 1

WE3K: 410 14:00 hrs

Safe Interaction Between AVs and Vulnerable Road Users

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Advanced automated driving vehicles (AVs) are expected to radically transform road transport by improving safety, increasing traffic flow efficiency, enhancing mobility for all, and reducing road congestion, fuel usage and emissions. To facilitate deployment research has vastly focused on ensuring the safety of AVs operation, investigating primarily the interaction between the human driver (or user depending on the level of automation) and the AV. In addition to the interaction between the AV and its user, the successful deployment of AVs depends also on the exchange between AVs and other road users, also known as vulnerable road users (VRUs), such as pedestrians and cyclists, as well as motor-cyclists, people with disabilities or reduced mobility and orientation. For instance, what do cyclists and pedestrians anticipate when interacting with AVs; are AVs capable of recognizing cyclists and pedestrians in time; can AVs predict accurately the intentions of VRUs; and how shall AVs communicate their intentions to VRUs? Focusing on vehicles with advanced automated driving features, that is vehicles that allow the human driver to not execute the driving task when automation is engaged[1], this paper contributes to the overall discourse on safety of automated driving vehicles in a twofold manner. First, it critically reviews the literature on the interaction between AVs and VRUs, discusses the recent developments and identifies the most prominent research gaps. Second, it shows results of an international online survey on the VRUs expectations, preferences and concerns with respect to their interaction with AVs. We expect our findings to not only provide new insights on the interaction between automated driving vehicles and vulnerable road users, but also be instrumental for policy makers and other relevant actors involved with the development of automated driving technology.

Keywords: Automated driving vehicles, Vulnerable road users, Safety, Communication, Trust, Acceptance, Online survey.

WE3K: 414 **14:20 hrs**

Rule-Based and Managed Safety: A Challenge for Railway Autonomous Driving Systems

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Safety is a key concern for road, rail, and air transport activities. It must be continuously ensured at the technical, operational and organizational levels. At the operational level, two types of safety come into play: (i) rule-based safety, which is based on standards, procedures and technical barriers and concerns known events, and (ii) managed safety, which is currently supported by human operators, mainly by drivers in the context of railway system, who tend to focus on unforeseeable events. In the context of autonomous trains, in which all or a part of the driver's activities and tasks are transferred to an automatic driving system, that integrating some advanced artificial intelligence technologies, the system should consider the managed safety, in addition to the rule-based one. In order to identify different possibilities for its integration and to feed a reflection around this question, we revisit in this paper the concepts of rule-based and managed safety in the transport domain and we analyze their future management in the context of autonomous systems. In addition, we present a study of two accidents which illustrate the impact of managed safety. The first one, a railway accident, illustrates the importance of managed safety in handling an accident to reduce or eliminate major consequences. The second one, an autonomous car accident, shows some accident consequences due to the lack of managed safety in an autonomous system of transportation.

Keywords: Rule-based safety, Managed safety, Operational safety, Autonomous vehicles, Railway trains, Human factors.

WE3K: 551 **14:40 hrs**

Comparing Rule-Based and Data-Based Approaches for Lane-Change Prediction

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Predicting lane-change intents is crucial for driving automation. Several rule-based models and data-based algorithms exist in the literature, amongs other modelling approaches. In this contribution, we compare lane-change intent prediction using MOBIL rule-based model and a decision tree algorithm. Both approaches are based on the speed difference and spacing with the four surrounding vehicles on current and intended lanes. The data are collected from the highway Drone (HighD) trajectory data-set of two-lane German highways.We extract from the trajectories lane-keeping and lane-changing maneuvers, including lane-keeping on right and left lane and lane-changing to the right and the left lane. The behavior of the driver significantly changes according to the maneuver. It turns out that changing the lane to the right (fold-down) is a more complex process than lane-changing to the left (overtaking). Indeed, overtaking results from a mechanism with the neighbors mainly based on three parameters, while folddown requires more complex combinations. This leads to different meanings of the spacing variables with the neighboring vehicles and requires analysing the maneuvers separately. We compute and compare the prediction errors of lane-changing and lane-keeping intents for the rule-based MOBIL and decision tree approaches. The databased algorithm, devoid of modeling bias, can predict both overtaking and fold-down maneuvers accurately.

Keywords: Autonomous and connected car, Lane-changing intent prediction, Highway trajectory data, Rule-based model, MOBIL, Data-based algorithm, Decision tree.

Session	[WE4A]—Risk Assessment
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Plenary Room

WE4A: 445 **16:10 hrs**

Challenges in Risk Assessment for Underground Gas Storage Activities in Italy

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The aim of this paper is to explain the activity carried out by a working group, instituted within the national coordination table on Legislative Decree no. 105/2015, the Italian implementation of the Seveso III directive. The scope is to provide technical support in safety reports evaluation of underground natural gas storage facilities, carried out by the Local Competent Authorities, in order to pursue a uniformity of evaluation throughout the national territory, taking into account plant and site-specific territorial aspects. In order to frame the issue, an overview of the Italian law and legal requirements concerning safety reports evalua-

tion and the natural gas sector is given, also focusing attention on the situation of Italian Seveso establishments. The other main issues concern: information about the establishment and the company organizational structure; information on classification of substance under Seveso directive; industrial safety of the plants; methodological approach for assessing the risk analysis of plants, in terms of: identification of events and accident scenarios, evaluation of events and scenario frequency, calculation of consequences; safety and technical systems. Some references are finally given to identify the most "critical" parameters of the different techniques for risk analysis which, if not adequately evaluated, can lead to an incorrect result of the analysis itself, also taking into account the correct safety measures in order to limit the consequences of an accident scenario.

Keywords: Seveso, Natural gas, Underground, Storage, Risk analysis, Safety report.

WE4A: 464 16:30 hrs

Numerical Verification of DICE (Dynamic Integrated Consequence Evaluation) for Integrated Safety Assessment

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IDPSA (Integrated Deterministic and Probabilistic Safety Assessment) is an integrated method combining deterministic and probabilistic approaches so that the effect of component reliability or operator's actions is reflected in a safety analysis process over time. Thereby we are able to identify risk factors that may be hidden in conservative assumptions or unidentified event scenarios.

DICE (Dynamic Integrated Consequence Evaluation) developed in this study is a tool to perform dynamic reliability analysis based on DDET (Dynamic Discrete Event Tree), consisting of a physical module supporting thermal hydraulic simulation, an automatic/manual diagnosis module governing branching rules on the basis of real time status of the physical module, an reliability module that represents an availability and performance of the safety systems using reliability information, and a scheduler that runs as a comprehensive controller by managing the overall information exchange between these modules.

This paper demonstrates a performance of DICE through a case study on SBLOCA (Small Break Loss Of Coolant Accident) in an NPP (Nuclear Power Plant), and verifies its numerical accuracy by cross-checking whether the simulation results match the outcomes computed by the conventional probabilistic and deterministic methods, respectively.

Keywords: IDPSA, DICE, DDET, SBLOCA.

WE4A: 515 16:50 hrs

Towards Risk-Based Autonomous Decision-making with Accident Dynamic Simulation

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Accidents involving maritime vessels can have severe consequences, i.e., high potential loss-of-life and environmental impact. Hence, risk assessment is essential to the safety of a vessel's operations. Risk assessment for conventional vessels can be considered well established - however, challenges are present for the risk assessment of vessels with autonomous behavior, and generally for complex and software intensive systems. Generally, traditional artificial intelligence methods used in a system to perform tasks autonomously are not risk-informed, which may later result in an accident scenario. For example, state-of-the-art autonomous navigation methods are reactive to risk, acting to avoid hazards or consequences only after identifying a potential accident scenario. By preemptively performing risk assessment and incorporating risk information in the autonomous decision-making process, we can proactively avoid an accident scenario altogether. In this paper, we present a novel framework for simulation-based Dynamic Probabilistic Risk Assessment (DPRA), using the Accident Dynamic Simulator (ADS) as the point of departure. We describe the concepts, structure, constituent parts of the DPRA framework, and how it will contribute to safer autonomous decision-making in the future.

Keywords: Autonomous systems, Probabilistic risk assessment, Autonomous decision-making, Accident dynamic simulator.

Session [WE4B]—Occupational Safety
Day/Date/Time Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue Atrium 2

WE4B: 240 **16:10 hrs**

Index Method for Risk Assessment Using Load Lifting (Crane) and People Lifting (MEWP) Equipment

Antonino Muratore[a], Giuseppe Giannelli[b], Vincenzo Nastasi[c], Giuseppe Sferruzza[d] and Giovanni Grillone[e]

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The safe use of load lifting equipment (various types of cranes) and people lifting equipment (Mobile Elevating Work Platform, MEWP) during use is regulated in European Union by directive 2009/104/EC, that concerns the minimum safety and health requirements for the use of work equipment by workers at work (second individual Directive within the meaning of Article 16 of Directive 89/391/EEC).

The use naturally occurs after the manufacturing and placing on the market phase, which in European Union must follow the machinery directive 2006/42/EC, in order to guarantee the minimum safety and health requirements ("MSR") of the product itself, which, in this case, are Cranes and MEWP.

The purpose of this article is to suggest to the employer an index risk assessment method to evaluate various risk-factors for Cranes and MEWP used in company or building site, with reference to the place of installation and their use, working methods, maintenance conditions, etc. etc., considering that numerous accidents occurred despite the equipment respects the "MSR".

The proposed method follows the UNI ISO 31000:2018 standard "Risk Management – Principles and guidelines", based on the technique called "Consequence Likelihood Matrix" provided by ISO 31010:2019 "Risk Management – Risk Assessment Techniques". The abovementioned method allows to evaluate the level of risk (acceptable / unacceptable) for the specific company/building-site context, where Cranes or MEWP are used.

Keywords: Risk assessment, Index method, Load lifting equipment, People lifting equipment.

WE4B: 243 **16:30 hrs**

Critical Assessment of the Technical Standards and Regulations about the Energy Isolation and Unexpected Start-Up in Machineries

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Several international standards and regulations specify the practices and procedures necessary to remove the supply of energy and to disable machinery or equipment, thereby preventing the release of hazardous energy while employees perform servicing and maintenance activities. Among them, LockOut-TagOut (LOTO) is a common safety procedure used in industry to ensure that dangerous machineries are properly shut off and not able to be started up again prior to the completion of service or maintenance. Also, the essential health and safety requirement 1.6.3 of the Machinery Directive 2006/42/EC reports provisions about the isolation of energy sources.

Despite all these documents address requirements to prevent unexpected machine start-ups to allow safe human interventions in hazardous zones, serious accidents continue to occur due to lapses and errors during these activities. Owing to these considerations, this paper compares standards and regulations dealing with unexpected machine start-ups and LOTO applications, discussing their strengths, weaknesses, and opportunities for improvements and making a comparison among the most relevant provisions. The aim is to critically discuss the most crucial requirements that users must follow when employees could be exposed to hazardous energy while servicing and maintaining equipment and machineries.

Keywords: Lockout, Tagout, Safety, Hazardous energy, Unexpected start-up, Standards and regulations.

WE4B: 261 **16:50 hrs**

Localization Systems for Safety Applications in Industrial Scenarios

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In this paper, main researches related to the implementation of tracking systems for the localization of workers in industrial areas are presented.Major systems already implemented will be investigated by focusing on hardware, software and different features. Particular attention is deserved to the passive Radio Frequency Identification (RFID) technology by virtue of its low cost, no energy consumption and possibility of identification of objects/persons with good accuracy.

Moreover, since the massive introduction of connected devices in industrial environment results in new requirement of interconnected systems, e.g. design/production department, maintenance service, general information through Internet of Things, a higher required performance level has to be assured for safety of machinery. Since an interconnection between localization systems and control system of the machine (or assembly of machinery) is not covered by a harmonized safety standard, the possibility of controlling parts of the machine through the remote server of the localization system is explored. The utilization of a specific smart mode selector on single machine of the system is foreseen to allow this type of man/machine interaction without unresolved safety issues.

Keywords: Localization for safety, Passive RFID localization, RFID for safety, Worker localization, Smart systems for maintenance of machinery.

WE4B: 305 **17:10 hrs**

Risk Assessment of Pressure Equipment During Use Phase

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The Directive 2009/104/EC regulates the safe use of pressure equipment (Steam Generators, Reactors, Pressure Vessels, Piping, etc.) during use phase in European Union. The directive concerns the minimum safety and health requirements for using work equipment at work. The use phase naturally occurs after the manufacturing and placing on the market phases, which in European Union must follow the directive 2014/68/EU (PED - Pressure Equipment Directive) in order to guarantee the Minimum Safety and health Requirements (MSR) of the product.

The purpose of this article is to suggest to the employer an index risk assessment method to evaluate various riskfactors for pressure equipment and assemblies used in company, with reference to the place of installation and their use, working methods, maintenance conditions, level of training of exposed workers, etc., considering that numerous accidents occurred despite the equipment respects the "MSR".

The proposed method follow the UNI ISO 31000:2018 standard "Risk Management – Principles and guidelines", based on the technique called "Consequence Likelihood Matrix" provided by ISO 31010:2019 "Risk Management - Risk Assessment Techniques". The abovementioned method allows evaluating the level of risk (acceptable/unacceptable) for the specific company context. If the risk is unacceptable, the employer must implement specific prevention and/or protection measures in order to protect the safety and health of the exposed workers.

Keywords: Occupational safety, Risk assessment, Index method, Pressure equipment and assemblies, Use phase.

Session [WE4C]—Petri Nets in reliability, safety and maintenance
Day/Date/Time Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue Espace Grand Angle2

WE4C: 109 **16:10 hrs**

A Petri Net Methodology for Modeling the Resilience of Nuclear Power Plants

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In the paper, a novel Petri Net (PN) method for assessing the resilience of nuclear reactors is presented. The PN model constructed aims to simulate the failure of the subsystems in a reactor caused by either natural degradation or external disruptive events such as tsunamis and earthquakes, the resultant accidents due to the failure of different reactor subsystems, the responses of the reactor to different accidents, and the recovery and maintenance of the reactor after the accident. The simulation results are analyzed to identify the key characteristics of the resilience of the nuclear reactor. To demonstrate the feasibility and the capability of the proposed approach, the failure of four heat transport pumps in the primary cooling system of an experimental reactor is chosen as a case study. The research shows that PN modeling is an effective tool for evaluating the resilience of nuclear power plants.

Keywords: Resilience, Nuclear power plant, Petri nets, Maintenance, Mathematical modeling, Simulation.

WE4C: 146 **16:30 hrs**

Dynamic Probabilistic Safety Assessment with Petri Nets

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The communication presents the dynamic method developed and used by Framatome for the Probabilistic Safety Assessment (PSA) of a Sodium-cooled Fast Reactor (SFR). The purpose of this communication is to highlight different ways to pass through some limitations of the static reliability tools by moving to a dynamic modelling.

For Pressurized Water Reactors (PWR) PSA models are commonly developed with fault trees and event trees. This kind of models can be qualified as “static” because it takes only partially the time factor into account. It is commonly admitted that this modelling is appropriate for PWR due to the relatively short mission time of safety features (some hours) related to the fast progress of physical phenomenon after an accident. When studying an SFR, one of the PSA objectives is to demonstrate that the frequency of the loss of Decay Heat Removal (DHR) is practically eliminated with a high level of confidence. For this type of reactor, the kinetic of an accident is different compared to a PWR and require the risk to be screened on a longer period for which repairs could be taken in account.

In this context, Framatome is developing a dynamic PSA based on Petri nets. Calculations are performed with a statistical method (Monte-Carlo). As a static model, the dynamic model has to take into account failures on demand, failures in operation, common cause failures, initiating events, dependencies between systems or components, human reliability and preventive maintenance.

Furthermore, to limit conservatisms, the dynamic model should be as close as possible to reality with real-time modeling of the plant configuration (repairs, number of available repairers, thermal-hydraulic situation at any time…). for that purpose, a “temperature module” has been developed. This module gives the image of the evolution of the primary sodium temperature at each time of the simulation. This module abolishes the use of pre-determined success criteria and replace it by a direct scanning of the real behavior of the installation (evolution of the reactor coolant temperature) allowing establishing a more realistic grace period towards adverse event (overtaking of limit temperature).

Our latest progress in dynamic PSA modelling with Petri nets allows, when repairs are not taken into account, comparison with static PSA modelling which shows similar results. However, dynamic PSA robustness is to be strengthened in the objective to, one day, play a role in the licensing of a Nuclear Power Plant in combination with static PSA. For this purpose, improvements in terms of modelling accuracy and results are encouraging to continue our development in the field of dynamic PSA.

Keywords: Petri nets, Dynamic PSA, Sodium-cooled fast reactor, PSA, Monte-Carlo.

WE4C: 163 **16:50 hrs**

A Modelling Framework for Dynamic Safety Assessment

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The concept of resilience is progressively making its way into the design, operation and management practice of complex engineering systems. The core of such trend lies with the integration of failure mechanisms in the modelling of systems since the very design phase, focusing on the ability to efficiently absorb and rapidly respond to threats rather than merely avoid them. This is expected to overcome the limitations of traditional designagainst- failure approaches, whose efficiency is often undermined by the strong uncertainty associated with rare or hardly predictable hazards. However, the potential advantages such a theoretical shift delivers have not yet been matched by the availability of adequate numerical tools and methodologies targeting the challenges associated with resilience analyses. The current literature and engineering practice lack of a widely agreed upon methodology for the assessment of systems resilience, or even for the definition of its metrics.

This study proposes a novel approach for the estimation of the dynamic response of complex systems to safetythreatening perturbations, aiming at providing a solid base for the evaluation of system resilience. The framework proposed relies on the use of Petri nets to capture both the physics of the processes entailed by the system operation and its interaction with the technological installation. The framework is applied to a case-study focusing on the response of a CANDU nuclear reactor to cyber incidents hindering the correct operation of the reactor control system and hence resulting in a loss of regulation threatening the structural integrity of the nuclear fuel.

Keywords: Resilience, Nuclear, Reactor, Safety, Cyber, Petri Nets.

WE4C: 699 **17:10 hrs**

RCM3 Methodology Applied to The Cooling System of Land Military Vehicle With the Application of Colored Petri Nets

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The main objective of this paper is to create a maintenance model for Land Military Vehicles, based on the study of reliability, maintainability, and availability throughout its life cycle. One other objective is the possibility to identify the logistical needs for the supply of spare parts for a military mission because of the number of engine hours that are expected to be operated. In the example shown, the model is applied to a cooling system for a Land Military Vehicle. The Reliability Centered Maintenance 3 (RCM3) methodology is applied to the physical system. Through simulations of the model of Colored Petri Nets (CPN), it is possible to investigate distinct scenarios and investigate the performance of the system. From the application of the RCM3, it is possible to conclude that this is a robust system, with several components with few failures, and in the case of the components with more recurrent failure modes, they present high Mean Time Between Failures (MTBF) values. It allows simulating the real situation and supports decision-makers in the dynamic formulation of the maintenance plan. It will be also possible to identify the logistical needs for the supply of spare parts for a military mission taking into consideration the number of engine hours that are expected to be operated in an operational mission.

Keywords: Maintainability, Reliability, Availability, RCM3, Simulation, Cooling system, Colored petri nets, Land military vehicle.

Session	[WE4D]—Prognostics and System Health Management
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Panoramique

WE4D: 522 **16:10 hrs**

Neurosingular Machines: New Results

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The article describes the construction of optimizing Self-maintenance solutions based on PHM systems, represented as neurosingular machines.

The main attention is focused on the description of singular processes in incoming data flows: topological singularities, strong asingularities, singular probability measures. On the basis of topological analysis and double microlocal analysis, predictors for the appearance of all types of singularities and their interconnection were determined.

The singularity progression timeline is constructed. It is shown that the singularity progression timeline predicts the occurrence of predictors of failure. That is, they are hidden predictors and the cause of failure predictors. Based on the analysis performed, the traditional version of the Failure progression timeline (FPTL) is corrected.

In particular, transient classes are defined between the FPTL classes.

In this case, the classes of transient processes are determined by the birth and evolution of singularities, and on the transient process, its own progression timeline of singularities is also determined.

The problem of calculating remaining useful life is discussed. Non-temporary characteristics of time series are introduced, reflecting the degree of proximity of the system to class boundaries and failure boundaries.

Taking into account the adjustment of the FPTL and the addition of singularities of the progression timeline to it, the description of selfmaintenance solutions optimizing to increase the life cycle of technical systems and reduce operating costs continues.

Keywords: Self-maintenance, Self-recovery, Non-improve RUL estimate, Digital twin, Uncertainty management.

WE4D: 524 **16:30 hrs**

Hierarchical Multi-class Classification for Fault Diagnosis

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This paper formulates the problem of predictive maintenance for complex systems as a hierarchical multi-class classification task. This formulation is useful for equipment with multiple sub-systems and components performing heterogeneous tasks. Often, the data available describes the whole system's operation and is not ideal for accurate condition monitoring. In this setup, specialized predictive models analyzing one component at a time rarely perform much better than random. However, using machine learning and hierarchical approaches, we can still exploit the data to build a fault isolation system that provides measurable benefits for technicians in the field.

We propose a method for creating a taxonomy of components to train hierarchical classifiers that aim to identify the faulty component. The output of this model is a structured set of predictions with different probabilities for each component.

In this setup, traditional machine learning metrics fail to capture the relationship between the performance of the models and its usefulness in the field.We introduce a new metric to evaluate our approach's benefits; it measures the number of tests a technician needs to perform before pinpointing the faulty component.

Using a dataset from a real-case problem coming fro the automotive industry, we demonstrate how traditional machine learning performance metrics, like accuracy, fail to capture practical benefits. Our proposed hierarchical approach succeeds in exploiting the information in the data and outperforms non-hierarchical machine learning solutions. In addition, we can identify the weakest link of our fault isolation model, allowing us to improve it efficiently.

Keywords: Fault diagnosis, Multi-class classification, Hierarchical classification, Automotive industry, Integral fault diagnosis, Structure prediction.

WE4D: 545 16:50 hrs

A Closed-Loop Prescriptive Maintenance Approach for an Usage Dependent Deteriorating Item – Application to a Critical Vehicle Component

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Connectivity and the huge data availability today open doors for modern and adaptable maintenance solutions. Nowadays, clients have the desire, not only to avoid breakdowns, but also to find out how to use their systems in order to reduce the overall exploitation cost and expand the remaining useful life. Researchers of different areas have worked to achieve such goal, but a complete solution that quantitatively assesses for different actions, costs and the degradation evolution was not proposed. In this paper, we will consider the example of a fleet of vehicles. We will model different operational costs as well as the degradation trajectory of a real component, and account for two possible actions: mission planning and maintenance operations scheduling. We highlight how those two actions are connected and propose a method for finding the optimal usage of the fleet. Finally, through simulations, we compare it to a maintenance/exploitation policy that mimics real fleet usage.

Keywords: Maintenance, Decision making, Multi-objective optimization, Degradation and reliability models, Automotive sector.

WE4D: 560 17:10 hrs

Design and Development of an Electromechanical Actuator Test Bench for Validation of Health Monitoring Models

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Electromechanical Actuators (EMAs) for aircraft flight controls are progressively replacing hydraulic systems in safety-critical applications. Hence, simple and accurate EMA numerical models are required for the real-time health monitoring of such equipment, as well as more detailed and computationally intensive simulations for design and training of machine learning surrogates. In order to validate these models, we developed a dedicated EMA test bench (Figure 1) intended to replicate the operating condition experienced by common flight control actuators. The bench is highly modular, allowing to easily replace components and test different EMA architectures. In order to contain costs and time associated to the development, we made extensive use of off-the-shelf hardware; most of the custom designed parts were manufactured through rapid prototyping techniques.

The test bench is able to simulate the operation of the actuator in nominal conditions and in presence of incipient mechanical faults, namely a variation of friction and an increase of backlash in the reduction gearbox. Sensitivity to electrical fault modes will be included in a future upgrade. The output of the test bench was compared to the predictions of numerical models in nominal conditions. The results showed a good matching between the two systems, which is promising for the use of such models within real-time health monitoring routines.

Keywords: Experimental validation, Lumped parameter models, Test bench, Electromechanical Actuator (EMA).

Session	[WE4E]—Autonomous system safety, risk, and security
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Amphi Jardin

WE4E: 519 16:10 hrs

Hybrid Modeling for the Assessment of Complex Autonomous Systems – A Safety and Security Case Study

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The automotive industry is facing various challenges with the introduction of autonomous vehicles. One significant aspect is the assessment and verification of safety and security concerns that the legislators and the public demand. New methods and tools are needed to analyze and assess these advanced systems by considering all relevant features and parameters, such as the interdependencies of safety and security while keeping the time effort reasonable. Hybrid models combining fast and accurate analytical approaches with relatively slow but realistic numerical approaches may be the answer to assess these complex systems while con-

quering state-explosion problems.

In this paper, we apply an existing hybrid model that combines an analytical and a numerical method on a complex autonomous system to perform a holistic safety and security assessment. Thereby we assess the system under two safety-relevant assessment modes, representing different fail-operational behaviors of the system. The goal is to show that the hybrid model is capable of assessing realistic system architectures while allowing the consideration of different assessment modes.

Keywords: Autonomous vehicles, Safety, Security, Reliability, Assessment, Hybrid model.

WE4E: 592 **16:30 hrs**

New Architecture for Determine the Safety- and Security Parameters Based on Standard for Autonomous Robotics

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In order to develop safe and autonomous systems in the automotive industry, for example, stable and reliable verification methods are of fundamental importance. In modern motor vehicles, more and more complex driver assistance functions are being implemented, such as the Electronic Stability Program (ESP), brake assistants or lane keeping functions. However, since malfunctions of the corresponding components cannot be completely ruled out, safety and fallback concepts must be provided for the event of a system failure. In this way, the driver can be assured of control over the vehicle.

In the following chapters, the practical and autonomous system problems are dealt with in detail and this is examined scientifically. Furthermore, possible malfunctions of an autonomous system, which can occur during driving, will be investigated and verified with a contribution based on a stochastic model. The most important foundations of a verification approach for an autonomous system, are the framework conditions. These should be as realistic as possible. In an autonomous system, such as a motor vehicle, the steering angle and steering speed are formed by the steering angle sensor. The vehicle speed is determined from the wheel speed sensors. To correctly detect the direction of travel, the wheel speed signals are signed. The yaw rate and lateral acceleration are redundant. Other model assumptions for the verification model can be based on the input signals, such as the sensors or switches and the electrical connection (CAN/ Flexray).

The monitoring algorithms are secured with the help of the software.

Keywords: Safety, Sensor, Probability, Reliability, Security.

WE4E: 620 **16:50 hrs**

The Use of Game Theory for Autonomous Systems Safety: An Overview

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The increasing use of autonomous systems (AS) aims to improve efficiency, costs, and safety of numerous operations. Yet, they also pose several safety challenges. Most of AS will operate in a dynamic environment, interacting with non-autonomous and/or other autonomous systems. The anticipation of both the AS and non-AS possible decisions during these interactions is crucial to identify and analyze potential hazards and risks, and to guarantee a safe operation. Game Theory (GT) has been increasingly used for modeling the interactions between AS and other agents in conflicting or cooperating situations. Recent applications of GT for AS also include the use of game-theoretical approaches for algorithm-testing and development, as well as for cyber-physical security assessment. Yet, the application of GT for analysis of AS operations under a risk perspective can still be considered in an early stage. This paper provides an overview of how GT is being applied to AS in the context of risk assessment. A review of the recent literature on GT applied to AS was carried out on the Scopus database using a combination of relevant keywords. It resulted in 100 articles within the period of 2015-2021. The articles were analyzed with regard to the technical domain of application and the scope of use of GT.

Keywords: Autonomous systems, Game theory, Game Theoretical approach, Risk assessment, Safety, Drones, Self-driving cars.

WE4E: 720 **17:10 hrs**

Social Engineering Exploits in Automotive Software Security: Modeling Human-targeted Attacks with SAM

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Security cannot be implemented into a system retrospectively without considerable effort, so security must be taken into consideration already at the beginning of the system development. The engineering of automotive software is by no means an exception to this rule. For addressing automotive security, the AUTOSAR and EAST-ADL standards for domain-specific system and component modeling provide the central foundation as a start. The EASTADL extension SAM enables fully integrated security modeling for traditional feature-targeted attacks. Due to the COVID-19 pandemic, the number of cyber-attacks has increased tremendously and of these, about 98 percent are based on social engineering attacks. These social engineering attacks exploit vulnerabilities in human behaviors, rather than vulnerabilities in a system, to inflict damage. And these social engineering attacks also play a relevant but nonetheless regularly neglected role for automotive software. The contribution of this paper is a novel modeling concept for social engineering attacks and their criticality assessment integrated into a general automotive software security modeling approach. This makes it possible to relate social engineering exploits with feature-related attacks. To elevate the practical usage, we implemented an integration of this concept into the established, domain-specific modeling tool MetaEdit+. The tool support enables collaboration between stakeholders, calculates vulnerability scores, and enables the specification of security objectives and measures to eliminate vulnerabilities.

Keywords: Automotive systems, Social engineering attacks, Design, Model-based development, Modeling, Security.

Session	[WE4F]—Civil Engineering
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Espace Grand Angle

WE4F: 289 **16:10 hrs**

Vehicular Loads Hazard Mapping Through a Bayesian Network in the State of Mexico

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Traffic counts collect information that is valuable, for example, in bridge and road design or maintenance processes. The average daily traffic volume is often the most collected measure of vehicular traffic, which is used in the design or assessment of major highways. Permanent control stations, situated in key locations of the highway network, gather data the entire year. However, one of the disadvantages of traffic count data is that most counters used, do not measure total vehicle weight and axle load data. Traffic counts display only the classification of vehicles, traffic volume, average daily traffic, and annual average daily traffic. Axle loads on the other hand are required, for example, as input in the design of pavement and new bridges, and the reliability assessment of existing ones.Weighin- motion (WIM) systems are usually used to collect vehicle load data. The State of Mexico (in central Mexico) has 115 permanent vehicle counting stations with 745 traffic counting points in its federally administered road network. However, due to the lack of WIM stations, it is not possible to obtain axle load data. In this paper, a Bayesian Network (BN) quantified with data from WIM stations in the Netherlands is used to describe the weight and length distribution of heavy vehicles registered in the permanent vehicle counting stations of the State of Mexico federal highways. The Dutch and Mexican vehicle types are matched according to similar characteristics. Later, synthetic WIM observations from the BN model are analysed through extreme value theory and vehicle loads with selected return periods are computed for all study counting points. The outcome is a mapping methodology with a linked database. The traffic volumes and extreme loads can then be easily found and compared with other highways in the network. This work shows that hazard maps can be implemented to provide importantly and summarized information to understand the risks of extreme traffic loads and to help in the reliability assessment and maintenance strategies of pavements and bridges.

Keywords: Traffic counts, Weigh in motion, Bayesian network, Traffic loads, Mapping, State of Mexico.

WE4F: 292 **16:30 hrs**

Bayesian Networks for Estimating Hydrodynamic Forces on a Submerged Floating Tunnel

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A submerged floating tunnel (SFT) is a novel structure that allows crossing waterways where immersed tunnels or bridges are not viable. However, no SFT has been built yet mainly, due to lack of experience. In consequence, there are several uncertainties regarding its design and construction. An effect that should be further investigated is the structural response of the SFT under the simultaneous action of waves and currents. For this purpose, extreme values of waves and currents that were generated through a vine-copula model are used as input in a statistical model based on Bayesian Networks (BNs). The BNs are used to study the conditional correlation (i.e the correlation between random variables conditionalized on a given event) between the hydrodynamic forces acting on the SFT and metocean variables such as waves and currents. This methodology was applied to a case study in China for a SFT aimed to be built at the Qiongzhou Strait. Moreover, the BN model was used to test twelve different configurations of the SFT, with varying submergence depths and diameter sizes. The proposed methodology can be used to provide a more realistic estimation of the forces on the SFT by considering the dependence between the variables of interest. Moreover, this methodology can be extended to test different configurations of the SFT and other hydraulic or maritime structures subjected to simultaneous loading.

Keywords: Submerged floating tunnel, Bayesian networks, Extreme values, Vine-copula, Waves, Currents.

WE4F: 302 **16:50 hrs**

Characterization of Long-period Ship Wave Loading and Vessel Speed for Risk Assessment for Rock Groyne Designs via Extreme Value Analysis

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During the last two decades, increasing vessel size in major German estuaries has led to the significant change of the local loading regime i.e. increased importance of ship-induced waves and currents. As a consequence, the intensity of ship-induced loads has increased considerably, resulting in damage to rock structures such as revetments, training walls, and groynes. Research into the causes of rock structure deterioration by the Federal Waterways Engineering and Research Institute (BAW) has shown that for large ships in relatively narrow waterways, the long-period primary ship wave loading has become the most prescient factor for rock structure damage. Looking into the future, it can be expected that the increase in the vessel dimensions will lead to an increase in the ship-wave loading. For this reason, analysing long-term changing trends of long-period ship waves and vessel speed to understand the wave-structure interaction is of significant importance. In this study, the stochastic characterization of long-period primary wave height, drawdown, and speed of the vessel through the water at Juelssand in the Lower Elbe Estuary was analysed via extreme value analysis and copula modeling, and the bivariate return periods were calculated. The one-parameter bivariate copula was utilized to analyse the data. The dependence pattern between the variables was investigated using five parametric copula families: Gaussian, Gumbel, Clayton, Frank, and student's t.

