2026 The 10th International Conference on System Reliability and Safety (ICSRS 2026)

➲➲➲ **Rome, Italy | November 23-25, 2026**

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►Conference Committees

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►Welcome Message

The 10th International Conference on System Reliability and Safety （ICSRS 2026） will be held in Rome, Italy, during November 23－25,2026. The conference is technically co-sponsored by Politecnico di Milano and the IEEE Reliability Society (Italy Chapter) On behalf of the Organizing Committee, we extend our warm welcome to all researchers, engineers and practitioners from academia, industry and government to join this annual event in Rome.

System reliability and safety have become increasingly important research areas as complex engineering systems are widely deployed in modern society. The continuous integration of intelligent and large-scale systems brings new challenges for reliability guarantee, risk mitigation and accident prevention. Robust reliability and safety technologies are fundamental to reducing operational hazards and supporting the sustainable development of critical industries.

ICSRS offers a dedicated forum for researchers and industry specialists to share cutting-edge progress, exchange innovative ideas and discuss practical challenges. The conference covers a broad spectrum of topics including fault detection and diagnosis, fault-tolerant control, risk assessment, safety-critical system design, reliability modelling, probabilistic safety analysis, maintenance decision-making and related emerging applications. It aims to promote cross-disciplinary communication and accelerate the development of advanced theories, methods and engineering solutions for system reliability and safety.

The conference program consists of plenary speeches, session keynote speeches and parallel technical sessions. We would like to express our sincere gratitude to the conference chair, technical program committee members, session chairs, reviewers, authors and volunteers. The high-quality technical program would not be possible without their dedicated work and valuable contributions.

We hope all participants can gain inspiring insights from the presentations and discussions, build academic connections, and enjoy the conference in Rome. We wish you a fruitful and rewarding conference experience!

ICSRS 2026

Conference Committees

▶Guideline

For Onsite Participants

Time Zone

- Italy standard time: UTC/GMT+1

Conference Venue

- NHOW Roma
- Address: Corso d'Italia 1, 00198 Roma, Italy

For Presentation

- The duration of Plenary Speech slot is 40 minutes (Includes a 2–3-minute Q&A).
- The duration of Session Keynote Lecture slot is 20 minutes (Includes a 2–3-minute Q&A).
- The duration of regular oral presentation slot is 15 minutes (Includes a 2–3-minute Q&A).
- Your punctual arrival and active involvement in each session will be highly appreciated.
- Get your presentation PPT or PDF files prepared and backed up.
- The regular oral presentation time arrangement is for reference only. In case of any absence or a presentation shorter than scheduled, please join the next presentation in the session.
- A best presentation will be selected from each session, announced and awarded a best presentation certificate.

Attention

- For security purposes, all participants are required to wear name badges at all sessions and social functions. Entrance into sessions is restricted to registered participants.
- For your personal and property safety, please take care of your belongings in public areas. The conference assumes no responsibility for loss of personal property.

Emergency Numbers

Medical Emergency	Police	Fire
118	112	115

▶Guideline

For Online Participants

Time Zone

- Italy standard time: UTC/GMT+1

Platform: ZOOM

- For general users, Zoom Download: https://zoom.us/
- For authors in China, Zoom Download: https://zoom.com.cn/download
- Password for all online rooms: **ICSRS2026**
- Please unmute your audio and start your video during your presentation.
- Use a headset with microphone, or an earphone with microphone.

Set up your Name

- Authors: Paper ID-Name, e.g. R7001-Jimmy Smith
- Delegate: Delegate-Name, e.g. Delegate-Jimmy Smith
- Plenary Speaker: Plenary-Name, e.g. Plenary-Jimmy Smith
- Session Keynote Lecturer: Session Keynote-Name, e.g. Session Keynote-Jimmy Smith
- Committee Member: Committee-Name, e.g. Committee-Jimmy Smith

Conference Recording

- The online sessions will be recorded. We appreciate your proper behaviour and appearance.