Keywords: Bivariate copula, Extreme value analysis, Juelssand, Long-period ship wave, Rock groyne, Wave-structure interaction.

WE4F: 446 **17:10 hrs**

Adverse Event Analysis in the Application of Drones Supporting Safety and Identification of Products in Warehouse Storage Operations

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The currently observed development of the Industry 4.0 concept causes the development of new technologies that support not only production processes in the smart factor, but also logistics processes including safety during warehouse inventories. For this reason, Logistics 4.0 systems use automatic data identification (barcodes, RFID) and autonomous vehicles. In the article, particular attention was paid to the use of unmanned aerial vehicles in logistic processes and thanks using them much higher level of safety during warehouse storage operations. They are used in particular for repetitive or hazardous operations where the human factor should be limited. The research area is the use of drones to support warehouse operations that are related to stock-taking. The aim of the article is to identify possible adverse events that may occur during the implementation of the drone mission and to classify them according to the selected classification criteria. The article presents the identified key adverse events and their causes. Then, they were classified based on the effects they generate for each stage of the measurement process. As part of the discussion, control measures and good practices were proposed that may reduce or even eliminate the occurrence of identified adverse events in the future. All the work was summarized in the final conclusions.

Keywords: Unmanned Aerial Systems – UAS, The drones, Logistics 4.0, Adverse events, Product identification, Inventory audit.

Session	[WE4G]—Asset management
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Atrium 3

WE4G: 345 **16:10 hrs**

Applying an Unsupervised Machine Learning Method for Defining Maintenance Significant Items

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The selection of Maintenance Significant Items (MSI) is a very important phase in the implementation of Reliability-Centered Maintenance (RCM) in any organization, being essentially a screening phase in which the number of items for analysis can be reduced and prioritized. Despite its importance, there are currently few studies that present systematic and structured methods for MSI identification. There are two phases to identify these items in a physical asset portfolio: firstly, based on the system study and analysis, the criteria and scales are established; secondly, the criteria evaluation for each item is performed. In the latter phase, generally, a Multicriteria Decision-Making (MCDM) method is used to rank the MSI. However, their intrinsic subjective evaluation can lead to bias results. To prevent this issue and simplify the process, this work proposes the use of an unsupervised method based on Principal Component Analysis (PCA). With this method application, not only the MSI of a system are defined, but also the importance of the criteria selected in the first phase is assessed based on the variability of the scores associated with each item. To demonstrate the method, it is implemented considering data from a hydroelectric power plant, and the results are compared to those obtained from a more traditional approach. It is noted that the proposed method points to a robust MSI selection, consistent with the analyzed system.

Keywords: Maintenance significant items, MSI, Machine learning, Principal component analysis, PCA, Multicriteria analysis, Multicriteria decision-making method, MCDM, Reliability-centered maintenance, RCM, Hydroelectric power plant.

WE4G: 444 16:30 hrs

The Ageing Challenge of Hazardous Installations in Italy: Accidents, Results of Inspections and Good Practices

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The Seveso III Directive 2012/18/EU, implemented in Italy by a legislative decree issued in 2015 (D.Lgs. 105/2015), imposes an obligation to provide a plan for monitoring and control of risks related to ageing of equipment and systems that can lead to loss of containment of hazardous substances, including the necessary corrective and preventive measures. In order to frame the issue, an overview of the Italian law and national standards and guideline concerning ageing and asset integrity is given, also focusing attention on the role of Public Authorities in addressing ageing in hazardous installations. The main outcomes of the analysis of some industrial accidents, that recently occurred at Italian "Seveso" establishments, where ageing mechanisms have been identified as a significant cause, in terms of technical and organizational factors, are then presented. Starting from some examples on how organizations manage these problems through specific procedures oriented to the "asset integrity management", a brief description of the processes and methodologies implemented and a focus on good practices about the methods used to assess industry's response to ageing issues are proposed. In addition, the paper describes the results, lessons learned and return of experience of Safety Management System inspections, conducted in Italy in the last three years, where weaknesses emerged with reference to ageing and asset integrity of the hazardous installations inspected (deterioration and degradation caused by corrosion, erosion, stress, fatigue).

Keywords: Seveso, Ageing, Integrity, Hazardous, Accidents, SMS, Inspections, Practices.

WE4G: 613 16:50 hrs

Benchmarking and Compliance in the UK Offshore Decommissioning Hazardous Waste Stream

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The decommissioning sector of the United Kingdom offshore oil and gas industry is growing rapidly due to the number of ageing installations within United Kingdom waters. In line with current United Kingdom requirements, installations must be decontaminated from hazardous waste before any part can be reused or recycled. This hazardous waste must be handled, transported, and disposed of in a way that does not impact safety or the environment. This research project analyses the key issues associated with the handling of hazardous waste during the decommissioning of offshore installations with the United Kingdom Continental Shelf. A comprehensive literature review and analysis of decommissioning close-out reports was conducted to allow for the key issues to be identified. Expert judgements were sought and analysed using an analytical hierarchy process. This study emphases the need to improve the handling of hazardous materials during the decommissioning process. The clarity of legislative requirements, identification of hazardous materials and sharing of knowledge and experience are areas that require improvement to meet the increasingly stringent environmental and sustainability requirements.

Keywords: Offshore decommissioning, Waste management, Legislation, Analytical hierarchy process, UKCS.

WE4G: 627 17:10 hrs

Analysis of Failure Rate and Time of Water Pipes Failure Removal

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The water supply system operation should be characterized by low operating cost and high operational reliability. The water supply system reliability involves operation with proper conditions so as to guarantee water supply to the recipients. The assessment of the reliability of the water supply system is considered in terms of ensuring the required pressure and the required water quality and at any time convenient to the water recipients. For this reason, the analysis of water supply network failure and related issues is an important issue in assessing the proper functioning of the water supply system. In this work, the analysis of selected factors influencing the failure removal time of water pipes on the example of the water supply system in the south of Poland was presented. The analysis of failure removal time was performed for the following factors: water pipe functions, water pipe material and diameter, type of water supply network, failure and season. The analysis was based on the real operation data obtained from the water company. The presented analysis of the failure removal time in terms of cost of planned maintenance is an important issue which will allow for failure prediction and the initial estimation of the costs of failure removal, which in turn, will allow for a long-term budget planning in water companies.

Keywords: Failure analysis, Failure time removal, Pipeline failures, Water pipes.

Session	[WE4H]—Automotive Industry
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Cointreau

WE4H: 112 16:10 hrs

Reliability Study of the Motor Controller of Pure Electric Vans

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The market of electric vehicles (EVs) is rapidly growing across the world attributed to their unique feature of zero carbon emission. Take the Chinese market as an example, 984,000 pure electric vehicles were sold in China in 2018, which is an increase of 50.8% over the same period of the previous year. This means there will be more and more electric vehicles will run on the road in the future. However, the reliability of these electric vehicles is still an open issue remaining to resolve today. In particular, the reliability of the motor controller in electric vehicles is receiving more concern than ever before. On the one hand, this is because it is well known that power electronic components in the controller are much less reliable than the mechanical components in other EV subassemblies. One the other hand, it is because the failure of motor controller may lead to dangerous accidents on the road. Previously, much effort has been made to try to predict the reliability of motor controller, however detailed investigation of its reliability issues has never been done before. In view of this, a detailed reliability study of the motor controller in pure electric vans will be conducted in this paper, with the consideration of the fact that more than 90% of sold commercial electric vehicles are pure electric vans. In the research, the detailed root causes of the reliability issues in the motor controller will be investigated first and then based on which the failure rates of individual components (e.g. control module, driver module, communication module, and discharging module) in the controller will be estimated with the aid of fault tree analysis and the international standards IEC TR62308-2004, MIL-HDBH-217E and the technical standards for the Chinese electric vehicle industry. Finally, the tendency of the unreliability index of the entire motor controller against the service life of the electric vehicle is estimated based on the fault

tree analysis results in order to obtain a more reliable understanding of the reliability performance of the motor controller over time. From such detailed reliability research, it has been found that the reliability performance of the motor controller will degrade gradually over time; and among the four functional modules of the controller the control module is most vulnerable, followed by driver module. This could be due to the application of more electronic components and thinner printed lines on the modules.

Keywords: Reliability, Pure electric van, Motor controller, Fault tree analysis, Motor system.

WE4H: 183 **16:30 hrs**

Reliability Engineering of Electric Vehicle Powertrains: Data Collection and Analysis Based on Products in the Usage Phase

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In recent times, the climate change has a massive impact on the choice of the drive technology of newly developed vehicles. The transformation to a reliable, safe and sustainable powertrain is pursued. The automobile industry is changing accordingly and the market shares of electric and hybrid vehicles have increased significantly. The data of electric vehicle powertrains differs from combustion vehicle powertrains for example in types of measurable and analyzable signals, usage behavior, and influence factors which have an impact on the components and systems of the powertrain. For the understanding and consideration of real conditions, it is important to collect field data of electric vehicles. To evaluate and improve the reliability, safety and sustainability of electric vehicle powertrains a comprehensive field data based assessment is needed. In this paper the acquisition and the analysis of field data of electric vehicles regarding the reliability, safety and sustainability of electric vehicle powertrains are presented. Requirements for the system architecture as well as data generation, pre-processing and management are outlined.

Keywords: Reliability engineering, Electric vehicle powertrains, Field data, Sustainability, Safety, Influence factors, Usage behavior, Data logging.

WE4H: 190 **16:50 hrs**

Driving Factors for Driving Simulators A Feasibility Study

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Simulators are used for training purposes in many sectors where humans are required to perform in a safe and reliable manner and the costs and consequences of accidents are high (e.g., aviation, nuclear, oil and gas). Driving simulators are sparsely used in driver training, even though performing in a safe and reliable manner is without a doubt of high importance, and traffic accidents are among the most common cause of deaths around the world. This paper evaluates the factors influencing the development towards increased use of simulators in driving training, both enablers and barriers, discussing both current condition and future scenarios. Four different fidelity levels in driving simulators are presented; very low, low, medium, and high, and scenarios where these are used are discussed. The conclusion of the feasibility study is that there exist several potential markets for all four levels of fidelity in simulators, particularly set by demographic parameters and simulator content. The exploitation of this market depends strongly on the suppliers' willing to adapt their product to market-specific needs and opportunities. Many simulator solutions reduce interaction between student and instructor. However, the driver instructor is still considered important in forming the students' holistic understanding of driving, road attitude and understanding of risk.

Keywords: Driving simulator, Training, Feasibility study, Enablers, Barriers, Technology adoption.

WE4H: 250 **17:10 hrs**

Simulation of Parallel Layered Air Cooling Thermal Management System for Li-ion Batteries

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Battery thermal management structure design is an important measure to ensure high reliability and long life of battery. This paper combines the advantages of parallel ventilation and layered air channels and proposes a new parallel layered air cooled structure to improve the heat dissipation effect of the battery pack. The structure uses thermal conductive partitions to divide the air channel into upper and lower parts, and adopts a design where two independent fan channels work simultaneously. The upper and lower channels adopt reverse Z Type ventilation. Firstly, the anisotropic heat transfer model of Li-ion battery is established based on the heat generation theory. Then, combined with the heat transfer model, the influence of different flow directions on the heat dissipation performance is studied by using FLUENT simulation software. Finally, the thermal management structure proposed in this paper is improved and optimized. The results show that the maximum temperature and the maximum temperature difference of the battery pack decrease after using the parallel layered air cooling structure, and the temperature field distribution of the battery pack is obviously improved; after increasing the number of outlets, the maximum temperature of the battery pack decreases by 9.55%, the maximum temperature difference decreases by 16.56and the heat dissipation performance is further improved.

Keywords: Li-ion battery, Layered air cooling, Thermal management, Dissipate heat, Structural optimization, FLUENT.

Session	[WE4I]—Artificial intelligence for reliability assessment and maintenance decision-making
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Giffard

WE4I: 540 **16:10 hrs**

Supplementing Fault Trees Calculations with Neural Networks

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The use of artificial intelligence algorithms is rapidly gaining ground in engineering applications, including safety engineering. In this paper, we investigate the possibility of using neural networks to supplement fault trees in the safety analysis for the estimation of reliability and importance metrics. For this aim, we employ data from an existing fault tree that models cruise ships blackouts to train a neural network that uses base-event probabilities as input and outputs the estimated top-event probability/frequency. This is done to reduce computational time, as the fault tree model has an extensive number of basic events and is thus computationally demanding. The information that is used as input to the Fault Tree is randomly sampled from a Sobol sequence and is used to estimate the top event probability. The resulting data cloud that corresponds to the faut tree's input-output pairs, is used to train the neural network. The two models, i.e. the probabilistic and the neural network model, are compared to each in other in terms of accuracy and computational cost correlated with the number of sampling points that is used. The Fault Tree is developed in Matlab/Simulink and the neural network in Python. For case where the Neural Network is trained using 10,000 points, a 350 times decrease in computational cost is observed compared to the fault tree model, while the mean absolute percentage error (MAPE) remains at under 15%. Based on the results, recommendations for the application and future improvement of the artificial intelligent algorithms in the specific context are made.

Keywords: Neural networks, Fault tree, Blackouts, Machine learning, Safety engineering, Metamodeling.

WE4I: 565 **16:30 hrs**

Prioritization of Culvert Maintenance Combining Multi Criteria Decision Models and Data Mining Techniques

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A current challenge of modern societies is to keep aging infrastructure systems operative and in good condition. Given limited maintenance resources, a risk-based approach to the prioritization of maintenance actions is required. Multi Criteria Decision Models are suited for this task because they allow a combination of qualitative and quantitative information about several risk indicators which are also characterized by different unit measures. However, complex decision problems characterized by too many alternatives, attributes, and criteria are difficult to be tackled. Therefore, methods are required which support and simplify the application of these models for the risk assessment of aging infrastructures. This paper proposes the integration of Multi-Criteria Decision Models with Data Mining techniques. A cluster analysis based on the K-medoids algorithm is carried out in order to reduce the number of alternatives and identifying those which dominate or are dominated within the decision problem. The SMARTS model is then applied in order to aggregate single-attribute utility functions and compute the preferences over the alternatives. The proposed approach is applied to a system of aging culverts of the German waterways network. Results show that the proposed procedure allows a quick but comprehensive and easy to interpret risk assessment of aging infrastructures. The method shows also a great potential for considering multiple system levels and failure scenarios. These represent the next steps of this research.

Keywords: Maintenance backlog, Risk-based maintenance, Multi-criteria decision models, SMARTS, Data mining, K-medoids algorithm.

WE4I: 600 **16:50 hrs**

Deep Reinforcement Learning-Based Maintenance Decision-Making for a Steel Production Line

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In the 4.0 industry, the adoption of system monitoring technologies provides a large amount of data about the health of the system, which raises a challenge to adopt condition-based maintenance (CBM). Due to its capability to act into the system in real-time based on its embedded condition monitoring equipment, which can help to reduce O&M cost and enhancing the system availability, CBM has become a relevant approach for industry competitiveness. However, to take the advantages of huge data in maintenance decision-making, an important issue to be considered is the large space of states and actions, which is difficult, even impossible, to cope with the traditional maintenance model. To overcome this issue, integrating emerging tools of Machine Learning and Artificial Intelligence into maintenance decision-making and optimization seems to be promising. Therefore, this work proposes a Deep Reinforcement Learning (DRL)-based maintenance optimization for a steel production line, in which the maintenance decisions are made based on the real-time data about the system condition. The production line under study uses metal scrap as the raw material for the steelmaking. Before its usage, the scrap needs to be crushed in a shredder machine, which is the most crucial process. An intermediated buffer is used to keep supplying crushed scrap for the remaining stations when the machine is turned off for maintenance actions. A simulation model is built to simulate the dynamic of the production line. A DRL framework is then built to learn through the interactions with the environment in finding the optimal maintenance policy with lowest maintenance cost. A numerical case study is performed to evaluate the proposed DRL maintenance approach comparing with conventional maintenance policies. As result, the proposed DRL approach shows a better result in terms of cost along with the increase of the system availability.

Keywords: Deep reinforcement learning, Maintenance, Steel production line, Simulation model.

WE4I: 763 17:10 hrs

A Method based on Gaussian Process Regression for Modelling Burn-in of Semiconductor Devices

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Burn-in is a systematic screening method to ensure the reliability of semiconductor devices. It consists in the operation of the manufactured devices under accelerated stress conditions, such as high temperature and voltage. The aim is to remove the devices that would fail in the initial portion of the bathtub curve of the failure rate and estimate the corresponding Early Life Failure Rate (ELFR) value. In practice, performing burn-in is costly and time-consuming, particularly for new technologies. In this context, the present work aims at developing an Artificial Intelligence (AI)-based method to: i) predict the number of defective semiconductor devices within a production lot by resorting to signals measured during the production process; ii) estimate the early life failure probability of the manufactured devices. The method combines: a) dimensionality reduction by Principal Component Analysis (PCA) for the extraction of features characterizing the production process from the measured signals and b) Gaussian Process Regression for the prediction of the number of defective devices in the lot. The method is applied to artificial data simulated to emulate burn-in process data. The obtained results show a satisfactory accuracy in the prediction of the number of defective devices in the lot and of the corresponding early life failure probability.

Keywords: Burn-in, Early life failure rate, Gaussian process regressiom, Principal component analysis, Semiconductor devices, Clopper-pearson test.

Session	[WE4J]—Effectiveness, Management and Reliability of Natural Risks Reduction Measures and Strategies
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Botanique 2

WE4J: 257 16:10 hrs

Coupled Numerical Model CFD-DEM of Debris Flows Impact to Improve the Vulnerability Quantification of Structures

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Debris Flows (DF) are dangerous events that can causes up to the complete destruction of structures (buildings, bridges…). They represent high risk for the public safety.

We developed a numerical model to evaluate the impact pressure (P) of mass flows by better describing the effect of boulders: the boulders' size strongly influences the impact pressure, which has a considerable effect on the structure's damage [1]. The model can help for the design of civil protection measures by quantifying the vulnerability of the structures. The numerical model proposed considers a one-way coupling granular-fluid model based on a Distinct Element Method (DEM), using separated Computing Fluid Dynamics (CFD) calculation results for the fluid phase.

This model estimates the impact of the boulders at the pillar' local scale (Fig.1). The pressure due to fluid phase can be added afterwards. These measures were validated by empirical models [2]. The vulnerability of the structure depends on the intensity of DF: P is chosen as an intensity that indirectly integrates the height, velocity and boulder' size of DF [3]. An improvement of the existing vulnerability function is proposed based on our simulations considering a new parameter as the maximal diameter d_{max}: we will be able to estimate the value of the pressure (therefore vulnerability) taking into account d_{max}. These results help engineers to prepare defense structures and to build advanced engineering solutions based on the boulder's size for the prevention and mitigation of risks caused by different flows.

Keywords: Debris flows, DEM, CFD, Impact pressure, Damage, Vulnerability.

WE4J: 275 **16:30 hrs**

Performance of the Sediment Control Dams Built After the 1999 Debris-Flow Disaster in Vargas

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The state of Vargas, in northern Venezuela, was devastated by multiple landslides and debris flows in December 1999. In a period of 8 years (2001-2008), 63 check dams were built by government authorities to protect the downstream population. The main function was to retain and sort the sediment material. A few of them were built to stabilize the river bed (consolidation dams). Basically, 37 of the structures are closed-type dams and 26 are open dams (slit, window or beam type). Regarding the construction material, 44 dams were made of gabions, 14 of concrete, three of steel pipe and two made of flexible barriers (Lopez, 2020). In this paper, a critical review of the performance of the check dams is attempted, based on 20 years of experience (field observations and topographical surveys). The morphodynamic effects in the channel beds after dam construction are discussed and summarized.

Dams were tested by two subsequent floods in 2005 and 2010, where thirteen dams retained about 300.000 m^3 of sediment protecting the towns of Maiquetia and Camuri of a new disaster. However, some dams were affected by the floods. Two gabion dams in Anare were destroyed by lateral bypassing of the flows. Another gabion dam in Caraballeda collapsed by scouring of a lateral abutment (Fig.1). Partial damages have also been observed in some structures due to abrasion of concrete coating and removal of gabion rows by rock impacts. Most of the dams were subjected to a rapid pace of sedimentation, even the open dams, due to large sediment yield and woody debris transported by the flows that clogged the openings. However, a partial selfcleaning process has taken place in some of the slit and beam dams. Additionally, channel degradation has occurred in some downstream reaches caused by the "hungry water" effect due to the interruption of bed load transport as sediment was being trapped upstream. Significant bed erosion, between 2 and 4.5 m has been measured at the foot of a few dams. In some cases bed lowering has been caused by downstream gravel extraction activities.

In conclusion: a) Six dams and three counter dams have been totally or partially destroyed by subsequent floods; b) Three dams are in imminent danger due to significant bed lowering at the foot of the structure; c) all closed dams (37) are already full of sediment, so they cannot mitigate future debris flows; d) maintenance has been poor or almost inexistent; e) in most cases no access roads for machinery and equipment were provided to remove the sediment material retained in dams; f) a feasibility study is required to analyze which one is the best solution: removing the accumulated sediment upstream of the structures or building new dams; g) the presence of the control works (dams and channels) has created a false sense of security and new houses have occupied the river banks. Efforts have to be made to improve land use regulations and enforce the law to prevent reoccupation of areas subject to high levels of hazard.

Keywords: Debris flows, Vargas, Venezuela, Check dams, Performance.

WE4J: 640 **16:50 hrs**

Optimizing Recovery Strategies for Interdependent Lifeline Systems Exposed to a Natural Hazard

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Natural hazard events can lead to large-scale failures in lifeline systems. By enabling a fast recovery of these systems following failure events, one enhances their resilience. However, this resilience also comes at a cost, e.g. if additional reparation crews need to be hired. In this contribution, we present a work towards the identification of a robust recovery strategy that optimizes the trade-off between the downtime and losses on the one hand and the cost for enhancing resilience on the other. We use a simplified model of the network [1] and simulate system failure events [2] based on a stochastic set of natural hazard scenarios. We employ the frameworks described in [3,4] for modelling the system recovery, and identify the relation between recovery costs and the losses associated with system downtimes. Furthermore, we investigate the influence of the interdependence between lifeline systems in identifying the optimal recovery strategy. We illustrate the methodology with an example of interconnected power and water networks exposed to a seismic hazard.

Keywords: Resilience engineering, Critical infrastructure, Lifeline systems, System recovery, Network analysis, Interdependent systems, Resilience cost.

WE4J: 670 **17:10 hrs**

Integrating Imperfect Information in the Deterioration Modeling of Torrent Protection Measures for Maintenance and Reliability Assessment

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Among several types of natural risks' protection measures, check dams are the most dominant in French mountains. Over their lifetime and while being subjected to severe phenomena such as torrential floods, the check dams' efficacy will be affected and therefore the level of protection provided by these structures will be reduced. Available budgets oblige risk managers to establish priorities between different maintenance strategies to be applied on structures that require maintenance. Modeling the dynamic deterioration of check dams and making decisions on their maintenance always depend on the amount of available data, diverse sources of data, assumptions, etc. This paper focuses on assessing the influence of uncertain inputs on the outputs obtained from a check dam's deterioration and maintenance model. The end purpose of such analysis is to support check dams' maintenance decision-making under the effect of information imperfection.

Keywords: Natural risk, Check dams, Deterioration modeling, Efficacy assessment, Maintenance decision-making, Information imperfection.

Session	[WE4K]—Manufacturing
Day/Date/Time	Wednesday, 22 Sep. 2021/16:10–17:30 hrs
Venue	Atrium 1

WE4K: 287 **16:10 hrs**

Causes of Failure of Experimental Molten Salt Research Device

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In today's practice, molten salts are used in thermal energy storage technologies, solar tower technology, and the development of Generation IV nuclear reactors. The paper deals with the construction of an original experimental device for the research of the physical and chemical properties of molten salts, the behavior of molten salts, and corrosion effects of molten salts on various construction materials built in the Research Centre Řež. Due to experience with the first device construction, the risk-based design was chosen for the final device. The procedure of risk-based design is described. Based on this analysis, the critical points of the device were identified, the geometric modifications were made to the structure, and, with the help of the CFD tools, three modes of operation were established: normal, abnormal, critical in the event of a power outage. Resulting changes together with precisely defined operating regulations ensure safe construction, operation, and maintenance of the experimental device.

Keywords: Molten salt, Device failure, Risk-based design, Risk-based operation, CFD tool, Checklist, Reconstruction, Molten salt loop.

WE4K: 403 **16:30 hrs**

Working Situation Health Monitoring: Proposal of Method and Case Study

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In a working situation on an automated assembly machine, technical drifts during operation can lead to machine dysfunctions. These dysfunctions may cause the operator supervising the machine to adapt and respond to reduce the effect of these technical drifts on the rest of the working situation. To respond to these dysfunctions the operator may expose him or herself to hazards and thus be in a hazardous situation. (Lamy & Perrin, 2020) showed the feasibility of identifying this kind of potentially hazardous situation by observing the working situation. Here, we propose a method called Working Situation Health Monitoring (WSHM). The goal of this method is to identify these potentially hazardous situations by analyzing the potential drift of working situations and monitor the advent of potentially hazardous situations using equipment and production data. It consists of three steps: firstly, we model the working situation studied to characterize the nominal working situation; secondly, we analyze cause-and-effect relationships between potential process drifts, potential operator responses and potentially hazardous situations; and thirdly, we construct a health indicator of the working situation based on knowledge of potentially hazardous situations identified in the second step and by equipment data. This paper also presents the application of the method to a case study (an educational automated assembly machine).

Keywords: Occupational safety, Dysfunctional analysis, Work situation, Technical drift, Human-Machine interactions, Human error, Hazardous situation analysis, System modeling.

WE4K: 589 **16:50 hrs**

Risk Assessment in the Manufactoring Work Environment: Towards a Customised Risk Assessment

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A general process of customization at the individual level is ongoing in several branches from the precision and personalized medicine (Duarte et al. 2016) to the individual financial and marketing methods (Matz, 2017).

Risk assessment in manufacturing generally neglected the influence of the personal characteristics of the worker involved, strongly limiting the effectiveness of the risk based decision making. This paper is focused on the development of an innovative approach to explicitly take into account the individual characteristics of the operators (human factor) within the risk assessment in the work environment.

Human factor is assessed with a set of tests applied during the working activity. The resulting method allowed the definition of a personalized risk assessment based on the individual skill and characteristics of each worker potentially involved (Human Capability) and the characteristics of the task (Workload).

Preliminary results showed a relevant influence of human factor on the risk and consequently allowed the identification of area of intervention not highlighted within the more traditional risk assessment approach.

First line of development is represented by a more detailed evaluation of the rules that manage the interaction between Human Capability and Workload. Promoting a more detailed analysis on the importance of the single index in relation to human error probability of occurrence would make the model more accurate. This could be done at level of the single task, identifying for any operations the variables (memory, dexterity, etc) more stressed and which are less solicited.

Second line of development could be focused on the shifting from practical test to the most recent tools related to the individual physical performance monitoring and visual behavioural monitoring.

This will allow a migration from a discontinuous to a continuous data collection with a consistent upgrade in term of representativeness of results.

Keywords: Workplace risk assessment, Human capability, Workload, Human factors.

WE4K: 609 17:10 hrs

Image Based Wear Behaviour Analyis of Cutting Tools

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In general, wear is caused by high mechanical forces acting on the cutting tool and the high temperatures generated by these forces. The mechanical and thermal loads depend on various parameters, such as the material of the cutting tool, the material of the workpiece, the cutting speed, the feed rate, the cutting fluid or the ambient conditions. To estimate the mechanical and structural reliability of the cutting tools, images of the teeth from different stages are analysed (after the cutting process and pregrinded). Depending on the sawn material, a rating can thus be made on the degree of wear and the remaining service life. The colour gradient of the images is determined and statistically evaluated in order to draw conclusions about the type of wear and defects of the cutting tool. The tool geometry of the teeth is recorded from different perspectives. Through the formation of characteristic values, a simple evaluation method of the tool reliability is presented. This research work contributes to the image based analysis of machining processes and wear behaviour of cutting tools using statistical methods that allow comparability. In this process, important knowledge is gathered with regard to the degradation behaviour and the prediction of the service life of cutting tools.

Keywords: Manufacturing, Cutting tools, Image analysis, Mechanical and structural reliability.

Abstracts — Thursday, 23 September 2021

Session	[TH1A]—Risk Assessment
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Plenary Room

TH1A: 517 **09:00 hrs**

Web App to Support Hazard Identification of Oil Refineries

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Hazard identification is one of the first steps of Quantitative Risk Analysis (QRA) and it is crucial to ensure the quality of the analysis. However, this step is very time consuming, especially for complex systems such as oil refineries, because risk expert need postulate all the accidental scenario. Thus, this process relies on examination of a variety of engineering documents and the attendance to numerous meetings. The hazards identified are usually recorded in form of textual data; thus, these documents store valuable information about the risks related to the analyzed system and that was widely discussed by experts. Natural Language Processing (NLP) allows extracting, organizing, and classifying information from text. For this reason, NLP was applied to build models to retain specialists' knowledge that can be lost overtime. Therefore, we developed Hazard Analysis based on Language processing for Oil refineries (HALO), a web app to support risk analyst in identifying and assessing different accident scenarios related to chemical spills in oil refineries. The app was built on valuable information gathered from past risk studies, allowing experts to use that entire source of knowledge in the early stages of QRA. In summary, the app contains NLP-based classifiers able perform different multi-classification tasks to identify three risk features: 1) potential consequences of accidents related to the operation of an oil refinery, and to classify each accidental scenario in terms of 2) severity of the consequence and 3) likelihood of occurrence. Moreover, the app displays visual outputs, including word clouds for the description of similar systems found in our database and a bar chart to illustrate the distribution of the potential consequences related to chemical spills in similar systems. These visual outputs summarize the knowledge contained in previous risk studies and allow the user (risk analyst) to gain insight into the analyzed system. Thus, it will be possible to support risk analysts to complete the early stages of a QRA.

Keywords: Risk analysis, Text mining, Natural language processing, Oil refineries, Web app, Major accidents.

TH1A: 531 **09:20 hrs**

Fault Tree Modeling of Human Error Dependency in PSA

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In probabilistic safety assessment(PSA) of a nuclear power plant, a human failure event is one of the events that have high risk contribution. In addition, dependency between the events may increase the risk contribution. This is because the success or failure of a previous action can affect the subsequent action. In the case of the scenario in which more than two human failure events occur, human error dependency should be analyzed and reflected in PSA. For this reason, the probability of a human failure event may be different depending on the accident scenario or other human failure events. When the residual heat removal is unavailable after failure of makeup the coolant in an overdrain accident at low power and shutdown, feed and bleed operation may be needed to prevent core damage. There are two cases when feed and bleed is required after the failure of coolant makeup due to machinal failures and due to a human failure event. The human error probability of feed and bleed after a human failure event of the makeup may be higher because of the dependency. [1,2]

Human error dependency has been reflected through the post-processing. There are several limitations in the existing method because the dependency is reflected after minimal cutsets are derived. Several minimal cutsets may be improperly truncated by the cut-off value. Propagation on a fault tree is also difficult. This study proposes a method of modeling the human error dependency on the fault tree. We also provide the applicable cases to model the human error dependency into the fault tree. This method can be practically applicable to a PSA model while supplementing the limitations of the existing method.

Keywords: Probabilistic safety assessment, Human error dependency, Fault tree, Post-processing.

TH1A: 535 **09:40 hrs**

Towards a Relational Model for Collaborative Safety and Security Risk Assessment Processes

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Risk assessment is an important issue in cyber-physical systems as they confronted to risks with accidental and malevolent origins. These risks fall respectively under the banners of Safety and Security and each discipline has a distinct set of practices for risk assessment and risk analysis. However, the growing need to combine and bring together risk assessment processes from safety and security has led us to look for ways to join the processes and thus deal with the various interactions between safety and security. We observed that risk assessment processes from safety and security dealt with several entities that sometimes overlap and that sometimes are linked together (such as feared events, requirements, risks, threats, countermeasures, etc.). We took interest in identifying these entities and the relationships that can occur between them in a relational model that would describe a Safety and Security joint risk assessment process. In this paper, we present our relational model to constitute a knowledge base that includes all the entities manipulated in Safety and Security risk analyses and their interrelations We further show the means to implement and use the knowledge base effectively to answer questions about Safety and Security risk interactions.

Keywords: Safety, Functional safety, Security, Cybersecurity, Risk analysis, Risk assessment, Relational model.

TH1A: 562 **10:00 hrs**

A Predictive Model for Quantitative Assessment of Aviation Terror Incidents Based on Geo-Political Environment

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Over the past 20 years the aviation industry demonstrated significant growth from 1.5 billion passengers travelled by air in 1998 to more than 4.3 billion in 2018. Managing security risks remain a significant challenge in the aviation industry because security events are rare and thus harder to predict. (Cliton et al, 2013). Industrial regulations of International Civil Aviation Organization (ICAO, 2013) and International Air Transport Association (IATA, 2019) require air carriers to conduct risk assessments. They, however, do not provide specific tools or standards for it.

At the same time, aviation stays an attractive threat for international terrorism. Since the attacks of September 11, 2001 that triggered most drastic changes in aviation security, a number of terror attacks against aviation involving casualties as well as foiled attempts occurred. Besides terror related events, several fatal incidents related to shooting at the civilian aircraft by surface-to-air missiles occurred.

In the past the spread of security related information was via traditional media. Therefore, the approach to assessment of threats was rather reactive due to limits in speed of information spread, the method of analysis and the distribution of information about potential risks for air operations (Cullen, 2014). Currently, information about terror attacks, wars or conflicts is instantly available through various internet channels, turning threat assessment to proactive and predictive ways. However, the most popular methodologies for threat assessment used by the industry are qualitative ('low', 'medium', 'high') and subject to misinterpretation by users (Renooij and Witteman, 1999). Therefore, this study explores the potentials to employ a quantitative approach. United Nations (UN) lists several factors that influence on aviation security, such as economic threats, internal and inter-state conflicts, terrorism and organized crime (UN, 2004). This paper examines how these factors influence security related incidents and develops a threat assessment model to predict the likelihood of terror incidents. The data employed includes 1079 cases of hijacking, 90 cases of bomb sabotage and 276 cases of surface-to-air shooting at aircraft between 1947 and 2018. The proposed methodology can complement the existing methodologies for aviation security risk assessment.

Keywords: Risk, Aviation, Security, Threat assessment, Quantitative, Predictive model.

Session	[TH1B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Atrium 2

TH1B: 580 09:00 hrs

Continuous Models for Discrete Data of Residual Contamination

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In the article, we focus on the residual contamination of surfaces with toxic agents, namely, on ways to model the measured residuals and on its statistical properties, which can serve as a basis for an automation procedure.

The efficiency of decontamination is assessed by point detectors, which is conditioned by finding contaminants on a contaminated person. An implementation of contamination control chambers with a suitable chemical detector able to perform analysis of contamination residuals was proposed. Based on the experimental results, optimal conditions for residual contamination control with the selected detector were introduced. And operation procedures for running a check on the decontamination efficiency in the contamination control chamber for Integrated Rescue System units were introduced.

The objective of this paper is to determine if there is statistical evidence for different behavior of the contaminant detection under different ambient conditions. Even though we are limited by the pieces of information available, we want to present a statistical evaluation, which shows possible ways of modeling.

The data are measured at discrete time points, although they represent a continuous function. Therefore, we introduce a functional data analysis approach. Functional data analysis deals with the data in their general form, i.e., with data in the form of curves or images. In our analysis, we employed parametric and nonparametric regression models to convert discretely measured data into a functional form. Then, we constructed a mean and variance function for the respective measurement conditions. The tests directed to validation of significant differences showed that a certain level of discrepancy is present; however, they are only in partial accordance with results given within the experiment description, namely, in terms of the ambient temperature and type of the toxic agent.

Keywords: Residual contamination, Regression model, Functional data, Non-parametric statistics.

TH1B: 621 09:20 hrs

Design Verification by Small Sample Locati Experiments

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The Locati method is a fast and efficient method for fatigue testing in technical areas. It is a accelerated version of the staircase test, which is applied in automotive engineering for the determination of a component's latent tolerance distribution. Especially for large and expensive components testing until failure by increasing stress levels is an attractive alternative to the staircase test procedure. But unlike for staircase tests it is not evident how to analyze the test results in order to obtain the required tolerance distribution. In this paper we present two methods, one based on a cumulative exposure model and the second based on the Miner rule of damage accumulation. We study their performance in a simulation experiment and based on the results finally give a recommendation.

Keywords: Locati, Sensitivity testing, Fatigue life, Miner rule, Wöhler curve, Step stress, Cumulative exposure.

TH1B: 648 09:40 hrs

Genetic Algorithm Approach with Network Configuration for Bi-Objective Network Optimization

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In the real world, many infrastructures, for example, Internet, power/water supply and traffics, are network systems needed high reliability. Independently, these systems may cost to construct or maintain links in the networks. In this study, we consider a bi-objective network with objectives of maximizing all-terminal reliabilities and minimizing costs. In general, these objectives are in trade-off relation, and cannot be optimized simultaneously. Therefore, solving the

problem is to find the set of all Pareto solutions.

On the other hand, the problem of evaluating all-terminal reliability of a given network is computationally intractable (Koide 2002), which suggests that our bi-objective problem is also computationally intractable. Therefore, Takahashi et al. (2018) provided a Genetic Algorithm (GA) to find a set of quasi-Pareto solutions. However, this algorithm needed much running time when the number of nodes was large.

In this study, we propose a GA algorithm which finds non-dominated solutions close to Pareto solutions. Proposed algorithm reconsiders the selection process to select all nondominated solutions and "good" solutions as parents in each generation. In addition, we analyze the GA process, and the crossover process reflects not only component criteria but network configuration. And then, the accuracy of our proposed algorithm is evaluated based on comparison with other algorithms.

Keywords: Network design problem, Bi-objective network, All-terminal reliability, Quasi-pareto solutions, Genetic algorithm.

TH1B: 653 **10:00 hrs**

Drone Fleet Evaluation by Structure Function based Method

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One of new devices in the monitoring is unmanned aerial systems (UAS) or drones which can be used of dangerous and inaccessible territories monitoring. The approaches for the decreasing of the failure rate should be developed. This investigation can be implemented based on method and approaches of reliability engineering. The first step in the reliability analysis is development of the mathematical model of the investigated system. In this paper the representation of the fleet drone is considered as the k-out-of-n system. The analysis of this mathematical model is implemented by the structure function based mathematical methods. The calculation of the availability, unavailability and some importance measures are considered.

Keywords: Availability, *k*-out-of-*n* system, Reliability analysis, Structure function, Drone.

Session	[TH1C]—Reliability and Maintenance of Networked Systems
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Espace Grand Angle2

TH1C: 095 **09:00 hrs**

Online Estimation of Resource Overload Risk in 5G Multi-Tenancy Network

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The technology of network slicing, as the most characteristic feature of the fifth generation (5G) wireless networks, manages the resources and network functions in heterogeneous and logically isolated slices on the top of a shared physical infrastructure, where every slice can be independently customized to fulfill the specific requirements of its devoted service type. It enables a new paradigm of multi-tenancy networking, where the network slices can be leased by the mobile network operator (MNO) to tenants in form of public cloud computing service, known as Slice-asa- Service (SlaaS). Similar to classical cloud computing scenarios, SlaaS benefits from overbooking its resources to numerous tenants, taking advantage of the resource elasticity and diversity, at a price of risking overloading network resources and violating the service-level agreements (SLAs), which stipulate the quality of service (QoS) that shall be guaranteed to the network slices. Thus, it becomes a critical challenge to the MNOs, accurately estimating the resource overload risk - especially under the sophisticated network dynamics - for monitoring and enhancing the reliability of SlaaS business.

While existing literature are mostly considering over-simplified models of slice resource load, in this paper we propose a novel approach assuming a Markov-Truncated-Gaussian-mixture model, which is capable of accurately approximating any practical resource load distribution. The proposed approach is demonstrated by numerical simulations to be effective and accurate.

Keywords: Outage control, Modeling, 5G, Network slicing, Multi-tenancy, Estimation.

TH1C: 336 09:20 hrs

A Hierarchical Predictive Maintenance Model for Networks

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Nowadays, with the emerging of enabling techniques, such as digital sensing, big data, machine learning techniques, predictive maintenance becomes a prevalent topic in system reliability. The blooming of the related research has already cause multiples paradigm shifts, such as industry 4.0 and digital manufacturing. Could predictive maintenance also shed light on resolving the problem at the network level and bring real value for servicing the macro-characteristics network is an essential question that to be answered. This research aims to design a hierarchical approach that enables scaling-up the effect of predictive maintenance to benefit systemic maintenance, and in turn, serve the network macro-characteristics. The hierarchical model integrates the component, system, network knowledge in a layered fashion. Such that, the model contains both actionable details and macro-characteristics.

At the component-level, we model the deterioration process of components as a multi-state multi-path stochastic process. We develop a novel approach for predicting the reaching time of the optimal condition for maintenance, based on the information from inspections. At the system-level, we highlight the heterogeneity of components in the system model. More often than not, practical systems are composited by multiple components whose downtime or failure might have different impacts on system performance. We employ the predicted information from the component-level to construct a group maintenance strategy. Components' maintenance activities will be actively grouped together for sharing the set-up cost and downtime. Different maintenance strategies may require different costs and result in different system performance. We utilize a genetic algorithm with agglomerative mutation (GA-A) for evaluating and optimizing the group maintenance policies to meet the different requirements of system performances. At the network-level, we consider the network is composed of multiple systems and select the system performance for satisfying the macro-characteristics. In such a way, predictive maintenance at the component level can support the decision making at the system level and subsequently serve the network. The overall approach will be applied to the transportation network. In practice, the transportation network is composited of multiple systems such as bridges, roads, and tunnels, which are composed of components such as concrete decks, wingwalls, and joints. It matches the model description.

Moreover, macrocharacteristics, such as connectivity and resilience, have important practical meaning in the transportation network.

Keywords: Predictive maintenance, System engineering, network, Group maintenance.

TH1C: 436 09:40 hrs

Maintenace Optimization of Networked Infrastructures Considering the Component Distribution Uncertainty: A Deep Reinforcement Learning Approach

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The continued effective performance of networked infrastructures, such as telecommunication system, is an issue of worldwide concern. Cost-effective maintenance is essential to ensure the system reliability of keeping the prescribed service quality continuously satisfied. In addition to the influence of maintenance actions on the system reliability when they are being conducted, the influence on the components' failure distribution after maintenance, is also need to be considered. To deal with this problem, the multi-period optimization of an infrastructure's maintenance planning was modeled as a Markov decision process (MDP). Moreover, a deep reinforcement learning (DRL) framework is developed to deal with the cumputation complexity of the objective function of the large-scale networked system and solve the descrived problem.

The main advantages of the proposed maintenance planning approach is four-folded: (1) the maintenance influence on both system and component distribution are considered, which is more practicle in the real world; (2) a customized deep neural network (DNN) is employed to learn the network feature, which is dependent on the optimiaztion objective, as well as the stateaction Q-value (defined as the predicted discounted expectation of the reward under a given state-action pair); (3) the reward of a policy could be model-free,and can be directly learned from real historical data; and (4) the framework is robust for different network topologies and objectives, so that only slight change to the neural network architecture is desired.

Keywords: Netwokred systems, Maintenance, Markov decision process, Distribution uncertainty, Deep reinforcement learning.

TH1C: 583 **10:00 hrs**

Robust optimization for network restoration under demand uncertainty

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With the development of science and technology, networked infrastructure systems, such as telecommunication networks, are indispensable to society (Brown, et al., 2006). The networked infrastructures confront huge threats, such as natural disasters, deliberate attacks, etc., therefore we must consider post-disaster restoration work. For the restoration of networked infrastructure, two factors must be simultaneously considered. One is that the components in the network are geographically distributed, and the other is that the flow transmitted in the network is related to the restoration states of the network. Since these components are geographically distributed, vehicle routing must be considered. In addition, the network flow scheduling and the demands of each customer must be considered. For this purpose, we propose a robust optimization model to simultaneously determine the maintenance routes and schedule network flow in the postdisaster restoration. Taking into account the uncertainty of customer demands, we seek to optimize the restoration task within the limited time to minimize the unmet demand of the whole network under the worst case. Finally, we develop an efficient algorithm to solve the proposed problem.

Keywords: Robust optimization, Disaster management, Critical infrastructure, Resilience, Maintenance planning, Workforce routing.

Session	[TH1D]—Land Transportation // Smart Cities and Systems
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Panoramique

TH1D: 309 **09:00 hrs**

Accident Experience, Subjective Assessment of Risk and Behaviour Among Norwegian Cyclists

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The aims of the reported study were to examine whether cyclists who had been involved in a traffic accident when cycling subsequently changed their behaviour, and how their experience of the accident was associated with their perceived risk, worry, and trust in authorities. Risk perception focuses on individuals' subjective assessment of risk, and worry is considered as an emotional reaction when thinking about the risk. Data were collected through an online questionnaire survey (n = 291). The respondents were asked about their accident and near-miss experiences when cycling during the last two years, and to rate their perceived risk, worry, and trust in authorities' ability to ensure cyclists' safety in summer and winter conditions. The cyclists who had been involved in an accident or near miss were further asked whether they had changed mode of transport, cycle route, or cycling behaviour after the accident. The results showed that there were significant associations between risk perception and worry, and accident and/or near-miss experiences. Additionally, the results revealed that the accident and near-miss experiences had influenced the respondents' choice of transport mode, and cyclists' route choice and behaviour when cycling. Finally, perceived risk and worry were found associated with behavioural changes after accident and/or nearmiss experiences. The knowledge gained from the study can be used in traffic safety work, through authorities' risk communications.

Keywords: Cycling behaviour, Traffic accidents, Risk perception, Worry, Trust in authorities, Traffic safety.

TH1D: 347 **09:20 hrs**

Finite State Machine Modelling for The Performance Analysis of An Integrated Road-Power Infrastructure with A Hybrid Fleet of EVs And ICVs

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Electric Vehicles (EVs) penetration in the car market affects the road networks that, to date, are not designed and optimized for a hybrid fleet of EVs and Internal Combustion Vehicles (ICVs). The strong dependency of EVs on the power distribution infrastructure, indeed, calls for an integrated road-power infrastructure. In this work, a Finite State Machine (FSM) approach is proposed for modelling EVs and ICVs motion in an integrated road-power infrastructure. FSM is shown to be a powerful modelling approach that can easily embed realistic characteristics such as drivers attitudes and traffic, but also effects of disruptions induced by natural hazards or traffic incidents when aimed at analyzing the performance, safety and resilience of integrated road-power infrastructures. As a realistic case study, we consider a road network in New York state, and the motion of both EVs and ICVs is simulated in various cases assuming different EVs penetration levels.

Keywords: Electric Vehicle (EV), Internal Combustion Vehicle (ICV), Road network, Power distribution network, Finite State Machine (FSM), Reliability, Safety, Resilience.

TH1D: 332 **09:40 hrs**

A Cascading Failure Model of Rail Transit Based on Application Cell

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Rail transit system deliver its application by transporting passengers to their destination. Succeed or not of application's delivery greatly affects the daily operation of it. Current research based on cascading failure mainly focus on the connectivity of network. Researches based on queuing theory, network calculus and BPR function focus on the performance of network. They all take transport process as homogeneous flow and consider the function-based or performance-based structure of network, ignoring that they essentially are applications with multiattributes (such as application classes, application process and so on), and these attributes have great impact on rail transit, which leads that current researches are unable to reflect the reliability from users' aspects. In this paper, we focus on the cascading failure process of rail transit, one call request of rail transit from a certain passenger is treated as one application. In order to map the features of application, we describe them as application cells, and multiattributes of transport process corresponds to the characteristics of cells. Then, the deliver process of application can be regarded as the interaction among cells in our model. The results of simulation show that our model can effectively depict the process of cascading failure among cells and can help to simplify the complexity of application process. Besides, we find the law that even holding the same amount of burst traffic flow, different application types have various cascading process and totally different network reliability.

Keywords: Rail transit, Congestion, Application cell, Optimization, Traffic model.

TH1D: 383 **10:00 hrs**

Data Oriented Optimization of Predictive Maintenance in Physical Networks : Application of Prioritization in Wastewater Network's Repairs

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Physical networks, such that potable water distribution networks, sewerage networks, electric networks made of power lines and transformers, telecommunication networks, are fundamental constituents of a complex urban monitored and optimized infrastructure. All these systems share the property of being computerized in a GIS (Geographic Information System), where physical units (pipes, electrical or optic fiber lines) are often buried under roads. It is thus common to consider that preventive renewals are the main maintenance actions of possibly degraded units that constitute the network. In that case, choosing when and where to place the worksites is a challenging problem. The main issue is the inconvenience caused by worksites that should be minimized. That is why a worksite should include a set of neighboring units to be changed simultaneously, as quickly as possible.

This paper proposes a methodology to provide opti-

mized allocation of preventive maintenance budget for worksites. Each potential worksite constitutes a geographical area that contains some units to renew. Each unit is identified by its localization, the indexes of units with which it is connected and some covariates, such that (for our example of a wastewater network) length, material, age, risk priority number, criticality index, probability to fail, etc.. . With the theory of graph, it is possible to construct a search algorithm that provided ranked potential worksites to investigate.

Keywords: Water networks, Worksite optimization, Simulation, Ressource allocation, Breadth-first Search algorithm.

Session	[TH1E]—Human Factors and Human Reliability
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Amphi Jardin

TH1E: 427 **09:00 hrs**

Determination of Level of Automation for an Adequate Human Performance

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The automation system has hugely grown during the last years, and it is the major trend of the 21st century. The automation system can provide superior reliability, improved performance, and reduced costs for many functions. The human-machine design could not be out of this development and technological advancement. Human-machine design takes into account the human factors and human and machine limitations and abilities through the levels of automation. Therefore, it is primordial to consider in the design of such systems, the automation level for adequate human performance. This paper has the purpose to present a preliminary approach for evaluating human performance during a car parking activity with and without car parking assistance (an automated system) and also to analyse the impacts associated with parking assistance in the human error contributing factors. The method for determining the level of automation is based on four generic functions intrinsic to man-machine domain, which's are: monitoring, generating options, selecting options, and implementing. The human performance analysis is proposed through the Bayesian Networks approach supported by Fuzzy Logic whose application is to model the performance shape factors and checking, through a causal inference and diagnosis, which factors most influence the performance of the tasks in a specific level of automation. The result indicated a positive aspect, the activity with a higher chance of occurrence of a human error in procedure without the parking assistance system was the activity with the parking assistance with higher automation level. The analysis recommends that the alarm and panel design should be revaluated since different alarms and equipment are used to offer the same information, causing the make decision slower and complacency. The button which turns on the parking assistance system also is the one that selects three types of manoeuvres; in addition, the throttle can be used for controlling the manoeuvres, and both information should be part of the training before using parking assistance. Despite workload increases with the parking assistance, the human error chance decreases.

Keywords: Level of automation, Human error, Bayesian network, Fuzzy logic and parking assistance.

TH1E: 437 **09:20 hrs**

Physiological Measurements for Real-Time Fatigue Monitoring in Train Drivers: Review of the State of the Art and Reframing the Problem

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The impact of fatigue on train drivers is one of the most important safety-critical issues in rail. It affects drivers' performance, significantly contributing to railway incidents and accidents. To address the issue of real-time fatigue detection in drivers, most reliable and applicable psychophysiological indicators of fatigue need to be identified. Hence, this paper aims to examine and present the current state of the art in physiological measures for real-time fatigue monitoring that could be applied in the train driving context. Three groups of such measures are identified: EEG, eye-tracking and heart-rate measures. This is the first paper to provide the analysis and review of these measures together on a granular level, focusing on specific variables. Their potential application to monitoring train driver fatigue is discussed in respective sections. A summary of all variables, key findings and issues across these measures is provided. An alternative reconceptualization of the problem is proposed, shifting the focus from the

concept of fatigue to that of attention. Several arguments are put forward in support of attention as a better-defined construct, more predictive of performance decrements than fatigue, with serious ramifications on human safety. Proposed reframing of the problem coupled with the detailed presentation of findings for specific relevant variables can serve as a guideline for future empirical research, which is needed in this field.

Keywords: Train drivers, Rail, Physiology, Fatigue, Attention, EEG, Eye-tracking, Heart rate.

TH1E: 460 **09:40 hrs**

SAM-L2HRA: Human and Organizational Reliability Analysis Method for Analyzing Severe Accident Management Strategies and Actions

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Human Reliability Analysis (HRA) is required to evaluate decision likelihood of severe accident management (SAM) strategies and adequately assess the reliability of human and organizational actions, and ultimately to incorporate those results into a Level 2 PSA model. A new Level 2 HRA method (SAM-L2HRA) consists of two parts of analysis: the first part deals with a time uncertainty analysis to the failure of a SAM strategy, of which probability is estimated from the convolution between two time distributions, i.e., time available and time required, and the second part is composed of task-based analysis of error potential or decision-making likelihood [1].

The time elements considered in the time uncertainty analysis include the distribution of time available with consideration of phenomenological uncertainty associated with a severe accident event such as a reactor vessel failure, the time elapsed (or required) (and its distribution) for each individual SAM strategy and the total integrated time (and its distribution) from the entry point into SAMG and to the completion point of implementation of a strategy under consideration.

The task-based analysis part deals with error potential or decision-making likelihood associated with critical steps or activities needed for decision-making and successful implementation of a strategy. The steps or activities to be analyzed include the availability or survivability of essential information needed for recognition of a strategy implementation and monitoring the progress and effectiveness of a strategy implementation, the impact of negative effects associated with a strategy on a decision-making of a strategy implementation and its probability of likelihood, and the reliability of the implementation activity in which coordination and cooperation between distributed organizations such as the technical support center (TSC), the main control room (MCR) and the local operating personnel in charge of actual implementation using installed or portable/mobile equipment are of critical importance.

Keywords: Level 2 HRA, Human reliability analysis, Severe accident management guideline, SAMG.

TH1E: 461 **10:00 hrs**

Investigation of a Domain-Specific Culture Shared by Operator Groups in Nuclear Power Plants

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The performance of human operators has a major impact on the safety of complex socio-technical systems such as nuclear power plants, thus it is important to understand the performance shaping factors to improve the safety of socio-technical systems. Among various factors affecting the performance of an operating team, its cultural characteristics is known as one of the dominant factors. To distinguish the cultural characteristics of each team systematically, it is important to confirm the existence of a domain-specific group culture which can be regarded as a reference to determine the nature of the culture processed by each team. In this regard, this study proposes how to identify a domain-specific culture in a certain domain and confirms its presence in nuclear industry. Four representative classes of cultural factors affecting the formation of group cultures are proposed and eight experimental sets are designed to capture the existence of the domain-specific group culture in nuclear power plants. Empirical cultural data based on Hofstede's indices is collected from different operator groups with diverse conditions according to the experimental design and analysed statistically. The results show that diverse operator groups share very similar cultural characteristics in terms of two kinds of Hofstede's indices and it is revealed that the transition of working environment from analogue to digital is the most influential factor on group culture in nuclear power plants.

Keywords: Socio-technical system, Nuclear power plant, Performance shaping factor, Group culture, Cultural factor, Hofstede's indices.

Session [TH1F]—Structural Reliability
Day/Date/Time Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue Espace Grand Angle

TH1F: 376 **09:00 hrs**

Design and Homologation of Fiberglass Insulators for High Voltage Switches: An Overview of Italian Regulation and a Proposal for a New Approach to Determine Safety Coefficients

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The Pressure Equipment Directive (PED), 2014/68/EU, applies to the design, manufacture and conformity assessment of pressure equipment. However, it does not apply to enclosures for high-voltage electrical equipment, such as switch-gear, control gear, transformers and rotating machines. In EU, the design and manufacturing of such casings are accomplished through regulations or guidelines defined by each Member State. Nowadays, in Italy DM 1.12.1980 is still in force, which provides for product type approval by means of tests on prototype. For metal and insulating materials, the overall safety coefficient is assessed by means of burst tests and specific tests.

The proposed article provides an overview of the approach followed by DM 1.12.1980 and a comparative analysis to the indications reported in EN 50052 and in the product standard IEC 61462. In addition, an ad hoc plan of activity will be outlined which is based on experimental lab tests on samples from production batch of fiberglass insulators. This will be coupled to a specific structural numerical analysis with Finite Element Analysis technologies (FEA) to support the evaluation of suitable safety coefficients for orthotropic composite materials to be adopted in the homologation of new products.

Keywords: Fiberglass insulators, High voltage switches, Homologation, Italian regulation, Innovative approach, Ring test, Hydraulic test, IEC 61462, EN 50052, Finite element analysis.

TH1F: 542 **09:20 hrs**

The Analytical Equivalent Drift Coefficient of EV-GDEE on Steady State for Several Nonlinear and Multi-dimensional Systems

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The joint probability density function (PDF) of response of structural systems subjected to Gaussian white noise is governed by the Fokker-Planck-Kolmogorov (FPK) equation. However, due to the nonlinearity and high-dimensionality of the real engineering structures, it is practically difficult to solve the FPK equation directly. To this end, by introducing the equivalent drift coefficient, Chen & Rui proposed the so called ensemble-evolving-based generalized density evolution equation (EV-GDEE), which can reduce the original high-dimensional FPK equation to a partial differential equation in only one or two dimensions[1]. In the EV-GDEE, the equivalent drift coefficient that represents the driving force the changing of PDF, is obviously essential but usually not previously known. Till now, the equivalent drift coefficient of an arbitrary multi-dimensional and nonlinear system is mainly estimated in numerical ways, e.g., by the regression methods, and generally it is hard to seek a universal and satisfactory result[1,2].

However, for some special multi-dimensional and nonlinear Hamiltian systems, the analytical solutions to the steady FPK equation is available[3,4], which allows the analytical expression of the equivalent drift coefficient. In this study, the analytical equivalent drift coefficient of steady state is derived based on the exact PDF solutions for several multidimensional and nonlinear systems under Gaussian white noise excitation. The derived analytical expression is also compared with the numerical regression method. In addition, the obtained analytical expression is used to promote the estimate of transient equivalent drift coefficient, and consequently, yield results of higher accuracy.

Keywords: EV-GDEE, Equivalent drift coefficient, Analytical expression, Hamiltonian systems, Steady state.

TH1F: 683 **09:40 hrs**

Estimation of Sampled Domain Probability using Convex Hull Approximation

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In various sampling methods developed for estimation of failure probability, there are stages at which it is useful to estimate the extent of the domain of basic variables which has already been covered by sampling points. This information is helpful for adaptive update of the sampling strategy. We propose using a geometrical representation of the explored part of the domain by a convex hull. Once performed, we may target at exploration sampling, as well as using convex hull for estimation measure of the (un)explored domain. Whereas in problems which feature just a few random variables we are able to set up convex hull bounding the given set of points precisely, in problems of high dimensions we only can assemble convex hull from a limited number of hyperplanes bounding a set of points. This paper compares various approximation to convex hull in small to moderate domain dimensions.

Keywords: Structural reliability, Spatial approach, Convex hull approximation, Failure probability, Monte carlo, Exploration sampling.

TH1F: 696 **10:00 hrs**

Finite Element-Fidelity Parametrization of Kriging Metamodels for Structutal Reliability Assessement

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It is critical to obtain a precise estimation of the probability of failure when doing the reliability analysis of a given structure. The Monte-carlo estimator is a non-intrusive and unbiased estimator than can be easily implemented to compute this probability. However, the Monte Carlo estimator requires to simulate the structure for a large number of realizations of input random variables due to its low convergence rate. For complex mechanical problems solved by the finite element method (FEM), the computational cost of this estimator may thus be important. Therefore, some reliability analysis are based on a metamodel built from a few calls to the finite element solver that allows to quickly approximate the structural response. To accurately estimate the probability of failure, the metamodel has to be precise close to the limit state delimitating the safe and failure zones. One of the common methods to construct a metamodel is kriging [2]. This estimation of uncertainty allows to couple the metamodel with the Monte-Carlo estimator, which enables to define an adaptative strategy to improve the quality of the metamodel near the limit state [1]. The discretization of the mechanical problem leads to an error in the structural response and thus in the estimation of the probability of failure. To control that error, multifidelity kriging was introduced in 2020 [3]. However, it requires the use of an expensive a posteriori discretization error estimate that is not available for every mechanical problem. This work exploits a priori knowledge of the FEM convergence rate to build a mesh size parameterized kriging metamodel. This metamodel allows to compute the probability of failure for any mesh size through Monte-Carlo sampling and thus check for mesh convergence.

Keywords: Multi-fidelity, Kriging, Probability of failure, Mesh convergence.

Session [TH1G]—Nuclear Industry
Day/Date/Time Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue Atrium 3

TH1G: 496 **09:00 hrs**

Development of Containment Failure Probability and Uncertainty Analysis Program, COFUN-M

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The feature of the COFUN-M is quantification of the containment state by point estimate value, importance analysis, sensitivity analysis and uncertainty analysis for internal and seismic event. The uncertainty analysis process of the level 2 PSA is that a level 1 PSA uncertainty propagate to a level 2 PSA uncertainty. In order to perform uncertainty analysis in the COFUN-M code, we need to prepare the input. The basic event probability data including probability distribution were needed and would be used for the level 1 PSA uncertainty analysis. To perform uncertainty analysis in a level 2 PSA, it is necessary to define the split fractional branch point and define the probability distribution and priority. Once the input is ready, uncertainty analysis is performed via Monte Carlo sampling. Finally, the uncertainty analysis is performed for the end point of the PDS, CET, STC and LERF. One of the outstanding characteristics of the COFUN-M is to perform level 2 PSA for multi-unit accident. The one of format of multi-unit level 2 PSA is combination of STCs but the combinations could be too many to acquire insight itself. The COFUN-M provides user-defined combination which makes STC combinations classified.

Keywords: Level 2 probabilistic safety assessment code, Level 2 probabilistic safety assessment uncertainty analysis, Level 2 multi-unit probabilistic safety assessment uncertainty analysis, Uncertainty propagation, Containment performance analysis, Nuclear safety.

TH1G: 507 **09:20 hrs**

Development of the Deep Learning Based Fast Simulation for Reducing the Uncertainty in Probabilistic Safety Assessment

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A Probabilistic Safety Assessment (PSA) has been used to estimate the risk of Nuclear Power Plants (NPPs). For more accurate analysis, the PSA analysis should be performed, as realistic as possible. The problem is that, however, the number of accident scenarios will drastically increase for a complicated system that comprises of many systems or components, such as NPPs. Indeed, this problem was the main obstacle hampering the introduction of reduction of uncertainty in PSA.

To handle this problem, as previous study, DeBATE (Deep-learning Based Accident Trend Estimation) was suggested and developed [1]. DeBATE can provide the whole trend of key process parameters calculated from any physical model after training the associated input to it. The schematic diagram of DeBATE is shown in the figure 1. In order to confirm the feasibility of DeBATE, total 80,000 accident scenarios of Steam Generator Tube Rupture (SGTR) and Main Steam Line Break (MSLB) reflecting of standard post trip action was prepared by MARSKR. As a result, the output was generated less than in 0.2s with about 5% error in average.

Keywords: Dynamic PSA, Deep learning, Fast simulation, Surrogate model.

TH1G: 509 **09:40 hrs**

A New Generation of RAM Models to Incorporate Obsolescence Management Issues

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This paper is focused on a study of the capability of the actual RAM models to propose recommendations and obtain a new generation of advanced models to characterize reliability, maintainability, and availability (RAM) behavior of critical components. In those new models, the effects of

aging and obsolescence, their causes and principal failure modes and surveillance and maintenance policies will be explicitly considered. These models can be used in the context of plant life extension, as aging and obsolescence management of the critical safety equipment are two key factors to guarantee a long term safe and sustainable operation of nuclear power plants.

Keywords: RAM, Aging, Obsolescence, Maintenance, PSA, Nuclear power plants.

TH1G: 512 **10:00 hrs**

Application of Layerwise Relevance Propagation for Explaining AI Models in Nuclear Field

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Recently, neural network is widely applied in various fields due to its superior performance. Accordingly, many researches on applying neural network to nuclear field have been conducted for enhancing safety of nuclear power plant(NPP). However, due to the black-box nature of neural network and the NPP's safety-critical characteristic, such researches share common limitations on the perspectives of reliability and practicality.

To deal with the explainability problem of neural network, numerous explainable artificial intelligence(XAI) methods have been proposed. Most of existing XAI methods can be classified into two categories. The first category is the XAI methods that provide model-wise explanations. These methods deduce the explanations on model itself, through extracting features within hidden layers or directly accessing to the model parameters. In contrast, the second category is the XAI methods that provide input-wise explanations. These methods deduce the explanations about specific input, through conducting sensitive analysis or relevance backpropagation. To make neural network models that are sufficiently reliable and practical for nuclear field, each category of XAI method should be thoroughly considered. However, only few studies are dealt with adopting XAI methods to nuclear field.