Conference Photo Album

Conference Agenda

►Conference Schedule Overview

November 23, 2026 / UTC/GMT+1

Time	Schedule	Venue
10:00-17:00	**Onsite Activities**	Lobby | NHOW Roma Add: Corso d'Italia 1, 00198 Roma
	Registration & Sign-in & Collecting Materials	
19:00-20:00	Dinner	F&B Area
14:00-16:00	**Online Activities (Zoom)**	Room A: https://us02web.zoom.us/j/87254995655 Password: ICSRS2026
	Online Session Keynote Lecturers & Online Session Chairs Test	
	Online Paper Presentation Test R7040, R7177, R7250, R7204, R7247, R7057, R7233, R7104, R7173, RS004, R7065, R7122, R7124, R7241, R7159, R7223, R7131, R7199, R7106, R7023, R7062, R7206, R7060, R7157, R7244, R7220, R7064, R7175, R7083, R7120-A, R7170, RS002, R7168, R7246, R7097, R7221, R7196	

November 24, 2026 / UTC/GMT+1

Time	Arrangement	Venue
8:00-9:00	Onsite Conference Sign-in	Lobby
9:00-9:10	**Opening Ceremony** Enrico Zio, Mines Paris, PSL University, France & Politecnico di Milano, Italy	TINTORETTO – RAFFAELLO
9:10-9:50	**Plenary Speaker I** Michael Pecht, University of Maryland, USA -- Speech Title: Why are So Many Lithium-ion Batteries Catching Fire? The Reliability and Safety-related Challenges of Using and Re-Using Lithium-ion Batteries	TINTORETTO – RAFFAELLO
9:50-10:30	**Plenary Speaker II** Michael Beer, Leibniz Universität Hannover, Germany -- Speech Title: Efficient Complex Systems Reliability Analysis	TINTORETTO – RAFFAELLO
10:30-11:00	***Coffee Break***	
11:00-11:40	**Plenary Speaker III** Luca Podofillini, Paul Scherrer Institute, Switzerland -- Speech Title: “When it rains, it pours”: novel challenges for Human Reliability Analysis	TINTORETTO – RAFFAELLO
11:40-12:00	**Plenary Conclusion** Enrico Zio, Mines Paris, PSL University, France & Politecnico di Milano, Italy	TINTORETTO – RAFFAELLO
12:00-13:30	***Lunch Break***	***F&B Area***
Onsite Session Keynote Lectures & Author Presentations		**Room**
13:30-15:50	**Session 1 - Reliability Engineering** Session Chair & Session Keynote Lecturer: Hon Keung Tony Ng, Bentley University, USA R7036-A, R7076-A, R7150, R7080-A, R7121, R7153, R7209, R7197	TINTORETTO
13:30-15:50	**Session 2 - Reliability in Critical Infrastructures and Transportation Systems** Session Chair & Session Keynote Lecturer: Alba Sofi, University "Mediterranea" of Reggio Calabria, Italy R7055, R7072, R7118, R7123, R7125, R7205, R7096, R7171	RAFFAELLO

Time	Arrangement	Venue
13:30-15:35	**Session 3 - Agentic Artificial Intelligence and Large Language Models for Reliability and Safety** Session Chair: Dario Valcamonico, Politecnico di Milano, Italy Session Keynote Lecturer: Jeroen Boydens, KU Leuven, Belgium R7255, R7059, R7074, R7151, R7082, RS003, R7084	TIZIANO
13:30-15:50	**Session 4 - Prognostics and System Health Management (I)** Session Chair & Session Keynote Lecturer: Fabio Postiglione, University of Salerno, Italy R7256, R7138, R7191, R7029, R7051, R7053, R7066, R7112	BOTTICELLI
13:30-15:20	**Session 5 - System-Theoretic Safety Analysis (STPA) and Resilience** Session Chair & Session Keynote Lecturer: Yuantao Yao, Politecnico di Milano, Italy (RS001) R7058, R7037, R7041-A, R7099, R7049, R7015	MASCAGNI
15:50-16:00	***Coffee Break***	
16:00-18:35	**Session 6 - Balancing AI-Driven Safety and AI-Induced Risks in Integrated Nuclear Systems** Session Chair: Ruixue Li, University of Maryland, United States Session Keynote Lecturer: Xi-Wei Wang, City University of Hong Kong, Hong Kong R7249, R7239, R7248, R7098, R7116, R7200, R7203, R7179, R7092	TINTORETTO
16:00-18:35	**Session 7 - Belief Reliability for Complex Systems: Uncertainty Management and Safety Assurance; Trustworthy Agentic Intelligence for PHM-Oriented Industrial Reliability and Safety** Session Chair: Xiaoyang Li, Beihang University, China Session Keynote Lecturer: Sylwia Werbinska-Wojciechowska, Wroclaw University of Science and Technology, Poland R7108, R7143, R7100, R7238, R7140, R7127, R7254, R7133, R7194	RAFFAELLO
16:00-18:50	**Session 8 - Artificial Intelligence for Reliability and Safety** Session Chair & Session Keynote Lecturer: Elena Zaitseva, University of Zilina, Slovakia R7056, R7144, R7077, R7067, R7181, R7187-A, R7201, R7215, R7216-A, R7093	TIZIANO