In this study, layer-wise relevance propagation(LRP) which is one of the representative XAI method was adopted. LRP explains the neural network model's output by deducing the relevance between each part of the input and corresponding output, and has shown better performance in most cases compared to other XAI methods. The authors applied LRP to two neural network applications on nuclear field; that are fast running and scenario classification. For the experiments, simulation was conducted and acquired data was used for model training. Results revealed that the application of LRP could provide explanations on model's output which can be used to enhance the reliability and practicality of neural network models in nuclear field.

Keywords: Nuclear field, Nuclear power plant, Neural network, Black-box, Explainable artificial intelligence, Layer-wise relevance propagation.

Session	[TH1H]—Automotive Industry
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Cointreau

TH1H: 318 **09:00 hrs**

Probabilistic Reliability Analysis of Screw Connections in Cast Aluminum Housings

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The design of screw connections is subject to standardized calculation recommendations based mainly on empirically determined parameters with defined material characteristics. Here, a probabilistic extension of this design methodology for strength design against static load is proposed, whereby probability density functions of characteristic component features are determined using statistical toleration. Contrary to conventional designs with empirically determined safety factors, this procedure can be used to refine component sizing through probabilistic optimization of target parameters within a feature chain.

Keywords: Screw connection, Thread reach, Reliability, Probabilistic analysis, Stress and strength, Safety factor.

TH1H: 570 **09:20 hrs**

Reliability Prediction of Electronic Devices for Combat Vehicles Based on Accelerated Testing

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The wide application of highly sophisticated electronic components in combat vehicles is a key trend in recent time. Transmission systems (including engines and automatic transmissions), weapons, security, reconnaissance, and communication systems based on digital technology and have been implemented in combat vehicles. Due to the increasing number of electronic devices in combat vehicles, it can be said that this is the process of digitizing military technology. Electronic devices experience vibration stress while combat vehicle operates in a ground space. Vibration may cause structural collapse, mechanical failure, fracture, cracking, physical breakdown of the seal, complete disconnection, or interruption of electronic parts. In order to ensure the reliability of electronic devices during operation, it is necessary to conduct vibration tests for a functionally test under severe vibration environments. The presented study has applied accelerated reliability testing methods for predicting the reliability of electronic devices built in combat vehicles. A special test system has been designed to practically realize pertinent accelerated tests. The system consists of a platform base for placing electronic devices, hydraulic equipment to vibrate the base, hydraulic control system and instrumentation of system performance. The paper presents methodology of the realized accelerated tests and demonstrates procedure of tests results evaluation. Selected results of electronic devices reliability prediction based on test data are also presented.

Keywords: Vibration, Accelerated testing, Electronic device, Reliability, Combat vehicle.

TH1H: 590 **09:40 hrs**

Accelerated Reliability Testing of Combat Vehicles Electronic Parts Based on Multifactor Stress

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Electronic elements are increasingly used in a variety of applications, including in civilian and military vehicles. Evaluating the lifetime of these elements helps to control the reliability of the devices using them. With the development of manufacturing technology, electronic elements become products with high reliability and long service life. Hence the Accelerated Test is used to evaluate their reliability, reduces the time and cost of testing them. The paper is focused on reliability prediction in the case of electronic parts of combat vehicles using accelerated reliability testing. An extensive experiment has been realized to predict the reliability/life of miscellaneous electronic parts used in the design of a combat vehicle with various stress factors. As an example of the tests realized the paper presents the procedure and results of LEDs accelerated testing based on multifactor stress of the LEDs. Three types of accelerating factors have been applied – high temperature, ON/OFF cycling, and loading current. The paper deals with the methodology of the realized accelerated tests and demonstrates the procedure of test results evaluation. Two methods are used for accelerated tests data evaluation – application of the Wiener process-based model, and classical approach based on international standard IEC 60605-4. The paper compares the results of both approaches and presents selected outputs of the supposed method of the LEDs reliability prediction for various operating conditions.

Keywords: Lifetime, Accelerated reliability testing, LED, Wiener process, Reliability prediction, Combat vehicle, Electronic part.

TH1H: 631 **10:00 hrs**

D-DEG: A Dynamic Cooperation-Based Approach for Reducing Resource Consumption in Autonomous Vehicles

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Operating a vehicle autonomously is a resource-intensive task. Since resources, like computing power, energy, and bandwidth, are limited in such vehicles, methods for reducing resource consumption are required. In this paper, we propose D-DEG, a cooperation-based approach for autonomous vehicles that is capable of reducing resource usage. The basis of our approach is that vehicles that are in close proximity and that use the same sensor and software set perceive and compute similar data. The idea is to share information, e.g., sensor data and application outputs, between vehicles using VANET (Vehicular Ad-Hoc Network) technologies. The transferred information is used to achieve resource preservation, whereby

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our approach aims to reduce resource consumption by degrading sensors and applications. To this end, we introduce the so-called *dynamic-degradation evaluator*. This component analyzes the information received by other vehicles to determine whether sensors and/or applications can be degraded. Besides the data received from other vehicles, the dynamic-degradation evaluator also considers the current operational design domain (ODD) and the system state, which includes, for instance, information about the current resource utilization and the safety level of the vehicle, to determine whether degradation operations can be performed. Those degradation operations can range from decreasing the sampling rate of a sensor or the output rate of applications to shutting down sensors or applications, respectively.

Keywords: Autonomous vehicles, VANET technologies, System architecture, Resource efficiency.

Session	[TH1I]—Security
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Giffard

TH1I: 547 **09:00 hrs**

Expert Judgement in Security Analysis – the Pros and Cons of Analytical Wargaming

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The lack of relevant and reliable information is a recurring challenge in analysis and decision-making related to security issues. Security analysis often relies on input from Subject-Matter Experts (SME). SME judgments are subjective, and the personal traits and cognitive and motivational biases of the experts may flaw the quality of the information. If not handled properly, this can threaten the validity and credibility of the collected information, the results of the analysis and, in the end, the supported decisions. Hence, we need structured, transparent and reliable methods for capturing knowledge from SMEs.

In this paper, we explore the benefits of using analytical wargames to facilitate information collection from SMEs and stakeholders related to security analysis. The main goal is to obtain valid and credible expert judgements as input to the analysis. “Analytical argaming” is a generic term for various types of games tailored to support data collection and analysis related to conflict and competition.

We argue that analytical wargames are well suited to support information collection in the different phases of the analytical process. Wargames provide settings that not only enable creative thinking, but also bring structure and traceability to the process of extracting information from SMEs. Our findings are partly based on a survey among researchers on their experiences in using wargames to support information collection.

Keywords: Security, Wargames, Analysis, Information collection, Elicitation, Experts, Judgements.

TH1I: 550 **09:20 hrs**

The Traffic Management Intrusion and Compliance System as Security Situation Assessment System at an Air Traffic Controller’s Working Position

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The need to protect air traffic control against attacks and detect security incidents is widely accepted. Nevertheless, depending on the systems and procedures, it is sometimes difficult to distinguish whether “something is not as it should be”. On the one hand, it could be due to a failure, on the other, it could be because of an intentional interruption/abuse. This paper lists five specific kinds of indications that may be found analyzing the traffic situation and the radio communication at a controller working position and details how they are detected. Those indications are non-conformant movements, conflicts, unusual clearances/behavior, unauthorized speakers and detected stress. Furthermore, a correlation function is described which determines the security situation indicator. This indicator categorizes the security situation into three different states expressing how likely it is that the detected indications may represent a security situation needing attention: “green”, meaning there are no security-related actions needed; “yellow”, meaning something seems strange, be aware; and “red”, meaning that there is most properly a security incident. The Traffic Management Intrusion and Compliance System (TraMICS) is supposed to assist as well the air traffic controllers and the operators in a security operation center by being part of an airport security architecture.

Keywords: ATC security, TraMICS, Correlated security indicator, Security situation indicator, Airport security, Controller working position.

TH1I: 588 **09:40 hrs**

Cyber Threats Affecting the Process Industry and Similar Sectors

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Cyber threats are becoming a growing concern for industrial facilities characterized by a high degree of automation, especially those that highly rely on Operational Technology (OT) systems such as process facilities. Fixed installations where chemical and petroleum products are manufactured and stored (e.g. Seveso sites in EU) are of primary concern since attackers may exploit their inherent hazardous conditions and trigger events with severe consequences on workers, population, the environment, and the company itself (e.g. major accidents). The study is based on the development of a database of 82 cybersecurity-related incidents (CSIs) and its analysis using Exploratory Data Analysis (EDA). Time-trend (from 1975 to 2020), geographical distribution, distribution among the industrial sectors, impacts of the incidents, and type of attackers (intentional external / intentional internal / accidental) were investigated, evidencing important findings. The attacks resulted to be able to affect not only the company Information Technology (IT) system, which is a threat common to several business sectors, but also to manipulate the control and safety systems (OT). Finally, the analysis of a sub-set of incidents with more detailed information allowed to identify the general phases of a cyber-attack to IT-OT systems of a process facility. The information obtained can be used to support the application of the techniques commonly used to handle security-risks in process facilities, such as Security Vulnerability Assessment (SVA) methodologies.

Keywords: Past incident analysis, Process industry, Cyber threat, Cyber-attack, Major accident, Security vulnerability assessment.

TH1I: 615 **10:00 hrs**

Risk Perception Biases to be Aware of in Terrorism Threat Asessments

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According to risk perception research, numerous factors influence risk perception, and these factors will also play a role in terrorism threat assessment. However, there have been few attempts to connect risk perception research with the practice of threat assessments. This paper aims to fill this gap by examine factors associated with risk perception that can influence terrorism threat assessments. The aim of this paper is to scrutinize the psychological biases that can influence risk perception and discuss how these biases can affect threat assessments. The conclusion is that terrorism scores high on all fear factors associated with risk, and therefore, when conducting terrorism threat assessment, it is especially important to acknowledge that threat assessment is a subjective matter prone to individual biases. Similarly, biases at the societal and cultural levels must also be taken into account. It is hoped that increased awareness of how risk perception influences threat assessments can help us build a strong foundation for improved critical evaluation and better decision-making about terrorist threats.

Keywords: Terrorism, Risk perception, Threat assessment, Bias, Heuristics.

Session	[TH1J]—Resilience Engineering
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Botanique 2

TH1J: 110 **09:00 hrs**

Study of the Resilience of Nuclear Power Plants in Response to Climate Change

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In recent years, it has become even more challenging to ensure the safety of nuclear power plants due to accelerated climate change. This is because some existing safety systems in the plants are not able to cope with new issues introduced or aggravated by climate change. In response to this need, this paper will analyze the present related reactor safety systems and propose and discuss a measure that can potentially improve the resilience of the reactor system to climate change. To facilitate the research, the intake structure blockage caused by the outbreak of a kind of marine organism whose size varies from 4mm to 40mm, is chosen as a case study. The study will consider the ability of the system to anticipate for the events, absorb the impact of the events to the system, and recover from perturbations. To facilitate the research, a mathematical model will be developed using Petri nets to simulate the reliability and health states of the related safety systems, the occurrence of disruptive events, the corresponding responses of the nuclear system, and the possible operation states and recovery of the system from the disruptive events. The results indicated that the intake structure blockage caused by such external events cannot

be ignored. The research is expected lay a solid foundation for future nuclear power system design and the resilience assessment of nuclear reactor systems.

Keywords: Resilience, Nuclear power plant, Petri nets, Mathematical modeling, Simulation, Climate change.

TH1J: 266 **09:20 hrs**

Towards a Novel Tiered Approach to Assess the Resilience Level in the Safety Domain

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Resilience is the system ability to adjust its functioning prior to, during, or following changes and perturbations. Resilience Engineering represents a new paradigm to improve safety, focusing on how to create resilience in systems. The resilience measurement supports decision making processes, but it is not a trivial task. Therefore, the objectives of this paper are: (1) to critically analyze the literature about quantitative resilience assessments in the industrial safety domain, and (2) to propose a novel three-tier approach for measuring and assessing the resilience potential in any organization in the same domain. To achieve our objectives, we performed a narrative literature review about the existing approaches, frameworks, and methods quantifying and ranking resilience indicators, and/or estimating an overall resilience score. Multi-Criteria Decision Making and Bayesian Network approaches are frequently employed for such purposes. The results gathered through the narrative review represent a key source for developing a novel tiered approach. We propose an approach able to quantitatively assess the resilience potential in the industrial safety domain that consists of three tiers. A knowledge-driven tier assesses resilience by using the knowledge of decision makers through techniques involving judgements, a knowledge and data-driven tier incorporates methods considering both expert knowledge under uncertainty and objective data, while a data-driven tier includes models performing resilience assessments entirely based on data provided by devices and information systems in the organization.

Keywords: Safety-II, Resilience quantification, Process safety, Occupational safety, Human factor, Safety management, Anticipation, Risk management, Dynamic assessment, Analytic Hierarchy process, Data envelopment analysis, Machine learning.

TH1J: 314 **09:40 hrs**

Formalization of Questionnaire-based Score Card Risk Control and Resilience Assessment for Critical Infrastructure Operators and Companies Countering Covid-19

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Questions and answers are a fast way to assess complex day-to-day situations. They can be adopted to the framing conditions and are path-dependent, allowing in-depth analysis of critical issues. Questionnaires try to take up the natural setting using pre-defined sets of questions that cover an area. Often, for comparison of results, they use fixed sets of questions. The paper shows how to use questionnaires to determine semi-quantitative scores of socio technical systems to assess the status of their risk and resilience analysis and management. It maps qualitative as well as quantitative questions on semi-quantitative scales at different system and analysis levels up to overall assessment level. Main focus is on a formalism that allows a dimensional analysis of ordered sets of questions. To this end the questions are related to resilience and risk dimensions understood as concepts allowing a semi-quantitative multiple binning of results, e.g., an answer can be attributed to one or more risk management phases, to resilience cycle or catastrophe management cycle phases, to system layers, and/or to technical resilience capabilities. This allows the simultaneous use of several risk control and resilience generation frameworks, analysis and management concepts. It is shown how extensive quantities are defined that do not depend on the number of questions using normalization conditions. Thus, the user can remove predefined and add new questions as appropriate. The approach is applied to the critical infrastructure domain and to companies affected by the Covid-19 pandemic.

Keywords: Resilience analysis and dimension, Expert questionnaire, Score card, Formalization, CI, Covid-19.

TH1J: 363 10:00 hrs

Framing Cyber Resilience for Critical Infrastructure in the Context of Resilience Engineering – A Literature Study

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The paper explores the common grounds of cyber resilience and resilience engineering and reports on a literature study of the term cyber resilience for the application of critical infrastructures. The term cyber resilience has during the last few years gained increasing usage. In the safety field of research, resilience engineering has facilitated alternative approaches to safety management, to cope with complexity. Along with its digitalization, critical infrastructures are getting increasingly more complex, by the introduction of information technology (IT) in already existing operational technologies (OT), and at the same time exposed to new threats, by the connection to internet. The paper investigates to what extent cyber resilience, as it is defined and used today in scientific literature for critical infrastructure, represent a symbiosis of the concepts of cybersecurity and resilience engineering, and possibly a new paradigm for cybersecurity practices, similar to how key ideas from resilience engineering have sparked a new paradigm for safety management – "Safety-II". The scope and applications of cyber resilience for critical infrastructure is examined based on a model describing the various levels of operationalization of cyber resilience. The paper also explores whether current interpretations of cyber resilience, alternatively, is a relabeling of existing cybersecurity (best) practices, and rather represent a form of "rebound or "cyber robustness" that is more loosely connected to resilience engineering concepts. The paper concludes with the implications for further research within the field of cyber resilience for critical infrastructure applications.

Keywords: Cyber resilience, Resilience engineering, Cybersecurity, Robustness, Information security, Cyber-physical system, Critical infrastructure.

Session	[TH1K]—Innovative Computing Technologies in Reliability and Safety
Day/Date/Time	Thursday, 23 Sep. 2021/09:00–10:20 hrs
Venue	Atrium 1

TH1K: 259 09:00 hrs

Performance Management of Safety Instrumented Systems for Unmanned Facilities Using Machine Learning: Decision Support System for SIS

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Performance management of safety instrumented systems (SIS) is a vital part of major accident risk management for oil and gas processing facilities. The requirements to performance management are provided in national regulations and governing standards for SIS, such as IEC 61508 and IEC 61511, and cover how the performance shall be managed. Many of the tasks related to performance management of SIS are resource demanding, manually carried out, and dependent on local presence of humans at the facilities. For some of the future offshore oil and gas facilities that are to be completely unmanned, with restricted access to humans, it is necessary to move to a higher level of automation and autonomy in performance management. This includes the utilization of artificial intelligence (AI), such as machine learning (ML), to determine the ability of the SIS to respond to demands under various operating conditions, based on historical or real-time process data and event data from multiple monitoring systems. The proposed decision support system for SIS (SIS advisor) shall provide valuable information on a given process system whether the system is under normal status according to its design intention.With this information, the operators will have a better chance to understand the current operating situation so that they will be able to make better decisions as a response. This paper proposes how ML can be used to enhance operator's awareness on the system, and set up a framework for processing input data into the information to support operator's decision. Moreover, it is discussed how to measure the risk reduction made by SIS advisor.

Keywords: Safety instrumented system, Unmanned facility, Machine learning, SIS performance measure.

TH1K: 419 09:20 hrs

A New Pivot-Based Approach to Constructing Prediction Limits and Shortest-Length or Equal Tails Confidence Intervals for Future Outcomes under Parametric Uncertainty

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It is often desirable to have statistical prediction limits available for future outcomes from the distributions used to describe time-tofailure data in reliability problems. For example, one might wish to know if at least a certain proportion, say γ, of a manufactured product will operate at least t hours. This question cannot usually be answered exactly, but it may be possible to determine a lower prediction limit $L(\mathbf{X})$, based on a random sample $\mathbf{X}$, such that one can say with a certain confidence $-(1-\alpha)$ that at least 100% of the product will operate longer than $L(\mathbf{X})$. Then reliability statements can be made based on $L(\mathbf{X})$, or, decisions can be reached by comparing $L(\mathbf{X})$ to t. Predictions limits of the type mentioned above are considered in this paper. A new approach is used to construct unbiased prediction limits and shortest-length or equal tails confidence intervals for future outcomes under parametric uncertainty of the underlying distributions through pivot-based estimates of these distributions. The approach isolates and eliminates unknown parameters of the reliability problem and uses the past statistical data as efficiently as possible. Unlike the Bayesian approach, the proposed approach is independent of the choice of priors and represents a novelty in the theory of statistical decisions. It allows one to eliminate unknown parameters from the problem and to find the efficient statistical decision rules, which often have smaller risk than any of the well-known decision rules. To illustrate the proposed approach, some practical applications are given.

Keywords: Underlying model, Parametric uncertainty, Isolation and elimination of unknown parameters, Efficient statistical decisions.

TH1K: 646 09:40 hrs

A Web Application To Predict State Of Charge Of Electric Vehicles Batteries

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With the increasing concern about environmental issues such as air/water pollution and global warming, searching for new alternatives to provide sustainable transportation devices is highly important to diversify the power source matrix as well as maintain logistic systems as they are today. Therefore, electric vehicles come as a feasible alternative to diversify the current vehicular system to decrease fossil fuels' impacts. Such devices are composed of certain components being the main one the battery, which is the core of electric vehicles, and its safety is crucial to avoid accidents (e.g. gas leakage, fires, and explosions). Lithium-ion cells are widely used as electric vehicle power sources; and considering Prognostic and Health Management context, information about the State of Charge is essential to ensure the system's safety. In this context, we develop a Web Application using Streamlit, an opensource Python library, to predict the State of Charge. As an input, the users can enter the monitoring data (e.g. temperature, current, voltage) from their system. In this web application, the user can set the model's parameters and as the obtained results, this web application is going to give the State of Charge prediction.

Keywords: Electric vehicles, State of charge, Batteries, Machine learning, Web application, Streamlit.

Session	[TH2A]—Risk Management
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Plenary Room

TH2A: 273 **10:35 hrs**

A Decision Support System for Multidimensional Risk Evaluation of Natural Gas Pipelines

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The distribution of natural gas has become an operation of great concern because of the hazardous conditions. In these systems, accidents can trigger losses concerning the human, environmental, and financial dimensions. Because of conflicting objectives, multidimensional risk analysis is fundamental to supporting decisions on pipeline operations. However, dealing with a large and dynamic amount of information may be inefficient for managers to plan mitigating actions to avoid losses. Thus, this paper proposes to develop a Decision Support System (DSS) based on using a multidimensional risk decision model to assess risk in natural gas pipeline sections. The DSS is developed in two main modules. The first module, which quantifies and sorts risks, uses Utility Theory and the ELECTRE TRI method to assess the level of risk in the sections of a pipeline. The second module conducts a sensitivity analysis that investigates the uncertainty in input parameters and the modification of output assessment. In general, the DSS contributes to structuring the decision-making process of risk assessment of natural gas distribution by monitoring the organization's limitations, following environmental regulations, and restricting human interference. Thus, this paper presents a possible way to overcome challenges regarding the planning of imminent risk and formulate uncertainty scenarios to manage risk in natural gas pipelines.

Keywords: Decision support system, Natural gas pipeline, Risk evaluation, Utility theory, ELECTRE TRI, Sensitivity analysis.

TH2A: 279 **10:55 hrs**

Risk Assessment in Magnetic Particle Inspection (MPI) of critical ferromagnetic parts via Bayesian Belief Networks and Analytic Hierarchy Process and the use of Goal Tree to Improve the on quality and Sustainability of Organizations

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This paper proposes a method for identifying the high-level risks in the Magnetic Particle Inspection (MPI) of ferromagnetic material parts, based on Analytic Hierarchy **Process (AHP)** and Bayesian Belief Network (BBN). The combination of probability and the impact identified the most significant risks, which needed to be addressed to improve quality management system and ensure organization sustainability. As a methodological approach, the estimated risk probabilities for the risk factors obtained from a case study and a survey with experts were loaded into Bayesian Belief Networks software to assess the probability of occurrence of undesirable events and AHP was utilized to rank the relative importance (effect) of risks. The combination of probabilities and the effects identified the most significant risks. The novelty of the paper is the combination of Bayesian Belief Networks with AHP and the use of Goal Tree dashboard to improve quality and sustainability in the inspection of critical parts. The application of the method revealed that the most significant risks in the inspection of critical hardware are related to operator failure, unfavorable control and environment, negative organizational factors. The paper proposes responses to these risks aiming at preventing the occurrence of failure in the MPI inspection of critical hardware. This paper contributes to the literature in the field non-destructive inspection of critical parts. The proposed model has also practical implications and is an invaluable source for non-destructive inspection professionals, safety engineers, quality managers and decision makers in companies.

Keywords: Risk assessment, Bayesian belief network, Analytic hierarchy process, Critical ferromagnetic parts, Magnetic particle, Goal tree, Quality management system, Organizational sustainability.

TH2A: 285 **11:15 hrs**

Challenges for Continuous Risk Assessment in Agile Development Environments

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Agile development (AD) represents a paradigm shift in how organizations manage their development projects and collaborate with internal and external project stakeholders. AD is a development approach based on iterative development, frequent adaptations, and incremental deliveries in which requirements and solutions evolve. AD could thus challenge the common Waterfall approach in risk assessment. The study starts with a literature query to identify challenges in AD using four quadrants of risk categorization (customer mandate, scope & requirements, execution, environment). The paper points to the problem of means-prescriptive quality requirements in AD and Agile software development (ASD). Semi-structured interviews and questionnaires with IT experts from various Swiss Federal Departments complement and substantiate the findings. A checklist based on the SWOT analysis summarizes the results to support transformation processes from sequential Waterfall to ASD at organizations. A proposal to incorporate these requirements for continuous risk assessment in ASD is presented.

Keywords: Risk assessment, Risk management, Agile development, IT security.

Session [TH2B]—System Reliability
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Atrium 2

TH2B: 483 **10:35 hrs**

Development of a Cause-Effect Relationship Model to Identify Influences on Load Conditions that Cause Bearing Damage

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When considering the influencing factors that may cause damage to occur within a bearing, it is important to note that one cannot trace the cause back precisely. These influencing factors may range from being temperature changes, external forces and lubrication choices. The load conditions in technical systems depend on many influences. This paper presents a model that supports the identification of the relevant influences on load conditions that cause bearing damage, to enable bearing durability tests. The development of the presented model is based on consideration of pitting as well as widening of the bearing raceway and edge throw-ups. The influences that the before mentioned considerations have on the load conditions as well on the occurrence of the damage were unknown. Furthermore, findings from damage catalogs and theoretical system analysis were used in combination with experimental investigations. The developed model links the following external influences to have an effect on bearing damage: load conditions, operation-dependent parameters in the bearing, physical and chemical mechanisms as well as appearance of the damage. The presented model can be used to identify the following: influences that lead to main loads, parameters that reinforce damage mechanisms, cycles that are self-reinforcing, and parameters that contribute to multiple damage mechanisms. The before mentioned facilitates the formulation of relevant influences on load conditions for bearing durability tests.

Keywords: Durability test, Bearing, Load conditions, Cause-effect relationships, Test rig, System analysis.

TH2B: 694 **10:55 hrs**

Reliability Assessment of Pressurized Pipelines Based on Corrosion Rates and Defect Dependencies

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Underground pressure pipes are subject to corrosion under various environment conditions. Such as the aggressiveness of the soil, which is influenced on the corrosion rates, and depends on one region to another at long of pipeline. This study will focus on evaluating the reliability of a corroded pipeline under pressure. Degradation of this asset is induced by localized corrosion, resulting in the loss of wall thickness. It has a significant effect on the probability of bursting and is influenced by external factors (spatial variability), which brings us back to the study of the distribution of corrosion rates along a pipeline, The failure probability is computed by using Monte Carlo simulation. This work will be applied to case study on an oil pipeline located in Algeria made of API 5L X52 steel.

We will study the effects of correlations between corro-

sion defects parameters on the probability of failure. The sensitivity of the design variables in the performance function on the probability of failure will be also studied.

Keywords: Pipeline, Reliability analysis, Corrosion, Monte-Carlo, Variable correlation, Sensitivity analysis.

Session	[TH2C]—Reliability and Maintenance of Networked Systems
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Espace Grand Angle2

TH2C: 641 **10:35 hrs**

Robust End-To-End Reliability Evaluation for Industrial 5G Communication Systems

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The end-to-end reliability evaluation of communication systems has long been a challenging task, due to the system's structural, protocol, logical and physical complexities and the environmental uncertainties in wireless communication transmission. Nowadays, world leading communication service providers are ambitiously planning to implement 5G communication systems in industrial scenes, to fully replace the current widely used industrial WIFI. However, new challenge arises since the high demand of production quality requires highly accurate realtime communication reliability guarantee, for the communication Quality of Service (QoS) targets such as latency and data rate.

In this work, we propose a robust framework to compute the end-to-end communication reliability index. The whole communication system is modelled as a queuing network with datadriven epistemic uncertain stochastic processes. By assuming stochastic monotonicity in the structure of uncertain distribution set, we can specify the worst-case distributions, and, then, approximate the worst-case system reliabilities through Monte-Carlo Simulation (MCS). A detailed implementation of MCS technique in the specified problem and benchmark testing are also presented in this work.

Keywords: Robust reliability evaluation, 5G, Communication network, Monte-Carlo simulation, Queuing network, Data driven model.

TH2C: 662 **10:55 hrs**

Spatio-Temporal Anomaly Detection for Large-Scale Dynamic Attributed Networks

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Dynamic attributed networks (DANs) provide powerful means of representing complex system, e.g., online social networks, financial networks, transactional networks, and wireless sensor networks. To facilitate situation awareness and critical decision-making, anomaly detection in DANs has become an increasingly active area of research in network sciences. However, most existing methods are only capable of detecting the temporal outliers, neglecting the potential benefits of jointly detecting the spatial outliers across the entire network. To address this issue, this paper presents a novel approach, which is also efficient for large-scale networks. Specifically, we first develop a novel recurrent neural network structure to explore the spatio-temporal correlations of the DANs. Furthermore, prediction residuals are monitored through an exponentially weighted moving average (EWMA) control chart. Experiments on synthetic and real-world datasets depict the properties and benefits of the method compared with existing methods in the literature.

Keywords: Dynamic attributed networks, Anomaly detection, Spatio-temporal correlations, Large-scale networks, Recurrent neural network structure, Exponentially weighted moving average control chart.

TH2C: 765 **11:15 hrs**

A Set of System Reliability Metrics for Mobile Telecommunication Network

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Telecommunication networks are one of the most important critical infrastructures in our society, as they transmit information among different people or entities. Starting from 1960s, several telecommunication network operators began to rely on the stable and non-stopping service to fulfil consumers' ever-rising demands for high quality communication services. Telecommunication network reliability has then become an important research topic as well as practical concern. After few decades of research and development, there are several reliability metrics proposed by researchers in literature and a set of Key Performance Indicators (KPIs) widely used by several companies in practice.

Any KPI anomaly is alerted, such that the operators are typically overwhelmed by KPI alerts every day. Moreover, the operators need to invest plenty of resources for maintenance to respond to these alters, which is simply not sustainable. Therefore, there is a strong demand from industry for a system-point-of-view reliability metric that severs as the foundation of scientific management of the maintenance activities of modern telecom network. However, there is still lack of such a metric in academia as well as in practice. In this work, we propose a set of metrics based on the concept of service reliability with the attempt to bridge such a big gap.

Keywords: Telecom network, 5G, System reliability metric, Consumer demand, Service reliability, Operation and management.

Session	[TH2D]—Prognostics and System Health Management
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Panoramique

TH2D: 652 **10:35 hrs**

A ROC Based Model to Maximize Global Detection Power of a Group of Detectors

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In many applications, detection methods are implemented to monitor systems. In a complex system many components may be monitored and each component detector must be tuned based on a tradeoff between false alarm and non-detection. The tuning of these detectors is an open question. A naive approach is to tune each detector individually.

In previous communications we have shown that this naïve approach leads to non-optimal global performance and can be significantly improved using an adequate setting and optimization method to tune jointly the detectors. The information needed to perform such optimization is the ROC curve of all individual detectors and the expected global performance as a final result.

In these first communications we assumed that the system under consideration is made of parallel units and that the failure probability of a produced good is independent of the units of the system that builds it. But to create a complete model, in many real systems, one needs also to consider the case of series components.

In this communication we consider series components and the goal is to tune detectors to satisfy a chosen performance constraint. For sake of simplicity the Neyman-Pearson setting is considered here. Two different situations are studied. In the first case detectors test different types of failure and are assumed independent of each other. In the second case all detectors are trying to detect the same defect type. A connection between that case and decision tree is drawn. In both case the model is introduced and illustration of the effect of detector tuning is shown. These results could be used to gain significant benefits in two cases: first, to improve the detection performance of an existing system whether the constraints are invariant or changing with time, second, when designing a new system to make a choice between different detection sensors and technologies that have their own cost and offer different performance profiles. The proposed approach is a step forward to enable comparison between different design options.

Keywords: Detection, ROC curves, Statistical models, Compound system, Global performance, Performance assessment.

TH2D: 663 **10:55 hrs**

Forecasting Components Failures Using Ant Colony Optimization for Predictive Maintenance

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Failures are the eminent aspect of any sophisticated machine such as vehicles. Early detection of faults and prioritized maintenance is a necessity of vehicle manufacturers as it enables them to reduce maintenance costs, safety risks and increase customer satisfaction. In this study, we propose to use a type of Ant Colony Optimization (ACO) algorithm to diagnose vehicles faults.We explore the effectiveness of ACO for solving fault detection in the form of a classification problem, which would be used for predictive maintenance by the manufacturers.We show experimental evaluations on the real data captured from heavy-duty trucks illustrating how optimization algorithms can be used as a classification approach to forecast component failures in the context of predictive maintenance.

Keywords: Ant colony optimization, Fault detection, Predictive maintenance.

TH2D: 673 **11:15 hrs**

Investigation of Features for Ball Bearings Remaining Useful Life Prediction

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The ability to accurately predict the remaining useful life (RUL) of rolling bearings plays an important role in the condition monitoring and maintenance of rotating machinery. Some practical challenges are related to the selection of optimal degradation features for effective and accurate RUL prediction. There are few works dedicated to the problem of selecting suitable features for RUL prediction based on physical modelling. This paper proposes a study for predicting RUL of rolling bearing considering various features and prediction methods based on physical fault crack growth modelling. Three feature sets (RMS, level crossing, multiple features (MFs)) are considered as degradation indicators. A nonlinear least squares method is used for initial parameters estimation. Bayesian method and particle filtering are applied for updating the values of the parameters of the physical model. The proposed framework is demonstrated using real test data provided by the FEMTO-ST institute. The results of two methods are compared, considering three different indicators. MFs indicator has the least error in the RUL estimation compared to other indicators. Particle filtering is found to perform more accurately than the Bayesian method when data are collected in real time.

Keywords: Remaining useful life, Rolling bearing, Vibration, Bayesian approach, Particle filter, Feature extraction.

Session	[TH2E]—Organizational Factors and Safety Culture
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Amphi Jardin

TH2E: 429 **10:35 hrs**

Human Reliability Analysis as Pedagogical Tool

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Chemical accidents involving explosions, large fires and leakages of hazardous substances occurring during transport, storage and industrial production of chemicals constitute a real challenge to health, environmental and industrial safety professionals. Human factor is one of main causes of fire and explosion accidents in petrochemical enterprises. Safety chemical industry process depends on many factors, one of them is the safety culture. Great efforts have been made for improving safety culture among operators and all agents. The technical education institution of chemical process that trains and prepares professionals are one of the fronts. The purpose of this article is to present an HRA (Human Reliability Analysis) as pedagogical tool to increase the safety culture of students and professionals from a technical education institution of chemical process, through routine manoeuvre in the prototype process unit, failure simulations, and to evaluate the effectiveness of the training given. The technical education institution with all attributes, including safety culture, and that it is willing to cooperate with this innovator project in formatting professionals and preparing workforce for Brazilian industry, it is National Service of Industrial Learning - SENAI, sited in the São Paulo industrial and metropolitan region, Brazil. In order to evaluate students' and professionals' interface, it is proposed a method for analysing the human interaction within the system to establish a generic causal framework aiming at the study of the human error mechanism. This analysis is proposed through the Bayesian Networks approach supported by Fuzzy Logic whose application is to model the performance shape factors and checking through a causal inference and diagnosis, which factors most influence in the performance of the students operation at a prototype process unit. The results recommended a design revaluation of prototype process unit regarding human interface and instructions procedures, to promote students critical thinking regarding human errors, and more practical trainings.

Keywords: Safety culture, Pedagogical tool, Human reliability, Bayesian network and fuzzy logic.

TH2E: 469 **10:55 hrs**

Sources of Underreporting of Adverse Events in the Chain from Individual to Regulator: A Short Literature Review

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Reporting of adverse events is an important part of safety management and a possible source for learning and continuous improvement. However, underreporting of such events remains an issue in working life. This short literature review is aimed to provide an overview of the current state of knowledge regarding the level and causes of underreporting, as well as the measures that are proposed in the literature to increase reporting. Reporting related to individuals, contractors, and authorities is considered. Identified causes for underreporting included lack of feedback, fear of reprisals, fear of negative attention, elements of the professional identity, lack of knowledge, high efficiency demands, safety culture and safety climate, company size, and system flaws involving practical problems with the reporting system. Proposed measures included simpler reporting systems that ensure confidentiality and system requirements for feedback, education, and training, and a general strengthening of safety management systems. Research on underreporting related to contractors and authorities is scarce and needs to be taken up by future researchers since new work arrangements are on the rise.

Keywords: Adverse events, Reporting, Underreporting, Contractors, Operators, Regulators.

TH2E: 585 **11:15 hrs**

Safety Knowledge in the General Population in the School Age

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Within the major risk reduction measures, the basic knowledge and awareness of safety issues in various environments must be highlighted for their importance. The knowledge of the main concepts of safety means that a good safety culture. As this knowledge grows, operators will be more willing to adopt the prescribed prevention and protection measures in the work environment. In addition, good knowledge can push operators to actively participate in data collection campaigns and proactive security measures. In fact, the safety regulations of various countries prescribe training and information campaigns for the safety in the workplace. To be effective, these training and information measures require the operators to have a basic safety culture and knowledge.

Poor data on the level of basic knowledge possessed by the general population are available.

The culture and basic knowledge about safety are acquired during the development phase of the individual. To evaluate at which level this knowledge is acquired, a data collection on the safety knowledge of children in primary and secondary schools was carried out. About 1600 students (around 800 in primary schools and 800 in secondary schools) from 5 different schools, aged between 7 and 15, were involved in the data collection. The schools where the data collection was carried out are in the city of Turin, Italy.

Data collection was carried out through a game-based approach, requiring the answer to a short series of multiple-choice questions. The questions changed according to the age of the participants. Based on the results obtained from the data collection, in this article it is shown how the knowledge about safety varies with the age, gender and location of the school (consequently with the socio-economic environment of the neighbourhood in which the school is located).

Keywords: Basic safety knowledge, Data collection and analysis, School age.

Session [TH2F]—Critical Infrastructures
Day/Date/Time Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue Espace Grand Angle

TH2F: 343 **10:35 hrs**

Safeguarding the Long-Term Condition of Logistics Infrastructure Assets: An Analysis of Concession Contracts

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The logistics of a country is essential to the subsistence and development of its population. In a global market, the challenge is to move goods quickly, reliably, and economically. Maintenance is a major player in the operational performance of a country's infrastructure. The functionality, safety, productivity, comfort, image, and conservation throughout the entire life cycle of ports, airports, roads, and railway connectivity depend on the maintenance function. In particular, this kind of maintenance is generally carried out via concession contracts or operating subsidiaries. After conducting an exploratory analysis, the authors identified the main trends, methodologies, research opportunities, risks, as well as recommendations to reduce hazards in contracts. We found that the number of publications about concession models and infrastructure contracts has been increasing, nevertheless most of the works correspond to BOT-type (buildingoperate- transfer) contracts, mainly focused on roads. Therefore, there is a need to increase in research regarding contracts that also involve maintenance of ports, airports, and other infrastructure. Particularly since we confirmed the evidence that PPPs (public-private partnerships) contracts offer great advantages for contractors to provide high quality infrastructure. Also, we identify four elements that are the most cited as key factors for an adequate concession contract: 1) Taking care of financial viability, 2) Procuring collaborative work, 3) Shielding against political instability, and 4) Being careful in the estimation of the contract concession period.

Keywords: Maintenance, Logistics, Infrastructure, Contracts, Concession, Best-practices, Systematic review.

TH2F: 385 **10:55 hrs**

How Corona Crisis Affects Critical Flows – A Swedish Perspective

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The functioning of modern societies is highly dependent on flows, relying on timely deliveries of goods and services. Critical flows are those particularly important, e.g., electricity, food, and pharmaceuticals. Infrastructures upholding flows often transgress national borders, where a disruption can escalate into wide-spread crises. Continuity of critical flows is hence of outmost importance under stresses. A worldwide ongoing stress is the coronavirus pandemic, strongly characterizing 2020 and dominating media, resulting in closed borders, lock-downs, halted production, and altered demand patterns. The corona crisis is foremost a health crisis, with devastating consequences on people's life and health. Many studies have focused on the healthcare sector, with limited attention on critical flows in other sectors. This study aims to explore effects on critical flows within four societal sectors (transport, energy, info-com and food) in Sweden to date. A scoping study of Swedish printed press throughout 2020 was performed, investigating actual and potential flow impacts, flow interdependencies, and implications for preparedness and resilience. The media database Retriever Research was used to identify 4693 news and opinion articles, of which 145 relevant articles were subjected to content analysis. Concluding that limited critical flow disruptions occurred despite many prophecies and predictions. The disruptions that occurred were short-lived, non-severe, and mostly originating from secondary effects, indicating that Swedish critical flows in these sectors are resilient to this type of pandemics.

Keywords: Critical flows, Corona, Covid-19, Pandemic, Critical infrastructure, Supply chains, Security of supply, Interdependencies, Transport, Energy, Information and communication, Food, Preparedness, Resilience, Scoping study, News, Media.

TH2F: 398 **11:15 hrs**

Good Practices for Critical Infrastructure Resilience: a classification and assessment framework

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The fast-growing occurrence of unexpected events affecting Critical Infrastructure (CI) systems in recent years fostered a shift from a protection-focused approach to CI Resilience (CIR). In this context, the increasing number of interdependencies, which generate domino effects and cascading failures, led to the call for establishing collaborative approaches and partnerships at the regional, national or international level. To support and implement CIR strategies, governments and CI operators often rely on Good Practices (GPs), generally defined as methods or techniques that are applied to solve existing problems producing effective results and bringing benefits to the users. Despite the high number of GPs, they are often insufficient to cover the wide spectrum of capabilities required for effective Emergency Management (EM). In this study, the systematic analysis and review of scientific literature and European projects in the CIR domain, led to the identification of 53 GPs that have proven to be effective in managing CIR. To enable comparison among the GPs the study proceeds with the development of a framework for classifying and assessing GPs according to their application context, the activities and functionalities covered, and the EM capabilities they are able to support. From a research perspective, the framework offers a robust background for future assessment and benchmarking of CIR related GPs; it is also useful for practitioners to assess and select the most suitable GPs under different institutional and operational contexts.

Keywords: Critical infrastructure, Resilience, Good practice, Emergency management capability, Collaborative approaches, Interdependence.

Session	[TH2G]—Asset management
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Atrium 3

TH2G: 633 **10:35 hrs**

Optimizing Condition Monitoring Retrofitting Decisions for Interdependent Multi-Unit Systems Under Dynamic Uncertainty

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In many industries, the employed maintenance policies contributed to the concentration of asset replacements in a short period of time. Thus, the number of O&M activities increases, leading to rising operational costs that are not compatible with the available resources. Moreover, these assets encompass multiple failure modes, which reduce asset availability and influence its longevity. Because asset degradation is stochastic, a considerable amount of uncertainty is associated with this problem. The recent technological advances in monitoring technology may foster a reduction in degradation uncertainty but the extra effort regarding the investment plan must be carefully planned.

Bearing this in mind, we propose a methodology to determine the investments in the installation of monitoring equipment accounting for the impact in maintenance budget for O&M activities for a resource-dependent asset portfolio with multiple failure modes. The budget is shared between multiple assets and must be determined, a priori, and managed throughout an established time horizon. Since investing in monitoring equipment requires substantial capital due to the system size, DMs have to define which and when a given asset monitoring technology will be installed. Hence, not every asset may have the same monitoring technology and, consequently, the same degradation uncertainty. We formulate the problem as a stochastic optimization problem to capture the dynamic uncertainty in the assets' condition. Due to its inherent complexity, we employ a meta-heuristic based on a co-evolutionary genetic algorithm to achieve high-quality solutions under reasonable computational time for real world-sized systems. The approach is validated in a case study in the electricity distribution in which a system operator has to manage a portfolio of power transformers operating under different operational conditions.

Keywords: Multi-unit system, Predictive maintenance, Stochastic optimization, Mixed-integer models, Risk assessment.

TH2G: 638 **10:55 hrs**

A Global Approach to Life Management of Pressure Equipment

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During the life cycle of pressure equipment, it is necessary to investigate the structural integrity in order to avoid failures and outages, which may affect safety and cause lost production. The fabrication phase is quite straightforward as pressure equipment in Europe must comply with Pressure Equipment Directive PED with the application of European or international standards. The following phase is the "putting into service" which is aimed at assuring a correct installation and operation according to the instructions. From this phase onward, the equipment is operated and maintained according to the operating instructions but unfortunately a detailed in-service inspection plan is seldom provided by the manufacturer. Therefore, in order to manage the integrity of the components during their whole life it is necessary for the User to define a general in-service inspection plan. To obtain this goal a specific procedure is under development by the Italian Thermotechnical Committee. According to this procedure it is suggested to carry out a preliminary inspection on the equipment at an early stage of service life which is useful to identify failure modes acting on the item under consideration.

The role of standards is essential to draw up a consistent inspection plan. For this purpose, this paper illustrates the national standards concerning the integrity of pressure equipment issued by the Italian Standardization Body UNI/CTI.

Eventually some case studies concerning failures of pressure equipment in Seveso establishments are presented, aimed at showing how the lack of a specific plan for inspection may bring to near-misses or accidents.

Keywords: Pressure equipment, NDT, Life management, Piping, Reactor, Inspection, SEVESO, Repository.

TH2G: 695 **11:15 hrs**

Mastering Smart Asset Management in Industry 4.0 Revolution

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Asset management becomes a significant issue in today's industry 4.0 globalization. When asset management is coupled with industry 4.0, mastering it brings us to new transition challenges in its implementation strategy, tactics, and execution. It is gradually being expanded so far as to all areas of industry. This research paves the way for further and deep research on comprehensive asset management in the dark side of the industry 4.0 transition. It is about achieving the best value of asset management implementation, through the right balance between quality, cost, delay, flexibility, and performance. In other words, it is a question of digging up the hatchet of war against the shadow mechanisms of power and influence, which covertly control the implementation of asset management within industry 4.0. This research is projecting to influence asset management policymakers in the industry 4.0 transition. Actors and organizations will use it to build transition strategic plans and to implement and manage sustainable asset networks knowingly. Based on a multiple-case study, this empirical study is explanatory intervention research. Its design is consistent with the epistemological paradigms of generic constructivism and ontological relativism. We use abductive reasoning combined with a qualimetric approach based on the socio-economic method, with priority for extra-accounting methods. This research makes three main contributions. First, it provides a framework of critical mechanisms to drive asset management implementation in industry 4.0 with confidence based on system assurance. Second, it offers governance tools to organizations to master sustainable asset management strategies from transition decisions to implementation. Finally, the study offers guidance to asset and risk managers as to which factors need to be considered to successfully manage assets in industry 4.0 through risk management.

Keywords: Asset management, Industry 4.0, Risk governance, Systems assurance, Business administration, Decision-making, Multi-modal mobility.

Session	[TH2H]—Safety and Reliability of Intelligent Transportation Systems
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Cointreau

TH2H: 104 **10:35 hrs**

Parametric Finite Element Analysis on the Design of Railway Crossings for Increased Reliability

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Crossings allow trains to change tracks and hence are an essential railway component. However, they are also bottleneck points on the rail network under increased rolling stock traffic. Crossings are subject to high loading conditions and therefore, their structural integrity is of critical importance for the safety and reliability of railway operations.

As the wheel switches from one track to another, a vertical impact on the crossing nose or wing rail occurs. Wheel impacts can lead to several forms of damage, such as impact damage, wear, rolling contact fatigue, plastic deformation, among others. The crossing geometry is of utmost importance as the wing rail angle or nose shape can act as stress concentrators, further propagating damage and reducing the asset's lifetime.

The UK railway network alone comprises around 6,000 crossings, which need to be assessed and maintained with a frequency that ranges from one to three years in busy routes [1]. Modelling techniques, such as finite element analysis, can provide a better understanding of the stress states involved in this complex dynamic problem, leading to the optimization of the crossing geometry for an extended lifetime.

In this paper, we evaluate changes in the design of railway crossings in a dynamic environment via finite element analysis. The effects of changes in the crossing length and angle, train speed, as well as nose design, are evaluated regarding impact and deformation. This paper provides advice on best design practices allowing for more reliable and long-lasting railway crossings.

Keywords: Parametric analysis, Railway crossings, Finite element analysis, Dynamic analysis, Design by analysis, Reliability.

TH2H: 199 **10:55 hrs**

Comparing Macroscopic First Order Models of Regulated and Unregulated Road Traffic Intersections

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Road traffic models allow understanding the properties of the traffic and improving traffic control. To do so, the models must be realistic and also understandable (i.e. with few parameters that can be interpreted and calibrated). Macroscopic models are in particular useful for the simulation of large traffic networks. Yet intersection models are under-represented compared to traffic models on links in the literature (especially urban regulated intersection models). In this contribution, we analyse and compare four minimal regulated and unregulated macroscopic intersection models of the first-order. The two unregulated models are the FIFO model (first-in-first-out, i.e. roundabout-type intersection) and an optimal non-FIFO model for which the flow by direction are independent (i.e. highway-type intersection). The control (i.e. traffic light) operates upstream on the flows going-in for the first regulated intersection model while the control takes place downstream on the directions for the second regulated model. We demonstrate mathematical relationships between the intersection models and analyze the performances using Monte-Carlo simulation. The numerical simulations are performed by assuming random demand upstream and supply downstream, and also random direction distributions. This approach allows us to account for average performances but also for standard deviations and more generally for the distributions of the performances. Indeed, reliable intersections should describe regular performances with small variations. We observe that the optimal regulated intersection models overcome the performances of the FIFO model, on average but also in terms of variability (i.e. reliability). Furthermore, bounds for the four intersection models are provided.

Keywords: Road traffic intersection, Macroscopic modelling, First-order model, Regulated intersection model, Unregulated intersection model, Monte-Carlo Simulation.

TH2H: 435 **11:15 hrs**

Dynamic Agent-Based Transit System Disruption and Recovery Simulation Model

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Transit system disruptions can have severe system-wide effects on service delays, crowding levels, and the ability of millions of travelers to reach their destinations routinely and unencumbered. This work therefore develops an agent-based simulation model to understand and augment the resilience of transit systems. Other than existing dynamic agent-based models that focus on small disturbances (1,2) or simplify the re-routing behavior and real-time information availability of passenger agents (3), the proposed simulation model concentrates on severe disruption scenarios and resulting system-wide redistribution of passenger agents that variably alter their decision behavior in response to delays and system alert information. Moreover, the simulation accounts for timetable rescheduling measures. The simulation model has been validated on a case study of the New York City (NYC) subway network with realworld passenger demand data and train vehicle schedules, and produces reliable predictions of passenger flows during both undisrupted and disrupted conditions. The versatility in testing diverse disruption and recovery scenarios (e.g., fig. 1) is a valuable addition to the preemptive assessment of disruptions and recovery schedules as well as to contrive contingency plans, identify potential bottlenecks, or prepare component and process redundancies to be swiftly engaged and dispatched when needed.

Keywords: Urban transit systems, Agent-based modelling, Discrete-event simulation, Disruption management, Simulation-based optimization, Recovery modelling.

Session	[TH2I]—Mathematical Models in Maintenance
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Giffard

TH2I: 714 **10:35 hrs**

Problem of Maintenance Resource Sharing in Physical Asset Maintenance – Case Study

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The authors propose a fuzzy AHP (Analytic Hierarchy Process) method implementation to system maintenance for the resource sharing strategy selection process in the presented paper. Thus, the paper includes a short introduction to the maintenance problems and a discussion of maintenance resource sharing issues. Later, the proposed fuzzy approach to maintenance resource sharing for production systems in the context of physical asset maintenance management concept is proposed. Then, based on the developed concept, a short case study is discussed. Finally, the presented paper gives the possibility to identify research gaps and possible future research directions connected with optimization of maintenance problems in industrial organizations.

Keywords: Maintenance, Physical asset, Maintenance management, Resource sharing, Production system.

TH2I: 277 **10:55 hrs**

Optimisation of Maintenance Policies for a System with Multiple Deteriorating Components

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Condition-based maintenance (CbM) is a useful technique for scheduling maintenance policies aiming to reduce operating cost, improving the security of management, and ensuring the stable quality of the products. This paper models the deterioration process of a system composed of multiple components. Each deterioration process is modelled with the Wiener process. When a linear combination of the processes exceeds a pre-specified threshold, the age replacement policy will be carried out as the preventive maintenance for the system. Based on these two replacement policies, the optimized maintenance intervals are then sought.

Besides, the paper also develops a cost process which considers the situation when the maintenance cost is higher than an expectation value, the decisionmaker will prefer to replace the whole system but not repair it. Numerical examples are given to illustrate the optimisation process.

Keywords: Condition-based maintenance, Wiener process, Gamma distribution, Cost process.

TH2I: 707 **11:15 hrs**

Multiple Deterioration Processes with Stochastic Arrival Intensity

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Many systems, such as electronic products, heavy machine tools and piping systems[3], are subject to multiple degradation processes for example. On a pavement network, several different degradation processes, such as fatigue cracking and pavement deformation, may develop simultaneously[4].

For systems subject to multiple degradation processes there are two approaches to model the degradation mechanism of the processes. The first approach considers that all the degradation processes start to deteriorate at the same time. However, as Kuniewski *et. al* claim[2], it is unlikely that all degradation processes appear at the same time. The second approach assumes that the degradation processes initiate at random times and then grow depending on the environment and conditions of the system. In this approach, two stochastic processes have to be combined: the initiation process and the growth process. For some special cases, the combined process of initiation and growth has a particular mathematical structure. For example, if the degradation processes appear following a non-homogeneous Poisson process (NHPP) and all these processes degrade following the same degradation mechanism, the number of degradation processes that exceed a fixed degradation threshold at time t follows a non-homogeneous Poisson process.

In this work, a system subject to different deterioration processes is analyzed. The novelty of this work is that the arrival of the degradation processes to the system is modeled using a Cox processes. A Cox process generalizes the non-homogeneous Poisson process since the intensity of arrivals is itself a stochastic process [1]. Using the properties of a Cox process, the combined process of initiation and growth is modelled and the system reliability is obtained.

Keywords: Cox process, Multiple degradation processes, Maintenance.

Session	[TH2J]—Energy
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Botanique 2

TH2J: 131 **10:35 hrs**

Testing a Novel Decision Support System to Identify the Most Suitable MCDA Method for Energy Systems Analysis

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Multiple Criteria Decision Analysis (MCDA) methods are widely used to aid the interpretation of results from energy systems analyses. This trend is justified by the capacity of MCDA methods to integrate a variety of factors, sometimes conflicting and measured on different scales, in an easily understandable decision recommendation, such as a ranking, sorting in preference-ordered classes, or selection of most preferred alternatives. In order to obtain credible results from the application of MCDA methods, they should be suitable for the study they have been used in. Limited research has been conducted on evaluating the match between the capabilities of the MCDA methods and the characteristics of decision-making problems. This study provides exploration in this direction by employing the following question: "Was the chosen MCDA method the best fit for your case study?". This question is being answered by means of a new Decision Support System (DSS) that the authors developed to recommend MCDA methods based on a comprehensive set of features describing complex decision-making problems. It was tested on a set of peer-reviewed case studies from the literature on energy systems analysis. The first main finding is that the authors of the case studies explore a limited set of features that would be needed to accurately describe complex decision-making problems. Furthermore, a few erroneous applications of MCDA methods were identified, among which (i) the use of criteria weights with a certain meaning (e.g., importance coefficients) in methods that require weights of a different type (e.g., trade-offs), and (ii) use of ordinal criteria in methods interpreting all scales of criteria as quantitative.

Keywords: Energy systems analysis, Decision making, Multiple criteria, Decision support system, MCDA, Method recommendation, Case studies.

TH2J: 186 **10:55 hrs**

Improving the Reliability of the Critical Asset Maintenance Plan Using Entropy and MAUT Approaches: A Hydropower Plant Case Study

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Achieving higher levels of asset availability is the goal of many industries in different segments. This purpose needs to be supported by actions that aim to increase the reliability of these assets. By improving the robustness of the equipment maintenance plan, operational campaigns can be successfully performed without the occurrence of unexpected system shutdown. The maintenance planning process must be capable of defining the most critical system components to keep asset performance. This research presents an innovative method that identifies critical components of a complex system. In this approach, Entropy method and Multi-Attribute Utility Theory (MAUT) are integrated to assign criteria weights associated with reliability, maintainability, environment, and safety, establishing the classification of criticality for components of a Kaplan hydropower unit, whose maintenance policy is used as a case study. The maintenance activities of the Kaplan system are analyzed and improved under expert opinion. The implementation of the proposed method allowed classifying the ten most critical items for the Kaplan unit and improving the robustness of its maintenance plan. The maintenance policy developed aims to improve the preventive maintenance and predictive monitoring plan of the hydro-generator, providing increased availability and ensuring the full supply of electricity to society.

Keywords: Kaplan hydropower unit, Enhance maintenance policy, Reliability, Critical components, Multi-Attribute Utility Theory (MAUT).

TH2J: 528 **11:15 hrs**

Resilience of the European Natural Gas Network to Hybrid Threats

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There is no commonly used definition of the term hybrid threat, but diverse characteristics and traits are often considered. These include: (1) a combination of coercive and subversive activity, (2) conventional and unconventional methods, (3) state or non-state actors, and (4) activities that remain below the threshold of detection and attribution. In general, hybrid threats affect multiple domains, create ambiguity, and are likely to exploit the vulnerabilities, caused by systemic risks. In recent years, the exposure of energy assets, such as the natural gas transmission system, on hybrid threats has significantly increased. Towards this direction, the current study aims to develop a composite index that measures at a country level the resilience of the European natural gas network against hybrid threats. For this purpose, a comprehensive set of indicators is established and quantified, categorized into four major resilience dimensions; (i) infrastructure, (ii) socio-economic, (iii) political, and (iv) external factors. Indicators are quantified based on in-house data of PSI, data from reliable international sources, or a combination thereof. The evaluation model to be constructed, based on the preference information, provided by selected experts, will be applied in conjunction with an MCDA aggregation framework. This will result in a composite hybrid threat resilience (HTR) index, measuring the performance of the individual countries, and ultimately providing insights and recommendations to support policy makers.

Keywords: Hybrid threat, Energy security, Risk assessment, Resilience, MultiCriteria decision analysis, Composite indicator.

Session	[TH2K]—Reliability and Availability Issues of the 5G Revolution
Day/Date/Time	Thursday, 23 Sep. 2021/10:35–11:35 hrs
Venue	Atrium 1

TH2K: 211 **10:35 hrs**

Complexity in 5G Network Applications and use Cases

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The fifth generation (5G) of mobile telecommunication network is designed with an ambition to be a network faster, stronger, better and smarter than its predecessor. With the digital transformation, all industry sectors will develop new applications with new requirements regarding telecommunication networks that 5G should be able to meet. To meet the requirement of future 5G use cases and applications, it is crucial to study the complexity of such network system by distinguishing different parts, layers, components as well as their interdependencies. This paper describes the 5G networks from an End-to-End perspective (device, radio network, core network, data network) and from a multi-layer perspective (orchestration, virtualisation/containerization and infrastructure) to show how this system (or system of systems) is complex, especially when we address resilience challenges. Resilience requirements and challenges are further explained by proposing relevant scenarios and use cases. In this paper, we mainly intend to highlight 5G network complexity and open a discussion on methodologies to model such complex network for its resilience study with the hope that this paper could inspire the future study of researchers in the related field.

Keywords: 5G network, Resilience quantification, Resilience metrics, Network applications, Complex system, vertical requirements.

TH2K: 322 **10:55 hrs**

Steady-State Availability Evaluation of Multi-Tenant Service Chains

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Nowadays, many telecommunication service providers (or tenants) share the same service infrastructure for cost optimization purposes, the so-called multi-tenant Network Service Chains (NSCs). These novel infrastructures are enabled by the Network Function Virtualization (NFV) paradigm that relies on the decoupling of the physical layer (i.e. hardware) from the service logic (i.e. software). NFV allows turning classic network appliances (e.g. routers, switches, etc.) into software instances often referred to as Virtualized Network Functions (VNFs). The composition (or chaining) of more VNFs results in NSCs which represent the modern way of providing network services. NSCs are failure-prone structures since the failure events can occur both at the physical and at the service logic layer. In this paper, we propose a methodology to ease the computation of the steady-state availability of multi-tenant NSCs, and to identify an NSC configuration respecting high steady-state availability constraints while minimizing deployment cost in terms of redundant subsystems. In our proposal, we: *i)* model an NSC as a Multi-State System, where the state is the delay introduced by the system and derived from queuing theory; *ii)* adopt an extended version of Universal Generating Function (UGF) technique, dubbed Multidimensional UGF (MUGF), to efficiently compute the delay introduced by the interconnections of various VNFs forming a service chain; *iii)* define and solve an optimization problem that allows retrieving, in a numerical setting, an optimal NSC deployment which minimizes the costs and guarantees high availability requirements (defined in terms of the delay metric), at the same time. The whole assessment is supported by an experimental part relying on IP Multimedia Subsystem, an NSC-like infrastructure widely adopted in the modern 5G-based networks to manage multimedia contents.

Keywords: Reliability, Availability, Universal generating function, Network service chains.

TH2K: 571 **11:15 hrs**

Availability of a Radio Channel: Application of the Neglected Failure Model

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Among the three types of services promoted by the 5G standard, ultra-reliable and lowlatency communications (URLLC) will be a cornerstone of new mission-critical services, such as industrial automation, autonomous driving, smart energy, remote surgery, etc.

A key element of 5G systems is the radio link, the availability of which is crucial: In a number of applications, an availability exceeding 99.999% is expected if not downright required. Data transmission must also be effective within an acceptable delay – from one to fifty milliseconds or more – depending on the application under consideration. Weather conditions may hamper transmission and lead to short-lived error bursts; radio links may actually be viewed as self-healing. If the transmission is successful within a “survival time” Δ, it is possible to neglect or omit the link temporary failure.

We address the availability of a radio link in the framework of neglected/omitted failures. Using a new approach, we have been able to compute the variation with Δ of the modified steady-state availability, as well as the Mean Time To Failure (MTTF). After a detailed analysis of the case of exponential lifetime and repair distributions, we turn to arbitrary, more realistic distributions and provide exact, analytical results in the cases of the Gamma, Birnbaum-Saunders, and Inverse Gaussian repair distributions. These expressions could be helpful to assess the availability “budget” of the radio link in the whole end-to-end 5G system. They may be also used in other domains in reliability and system safety where neglected failures are routine, especially in more complex systems.

Keywords: 5G communications, Radio link, Survival time, Availability, Mean time to failure, Neglected/omitted failures, Repair distributions.

Session	[TH3A]—Risk Assessment
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Plenary Room

TH3A: 567 **11:35 hrs**

Understanding Wildfire Induced Risk on Interconnected Infrastructure Systems Using a Bow-Tie Model with Bayesian Network and Self Organizing Maps

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With increased global warming and urbanization, the risk of wildfires impacting the critical infrastructure systems like electricity distribution and transmission, telecommunication, and buildings is increasing in several parts of the world. With such critical infrastructure systems becoming increasingly interdependent, failure of one infrastructure may easily cascade to other dependent networks causing a widespread national scale failure. To analyze the risk of such infrastructure-failures, most of the studies have used either a fault tree or event tree analysis which often underestimates the risk leading to sub-optimal decision making. To address this gap, in this paper we propose a holistic infrastructure risk assessment framework that can integrate both the fault and event tree methods into a single bow-tie model to capture the wildfire-induced risk on multiple interdependent infrastructure systems. The proposed framework can capture multiple dimensions (i.e., physical, logical and geographical) of infrastructure interdependenciesincluding intra-infrastructure, and inter-infrastructure dependenciesonto a pixel-based risk map. We proposed a conceptual framework to calculate risk of wildfires on electricity system considering a simplified fault tree model of the electricity distribution network. Furthermore, using self-organizing maps we create quantized dynamic risk maps for efficient risk zoning and risk communication to the respective stakeholders. Our proposed framework will help the federal and state governments as well as the utilities to make risk-informed decisions related to resource allocations, and planning for wildfire risk mitigation.

Keywords: Wildfire, Infrastructure risk, Bow-tie model, Self-organizing map, Risk-informed decision making, Dynamic risk map, Risk visualization and communication.

TH3A: 603 11:55 hrs

Real Time Assessment of Building Envelope Systems Subject to Hurricanes Through Kriging Metamodels

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Real time damage assessment of building systems subject to hurricanes has attracted significant interest over the past few years owing to its potential to facilitate emergency response and management. The major difficulty in its application lies in the high computational demand stemming from the need to propagate uncertainty through systems that present significant complexity. In this paper, a Kriging metamodel based rapid damage assessment methodology for building envelope systems of engineered buildings is developed to address this issue. Based on the recently proposed framework, envelope damage is characterized through progressive multi-demand coupled fragility models. Within this context, damage measures are defined for each coupled damage state of the system and a full range of uncertainties in structural properties, capacities, as well as wind load stochasticity. By calibrating the metamodels for damage prediction, deterministic mappings are defined from the input space of the site specific wind speed and direction to the output space of the means and standard deviations of the damage measures of the envelope components. The calibrated metamodels can then be used to rapidly predict the expected (with variability measured through the associated standard deviation) envelope damage in terms of predicted site specific maximum wind speed and direction, where these last are estimated in real time through parametric hurricane models. To demonstrate the applicability of the approach, a case study consisting in a 45-story steel building located in Florida is presented. The accuracy and efficiency of the proposed framework, around five orders of magnitude faster than high-fidelity models, illustrate the capability of the approach to provide real time information necessary to facilitate emergency response decision making.

Keywords: Real time assessment, Building envelope, Hurricane damage, Uncertainty propagation, Metamodeling.