Time	Arrangement	Venue
16:00-18:35	**Session 9 - Industrial Reliability Analysis and Optimization under Limited Data** Session Chair: Cheng Liu, City University of Hong Kong, China Session Keynote Lecturer: He Li, Liverpool John Moores University, UK R7211, R7164-A, R7161-A, R7183, R7184-A, R7222-A, R7180, R7234-A, R7198-A	BOTTICELLI
16:00-18:20	**Session 10 - Safety Analysis (I)** Session Chair: Jeroen Boydens, KU Leuven, Belgium Session Keynote Lecturer: Yanhua Zou, Wuxi University, China R7028, R7141, R7208, R7073, R7069, R7039, R7052, R7232	MASCAGNI
19:20-21:00	***Dinner***	***F&B Area***

November 25, 2026 / UTC/GMT+1

Onsite Session Keynote Lectures & Author Presentations		Room
9:00-11:10	**Session 11 - AI-Augmented Predictive Maintenance for Complex Industrial Systems** Session Chair: Bin Wang, Politecnico di Milano, Italy Session Keynote Lecturer: Umberto Alibrandi, National University of Singapore, Singapore (R7252) & Bin Wang, Politecnico di Milano, Italy (R7235) R7090, R7147, R7091, R7213, R7245, R7257	TINTORETTO
9:00-11:20	**Session 12 - System Reliability** Session Chair & Session Keynote Lecturer: Qingyuan Zhang, Hangzhou International Innovation Institute of Beihang University, China R7207, R7042-A, R7086, R7128, R7154-A, R7188, R7240, R7045	RAFFAELLO
9:00-10:50	**Session 13 - Maintenance** Session Chair: Yiliu Liu, Norwegian University of Science and Technology, Norway; Masoud Naseri, UiT The Arctic University of Tromsø, Norway Session Keynote Lecturer: Masoud Naseri, UiT The Arctic University of Tromsø, Norway R7050, R7054, R7063, R7033, R7167, R7258	TIZIANO