TH3A: 619 12:15 hrs

Exploring the Nexus Between Organizational Anticipation and Adaptation in Crisis Management

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Organizational anticipation involves the ability to foresee and analyze potential threats and disturbances as a means to minimize the likelihood of hazard occurrence and to reduce the potential impacts. Common methods include Risk and Vulnerability Assessments (RVAs) and contingency planning, where potentially harmful events are identified and analyzed, and where measures to prevent, respond to and recover from these events are suggested. This includes the development of plans and procedures for what actions to take in case calamities, identified in the assessment, occur. While highly important as a strategy to risk reduction, these anticipatory efforts will never be sufficient for eliminating and treating all potential threats, especially in situations characterized by large uncertainties and high complexities. In the last decade, the dangers of black swan events, i.e. surprising events that have not been anticipated, have gained increased attention to illuminate the limits of the anticipatory approach. As a complement, many scholars have therefore highlighted the value of promoting adaptive capacities as a means to perform resiliently and reduce risks in the face of sudden disturbances. Despite clear interconnections, the anticipatory and adaptive perspectives have been studied in partly disparate scientific strands of research. The purpose of this paper is to explore the nexus between these areas to provide ideas on how they can be combined in a proactive crisis management setting. The paper constitutes a continuation of a three-year researcher-practitioner collaboration in the municipality of Malmö, Sweden, where a method for RVA previously has been developed. The method relies strongly on an anticipatory perspective, but the occurrence of Covid-19 has highlighted the need to integrate or complement it with efforts that facilitate adaptative behavior in the face of sudden shocks and disturbances. The paper draws on a literature review of the anticipatory and adaptive perspectives, focusing on how the anticipatory perspective can be complemented with actions that promotes adaptative capacity. Particular emphasis is placed on the applicability of the adaptive approaches identified in the literature for the context of municipal RVA.

Keywords: Anticipation, Adaptation, Crisis management, Risk and vulnerability assessment.

Session [TH3B]—Risk Management
Day/Date/Time Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue Atrium 2

TH3B: 548 **11:35 hrs**

Community Resilience: How to Measure Interactions Among Society and Authorities?

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Community resilience is an intrinsic, relational property of a community; that is built and influenced by the interactions and relationships of all members of society. This interaction could be in the form of exchanging information and knowledge, sharing resources, relying on each other, and mutual assistance. In this paper, we are interested in revealing how to measure the interaction and collaboration between all stakeholders in a community; individuals, authorities, and emergency organizations; and how this collaboration affects the different aspects of community resilience. Building upon the literature, we identified six dimensions that unfold the interaction between stakeholders in a community: 1) communication and risk awareness, 2) resource allocation, 3) community networks, 4) preparedness, 5) governance and leadership, and 6) community involvement. Afterward, we identified factors and indicators to measure the stakeholders' interaction and matched them to their corresponding community resilience dimension. We found that there is a lack of indicators representing community involvement and resource allocation dimensions. Moreover, the majority of the indicators identified follow a rating scale (ordinal variables), not an interval variable (absolute number or a percentage) that makes them highly subjective and harder to quantify and assess; necessitating efforts to find easily quantifiable indicators that can be used as proxies for certain variables.

Keywords: Community resilience, Resilience indicators, Resilience measurement, Interactions between individuals and authorities, Disaster management, Society's networks, Disaster resilience.

TH3B: 569 **11:55 hrs**

Addressing Risks and Challenges for the Pilot Sites Installing the E-Land Solution

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New technology and access to renewable energy sources enable production of electricity by new actors on the energy markets. One such actor is the energy islands, isolated communities that produce and consume a part or all their energy needs. The E-LAND project is developing a toolbox that use consumers data and external data (weather, energy prices) to deliver an optimal energy schedule, that minimizes the cost of energy production and consumption. The E-LAND solution should support the energy islands to emerge on the energy market using a new technology, with new functionalities, and new ways of thinking performing both their operational and business processes: these changes come with new risks. This paper presents how risks are understood and managed, firstly by the project with regards to the pilot sites, that constitutes a set of first users chosen to represent different industries and energy technologies; and secondly, by the pilot sites themselves. The analysis identified risks with a top-down approach, based on different use cases, designed for each pilot sites. This article is focusing on the development of the risk at the half-way to completion of the project, and the accuracy of the risks seen for the pilot sites as the toolbox is being installed and tested.

Keywords: Energy island, Smart grid, E-LAND, Risk management.

TH3B: 677 **12:15 hrs**

Decision Making for the Prevention of Intentional Third-Party Damage: An Evolutionary Game Perspective

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Traditional risk decision-making method cannot simulate the strategic interaction between the pipeline company (PLM) and the intentional third party (iTP). In order to overcome this, the evolutionary game theory is adopted firstly to analyze the long-term dynamic complex imitation and learning behavior between the PLM and the iTP, under the hypothesis of bounded rationality and incomplete knowl-

Thursday, 23 Sep. 2021

edge. Firstly, the mental model is used to simplify the complex analysis process of the traditional Wright manifold theory, following cognitive rules. A threshold value which means a group proportion of the iTP adopting the damage strategy is obtained. It can guide the PLM to adjust the defense strategy flexibly. And then, the prospect theory is adopted to improve the traditional expected return matrix into the income perception matrix. Four equilibrium conditions that both parties need to actively protect the pipeline are obtained. From the view of cognitive ability, fluke mind and psychological of adventure, the two parties of the game are often unable to fully satisfy the conditions and cause frequent accidents. The results of evolutionary game analysis show that increasing the awareness of management/learning costs, probability of occurrence, severity of consequences and punishment of the PLM and the iTP can reduce third-party damage (TPD) accidents and enhance pipeline risk management.

Keywords: Decision making, TPD prevention, Evolutionary game theory, Mental model, Prospect theory.

Session	[TH3C]—Maintenance Modeling and Applications
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Espace Grand Angle2

TH3C: 644 **11:35 hrs**

Queuing Theory and Regression Approach for Maintenance Personnel Estimation: A Case Study of a Brazilian Power Distribution Company

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Power distribution companies are currently faced with a great challenge: selecting optimal maintenance team size so as to comply with regulation while having below tolerable risk and minimum budget. If concessionary companies select adequate maintenance resources, it will lead to a reduction in operation costs and an increase in profitability at any level of tariffs. Given its complexity, there is no tool aimed to solve such a problem, therefore these companies must adjust their teams empirically based on feelings. Thereby, this problem is going to be presented herein as a case study. Some power interruptions can be avoided by preventive services such as pruning and mowing, since many of these occur during storms on account of vegetation (trees) contact with electric aerial networks. Other power interruptions cannot be prevented by these services, and thus maintenance crews must act as quickly as possible in order to minimize logistic repair time. Nevertheless, it is not only possible to minimize interruptions and logistic time, but also their incurred costs by a larger maintenance crew. The number of interruptions is estimated using the multiple regression theory, given that the more often preventive services are performed, the greater a reduction in interruptions becomes. On the other hand, logistic time is calculated through the queuing theory, since this is the case. It is also worth mentioning that an increase in maintenance personnel and other resources pushes up costs, but it reduces the length of power outages experienced by customers.

Keywords: Power distribution, Team sizing, Backlog, Queuing.

TH3C: 647 **11:55 hrs**

Quasi-Opportunistic Inspection of a Critical System

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We propose a maintenance policy in which inspections are performed mostly but not exclusively at opportunities that arise at random. The model is motivated by the inspection of pumps in artesian wells that are geographically remote. The system has three states: good, defective and failed. The system operates when it is good or defective. The failed state is immediately revealed. The defective state, which acts as a warning stage prior to failure, is revealed only by inspection. At a positive inspection (defect found) the system is replaced. Maintenance interventions at other nearby systems are opportunities. In our quasi-opportunistic policy, inspection neither uses an opportunity if it occurs too soon nor waits too long for an opportunity. The policy mimics inspections that are planned flexibly so that production stoppages or missions or other events determine the times for inspection, while accommodating statutory or safety regulations about the maximum allowable time between inspections of a system. It also generalises the delay time model. We study the behaviour of the policy numerically for a range of values of the parameters of the model. The

proposed policy is always superior in cost terms to both a purely opportunistic policy and a periodic inspection policy.

Keywords: Maintenance, Replacement, Inspection, Opportunistic, Artesian well.

TH3C: 657 **12:15 hrs**

The Use Machine Learning Model to Predict Number of Interruptions in Power Distribution Systems

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The performance of power distribution companies depends on the availability of electrical energy supply to costumers according to contract between governmental institution and the utility. On the other hand, utilities must be profitable for their stakeholders and must carry out optimization of maintenance's resources. In this effort, the prediction of interruptions is an important topic since it determines resources of preventive and corrective maintenance.

There are several causes of energy interruptions ranging from collision between cars with posts up to shutdowns for expansions. Some of these causes can be reduced with preventive services such those of pruning and mowing and, consequently, reduce the number of interruptions. There are other causes that appears to happen randomly over time (lightening, fire etc.) and cannot be prevented with preventive services.

The model to predict the number of interruptions is a supervised machine learning based on multivariate regression composed of 35 independent variables. The database consists of monthly data ranging from 2016 until 2019 for 21 maintenance sectors. Among these 35 variables there are causes such as pruning, mowing and others. For these causes, an increase in maintenance services will decrease the number of interruptions, but because of the small database it is not possible to see this feature in the data. On the other hand, the model fitted consider this characteristic even with small database (normally this is the case in the reality of utility companies) and provides an interesting contribution to support managerial decisionmaking.

Session	[TH3D]—Prognostics and System Health Management
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Panoramique

TH3D: 681 **11:35 hrs**

Establishment of EHA Performance Degradation Model Based on PMSM and Its Active Fault Tolerant Control

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The electro-hydrostatic actuator (EHA) is currently the most widely used and most mature actuation method. It has the advantages of high control accuracy, good stability and high reliability. As the power source of the hydraulic pump in the EHA, the motor can drive the load to run with or without load through positive and negative rotation. This article takes the rudder control system of an underwater vehicle as an example, first analyzes the working principle of EHA, and proposed an EHA model based on permanent-magnet synchronous motor (PMSM). By analyzing the different performance degradation degrees of different parameters of the motor, and comparing it with the traditional brushless DC motor model and its performance degradation to verifiy the validity and accuracy of the model. Then combined with adaptive active fault-tolerant control (AFTC) based on Radial Basis Function Neural Network (RBFNN) to provide a basis for reliability analysis based on EHA.

Keywords: Electro-hydrostatic actuator, Permanent-magnet synchronous motor, Performance degradation, RBF neural network, Active fault-tolerant control.

TH3D: 688 **11:55 hrs**

Research on Performance Degradation of Inverse Gaussian Process Based on BPNN Data Screening

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For a series of high-reliability and long-life systems, the performance degradation data obtained within a certain period of time can predict the performance degradation of the system well. In this paper, the inverse Gaussian(IG) process is used to describe the performance degradation process of the pressure sensor at the centrifugal pump of the underwater vehicle. And in the degradation process, introduce the difference mean function between different individuals to describe the performance degradation process. By introducing multiple sets of data and using Back Propagation Neural Network(BPNN) to filter the data, a set of reliable performance degradation data is obtained. And proposed to use Bayesian theory and Expectation-Maximization(EM) algorithm to collaborate on research and give an explicit expression to obtain the effective estimated value of the model. Through continuous updating and iteration to improve the estimation accuracy, the system's performance degradation trajectory, Remaining Useful Life(RUL) and RUL probability density distribution graphs are obtained. Using the $\alpha - \lambda$ index to verify that the accuracy of the actual range and the estimated range can be above 85%, which provides a direction for future research on fault-tolerant control based on performance degradation.

Keywords: BP Neural network, Inverse gaussian process, Performance degradation, Random diffusion coefficient.

TH3D: 725 12:15 hrs

Status Set Sequential Pattern Mining Based on Improved-Apriori Algorithm

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Sequential pattern mining is a hot topic in recent years, but in today's increasingly diverse customer needs, especially for the related industries that expect to consider the status attribute of project, it still faces great application limitations. Based on this problem, this paper studies the sequential pattern mining of status set, and explains the related concepts and constraints. In addition, aiming at the shortcomings of traditional Apriori algorithm, such as high computational cost and low computational efficiency, this paper introduces Boolean matrix to improve the algorithm, proposes Improved-Apriori algorithm, and explains the basic idea of the algorithm. Finally, small-scale and large-scale examples are used to verify the proposed method and algorithm. The results show that the proposed method and algorithm are feasible and efficient, Status set sequential pattern mining can mine more rules than sequential pattern mining, and Improved-Apriori algorithm has higher computational efficiency than traditional algorithm.

Keywords: Data mining, Apriori, Improved-Apriori, SPM, SSPM, Boolean matrix.

Session	[TH3E]—Organizational Factors and Safety Culture
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Amphi Jardin

TH3E: 612 11:35 hrs

Learning From Accidents and Incidents – Underlying Rationalities

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The objective of this paper is to discuss the learning from accidents and incidents in the high-risk industries. Theoretical framework consists of theories of learning, institutions, organisations and leadership. The paper is motivated by the principle of continuous improvement based on learning from accidents, incidents and near-misses in the high-risk industries. There is a growing tendency to learn from the less important incidents. However, incident reports do not often contribute to the learning from organizational viewpoint. The specific goal of the paper is to examine the patterns and assumptions regarding learning from the accidents and incidents.

Research questions are the following:

1) What kinds of rationality guides the identification, handling and learning from accidents and incidents?
2) What do the identification, handling and learning of accidents and incidents tell about the institutional strength-in-depth?
3) How could organization learn more?

The study consists of the following data and methodologies. First, fundamental features of learning from accidents and incidents are researched via cases, such as Boeing 737 Max aircraft accidents in 2018 and 2019 which led together to 346 fatalities, and Deep Water Horizon accident in 2010 in the Gulf of Mexico, that led to 11 fatalities, and related accident investigation reports. Second, 19 incident reports, and interviews with 3 experts from a nuclear power company regarding incidents are analysed. Interviews and reports are studied based on the qualitative content analysis. Main findings are discussed in terms of learning, organizations and leadership. Furthermore, suggestions for better learning are made.

TH3E: 617 **11:55 hrs**

Public Procurement of Critical Services – Effects of Service Transfer on Organizational Reliability

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In line with (neo)liberal forms of governing, many services critical for covering the population's basic needs are procured through competitive tendering processes. The effects of public procurement on the reliability of such services and the organizations providing them have been discussed in several studies building on high reliability theories. However, one aspect that remains underexplored is how the transfer of service provision between two contractors influences output reliability and why this is so. In this paper, the case of the latest procurement of Norwegian fixed-wing ambulance services is examined to show how service output was affected. Interorganizational challenges and the process of transferring sharp-end personnel (pilots) to the incoming operator are discussed as two factors influencing output reliability. In terms of the change of operators, coordination and cooperation became challenging, partly due to conflicting views of the procurement process and because of the contractual arrangement. The transfer of pilots resulted in a lack of employermanagement trust, in turn affecting pilots' completion of mandatory training programs. Overall, the study shows how critical service reliability can be affected when involved organizations and occupational groups pull in different directions. The transition phase represents a discrete and potentially vulnerable aspect of critical service tendering, as the splitting of service supply into contract periods leads to a temporal fragmentation of service supply.

Keywords: Critical services, Emergency services, Reliability, Fragmentation, Restructuring, Competitive tendering, Inter-organizational.

TH3E: 655 **12:15 hrs**

Teaching of Safety Engineering during the COVID-19 Pandemic

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In this article, the authors describe the evaluation of safety-oriented teaching at a technical university during the COVID pandemic under the long-term closure of universities in the Czech Republic. Three practical case studies are presented to illustrate the current level of sophistication of virtual reality technology for industrial safety teaching.

The case studies are focused on the environment of small and medium-sized enterprises (SMEs) and cooperation with them. The proposed affordable and simple approaches describe virtual teaching at universities providing education in the field of safety engineering.

Keywords: Virtual reality, Safety, Teaching, Digital twin, Mechanical engineering.

Session	[TH3F]—Critical Infrastructures
Day/Date/Time	Thursday, 23 Sep. 2021 / 11:35–12:35 hrs
Venue	Espace Grand Angle

TH3F: 399 **11:35 hrs**

Impact of Distance Rules on Infrastructure Resilience

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Due to the current pandemic situation, distance rules have been implemented in most countries to reduce contact and thus infection risk. The impact of these distance rules can be experienced in everyday's life but it also influences infrastructure processes. In this work, the quantified impact of distance rules on infrastructure performance is investigated. The example infrastructure considered here is an international airport and the passenger behavior is represented using an Agent-Based Model (ABM) which has been developed in the EU-H2020 project SATIE (Security of Air Transport Infrastructure of Europe). Varying distance rules in the ABM enables to quantify the impact on the airport's performance during normal operation but also under specific cyber-physical threat scenarios and to estimate the infrastructure resilience.

Keywords: Agent-based model, Airport, Pandemic, Distance rule, Cyber-physical threat scenarios, Resilience.

TH3F: 431 **11:55 hrs**

ABM-Based Emergency Evacuation Simulation Considering Dynamic Dependency in Infrastructures

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Nuclear or radiological accidents can cause significant consequences to people and the environment and may lead to a massive evacuation. Emergency preparedness and response plans are inevitable to mitigate and minimize the consequences. Generally, evacuation planning is based on various assumptions to simplify situations, and the effect of infrastructure systems is not considered explicitly. The infrastructures' availabilities are highly uncertain and difficult to be quantified due to their dynamic dependency, on each other. In this study, we propose a method to optimize the scenarios of emergency response and evacuation using an agent-based model. Within the simulation platform, the dynamic dependency in infrastructures is modelled by constructing loading-dependent state transition probability. Moreover, we demonstrate how to find major elements in evacuation using importance measures.

Keywords: Emergency evacuation, Dynamic dependency, Agent-based model.

TH3F: 772 **12:15 hrs**

Network Reinforcement Strategy Against Cascading Failures

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Network resilience, characterizing the ability of a system to adjust its activity to retain its basic functionality in the face of external perturbation, is highly related to capability against a cascading failure. However, the network resilience evaluation and enhancement strategy remains challenging [1][2]. Here, considering both the structure and nodal load, we develop a network resilience assessment method, and propose a novel resilience reinforcement strategy. We find the performance of the reinforcement strategy has a close correlation with the nodal capacity redundancy. The node with larger capacity redundancy is reinforced, the better reinforcement efficiency. Numerical simulations for both the BA and ER networks showing in Fig. 1 demonstrate that the proposed reinforcement strategy outperforms existing methods in terms of the reinforcement efficiency. We provide a general method to address the potential cascade risk, which will enable us to design more resilient networks against cascading failures.

Keywords: Cascading overload failure, Resilience assessment, Reinforcement strategy.

Session	[TH3G]—Mechanical and Structural Reliability
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Atrium 3

TH3G: 484 **11:35 hrs**

Analysis Over Detection of Areas Responsible for Failure to Crude Oil Transporatation Line

The Safety and reliability are the essential requirements for smooth transportation of crude oil as considered as the main concern. The problems associated with the supply of crude pipe and to control the losses at downstream because of increase in abrupt pressure, temperature and chocking of line of crude production. It affects the smooth and safe supply of crude oil towards the process plant.

The focus of this study is to analyze the root cause analysis of such abruption witnessed at pipe line which identifies the problems and associated solutions to the problems. The damaged line takes time, cost and loss of crude products which can be saved by developing the reliable solution of adding bypass lines on the critical roots for identification of such point and areas for onward rectification to sustain the safe and smooth process. The failure may not be existing after installation of PSV's and Bypass lines to ensure the reliability of system. Such technique not only save the time and losses but also maintain the flow rate of crude oil.

TH3G: 555 **11:55 hrs**

Estimation Of The Remaining Lifetime Of Shape Memory Alloy Actuators During Prototype Testing: Analysis Of The Impact Of Different Currents

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The shape memory technology is one innovative possibility to replace conventional technologies and components like actuators and achieve new creative solutions that would not be possible with conventional methods. A major issue is the lack of standardized test programs (including test rigs as well as test plans). It is not possible yet to achieve reproducible test results testing different actuators. In addi-

tion, a very long test time is required compared to conventional technologies. Uniform test stands, test procedures and accelerated testing are required to optimally design the testing program. Additionally, the development of a prediction algorithm to determine the (remaining) lifetime during a fatigue test can lower the testing time even further. This paper describes the fundamentals of SMAs before outlining a case study of SMA wires that are tested with an endurance test rig using different loadings. The aim of the case study is to determine the influence of the different loadings (accelerated testing) on the degradation behavior. Within the case study 30 actuators are tested using 10 different currents. Finally, the measurement series of the fatigue tests are analyzed using several (statistical) methods and techniques. The results focusing on the detection of impending failures and possibilities to predict the (remaining) lifetime are discussed in detail. This analytics of failure behavior and long-term reliability are the base of operations for the development of different SMA applications.

Keywords: Smart material, Smart material actuator, Shape memory alloy, Shape memory actuator, Data analysis, Reliability analysis, Degradation analysis, Lifetime estimation, Accelerated testing.

TH3G: 636 **12:15 hrs**

Predicting Reliability of Bolted Structure Using Monte Carlo Simulation

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Bolted structures are commonly used in many automotive and aerospace industries, due to its easy assembly method and low cost. They involves different sources of uncertainty and nonlinear characteristics. The aims of this communication is to model the predictive reliability of these bolted structures by using Monte Carlo Simulation. Firstly a stochastic Finite-Element Method (SFEM) is carried out using Abaqus Software in order to evaluate the dynamic behavior with taking account many stochasticals variables (Load applied, Plates geometries, Material…), Furthermore, we integrate these results with an effective method for reliability assessment based in Monte Carlo simulation. A Correlation between these parameters and structure failure probability (Ps) is carried out. Also, we estimate the model parameters by the Euler-maximum Likelihood estimation method. Finally the proposed model is applied in real case, results and conclusions are highlighted.

Keywords: Reliability, Finite monte carlo simulation, Bolted structure, Model, Euler-maximum likelihood estimation.

Session	[TH3H]—Safety and Reliability of Intelligent Transportation Systems
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Cointreau

TH3H: 458 **11:35 hrs**

Degradation Assessment of Train Axle Bearing based on A Deep Transfer Learning

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Train axle bearings which support whole vehicle weight and transmit speed are one kind of key components in railway system. Degradation assessment of train axle bearings is significant for ensuring the safety and reliability of train operation. Deep learning algorithms have been widely applied for machinery degradation assessment using run-to-failure datasets. However, it is hard to collect railway train bearings' run-to-failure datasets in the real operating condition. In this paper, a deep transfer learning algorithm is proposed to address this problem. In the proposed method, the deep convolution inner-ensemble learning (DCIEL) model is firstly trained by using source domain data and labels. The labelled data in the target domain are then fed into the DCIEL model. The trained model is used to obtain pseudo-labels for unlabeled data in the target domain. Finally, the model for health indicator construction can be obtained by minimizing the loss function. Experiments are conducted to test the proposed method and results verified its effectiveness.

Keywords: Railway bearing, Deep convolution inner-ensemble learning, Deep transfer learning, Degradation assessment

TH3H: 572 11:55 hrs

Certification of Deep Reinforcement Learning with Multiple Outputs Using Abstract Interpretation and Safety Critical Systems

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The certification of machine learning models based on deep learning technics becomes a major research topic of AI scientific community. In the current decade, several approaches were explored to certify the deep learning outputs by evaluating its robustness. The deep reinforcement learning, to our knowledge, is less studied due to its complexity of output evaluation. Indeed, the output of the classification is binary where it is obvious when the model misses the correct classification by giving non-expected results. However, for the deep reinforcement learning, the decision of the agent could be modified without any safety critical effect. Therefore, a new approach considering these variabilities of decision is needed to be explored. In the current work, we proposed a new approach mixing the robustness and the safety requirements. The approach is applied on autonomous driving and implemented on an Open-Source environments using algorithm of deep reinforcement learning (PPO). The implementation uses the abstract interpretation theory for the robustness whereas the safety processes is based on SOTIF norms. The approach shows promising results and an important contribution of the safety critical systems in AI certification.

Keywords: Safety of deep reinforcement learning, Certification, Validation, SOTIF, Autonomous driving.

TH3H: 743 12:15 hrs

Functional Safety of Railway Signaling Systems: Performance Requirements and Evaluation Methods

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Signaling is fundamental to the safe operation of the railway, ensuring that trains are spaced safely apart and conflicting movements are avoided. Railway signals are 'traffic light' devices, which tell a train driver if it's safe to proceed along the track. A railway signaling system consists of several complex subsystems, e.g. trackside- and onboard signaling systems, which cooperate to ensure the safe operation of railway traffic. The failure of signaling system will weaken both capacity and safety of the railway. It is therefore important to keep the railway signaling system complying with the defined performance requirements. The purpose of this study starts with the summarization of railway RAMS, focusing on railway signaling systems. The tolerable hazard rate (THR) which is an indicator of signaling system performance in EN 50129 (2018) has been compared with the similar indictor PFH (probability of failure per hour) for safety-related systems in IEC 61508 (2010). Based on the commonly used methods for safety-related systems in IEC 61508 (2010), several reliability modeling and analysis methods have been listed and reviewed for the specific system. This paper aims to provide clues for the engineers and analysts in the performance evaluation for the railway signaling system.

Keywords: Railway signaling system, Performance assessment, Tolerable hazard rate, Probability of failure per hour.

Session	[TH3I]—Cyber Physical Systems
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Giffard

TH3I: 173 **11:35 hrs**

Mobile Cyber Gateway Security Control

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The necessity to protect the critical infrastructure in way as the cyber-physical system (CPS) is growing with the development of communication and control technologies. The one of elementary approach of protection is to close critical elements to a protected area with secure access. This principle is used in both spaces, the physical and the cyber. Access to these protected areas is then through the gateways. Gateways shall be able identify and authenticate of persons or processes with authorized access and to prevent the access of unauthorized.

The presence of many moving elements (for example, trains) is the specific problem of transport infrastructures, as railway is. The security of moving elements within the CPS must therefore be ensured against both physical and cyber intrusion. We will deal with the cyber gateway of the train at this article, which is called a mobile communication gateway (MCG). The MCG is associated with problems of the standard cyber gateway and the problems specific to the moving systems. It is impossible to secure communication between train and control centrum through a closed communication system only, it must take place through open space because of extensive infrastructure with assistance of ground communication gateway (GCG).

The MCG design shall ensure the security functions of the gateway as well as sufficient communication capacity. Our control over environmental conditions of MCG is limited because it is in open space, both physical and cyber, often in motion. The MCG therefore needs to be able to respond dynamically to environmental changes caused by deliberate attacks or unintentional changes in the system. The ability of the adaptability must be given to the MCG in design.

Keywords: Cyber-physical system, Multiple independent levels of security, Mobile communication gateway, Railway, Security.

TH3I: 457 **11:55 hrs**

Resilience Assessment Framework for Cyber-Physical Systems

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Automation and digitization trends have caused cyber-physical systems (CPSs) to be deployed at an extremely fast rate. Owing to their complexity and to the heterogeneity of their components, CPSs face significant challenges to their security and privacy protection. In recent years, several standards and guidelines have been published to ensure the cyber-security of these systems. However, this recent stream of literature adopts a risk-based approach and assumes that attacks are identifiable and quantifiable. Moreover, it often focuses on security issues related to the cyber system, without consideration of the direct effects of cyber attacks on the dependent physical system. Finally, existing cyber-security standards and guidelines are mostly qualitative, and a common framework for their assessment is still lacking.

In order to fill these gaps, we propose a resilience assessment framework for CPSs. Specifically, the framework addresses the problem of cyber-security from a resilience perspective, in which cyber threats might be unknown and unforeseeable. In this context, the framework provides quantitative methods for the generation and assessment of both known and unknown threats, e.g., attack paths, and integrates the analysis of the recovery phase following a disruption. Moreover, the framework is constructed around the three subsystems constituting a CPS, namely the physical, control, and cyber subsystems. The physical subsystem is controlled by the control subsystem, which processes physical system state data and returns action commands by receiving data and transmitting action commands through the cyber subsystem. The framework proposes a standardized workflow to assess the resilience of CPSs before and after the occurrence of a disruption (Fig. 1). Accordingly, established methods are deployed for (1) modeling the CPS, (2) identifying disruption scenarios that may impact CPS performance, and (3) assessing the benefits of resilience strategies to prevent and react to disruption scenarios. The proposed framework is demonstrated with reference to a power substation and associated communication network and is a first step towards quantifying the 'value of resilience' in CPSs.

Keywords: Cyber-Physical System (CPS), CPS modeling, CPS recovery, Resilience.

TH3I: 651 **12:15 hrs**

Using Decision Trees to Select Effective Response Strategies in Industrial Control Systems

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Incidents in Critical Infrastructures (CIs) like smart grids would have a negative effect on the well-being of people and the economy of the country. CIs are increasingly dependent on Industrial Control Systems (ICS) to monitor and steer industrial processes like power generation, transmission, and distribution. Modernisation of such systems enable them to be directly/indirectly connected to the internet. This connectivity makes it susceptible to cyber-attacks in addition to technical failures. There is a need to effectively respond to incidents to recover the system from adversaries promptly and minimise negative impacts. In our previous work, we developed attackfailure distinguisher framework for constructing Bayesian Network (BN) models to support operators to distinguish between attacks and technical failures. Furthermore, we also proposed root-cause analysis framework for constructing BN models to aid operators to determine the attack vector (in case of an attack) or failure cause (in case of a technical failure). However, decision support that enable operators to choose effective response strategies based on the inputs from the above-mentioned BN models is missing, which is the aim of this present study. The structure of decision trees has the capability to tackle this challenge especially based on their existing applications in domains like medical, safety. In this study, we proposed the decision tree framework to visualise the effective response strategies and demonstrated it using an example from the energy domain.

Keywords: Attack vector, Cyber-attack, Decision tree, Failure cause, Incident response, Technical failure.

Session	[TH3J]—Renewable Energy Industry
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Botanique 2

TH3J: 315 **11:35 hrs**

Influence of Starts and Stops on the Aging of Hydroelectric Generator Stators by Thermal Cycling: Empirical Study and Accelerated Lifetime Model

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Due to the deregulation of the energy market and the integration of renewable energies, hydropower plant operators are faced with an increasing number of start and stops and load changes that can reduce the life of equipment. This paper proposes to assess the influence of the start and stop cycles on the ageing of stators in hydroelectric generators. In a first step, different modes of generator degradation are identified. The most affected component by start and stop cycles is the stator insulation, because of the thermal stress induced by these cycles, and the insulation default is considered to be the first cause of a premature end-of-life. The stator lifetime is first estimated using a Weibull analysis on the winding replacement dates recorded on a large number of units subject to a variable number of start and stop cycles per day. The results show that there is a significant difference in lifetime between installations subject respectively to a high or a lower number of start and stop cycles. As the degradation of the generators' insulation is mainly due to thermal stress, a model using Coffin Manson's law is then used to explicitly take into account this stress and to determine the acceleration factor that allows predicting the reduction of the stator's lifetime due to thermal cycling. The proposed accelerated model is used on actual temperature monitoring data and the results show that the value of the acceleration factor is greater than one and increases with the cycles frequency which means that the life of the generator stator decreases as the number of starts and stops per day

increases.

Keywords: Hydroelectric generator, Stator, Start and stop, Rewinding, Lifetime, Weibull, Thermal cycling, Coffin Manson.

TH3J: 368 **11:55 hrs**

A Short Review on Mathematical Algorithms for Predictive Maintenance Techniques and Anomaly Detection in PV Systems

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The applicability of PhotoVoltaic (PV) systems as an efficient renewable energy supply for an average lifespan of twenty-five years, is backpedalled after being confronted with fault events. Just like all outdoor systems, PVs are often subject to various types of faults and undesired working conditions. At any instance, PV modules can interact with different electrical faults. On the other hand, harsh external conditions can also affect a proper PV system functioning. Efficiency reduction and output deficits are most common results of PV system's interaction with faulty events, reflected as improper behaviour of the system. From this point, arises the need for a diagnostic and prediction system, which estimates the possibility of a future achievable potential and partially observable fault among a large set of possible failure modes, prior from happening, regardless of the PV cells raw materials being used. In the interest of a sustainable and reliable PV system design, this paper aims at exploring different mathematical models of fault predictive techniques. Underlying the artificial intelligence and algorithm-based decision making, various predictive algorithms are surveyed and compared with reference to their event risk's accuracy. For instance, Markov chains based probabilistic model computes failures rates, where convolutional neural networks indicate a malfunctioning panel, and supervised machine learning based automated barcode detection algorithms detect PV module's defects. The critical assessment between different models would serve as an informative background when choosing a PV fault predictive technique.

Keywords: Maintenance, PV, Predictive, Corrective, Durability, Error, Efficiency, Faults.

TH3J: 704 **12:15 hrs**

A Reliability, Durability and Safety Study of Alkaline and Polymer Electrolyte Membrane Electrolyzers

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GRTgaz is the French owner and operator of the longest high-pressure natural gas transmission network in Europe. GRTgaz has its own research center, the Research and Innovation Center for Energy, RICE. For several years, RICE has been working to transform gas infrastructures and to accelerate the integration of renewable gases and hydrogen in the gas networks.

The current energy infrastructure must evolve towards new competitive large-scale storage solutions. One solution studied by GRTgaz is chemical storage in hydrogen. In this context, project Jupiter 1000 was launched, with the contribution of engineering, technical and research teams from GRTgaz and its partners. The main goal is to conduct an industrial scale experiment on a Power-to-Gas pilot installation with injection into the natural gas transmission network. Jupiter 1000 is the first industrial demonstrator of Power-to-Gas in France with a power rating of 1 MWe for electrolysis and a methanation process with carbon capture. Green hydrogen is produced from 100% renewable energy, using two different technologies of electrolyzers: an alkaline electrolyzer and a Polymer Electrolyte Membrane (PEM) electrolyzer.

This will allow RICE's research team to compare the two technologies on an economical, performance, and safety points of view.

The aim of this paper is to provide an overview of the current development status of the reliability study conducted on both types of electrolyzer of Jupiter 1000. The project will be conducted in two phases:

- The first one will focus on understanding the reliability of both technologies, meaning their ability to perform as required, without failure, for a given time interval. This part breaks down the mechanisms of both technologies to simple elementary functions and/or components that will then allow to conduct a Failure Modes and Effects Analysis (FMEA). The FMEA evaluates the severity and probability of occurrence of failures that may occur on these electrolyzers, to prioritize the most critical ones. It also documents current knowledge and actions about the risks of failures, and how to use them to improve the system.
- The second phase will focus on the durability, which is their ability to perform as required, under given condi-

– tions of use and maintenance, until the end of service life. It will attend to finding the degradation phenomena that affect the durability and safety of alkaline or PEM type electrolyzers.
– The last one will focus on safety-related issues on hydrogen production in electrolyzers, in order to point out recommendations on vessel design and operating mode that will allow to meet its particular safety demands.

Based on this, it will be possible to identify the critical elements in terms of reliability, safety and durability and examined them thoroughly in order to advance the understanding of phenomena that can reduce the service life or degrade the safety of alkaline and PEM type electrolyzers, and thereby provide recommendations in terms of safety-related functions, monitoring functions, maintenance policy and operational conditions for each technology of electrolyzer.

Keywords: Operational risks, Risk analysis, Risk assessment, Risk management, Gas network, Gas pipeline, Reliability, Durability, Safety, Maintenance, Alkaline electrolyzer, PEM electrolyzer, Power-to-Gas.

Session	[TH3K]—Reliability and Availability Issues of the 5G Revolution
Day/Date/Time	Thursday, 23 Sep. 2021/11:35–12:35 hrs
Venue	Atrium 1

TH3K: 573 **11:35 hrs**

Handover Rate in Cellular Networks With Anisotropic Random Waypoint Mobility Model: The Elliptic Case

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Successful operation of a mobile network means preserving the active call when a customer moves from one cell to a neighboring one. Switching from one base station (antenna) to the next necessitates a procedure called handover or handoff, which involves resources that could have been used for establishing calls for new clients. The knowledge of the handoff rate – the number of crossings of the boundaries between cells per unit of time – is therefore important for the assessment of the probability of cut or rejected calls (bad news for a telecommunications company) and/or for the adequate provisioning of network resources. It becomes even more important in 5G communications[1,2], as handover failures hamper the end-to-end Quality of Service (QoS).

The number of handovers depends on the mobility pattern of customers. The Random WayPoint (RWP) model provides a commonly used and reasonable description of realistic behavior, and lies at the heart of a general framework proposed by Hyttiä and Virtamo[3]. In previous works[4,5], we were able to compute the probability of handovers for circular and triangular RWP domains, with polygonal or circular cells. We demonstrated a quasi-linear dependence of the handover rate on the cell perimeter, the linear dependence being exact for isotropic domain or cell.

We address here the case of an anisotropic RWP domain, namely an ellipse, in order to quantify the influence of the anisotropy on the handoff rate, namely the error being made when using the expression proportional to the cell perimeter. Analytical expressions have been found, which could be useful for other practitioners in the reliability of mobile communications.

Keywords: Cellular networks, Handoff rate, Random waypoint model, Mobility model, Fluid model, Network reliability.

TH3K: 574 **11:55 hrs**

Reliability and Latency: A Joint Framework

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Along with enhanced Mobile Broadband (eMBB) and massive Machine Type Communication (mMTC), Ultra-Reliable Low-Latency Communication (URLLC) will bring new types of 5G services that may profoundly affect current industries and develop new ones. URLLC applications require end-to-end data transmissions that are very reliable (with error rates lower than 10^{-5}) while exhibiting a small latency (from one millisecond for automated industry to ten milliseconds for virtual reality).

Assessing a system's reliability or availability due to equipment failure may become a challenging task, when its architecture cannot be described by a simple series-parallel, underlying graph [1,2]. Likewise, calculating the probability that the latency of the service remains below an acceptable upper bound is no easy task [3,4] even when limited to a radio link, all the more so because of the usual heavy tail of the latency distribution. The probability of a successful operation is expected to decrease because of the introduction of latency constraints.

A proper description of the Quality of Service (QoS) of URLLC should take the two facets of the problem, namely reliability and latency, simultaneously into account. In the present study, we propose such a general framework in order to calculate the probability of successful endto-end data transmission, where reliability and latency are assigned to each link and node of the system. We then apply our model to a few simple architectures that may be implemented in industrial applications. We also address the delicate issue of numerical estimating the Quality of Service.

Keywords: 5G communications, URLLC, Reliability, Availability, Latency, Weighted network model.

TH3K: 691 **12:15 hrs**

A Fast Method to Compute the Reliability of a Connected (r,s)-out-of-(m,n):F Lattice System

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An m-by-n matrix of binary components roughly mirrors the arrangement of base stations in a 5G mobile network. As follows from simple geometry, the failure of all four stations in any 2-by-2 submatrix results in lack of signal in the neighboring area. Therefore, a connected (2,2)-out-of-(m,n):F lattice system can serve as an approximate reliability model for a grid of base stations. Such a system is a special case of a connected (r,s)-out-of-(m,n):F lattice system, defined, inter alia, in Zhao et al. (2011). Its reliability is defined as the probability that an m-by-n matrix of binary components contains an r-by-s (or larger) submatrix of failed ones. Computing this probability's exact value is a highly complex task, as can be observed in Nashwan (2018) and Zhao et al. (2011). Its complexity can be reduced only in some special cases, as shown in Nakamura et al. (2018). It is therefore useful, in the context of mobile networks, to have a possibly efficient near-exact method for computing the reliability of a connected (2,2)-out-of-(m,n):F lattice system. In this paper a fast method is presented allowing to calculate, with good accuracy, the reliability of such a system. The proposed method is based on recursive procedures computing the exact system reliability for m=2,3,4. The obtained results are particularly useful for estimating service availability of a 5G mobile network, where the required value of this parameter is close to one. Thus, the network designer and/or operator should be able to estimate it with high accuracy provided by the presented method.

Keywords: Mobile network, Connected (r,s)-out-of-(m,n):F lattice system, Network reliability, Availability, Recursive algorithm, Approximation.

Session	[TH4A]—Risk Assessment
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Plenary Room

TH4A: 628 **14:00 hrs**

Resilience of the European Natural Gas Network to Hybrid Threats

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There is no commonly used definition of the term hybrid threat, but diverse characteristics and traits are often considered. These include: (1) a combination of coercive and subversive activity, (2) conventional and unconventional methods, (3) state or non-state actors, and (4) activities that remain below the threshold of detection and attribution. In general, hybrid threats affect multiple domains, create ambiguity, and are likely to exploit the vulnerabilities, caused by systemic risks. In recent years, the exposure of energy assets, such as the natural gas transmission system, on hybrid threats has significantly increased. Towards this direction, the current study aims to develop a composite index that measures at a country level the resilience of the European natural gas network against hybrid threats. For this purpose, a comprehensive set of indicators is established and quantified, categorized into four major resilience dimensions; (i) infrastructure, (ii) socio-economic, (iii) political, and (iv) external factors. Indicators are quantified based on in-house data of PSI, data from reliable international sources, or a combination thereof. The evaluation model to be constructed, based on the preference information, provided by selected experts, will be applied in conjunction with an MCDA aggregation framework. This will result in a composite hybrid threat resilience (HTR) index, measuring the performance of the individual countries, and ultimately providing insights and recommendations to support policy makers.

Keywords: Hybrid threat, Energy security, Risk assessment, Resilience, Multi–criteria decision analysis, Composite indicator.

TH4A: 702 **14:20 hrs**

A Multistate Bayesian Network Integrating MISOF and Probit Modelling for the Risk Assessment of Oil and Gas Plants

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In this work, we integrate in the multistate Bayesian Network (BN) modelling approach developed in (Di Maio et al., 2020a) i) the Modelling of Ignition Sources on Offshore oil and gas Facilities (MISOF) for characterizing the mitigative safety barriers and ii) a probit modelling for ultimately evaluating the severity of the accident scenarios (namely, Flash Fire (FF), Jet Fire (JF), Pool Fire (PF), Explosion (EX) or Toxic Dispersion (TX)) and properly assessing the probability of fatality following an accident by considering the actual effects of the mitigative safety barriers in place. The proposed approach is applied to a case study concerning a Loss of Primary Containment (LOPC) accident in the slug catcher of a representative onshore Oil & Gas (O&G) plant.

Keywords: Quantitative Risk Assessment (QRA), Loss of Primary Containment (LOPC), Multistate bayesian networks, Ignition probability, MISOF, Safety barriers.

TH4A: 752 **14:40 hrs**

Risk Assessment of Fires in Residential Buildings – A Case Study in Norway

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Every year, many fatal and non-fatal residential fires pose a real threat in many countries such as U.S., Norway, Denmark, and Sweden. These fires cause a large number of fatalities, injuries and a huge property damage depending on the fire detection time, designed building, response time by the occupants and etc. Thus, risk assessment of residential fires is of great importance toward elevation of home fire safety towards an acceptable level for everyone. The statistical analysis of the data regarding Norwegian residential fires were mostly related to 1990 to 2014, while there has not been much research on the last five years. This paper analyses the real data of fires in dwellings in Norway from 2015 to 2020 in order to develop a fire risk assessment. For this purpose, two main fire scenario clusters were adopted which considered both measures to prevent fire from occurring and measures to control the fire growth and smoke spread. In Fire extinction scenario, a basic residential sprinkler was designed and investigated in more details to calculate the probability of failure on demand and reliability of the system at different time intervals. Furthermore, some additional measures were introduced to increase the building fire safety grading and to evaluate how they can affect the fatality and injury rate.

Keywords: Risk assessment, Fire, Residential buildings, Scenario clusters, Fire extinction system, Sprinkler reliability.

Session	[TH4B]—Mathematical Methods in Reliability and Safety
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Atrium 2

TH4B: 700 **14:00 hrs**

An Analytical Variance Estimator for Separable Importance Sampling with Applications to Structural Reliability

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In recent years, reliability-based designs gained a growing interest in scientific community. Effects of uncertainties in input variables are often taken into account in terms of *failure probability*. In structural design applications, this is intended as the probability of exceeding the limit capacity of a structure. To estimate failure probability, several Monte Carlo based methods are widely applied [1]. In Classical (or Crude) Monte Carlo procedure (CMC), samples are extracted following input distributions, making the number of needed simulations quadratically proportional to the inverse of target probability. More advanced techniques thus seek to evaluate this probability with fewer samples. *Importance Sampling* (IS), for example, only considers samples generated from an auxiliary distribution and proved quite useful to estimate small probabilities with a reduced number of simulations.

Thursday, 23 Sep. 2021

In a number of applications, stress and strength of a structure – or more generally response and capacity – are actually independent. This was exploited in [2], where classical Monte Carlo was applied to sample separately stress and strength – from here, the name Separable Monte Carlo (SMC) -, thus leading to variance reduction and consequently decrease of needed analysis. Practically, every stress sample is compared to all strength samples, exponentially increasing the global amount of combinations generated with few simulations. This latter technique was also combined to Importance Sampling [3] (Importance SMC or ImpSMC). However, no analytical variance estimation was provided therein, making the gains in terms of number of needed simulations difficult to evaluate.

In the present work we build an analytical variance estimator, devoted to show the power behind the ImpSMC procedure. The analytical estimator itself is used to stop simulations when the required coefficient of variation limit is reached. Applications of ImpSMC to two academic examples are presented in this work. Unbalanced dataset are allowed, opening to the possibility of reducing even more the amount of more complex simulations (often deriving from stress samples generation). In the applications considered herein, the number of required runs is reduced by a factor of 5 with respect to IS, 6:5 to SMC and even 320 if compared to CMC. Gains with respect to CMC and SMC approaches increase as failure targets decrease.

Keywords: Reliability analysis, Separable monte carlo, Importance sampling, Variance estimation.

TH4B: 717 **14:20 hrs**

Updating Structural FE Models of Cultural Heritage Assets based on Probabilistic Tools

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The deterioration of Cultural Heritage assets due to the climatic change and natural hazards is a pressing issue in many countries. In this sense, the assessment of their actual structural integrity based on higher-scale structural responses is key to assess the resilience of these important assets. This paper proposes a rational methodology to integrate modal vibration data into structural FE models based on probabilistic tools. The methodology is based on solid Bayesian probabilistic principles thus allowing uncertainty quantification in the assessment. A real case study for a sixteenth century heritage building in Granada (Spain) is presented. The results show the efficiency of the proposed methodology in identifying the probability density functions of basic material parameters such as the Bulk modulus of the building stones or the modulus of soil reaction among others.

Keywords: Ambient vibration test, Bayesian system identification, Cultural heritage buildings, Finite element models, Global sensitivity analysis, Operational modal analysis.

TH4B: 729 **14:40 hrs**

A New Model of the Network Design Problem with Relays for Maritime Rescuing with Uncertainties

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In this paper, we presented a mixed-integer linear programming (MILP) model for a new variant of the network design problem with relays (NDPR) and introduced its application on maritime rescuing where aircraft and vessels could be routed as commodities on the network. With the fast development of marine economic all over the world, the security guarantee and disaster relief in open sea area are becoming more important and challenging tasks. Given that uncertain events might occur in any specified open sea areas with estimated probabilities, our proposed model is able to find out the optimal rescuing routes with optimal location of relay stations for a fleet of heterogeneous rescue aircraft/vessels in advance. We considered multiple practical factors faced in the today's maritime rescue problem, such as the uncertainties of the events, concurrences of multiple missions, heterogeneous types of rescuing equipment, and the return after rescue. The economical efficiency was also included in the model to serve as an important evaluation index of the rescuing operation plans. Computational experiments on a randomly generated data set were carried out to simulate various types of random multitask with uncertainties and verified the validity of the proposed model. These experiments demonstrated that the model can obtain practical maritime rescue solution with a lower total cost.

Keywords: Network design with relays, Maritime rescue, Demand uncertainty, Mathematical programming, Optimization, Offshore support vessels, Location problem.

TH4B: 736 15:00 hrs

Importance Sampling and Sensitivity Analysis for Reliability Assessment of Hybrid Dynamic Systems Represented by Piecewise Deterministic Markov Processes

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A natural way to assess the reliability of a complex industrial system is to carry out numerical simulations that reproduce the behavior of the system. The PyCATSHOO[1] tool developed by *Eĺectricité De France* (EDF R&D) allows the modeling of such systems through the framework of piecewise deterministic Markov processes (PDMP). These processes have a discrete stochastic behavior (failures, reconfigurations, control mechanisms, repairs, etc.) in interaction with continuous deterministic physical phenomena.

It is well known that for sufficiently rare events, crude Monte-Carlo methods require a very large number of simulations to accurately estimate their probability of occurrence. We propose an adaptive importance sampling strategy based on a Cross-Entropy method to reduce the cost of estimating the probability of system failure[2]. The success of this method depends crucially on the family of instrumental laws used to approximate the optimal law. We construct this family according to the PDMP structure of the system, in particular according to the configuration of its minimal failure groups. Finally, we propose different sensitivity analysis techniques3 to reduce the dimension of the problem and to determine the respective contributions of different component failure modes to the probability of system mission loss. We present an application of this strategy on a test case from the nuclear industry: the spent fuel pool.

Keywords: Piecewise deterministic Markov processes, Hybrid dynamic systems, Rare event simulation, Importance sampling, Cross Entropy, Sensitivity analysis, Dimension reduction.

Session	[TH4C]—Maintenance Modeling and Applications
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Espace Grand Angle2

TH4C: 676 14:00 hrs

Joint Selective Maintenance and Multiple Repairpersons Assignment Problem under Uncertainty

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In many industrial maintenance applications, maintenance activities can be simultaneously performed by multiple repairpersons, that is, repairperson assignment problems. The existing works on selective maintenance with multiple repairpersons all assume that the durations of selected maintenance actions to be performed are preciously known in advance as deterministic values. To fill this gap, a new selective maintenance model is proposed in this work to consider uncertainties that originate from multiple repairpersons. Because of the uncertainties associated with the durations of maintenance actions, the state of each unit at the beginning of the next mission is also uncertain, posing a new challenge in the context of evaluating the success of the subsequent mission. Such uncertainties are quantified by evaluating the probabilities that system performance capacity meets the demand of customers. Consequently, a new selective maintenance model is developed and formulated as a cost-minimizing optimization subject to a predetermined constraint on the system mission reliability of the next mission. The multi-state coal transportation system is presented to examine the effectiveness of the proposed method.

Keywords: Selective maintenance, Multiple repairpersons, Performance capacity, System mission reliability, Multistate system, Uncertainty.

TH4C: 685 **14:20 hrs**

Optimal Heuristics for Reliability-Based Inspection and Maintenance Planning

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Inspection and maintenance planning of most engineering systems is based on prescriptive rules and ad-hoc planning. There is hence a significant potential for savings or improved performance by the application of smarter inspection and maintenance (I&M) planning. In general, I&M planning belongs to the class of sequential decision processes. Finding the theoretically optimal solution for such processes in realistic engineering systems is not possible at present, due to the complexity of these systems and the involved maintenance processes, which lead to intractably large state and policy spaces. Heuristics, which parametrize the policies, offer an alternative that is computationally tractable. If chosen well, these heuristics can lead to near-optimal I&M policies. In addition, they have the advantage of being easily interpretable, which is of importance in practical implementations.

In this contribution, we look at two example systems, offshore steel structures and feeder pipes in nuclear power plants. We utilize physics-based stochastic models to describe the system performances and to assess the effect of inspections and maintenance on the system reliability. We discuss the formulation of possible heuristics for inspection and maintenance policies. On this basis, we calculate the benefit of using advanced reliability-based I&M planning over existing rule-based I&M planning in terms of the I&M costs and the resulting risks.

Keywords: Deterioration, Reliability, Inspection, Maintenenance, Sequential decision making.

TH4C: 693 **14:40 hrs**

How to Use Prescriptive Maintenance to Construct Robust Master Production Schedules

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Prescriptive maintenance is positioned as the highest level of maturity and complexity of knowledge-based maintenance. It seeks in part to integrate actions on future constraints, especially operational constraints, into decision making. It is in this context of production management that our work is positioned, with planned production defining here the operational constraint that can be modulated to a certain extent. However, it should be noted that, although a desire for agility in production is sought, master production planning remains the steering production tool. The goal of this paper is to elaborate a methodology for providing optimized tactical production plans that remain robust to a dynamic maintenance decision based on the overall production system health state. The robustness of the tactical planning is defined here as a decision parameter and reflects the probability that the Master Scheduling Program will be realized. The methodology has been implemented in a decision-making program that will be briefly presented.

Keywords: Maintenance, Master production scheduling, Feasibility.

TH4C: 773 **15:00 hrs**

Improvement, Application and Verification of a New Multivariate Forecasting Model for Real Industry Related Issues

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With this work, a research contribution in the field of reliability theory has been made, with which a realistic prognosis of reliability parameters of technical systems can be carried out. The motivation to deal with this topic resulted from the realization that the prognosis quality of established prognosis models must be optimized. An early and realistic prognosis of reliability parameters contributes to the success of a concern, mainly through the early implementation of quality measures. The work focuses on the development of a new multivariate prognosis model, which uses multivariate stress parameters as reference variables. Its application enables the prediction of reliability parameters for electronic control units. The predicted reliability parameters can be specified as stress-dependent (bivariate/multivariate) or time-dependent variables. While univariate reference quantities usually use the time dwell time of a technical system, the prognosis model newly presented here can process multivariate reference quantities. During the time in the field, technical systems are not only exposed to different usage behavior, but also to other stresses and influences that make a not inconsiderable contribution to failure. The use of time in the field as a univariate reference variable does not allow for this differentiated consideration and does not take into account relevant information in the reliability analysis. All existing prediction models have in common that only univariate reference parameters can be processed. For a fully comprehensive reliability analysis, all stress variables that lead to a failure must be considered. This is not sufficiently possible with a simple univariate approach. With the new approaches, it is now possible for the first time to consider different stress variables, their changes and their effects on the technical system under investigation in a field data analysis. The presented approach for the multivariate prognosis model considers in its general idea the prognosis of stress-dependent reliability parameters. Usually, time-dependent reliability metrics are specified in practice. A new approach is presented that transforms stress-dependent reliability metrics into time-dependent reliability metrics using the multivariate annual stress distribution. Furthermore, model corrections are introduced to increase prediction quality, which provide significant improvements in prognosis quality.

Keywords: Failure, Reliability, Electronic control unit, Multivariate reliability parameters, Prediction, corrective models.

Session [TH4D]—Uncertainty Analysis
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Panoramique

TH4D: 465 **14:00 hrs**

On the meaning of assurance

Andreas Hafver[a], Carla Ferreira, Christian Agrell, Dag McGeorge, Erik Andreas Hektor, Frank Børre Pedersen, Meine van der Meulen, Odd Ivar Haugen, Simen Eldevik and Tore Myhrvold

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In this paper, the concept of assurance is discussed in relation to knowledge, uncertainty, risk and complexity. This is motivated by the authors' belief that fundamental principles from risk management and complexity science will be important to tackle future assurance needs posed by increasingly complex socio-technical and cyber-physical systems.

It is argued that the presence of risk is what makes assurance warranted. Specifically, it is argued that assurance may be understood as the management of risk related to knowledge-based claims, in contexts where trust in the claims is consequential. Knowledge is here understood as justified beliefs derived from information and scientific reasoning. Since both information and reasoning in general will be incomplete and imperfect, a degree of uncertainty is associated with the validity and veracity of claims. The association of uncertainty and consequence to claims in assurance indicates a relationship between assurance and the concept of risk, with risk defined as a combination of consequences and uncertainty.

Part of the risk of concern in the context of assurance stems from complexity which can make systems difficult to understand and predict. Accordingly, complexity is discussed as a driver for assurance needs, especially the need for validation of claims about complex assurance targets and assurance target properties.

In relation to trust, we discuss the role of trust providers, and trust enablers such as independence, transparency, and governance.

Keywords: Assurance, Uncertainty, Risk, Complex systems, Trust, Verification, Validation.

TH4D: 616 **14:20 hrs**

Uncertainty in a Hurricane Vulnerability Model

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This paper deals with the treatment and effect of uncertainty from stochastic variables in the Low-Rise Commercial Residential (CRLR) component of the Florida Public Hurricane Loss Model (FPHLM), for buildings with 1 to 3 stories. The FPHLM is a probabilistic risk model sponsored by the Florida Office of Insurance Regulation to estimate insured losses in residential buildings due to hurricaneinduced wind and rain, in the State of Florida. The FPHLM uses Monte Carlo simulations to model the wind, wind debris, and winddriven rain induced damage to the components of the building envelope and the building interior. The final outputs are a library of vulnerability functions that provide monetary damage ratio (cost of repair to building value) as a function of wind speed for different building classes. This paper discusses the most recent model updates (version 8.1), with a focus on the quantification of interior and contents damage from water ingress, and the corresponding uncertainties. In the new 8.1 version, the model adopts a component approach to explicitly propagate the water ingress among interior and contents components of the building. The resulting moisture content level of each interior component defines its damage while the volume of water reaching each component defines the damage to contents. In this new approach, many of the variables involved are stochastic, including the water absorption capacity of each interior component. A variety of sources, including laboratory tests, industry standards, and manufacturer catalogues informed the probability distribution functions (pdf)

of these variables. The paper describes how the FPHLM team characterized the pdfs of these variables and investigates the relationship between the variables and the nonlinear processes leading to the vulnerability functions. The types and sources of uncertainty are identified, and strategies to quantify and reduce the uncertainty are proposed.

Keywords: Loss prediction model, Interior damage, Stochastic Vulnerability process, Non-linearity.

TH4D: 630 **14:40 hrs**

Hierarchical Bayesian Inference for Quantification of Uncertainty in Multi Level Models of Dynamical Systems

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Calibration of model parameters is increasingly playing a key role in the process of accurately predicting the responses of full-scale dynamical systems. Such systems often exhibit complexities arising from the assembling process and nonlinearities manifested at various modelling levels, from material to component to sub-system to system level, during operation under harsh environments. Recent advances [1-3] have enabled to calibrate the model parameters, quantify the uncertainties and predict uncertainties to output quantities of interest using data obtained from the system level. However, data at the system level may be lacking or be expensive to obtain or, usually, are not adequate to reliably calibrate material, component or subsystem parameters. In this context, we extend the framework in [2, 3] and present a systematic approach to calibrate the system model parameters using information and data from lower system levels which share common parameters with higher system level. The proposed approach can properly take into account the uncertainty in the component model parameters due to variabilities in experimental data, environmental conditions, material properties, manufacturing process, assembling process, as well as nonlinear mechanisms activated under different loading conditions. For this, the uncertainty is embedded within the structural model parameters by postulating a probability model for these parameters that depend on hyperparameters. Sampling techniques as well as asymptotic approximations are used to carry out the computation or reduce the computational burden in the proposed Bayesian multi-level modeling framework. Selected applications in structural dynamics are used to demonstrate the effectiveness of the proposed framework.

Keywords: Hierarchical bayesian inference, Parameter estimation, Uncertainty quantification and propagation, Multilevel models, Structural dynamics.

TH4D: 755 **15:00 hrs**

A Probabilistic Approach for the Consideration of Measurement Errors in Metrology

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Metrology is a key stage in industry as it validates the quality requirements at different steps of the production process. In dimensional metrology in particular, validation consists in its classic form, in measuring dimensions of interest – dimensions intended for an assembly for example. Two sources of uncertainties can be associated with measured dimensions:

- Uncertainties in the true value of the dimension, which are caused e.g. by the vibrations of the machines during the manufacturing process, tear and wear of the tools, etc.;
- The measurement errors, which cannot be avoided and are caused e.g. by thermal expansion of the parts, inaccuracies of the measurement tools.

The probabilistic approach is used and these uncertainties are modeled as random variables. The distribution associated with the measurement error is assumed to be known.

The objective of this work is the "correction" of the measurement errors. At first, the probability density function associated with a measurement for a batch of parts is considered. A deconvolution procedure is applied to identify the distribution of the true dimension. The method of the maximum of likelihood is used here. An arbitrary distribution (Gaussian, lognormal, Weibull, etc.) is selected for the true dimension and its parameters are identified such that they lead to the best fit with the measurement data.

The correction is then applied for each measured value using a Bayesian method. The probability density function identified at the previous step is used as the prior distribution and the measurement error defines the likelihood function. The posterior distribution is then associated with the true value of the dimension. This provides the engineers with the best information available regarding the true dimension; its exact value cannot be identified and is therefore modeled as a random variable

Keywords: Metrology, Uncertainties, Statistics, Deconvolution, Bayesian.

Session [TH4E]—Human Factors and Human Reliability
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Amphi Jardin

TH4E: 500 **14:00 hrs**

Examining the Effect of a Proposed Operator Support System on Human Error Probability Estimation

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As the name implies, an Operator Support System (OSS) is meant to ease the work of operators as they perform the task of managing the operations of a complex system; in this case, a nuclear power plant (NPP). This is to ensure that from a human reliability analysis (HRA) perspective, the human error probabilities (HEPs) are reduced while keeping the same level of efficiency in the operations. However, it is necessary to confirm that the intended goals of the OSS are being achieved. The advanced power reactor 1400 (APR- 1400) can be regarded as an evolutionary nuclear power plant and has a fully digitalized main control room (MCR). Recently, further improvements are being planned to support the operator tasks within its MCR. The possible OSS features currently undergoing testing are introduced in this paper. This work evaluates the effects of some proposed operator support features in the MCR. This evaluation is done by comparing the human error probabilities estimated via the cause-based decision tree (CBDT)/ technique for human error rate prediction (THERP) method for both general and abnormal operations. The results show that the effect of the OSS based on the HEPs depends on the type of operation and scenario. The limitations to the use of the current HRA methods in general, including the CBDT/THERP method for estimating HEPs in such MCRs are discussed. The framework presented in this paper will be useful in future efforts to analyze OSS effects with other human reliability analysis methods.

Keywords: Operator support, Control room, Human error probability, Human factors, Digital MCR, CBDT.

TH4E: 575 **14:20 hrs**

Handling the Uncertainty with Confidence in Human Reliability Analysis

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Most of the attempts aimed at substituting expert-driven human reliability assessment methods with empirical data-driven techniques have failed due to the high uncertainty of human reliability databases and limitations of traditional probabilistic tools to deal with it. Although recent research suggests Bayesian and credal networks could be a more suitable approach to model human reliability data, such analyses implies the need for the assessment of a conditional probability distribution for each variable requiring a much larger amount of data than other traditional tools. Therefore, 'the problem of sparse data' continues to play a crucial role in hindering the feasibility and credibility of human reliability analysis. This has fuelled research aiming at tackling data scarcity through the use of expert elicitation and, more recently, of imprecise probability. In addition to issues inherent to the nature of the available data, some modelling procedures such as normalisation have the potential to implicitly affect the degree of knowledge carried by such data, resulting in loss of reliability. For instance, our confidence about the probability of an event that has been observed in only one of ten trials (1/10) is not the same as that of an event observed to occur ten times in one hundred trials (10/100). Hence, the output of such a procedure does not carry any information regarding the unevenness of sample sizes. In this paper, we propose to tackle these limitations by using confidence boxes (c-boxes) with credal networks, aiming at providing risk assessors with a rigorous framework for data uncertainty guiding towards more efficient and robust modelling solutions. The approach is tested with a simple model of the causes of fatigue in the work environment.

Keywords: Credal networks, C-boxes, Bayesian networks, Human factors, Human reliability analysis, Fatigue.

TH4E: 737 **14:40 hrs**

Analyzing the Validity of a Systematic Human-HAZOP Method for Human Error Identification in the Process Industries

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The rate from process-industry accidents has risen considerably in recent years. These accidents often cause human casualties, economic loss, and environmental pollution. Statistics show that majority of process-industry accidents (over 80%) are resulted from unsafe behaviors. Identifying human errors allow the development of appropriate prevention and mitigation strategies. Therefore, a systematic Human-HAZOP method is proposed in this paper. To illustrate its validity, the "7·12" major explosion and fire accident of Yibin Hengda Technology Co., Ltd. is selected as a case study. The effectiveness and rationality of the proposed method are also verified by comparing with similar identification results from the SHERPA. In conclusion, the systematic Human-HAZOP method can be popularized for a thorough and consistent identification of human errors in the process industries.

Keywords: Human error identification, Systematic Human-HAZOP, Process-industry accidents, SHERPA, validity.

Session	[TH4F]—Civil Engineering
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Espace Grand Angle

TH4F: 447 **14:00 hrs**

Probabilistic Design for Civil Engineering Infrastructure Using Vine-Copulas

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In practice, when it comes to the reliabilitybased design of infrastructure it is most common to treat random variables as independent. While this assumption simplifies the probabilistic analysis considerably, it leaves out useful information that may result in a safer and more efficiently designed structure. Often there are suitable data to quantify the dependence between random variables in a particular problem, but appropriate numerical methods are not readily available or known to the analyst. Alternatively, design codes and assessment protocols in general have not been developed which provide guidance on how to include multivariate analysis in the design of a structure, especially in the context of a univariate return period (or exceedance probability) based procedure. Thus, many design decisions are made after assessing multiple failure mechanisms independently, despite being influenced by the same random variables, or by relying mostly on well-informed, but subjective, decisions.

As such, the need for incorporating multivariate analysis into the reliability-based design approach is becoming increasingly recognized. Three example cases from our experience at the Delft University of Technology are provided where vine-copulas have been used to improve the design of a structure. The case studies consider open-sea waves or ship berthing loads, with up to six variables considered in the vine-copula model. Apart from vine-copulas, probabilistic methods include extreme value analysis, Monte Carlo simulation and the firstorder reliability method. When compared to a conventional reliability-based design approach, a more efficient final design was produced for some case studies, in terms of size and/or cost, for the same safety level. In addition, for a design methodology based on load scenarios with a specified exceedance probability, a higher confidence in the final design reliability is obtained when information from the dependent multivariate analysis is considered. The approach described herein is based on open-sourced computational tools and can be immediately used to improve the insight and decision making capability of infrastructure designers and owners. Future work should consider design cases where a vine-copula can be applied to a situation with strong dependence between up to seven variables.