9:00-10:35	**Session 14 - Prognostics and System Health Management (II)** Session Chair: Hao Rong, Liverpool John Moores University, UK ; Matteo Davide Lorenzo Dalla Vedova, Politecnico di Torino, Italy Session Keynote Lecturer: Hao Rong, Liverpool John Moores University, UK R7253, R7129, R7186, R7061, R7078	BOTTICELLI
9:00-11:05	**Session 15 - Safety Analysis (II)** Session Chair & Session Keynote Lecturer: Rui He, University of Electronic Science and Technology of China, China R7020, R7126, R7135, R7237, R7145, R7142, R7148	MASCAGNI
10:00-11:00	***Coffee Break***	
Online Session Keynote Lectures & Author Presentations		**Room**
Room A: https://us02web.zoom.us/j/87254995655 Room B: https://us02web.zoom.us/j/85980222934		**Password ICSRS2026**
9:00-11:50	**Online Session A - Machine Learning and Data Analysis in Reliable Engineering; Engineering Reliability Maintenance and Safety Management** Session Chair & Session Keynote Lecturer: Waichon Lio, Beihang University, China R7040, R7177, R7250, R7204, R7247, R7057, R7233, R7104, R7173, RS004, R7137	Room A
10:00-12:00	**Online Session B - AI-Augmented Predictive Maintenance for Complex Industrial Systems** Session Chair: Yasi Shen, Powerchina Zhongnan Engineering Corporation Limited, China R7065, R7122, R7124, R7241, R7159, R7223, R7131, R7199	Room B
12:05-13:30	***Break***	
13:30-16:35	**Online Session C - System Design and Modeling Based on Reliability** Session Chair & Session Keynote Lecturer: Emmanuel Fragniere, School of Management Valais-Wallis (HES-SO), Switzerland R7106, R7023, R7062, R7206, R7060, R7157, R7244, R7220, R7064, R7175, R7083	Room A
13:30-16:05	**Online Session D - Product Reliability Assessment and Management** Session Chair & Session Keynote Lecturer: Huixing Meng, Beijing Institute of Technology, China R7120-A, R7170, RS002, R7168, R7246, R7097, R7221, R7196, R7103	Room B

▶Plenary Speakers

November 24, 2026, Tuesday | UTC/GMT+1

9:10 - 9:50 | Onsite - TINTORETTO – RAFFAELLO



Michael Pecht

Distinguished Professor, University of Maryland; Director,
Center for Life Cycle Engineering (CALCE), USA

Bio: Prof. Michael Pecht (74,000+ citations, 120+ H-Index) has a BS in Physics, an MS in Electrical Engineering and an MS and PhD in Engineering Mechanics from the University of Wisconsin. He is a Professional Engineer, an IEEE Fellow, a PHM Society Life Fellow, an ASME Fellow, an ASM Fellow, an SAE Fellow and an IMAPS Fellow. He served as Editor-in-Chief of Elsevier ePrime Journal for four years, IEEE Access for six years, IEEE Transactions on Reliability for nine years, Microelectronics Reliability for sixteen years, and Circuit World. He served on three U.S. National Academy of Science studies, two US Congressional investigations in automotive safety, and as an expert to the U.S. FDA. He is the Director of CALCE at the University of Maryland, funded by over 150 of the world leading electronics companies at more than US$6M/year. He has written more than thirty books on product reliability, development, use and supply chain management, and over 1000 technical articles with 13 patents.

Speech Title: ***Why are So Many Lithium-ion Batteries Catching Fire? The Reliability and Safety-related Challenges of Using and Re-Using Lithium-ion Batteries***

Abstract: Li-ion batteries are commercially successful power sources for a diverse range of applications, including EVs, energy storage systems, and consumer products. However, the characteristics of Li-ion batteries make them susceptible to both swelling and thermal runaway, resulting in failed products, and with surprising frequency in fires and explosions. In most cases, defects in lithium batteries are not detected prior to use. For example, GM, Chrysler, Hyundai and Stellantis had to recall their EVs due to defects in their batteries that resulted in reliability issues and, in many cases, fires. In addition, there have been numerous battery fires in e-bikes, computers, smartphones and vaping devices. In other cases, companies manufacture batteries with inadequate safety features or misrepresent the true nature of their battery by re-using, re-wrapping or counterfeiting batteries. This talk reviews the reliability and safety issues and mitigation strategies for Li-ion batteries, as well as challenges with their re-use and disposal.

▶Plenary Speakers

November 24, 2026, Tuesday | UTC/GMT+1

9:50 - 10:30 | Onsite - TINTORETTO – RAFFAELLO



Michael Beer

Professor and Head, Institute for Risk and Reliability,

Leibniz Universität Hannover, Germany

Bio: Michael Beer is Professor and Head of the Institute for Risk and Reliability, Leibniz Universität Hannover, Germany. He is also part-time Professor at the University of Liverpool and guest Professor at Tongji University and Beijing University of Science and Technology, China. He obtained a doctoral degree from Technical University Dresden, Germany, and worked for Rice University, National University of Singapore, and the University of Liverpool, UK. Dr. Beer research is focused on uncertainty quantification in engineering with emphasis on imprecise probabilities. He is Editor-in-Chief of the ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems (Part A and Part B) and of the Encyclopedia of Earthquake Engineering, and past Chairman of the European Safety and Reliability Association (ESRA). He is President-elect of IASSAR for 2027-2031 and a Fellow of the Alexander von Humboldt-Foundation.