Keywords: Vine–copula, Structural reliability, First-order reliability method, Rosenblatt transformation, Probabilistic design, Civil infrastructure.

TH4F: 577 **14:20 hrs**

Surrogate-Assisted Versus Subset Simulation-Based Stochastic Comparison Between Running Safety and Passenger Comfort Design Criteria of High-Speed Railway Bridges

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Limiting the maximum vertical acceleration and deflection of the deck are two principal design criteria of high-

speed railway bridges. The former prevents ballast instability to ensure running safety, and the latter attempts to limit the acceleration of the car-body below the level at which passenger comfort is disturbed. The previous studies are mainly concerned with the destabilization of the ballast, nevertheless the possibility of the maximum deflection occurrence should not be underestimated. Moreover, the literature indicates the need to improve the current design requirements including the minimum allowable mass and frequency of bridges, which requires solving optimization problems based on modern requirements. Therefore, a probabilistic framework with simulation-based techniques is used to evaluate the violation probability of the above limit states and distinguish dominant criteria under different conditions, i.e., bridge span length and operational train speed. First, the performance of the subset simulation method is compared with the Latin Hypercube-sampling based Monte-Carlo approach supported by surrogate models. Polynomial chaos expansion (PCE) surrogate models are trained for this objective. Then, the resulting violation probabilities are evaluated for the two considered limit states using the approach with better performance.

Keywords: High-speed railway bridges, Bridge dynamics, Running safety, Passenger comfort, Structural reliability, Subset simulation, Surrogate model, Polynomial chaos expansion.

TH4F: 668 **14:40 hrs**

From a Microscopic Model to the Determination at the Structure Scale of the Reliability of an Alkali-silica Reaction Affected Dam

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Alkali-Silica Reaction (ASR) occurs between non-crystalline silica in reactive aggregates and the highly alkaline pore solution in concrete. ASR causes cracking of the concrete at the micro-level, thus deformations and cracks at the macro-level of structural scale. Concrete dams are prone to degrade due to ASR because the moisture conditions in bulk concrete favour ASR. The dysfunction of spillway gates is one of the harmful consequences of this degradation. The random nature of many involved material parameters imply to evaluate the occurrence probability of such a dysfunction in a probabilistic context. The proposed study aims at assessing the failure probability with regard to the blocking of a spillway gate. To reach this goal, a microscopic ASR physical model is considered whose output is the swelling of a representative elementary volume. An efficient surrogate model, derived from the microscopic physical model and based on a polynomial chaos expansion, allows incorporating the swelling at the structural scale within a second physical finite element model of the spillway pier. The safety margin is expressed in terms of clearance between the gate edges and the semi-circular guide grooves of two adjacent piers. The results show the time evolution of the reliability and underline the relative importance of input parameters. It is pointed out that the most influencing parameter remains the reaction rim thickness of silica gel around the aggregates.

Keywords: Structural reliability, Microscopic model, Surrogate model, Alkali-silica reaction, Dam.

Session	[TH4G]—Nuclear Industry
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Atrium 3

TH4G: 533 **14:00 hrs**

Nonparametric Confidence Interval for Quantiles. A Comparison of Methods in the Context of Safety Analysis of Npps

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This paper presents a comparison between different nonparametric methods for quantile and confidence interval estimation for obtaining a more realistic safety analysis of nuclear power plants based on the Best Estimate Plus Uncertainties (BEPU) approach. In this study, ten different quantile and two confidence interval estimation methods to sample sizes of 59 and 93 are applied in the uncertainty analysis of a Large-Break Loss of Coolant Accident, LBLOCA, in the cold leg of a Pressurized Water Reactor using the thermal-hydraulic code TRACE. The results obtained with the different methods considered are compared with the Wilks' method with respect to the average coverage probability, accuracy, and bias.

Keywords: Uncertainty, Quantile estimation, Confidence

interval, Wilks' method.

TH4G: 624 **14:20 hrs**

Characterizing Previously Unknown Dependencies in Probabilistic Risk Assessment Models of Nuclear Power Plants

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The US Nuclear Regulatory Commission (NRC) maintains a set of Level-1 probabilistic risk assessment (PRA) models, called standardized plant analysis risk (SPAR) models, which are the analytical tools used by the agency to perform risk assessments. The SPAR models include elements of the initiating events (IE), mitigating systems (MS) and to a limited extent barrier integrity (BI) cornerstones.

Over the last 10 to 15 years, several events have occurred at nuclear power plants (NPPs) in the US which had substantial risk and where multiple cornerstones were simultaneously affected. The risk insights from these domestic events may indicate an existing completeness uncertainty, specifically that there are 'dependencies' between certain initiating events and availability/reliability of mitigating systems which are not currently captured in the PRA models.

These previously unrecognized dependencies can be included in the SPAR models and thus captured in subsequent risk assessments. This paper will review several examples from US commercial NPPs where these dependencies manifested themselves and demonstrate that the risk of lower intensity events (far less than a beyond design basis event) can be significant. Further, this paper will describe potential PRA modeling improvements and provide insights that may lead to modifications to existing procedures, plant structures, systems & components such that the previously unmeasured risk might be lowered, providing a benefit to public health and safety.

Keywords: Nuclear power, Dependency, External event, PRA, 'sunny day' event, Fukushima dai-ichi.

TH4G: 732 **14:40 hrs**

Modeling Infrared Spectra : An Algorithm for an Automatic and Simultaneous Analysis

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Infrared spectroscopy is a widely used technology for nondestructive testing of materials. We propose a novel approach to automatically and simultaneously analyze a dataset of infrared spectra. They are modeled by linear combinations of peaks whose shape and position are parametrized. The observed data consist of linear combinations of the time-discretized peaks with an additive noise. In order to recover the peak parameters, common to all the dataset, and the associated amplitudes, which are specific to each spectrum, we formulate a penalized non-linear optimization problem. In this context, the penalization ensures that the spectra are recovered using a sparse set of common peaks.

Due to the non-convex nature of the problem and the continuous nature of the parameters, a resolution via standard procedures is out of reach. Therefore, we propose an off-the-grid algorithm with alternating convex optimization updates (to estimate the amplitudes of the peaks) and non-convex steps (to estimate the location and the scale of the peaks). In practice, this gives satisfactory results and provides sparse solutions.

We also study the numerical performances of the algorithm on simulated data and on real infrared spectra. The latter come from polychloroprene rubbers used in a marine environment at different aging levels. Eventually, we use a clustering algorithm in order to identify the peaks corresponding to the chemical components involved in the aging process of this material.

Keywords: IR spectroscopy, Convex optimization, Non-convex optimization, Group-Lasso, Sparsity.

Session [TH4H]—Maritime and Offshore Technology
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Cointreau

TH4H: 604 **14:00 hrs**

Future Risk Scenarios Regarding the use of the Northern Sea Route

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As the ice-sheet of the Arctic is melting due to the effect of global climate change, the Northern Sea Route stretching from the Kara Gate to the Bering Strait has seen a resurgence in interest. Stakeholders see the prospects of the route as a valuable alternative to the Malacca Strait, and Panama and Suez Canals, but also as a new venue for transporting petroleum, liquefied natural gas, and for tourism. Consequently, this spur of interest has given rise to new challenges within polar maritime and environmental safety, leading to the development of its corresponding international and national legal frameworks. The purpose of this paper is therefore to uncover the possible future scenarios of the Northern Sea Route and their corresponding risks, by considering the involved stakeholders, the development of technologies, legislature, regulation, and the global geopolitics that shape it. To achieve this, we employ the general morphological analysis framework to address the state of affairs of the problems to counteract the subjective, nonquantifiable, non-linear, and non-delineated nature of the scenarios. The result is an interactive inference model, which was employed with contextual agency to deduce that the following dimensions: East/West Relations, Global Environmental Politics, and Technical and Navigational Requirements, were the most pivotal for the formation of different futures. The interplay between the connections of these dimensions as parameters clearly formed distinct opposing scenario clusters for possible futures. Concluding, we identify relations, technology, and environmental politics as the strategic areas to target to shape the future of the Northern Sea Route.

Keywords: Methodology, Scenario, General morphological analysis, Risk, Uncertainty, Northern sea route.

TH4H: 606 **14:20 hrs**

Availability Analysis of Marine Multistate Systems Using Ship Scrubber Systems

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Maritime transportation plays a crucial role in global trade. The environmental issues caused by the shipping industry imply that certain measures are necessary to be taken in order to deal with the problem of gas emissions by applying the IMO's directives. The reduction of the emissions is a complicated challenge and possibly it is difficult to reach without intervention to the exhaust system of the ship. Ship scrubber systems are an alternative solution to manage the problem of gas emissions in maritime shipping industry. Thus, they are important for the normal operation of the ship. Since there are significant costs related with the use of these systems, the evaluation of their operational performance and availability is a major tool contributing to the decision-making process of the maritime industry stakeholders. This paper is an attempt to study the use of the ship scrubber systems aiming to the evaluation of their availability. Using different scenarios on the layout of the system, its components, the maintenance intervals and the stochastic modelling approach on the other hand, the authors attempt to identify that combination maximizing the availability of the system, proposing a set of operational and maintenance parameters that improve the environmental related performance.

Keywords: Reliability, Markov chain, Ship Scrubber, Maritime Transportation, Multi State Systems, Marine Fuels.

TH4H: 632 **14:40 hrs**

Application of Failure Mode, Effects and Criticality Analysis (FMECA) to Prioritize the Equipment And Components of the Subsea Christmas Tree System

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Offshore installations spend millions annually trying to guarantee the integrity of their equipment. The challenge lies in determining where to apply the industry's always finite and limited resources to provide the greatest benefit. Risk-based inspection (RBI) was developed in the oil industry to assist in the identification of the highest risk equipment (working with the respective failure modes) and also to design an inspection program that not only identifies the most relevant failure modes but also reduce your chances of occurrence.

This study is part of a project whose objective is to develop a methodology to monitor the integrity of the equipment, optimizing inspection policies, based on the risk associated with the operation of Christmas trees in subsea operations.

The results of this phase of the project include the study of two typical configurations of Christmas trees and the evaluation of their FMECAs; which were based on the database OREDA (SINTEF 2015a; SINTEF 2015b), on information available in the literature and information of equipment suppliers. Finally, a classification of Christmas trees components is provided based on their risk indices.

These results contribute to the performance of more effective risk analyses in the offshore industry, since data on this equipment is scarce in the literature, especially data related to their configurations, failure probabilities, inspection methods and failure detection probabilities.

Keywords: Xmas tree, FMECA, RBI, Criticality, Failure modes, Subsea, Offshore.

TH4H: 758 **15:00 hrs**

An Artificial Neural Network Based Decision Support System for Cargo Vessel Operations

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There is increasing interest in understanding fuel consumption from the perspective of increasing energy efficiency on a vessel. Thus the aim of this paper is to present a new framework for data-driven estimation of fuel consumption by employing a combination of (i) traditional statistical analysis and (ii) Artificial Neural Networks. The output of the analysis is the most frequently occurring fuel-speed curves corresponding to the respective operational profile. The inputs to the model consider important explanatory variables like draft, sea current and wind. The methodology is applied to a case study of a fleet of 9000 TEU vessels, in which telemetry data on the fuel consumption, vessel speed, current, wind direction and strength were analysed. The performance of the method is validated in terms of error estimation criterion like R^2 values and against physical phenomena obtained from the data. The results can be used to study the economic and environmental benefits of slow-steaming and or fuel levies, or by extending this part of the model into exergy analysis for a more holistic review of energy saving initiatives.

Keywords: Fuel consumption in vessels, Artificial neural networks, Telemetry data.

Session	[TH4I]—Human factor in the smart industry
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Giffard

TH4I: 311 **14:00 hrs**

Decision Making Approaches for Safety Purposes in Working Environments with Human-Technology Interaction

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Human-Machine Interaction (HMI) appeared during the first Industrial Revolution, when machines were introduced as tools functional to workers' needs. With the arrival of automation systems in the 70s, workers discovered the necessity to be re-skilled to work alongside machinery. The recent advent of Industry 4.0 also led to Human-Technologies Interaction (HTI), since new technologies furnish connections and algorithms for a safe and effective interaction between humans and autonomous systems.

Today a transition from "interaction" to real "collaboration" between humans and machines can be observed and companies need to adopt adequate decision making approaches. A careful assessment of both advantages and disadvantages of using technologies is needed, since they can improve safety, but they can also add new industrial and occupational risks.

Based on an analysis of international literature and European technical standards, the present study aims to lay the foundation for a methodological framework supporting companies during the decision process of establish-

ing safety convenience of integrating human and technological components. Some possible models and decisional approaches are extracted from literature and used to identify useful criteria to be declined for the specific topic of safety.

The study is also thought as a support for possible future introductions of new safety standards and validation procedures for safety skills of industrial collaborative technologies.

Keywords: Human-machine interaction, Industry 4.0, Safety, Emerging risks, Standards, Decision making.

TH4I: 415 **14:20 hrs**

Human – Collaborative Machine Interaction: The Effects on the Standardization

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Recent studies have highlighted the need to investigate the new human-machine interaction in smart factories. The enabling technologies of the fourth industrial revolution allow new modes of interactions between operators and machines; they cooperate in executing numerous complex and high-precision tasks sharing the same workspace. According to the concept of Operator 4.0 proposed by Romeo [1], the collaboration between man and machine includes both "cooperative work" with robots, but also "work aided" by machines.

In particular, among the types of Operator 4.0, the collaborative operator works together with collaborative robots, while the super-strength operator uses wearable exoskeletons to increase his strength to perform manual activities without effort.

In this perspective, this work wants to highlight the regulatory aspects concerning the safety aspects of human interaction with collaborative robots, autonomous guided vehicles and exoskeletons. This paper focuses on emerging safety aspects related to these collaborative machines and their impact in terms of Essential Health and Safety Requirements (EHSRs) in the Machinery Directive. In this regard, it is necessary to underline the gap among the increasing maturity of the technology and the lack of analysis and route for this specific field in the current legislation and standardization.

Keywords: Industry 4.0, Safety 4.0, Collaborative robot, Autonomous mobile robot, Exoskeleton, Risk assessment.

TH4I: 453 **14:40 hrs**

An Allostatic Load Measurement Model in Industrial Production Processes for Work-Related Stress Risk Assessment

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The current European regulatory framework for work health and safety has identified work-related stress as one of the risks to be considered and to be managed properly. In particular, the new legislation has implemented interest in the topic of "work-related stress". The proposed paper aims to offer theoretical principles and operational information about how to assess work-related stress risk. The study proceeds from the assumption that the danger is due to the human being. Consequently, that certain "event" depends on the combined disposition of the industrial process to which the subject is assigned and, above all by the intrinsically individual characteristics of the human resources be considered. The paper meant to be a contribution to the identification of methodologies applicable to the assessment of work-related stress in the workplaces for the identification of shared diagnostic paths in the field of psychosocial risk. In this context, the allostatic load of the subject under examination can measure, monitor, and observe the resilience or the risk in developing a mood disorder, depressive, anxiety, psychosomatic or somatoform (overt or potential) through vital signs and personality of the subject. It is a way to observe the consequences (stress) of factors that seem unrelated to each other and allows us to relate a series of behavioral profiles that are correlated by known pathophysiological links with industrial processes, both in terms of probability of occurrence and consequences that is the severity of the impact.

The proposed procedure based on a semi-quantitative approach considers a four-dimensional domain that will allow the definition of a risk matrix based on an objective indicator of assessment risk. This model will tell us the tendency to develop a somatoform or psychosomatic as well as mood, depressive or anxiety disorder, relative to a specific activity and, considering the different hazards present in the company; it will be possible to reconstruct the overall level of risk held by the plant under examination.

Keywords: Work-related stress, Safety, Risk matrix, Psychometric test, Industrial processes.

TH4I: 525 **15:00 hrs**

Individual Situation Awareness to be Set Free from the Collaborative Robot

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Human Factors (HF) is the scientific discipline concerned with the understanding of interactions among human and other elements of a system with the aim to optimize system performance. One important concept within HF is Situation Awareness (SA). Since the early 1990s, the original models of individual SA have been complemented by additional models of shared and distributed SA. Although SA has already been the subject of investigation in many complex socio-technical systems, there is not a great body of scientific work on SA in relation to collaborative robots (cobots). This paper explains and reviews the most relevant models and evolutions in SA thinking and examines to which extent the concept of SA, and more particularly Distributed Situation Awareness (DSA), can be applied to cobots. Individual models of cobot SA to detect human presence and predict future human activity from a cobot-centered perspective are technologically feasible and are currently applied in industrial applications. We defend that the SA within the cobot has to be of a higher order than the level of the individual human or technological agent, and needs to be 'set free' in order to not only be shared with human team members, but also to understand how SA is distributed throughout the system as a whole. This paper proposes to inform future cobot design with DSA analysis from a socio-technical perspective.

Keywords: Collaborative robot, Cobot, Human-robot collaboration, Situation awareness, Distributed situation awareness, Human factors.

Session	[TH4J]—Resilience Engineering
Day/Date/Time	Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue	Botanique 2

TH4J: 377 **14:00 hrs**

An Innovative Approach for Ongoing Assessment of Critical Infrastructures' Resilience based on a Nonfunctional Requirement Ecosystem

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Geopolitical context or climate change induced more and more disasters in the two last decades. Particularly, Critical Infrastructures (CI – e.g., water distribution, health care) that support the daily life of societies are impacted by these disasters. These CI are indeed essential. By their various interactions and links, they become more fragile when facing complex situations. For instance, a local event, occurring in a CI (e.g., an accident), can propagate throughout these interactions, impacting other CI, leading to a higher intensity and to a global impact. Classical risks analysis is limited in terms of global and dynamic vision of these CI, to manage these events efficiently and to recover to an acceptable functioning state for the end users. To this purpose, resilience is a useful concept, highlighted by numerous research works and organizations to characterize the best way a CI has to react to an undesirable event and avoid, if possible, its propagation. The purpose of this paper is to present the main principles of a methodology to assess and analyze resilience of a CI based on a multi views and systemic model formalized as a digital twin. This work is done in the frame of the project RESIIST supported by the French research agency ANR (Résilience des infrastructures et systèmes interconnectés, 18-CE39-0018-05) to provide scenarios to test and evaluate the proposed methodology.

Keywords: Resilience, Non-functional requirement, -ility, Digital twin, Modeling, Simulation.

TH4J: 498 14:20 hrs

Investigating Resilience

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The notion of resilience is an interdisciplinary notion whose development and use has accelerated significantly over the past twenty years. Since its first use in materials science, ecology, and psychology, many disciplines have adopted it, particularly the sciences of safety and security. More recently, resilience is at the center of public policies for preventing and managing crises globally, nationally, and locally. The diversity of theoretical and empirical perspectives on resilience allows this concept to integrate : i) objects of different scales (from the technical object to the socio-ecological system); ii) different temporalities (before, during, and after the occurrence disturbance); iii) disturbances of various kinds (internal or external origin to the object, anticipated or unanticipated nature, positive (opportunity, innovation) or negative (accident, crisis, disaster)); iv) different perspectives concerning the disturbance (return to a normal state, robustness, management of the limit of the object's control capacity). The design of definitions, models, methods, and indicators of resilience creates a potential for enhancing the safety and the security of objects. Nevertheless, the absence of a unique resilience culture creates confusion, ambiguities, misunderstandings, or contradictions between stakeholders.

The paper's contribution is an interdisciplinary conceptual and methodological framework aiming at supporting resilience studies. John Dewey's theory of inquiry and methodological literature about qualitative analysis ground the framework. The diversity of perspective on resilience guides the application of the four phases of the framework: 1) defining the resilience problem; 2) collecting data; 3) analyzing data, and 4) restituting results. The first part of the article presents the diversity and the complexity of resilience theories. The second part describes basis of the framework. The third part presents and illustrate the framework.

Keywords: Resilience, Transdisciplinary, Investigation.

TH4J: 552 14:40 hrs

Insights About What Authorities and Emergency Services Need and Expect from Society

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When crises occur, the society plays significant roles, such as assisting victims, helping vulnerable groups, sharing information, allocating resources etc. However, for the response to crises to succeed, society, authorities and emergency services should align their efforts and needs in a coordinated way. To identify this alignment, we designed an internet-based survey asking authorities, emergency services, and volunteer organizations about the needs and expectations they have from the society to better handle crises. The questionnaire is divided into two main sections: the first section covers the responders' risk awareness, and the second gathers the needs they have from society in the following items: social norms and sense of communality, coping skills, resources to face a crisis, perception of trust, perception of responsibility, crisis knowledge, crisis communication, communication channels, information sharing and preparedness. The survey was launched in 7 European countries and this paper presents the results collected in Spain. The answers show that in general there is a high consensus in the analysed items, though the distribution shows that authorities differ the most from the other responder profile groups. The results show that the responders are more aware of pandemics followed by extreme weather related events. We think this is because of the huge impact that is creating the current coronavirus pandemic.

Keywords: Societal resilience, Societal resilience dimensions, Needs and expectations from society, Internet-based survey.

TH4J: 601 15:00 hrs

A Comparative Analysis of Dynamic vs. Quasi-static Approaches for Resilience Assessment of a Bulk Power System Against Severe Wind Events

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Severe weather-related events are one of the main causes of large-scale electric power outages worldwide. Although the probability of occurrence of these events is low, they are considered into the high-risk category due to their significant consequences. The intensity and frequency of these events have gradually increased in the last decades and are expected to keep increasing in the future due to climate change. To this end, power grid resilience is critical to reduce the risk and vulnerability to these events. In the context of resilience assessment, an important step is the simulation of the performance of power systems during these highly impactful events, which can be performed either by quasi-static or dynamic approaches. In this work, both approaches are applied for the assessment of the resilience of a bulk power system against severe wind events, and a comparative analysis of the results is provided. The main advantage of using dynamic simulation is to detect the outages of the system assets related to electrical instability during the events. Eurostag software is used to perform the dynamic simulation with a variable time step to increase the efficiency of the computational module. The results show that the analysis of the resilience of power system by a quasi-static approach leads to a considerable underestimation of the resilience metrics, mainly related to ignoring the intervention of protection systems during severe wind events.

Keywords: Power system, Wind events, Quasi-static approach, Dynamic simulation, Reliability, Resilience, Monte Carlo sampling.

Session [TH4K]—Software Reliability
Day/Date/Time Thursday, 23 Sep. 2021/14:00–15:20 hrs
Venue Atrium 1

TH4K: 157 14:00 hrs

Improving the Reliability of Autonomous Software Systems through Metamorphic Testing

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Autonomous software systems such as self-driving cars or exploratory robots have a certain degree of self decision capabilities. Some have increased skills for the perception of the environment, some can plan and execute complex tasks, others can respond to environment changes with limited human intervention. Autonomous software systems are intended to manage unexpected events such as faults or hazards in uncertain environments. Therefore, controlling their reliability and their ability to recover from erroneous states is crucial to ensure system safety. Verifying the safety of autonomous software systems is typically based on model-checking, but this method requires strong human specification of the properties to verify, and it only exercises an abstract model of the real system. Unlike model-checking, automated testing evaluates the system by selecting test scenarios where the chance to reveal faults is high, even though defining accurately the expected results of those scenarios is difficult and time-consuming. In software testing, this latter problem is known as the test oracle problem[1] and solving it for real-world autonomous software systems remains an open problem because:

(1) Testing perception systems of autonomous software systems needs to generate tests under consideration of environment uncertainties
(2) Motion planning involves solving complex non-deterministic planning and optimization problems for which there exist no general analytical solutions
(3) Validation of learning systems requires to define tolerant test oracles

In our talk, we address specifically the second item, focusing on the testing of automated planning systems.[2] We explore the usage of Metamorphic Testing (MT) which exploits known input-output relations of the system under test for either generating the next test case to use or to check expected results of multiple executed test scenarios.[3] Planning problems are modeled through a domain-specific language with predicates called PDDL (Planning Domain Definition Language), which captures the autonomous system's behavior and enables automated task planning. By specifying an initial system state and a goal to reach, a planner computes an optimal sequence of actions that reaches a state compatible with the goal. Testing and controlling both the planning domain and the optimal planner is crucial for increasing the reliability of autonomous software systems which embed automated planning, since it affects the high-level decision-making capabilities and therefore influences the overall system behavior. By using metamorphic testing, we propose an automated technique for both generating the next test case and checking the expected result returned by the planner. In our work, we deploy metamorphic testing for testing automated planners that are used in collaborative robotics. To the best of our knowledge, it is the first application of metamorphic testing on automated planning systems.

TH4K: 262 **14:20 hrs**

A Comparison of Different Approaches for Verification and Validation of Software in Safety-Critical Systems

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The increased reliance on software in safety-critical systems requires an added emphasis on software verification and validation. To ensure, with sufficient confidence, compliance with functional safety requirements and avoidance of hazardous states, effectiveness and coverage of approaches to software verification and validation are crucial. This paper present an all-electric control system in subsea oil production that faces this challenge, a case study for our research into a digital twin for safety demonstrations. The paper highlights some promising ideas and approaches from academia and industry seen as beneficial for cross-domain knowledge transfer, set in context to recommended tools, methods, and techniques from standards, e.g., IEC 61508 and ISO 26262. Beyond industrial insights, the article is self-serving for knowledge and ideas adaptable to an intended approach of verification and validation of safety-critical software using a digital twin.

Based on the literature survey, recommended ideas to utilize in our approach are presented in this paper.

Keywords: Software verification & validation, All-electric control system, Software development, Standards.

TH4K: 661 **14:40 hrs**

Locks for the use of IEC 61508 to ML Safety-Critical Applications and Possible Solutions

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In the past few years, Artificial Intelligence (AI) and more precisely Machine Learning (ML), have been developing quickly and have found applications in a lot of various fields, including industry. The process industry and the use of machinery are critical because they represent a high risk for the surroundings, humans, goods and environment. To mitigate those risks, safety devices carrying out safety functions are used to monitor and control processes and machinery in real time. IEC 61508 which gives a framework to certify the Safety Integrity Level (SIL) of such systems is not suitable for complex algorithms like ML algorithms can be. We will attempt in this paper to discuss the general concepts of the standard that hinder the development and assessment of a safety devices using AI in the current state of knowledge. To the end, after describing the specificities of safety-critical systems and presenting the basic principles of AI and ML, this paper highlights the locks for the use of IEC 61508 and suggests some leverages, such as the use of a new safety lifecycle, a minimal level of transparency and explainability as well as the demonstration of robustness based on formal verification, testing and new metrics.

Disclaimer: AI is an area of research which is currently booming, the scientific knowledge is progressing rapidly, especially on the topics of safety assurance, testing, V&V, robustness, explainable AI (XAI). Thus, this article could not be exhaustive and represents our current state of knowledge on that matter. Some information in this paper have been taken from standards projects of the ISO/IEC JTC 1 SC42.

Keywords: Functional safety, Software reliability, Process industry, Machinery, Machine learning, Artificial intelligence.

TH4K: 697 **15:00 hrs**

Review of Reliability Modelling Methods for Safety-critical Software in Nuclear Power Plant

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Safety-critical software plays an important role for the safe operation of a nuclear power plant (NPP). However, it also brings challenges both to the reliability analysis of the safety system and to the Probabilistic Safety Assessment of the NPPs. The reliability analysis of safety-critical software is also expected by the nuclear regulation agencies and the software development groups for test evaluation and optimization. It is essential to carry out reliability modelling research on nuclear safety-critical software. The detected faults during software test process are regarded to have close connection with the software reliability and there have been hundreds of test-based software reliability models. Software reliability growth models are very commonly used in software reliability evaluation. To incorporate more information and provide more accurate analysis, modelling software fault detection and correction processes has attracted widespread research attention recently. This paper reviews the research progress of software reliability in the field of nuclear power in recent years. Combining with the characteristics of safety-critical software, this article makes a detailed analysis of software reliability growth model which helps to analyse the reliability of safety-critical software.

Keywords: Safety-critical software, Reliability modelling, Software severity, Critical fault, Software reliability growth model, Nuclear power plant.

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NOTES

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ESREL 2021 – PROGRAMME OVERVIEW

17:00-20:00	Welcome cocktail @ Jean Monnier Congress Center on Sunday 19, 2021

Monday, September 20, 2021

Time/Venue	Auditorium										
09:00-09:30	Conference Opening										
09:30-10:10	Plenary I: Artificial Intelligence, Safety and Reliability : an old story or a new age? *By Patrice Aknin*										
10:10-10:25	Coffee Break										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
10:25-11:25	MO1A	MO1B	MO1C	MO1D	MO1E	MO1F	MO1G	MO1H	MO1I	MO1J	MO1K
11:30-12:30	MO2A	MO2B	MO2C	MO2D	MO2E	MO2F	MO2G	MO2H	MO2I	MO2I	MO2K
12:30-14:00	Lunch										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique							
14:00-15:00	Panel I	Panel II	Panel III	Panel IV							
15:00-15:20	Coffee Break										
Time/Venue	Auditorium										
15:20-16:00	Plenary II: From Parameter Design to Data Science *By Jeff Wu*										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
16:10-17:30	MO3A	MO3B	MO3C	MO3D	MO3E	MO3F	MO3G	MO3H	MO3I	MO3J	
17:30-19:00	Visit Tour										
18:00-19:00	ESRA Assembly										
19:00-20:30	ESRA Dinner										

Tuesday, September 21, 2021

Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
08:30-10:10	TU1A	TU1B	TU1C	TU1D	TU1E	TU1R	TU1G	TU1H	TU1I	TU1J	TU1K
10:10-10:25	Coffee Break										
10:25-11:45	TU2A	TU2B	TU2C	TU2D	TU2E	TU2R	TU2G	TU2H	TU2I	TU2J	TU2K
Time/Venue	Auditorium										
11:50-12:30	Plenary III: Extending the Service Life of Civil and Marine Structures: Role of Monitoring, Probabilistic Life-cycle Management and Risk-based Decision Making *By Dan Frangopol*										
12:30-14:00	Lunch Break										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique							
14:00-15:00	Panel V	Panel VI	Panel VII	Panel VIII							
15:00-15:20	Coffee Break										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
15:20-16:20	TU3A	TU3B	TU3C	TU3D	TU3E	TU3R	TU3G	TU3H	TU3I	TU3J	TU3K
16:30-17:30	TU4A	TU4B	TU4C	TU4D	TU4E	TU4R	TU4G	TU4H	TU4I	TU4J	TU4K
17:30-19:00	Visit Tour										

Wednesday, September 22, 2021

Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
08:30-10:10	WE1A	WE1B	WE1C	WE1D	WE1E	WE1R	WE1G	WE1H	WE1I	WE1J	WE1K
10:10-10:25	Coffee Break										
10:25-11:45	WE2A	WE2B	WE2C	WE2D	WE2E	WE2R	WE2G	WE2H	WE2I	WE2J	WE2K
Time/Venue	Auditorium										
11:50-12:30	Plenary IV: Cognitive, practical, organisational and regulatory safety challenges of a new era *By Jean-Christophe Le Coze*										
12:30-14:00	Lunch Break										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
14:00-15:00	WE3A	WE3B	WE3C	WE3D	WE3E	WE3R	WE3G	WE3H	WE3I	WE3J	WE3K
15:00-15:20	Coffee Break										
Time/Venue	Auditorium										
15:20-16:00	Plenary V: Plenary Session: Safer by design concept *By Catherine Mouneyrac*										
Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
16:10-17:30	WE4A	WE4B	WE4C	WE4D	WE4E	WE4R	WE4G	WE4H	WE4I	WE4J	WE4K
19:00-23:59	Gala Evening										

Thursday, September 23, 2021

Time/Venue	Auditorium	Atrium 2	Escape Grand Angle 2	Panoramique	Amphi Jardin	Escape Grand Angle	Atrium 3	Cointreau	Goffard	Botanique 2	Atrium 1
09:00 - 10:20	TH1A	TH1B	TH1C	TH1D	TH1E	TH1R	TH1G	TH1H	TH1I	TH1J	TH1K
10:20-10:35	Coffee Break										
10:35-11:35	TH2A	TH2B	TH2C	TH2D	TH2E	TH2R	TH2G	TH2H	TH2I	TH2J	TH2K
11:35-12:35	TH3A	TH3B	TH3C	TH3D	TH3E	TH3R	TH3G	TH3H	TH3I	TH3J	TH3K
12:35-14:00	Lunch										
14:00-15:20	TH4A	TH4B	TH4C	TH4D	TH4E	TH4R	TH4G	TH4H	TH4I	TH4J	TH4K
15:20-15:50	Closing Session										

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