Speech Title: ***Efficient Complex Systems Reliability Analysis***

Abstract: Engineered systems are most important for our daily life, they are the technical backbone of our society. A key requirement is, thus, to ensure their reliable performance. Reliability and performance analysis, however, become increasingly complicated due to uncertainties and complexity. This challenge needs to be addressed by a powerful modeling and analysis technology, which is able to deliver high-quality results quickly and to capture uncertainties comprehensively and realistically. The concept of survival signature provides a technology to summarize the systems availability in a condensed, statistical manner exploiting exchangeability of components of the same type. The systems reliability can then be formulated as a conditional probability, given that a certain number of components are still working, multiplied by the probability that this condition holds, which is controlled by the lifetime distributions of the components. Hence, the analysis of the system, to determine the conditional probability, is separated from the sampling on the lifetime distributions. The condensed systems representation, the survival signature, is used as a surrogate in the sampling approach, making it highly flexible and efficient. However, the determination of the survival signature remains as a combinatorial challenge with limitation to binary state components and systems.

▶Plenary Speakers

November 24, 2026, Tuesday | UTC/GMT+1

11:00 - 11:40 | Onsite - TINTORETTO – RAFFAELLO



Luca Podofillini

Paul Scherrer Institute, Switzerland

Bio: Luca Podofillini has a Nuclear Engineering degree and a Ph.D. in Nuclear Engineering from the Polytechnic of Milan (2004). His current activities include Human Reliability Analysis research and regulatory support tasks for the Swiss Federal Nuclear Safety Inspectorate. His research addresses the development of quantitative models of human performance in industrial systems, with focus on errors in decision-making, dynamic safety assessment and the collection of data in simulated emergencies. He is co-author of about 30 publications in peer-reviewed international scientific journals. In September 2010 he participated in an IAEA mission as member of the International Probabilistic Safety Assessment Review Team (IPSART). He is Chair of the ESRA Technical Committee for Human Factors in Safety and Reliability and member of the Board of the Human Reliability Analysis (HRA) Society.

Speech Title: ***"When it rains, it pours": novel challenges for Human Reliability Analysis***

Abstract: Human Reliability Analysis (HRA) has evolved over the past decades, reflecting advances in human–system interaction concepts and technologies, developments in cognitive science, and the changing needs of risk and safety assessment. The growing role of automation and AI is changing the nature of human–machine interactions relevant to safety analysis, placing greater emphasis on supervisory roles rather than direct, immediate interventions during accidents. Coping with automation failures, maintaining situation awareness, and sustaining vigilance are among the concerns consistently raised regarding human performance in future technological systems. Addressing these issues is testing the limits of HRA and reinforcing the need to tackle longstanding challenges, including the treatment of decision failures, data scarcity, dependence, and stronger integration with cognitive science. The presentation will highlight recent research efforts aimed at advancing HRA in these areas. The aim is to stimulate discussion on how HRA should adapt to evolving human–automation and human–AI interactions. Key questions concern the identification of new failure modes, the role of trust and automation transparency, and the empirical and theoretical foundations needed to assess the reliability of human–AI teams.

►Session Keynote Lecturers



Alba Sofi

University "Mediterranea" of Reggio Calabria, Italy



Sylwia Werbinska-Wojciechowska

Wroclaw University of Science and Technology, Poland



Jeroen Boydens

KU Leuven, Belgium



Yuantao Yao

Politecnico di Milano, Italy



Hon Keung Tony Ng

Bentley University, USA



Fabio Postiglione

DIEM, University of Salerno, Italy



Rui He

University of Electronic Science and Technology of China, China



Elena Zaitseva

University of Zilina, Slovakia



Yanhua Zou

Wuxi University, China



Masoud Naseri

University of Tromsø, Norway



Huixing Meng

Beijing Institute of Technology, China



Qingyuan Zhang

Hangzhou International Innovation Institute of Beihang University, China



Umberto Alibrandi

National University of Singapore, Singapore



Emmanuel Fragnière

School of Management Valais-Wallis (HES-SO), Switzerland



Xi-Wei Wang

City University of Hong Kong, Hong Kong



Bin Wang

Politecnico di Milano, Italy



Waichon Lio

Beihang University, China



He Li

Liverpool John Moores University, UK



Hao Rong

Liverpool John Moores University, UK

►Session 1

► Reliability Engineering

► Session Chair: Hon Keung Tony Ng, Bentley University, USA

► 13:30-15:50 | November 24, 2026, Tuesday | TINTORETTO

► R7036-A, R7076-A, R7150, R7080-A, R7121, R7153, R7209, R7197



Session Keynote Lecturer 13:30-13:50

Hon Keung Tony Ng, Bentley University, USA

Speech Title: Reliability Analysis of One-shot Devices with Manufacturing Defects

Abstract: In this talk, we discuss the challenging issues that reliability practitioners face in conducting destructive tests for one-shot devices, especially in estimating the defect rate of products. The working condition of a one-shot device is unknown until testing the device. We consider one-shot device test data with defects induced in a realistic manufacturing process. Manufacturers need to measure the defect rate for quality control purposes, but obtaining enough defective devices for accurate estimation is challenging when the defect rate is relatively low. Frequentist and Bayesian approaches are proposed to estimate the mean-time-to-failure and defective rate. Masked data are also considered when we cannot distinguish whether a failed device is initially defective. A Monte Carlo simulation study is conducted to evaluate the impacts of the masking effect on the estimation under different settings. Some practical guidelines and recommendations are provided.

R7036-A 13:50-14:05	The Development of the High-Temperature Storage Test for Motor Oil Cooler Gaskets Using Customer Data **Author(s):** Kyungwook Baek **Presenter:** Kyungwook Baek, Hyundai Motor Company, Seoul, Republic of Korea **Abstract:** To optimize durability, weight, and cost, durability analysis must be based on data that is sometimes difficult to acquire, especially for new technologies in electric vehicles. In this study, we used Vehicle Customer Road Monitoring (VCRM) data to analyze the durability severity of oil cooler gaskets. Thermal damage was calculated using oil temperature profiles based on Arrhenius relation. For driving conditions, we categorized the duration into several temperature ranges and determined the time periods during which the temperatures fell within each range. We applied a similar process for non-driving conditions. By combining the results, we obtained time distributions across several temperature intervals. Finally, the information on time distributions allowed us to compute thermal damage based on the well-known Arrhenius model. Several simple machine learning methods were employed to predict thermal damage under extreme climate conditions, demonstrating that the methods are also valid for higher and lower temperatures than those observed in VCRM (domestic data). Additionally, we verified that the brand-new oil cooler gasket is sufficiently robust for field usage through validation testing with 10 prototype samples.

R7076-A 14:05-14:20	A Comparative Study on the Severity of Voltage Environmental Tests Based on Major International Standards **Author(s):** Suyeon Kim, Si-il Sung, Donggeun Lee, Jiyun Baek **Presenter:** Suyeon Kim, Kyonggi University, South Korea **Abstract:** Overvoltage and ripple voltage conditions are electrical stress application methods that can be applied to power systems, and they serve as environmental test factors for ensuring the functional performance and reliability of electronic equipment. However, international and military standards such as ISO, RTCA, and MIL define different overvoltage magnitudes and durations, ripple voltage waveforms and levels, stress application methods, and acceptance criteria depending on their target applications and design purposes. Therefore, even tests with the same objective are difficult to compare in terms of severity across standards. Accordingly, this study aims to qualitatively compare the test severity of overvoltage and ripple voltage tests specified in major international and military standards. To this end, differences among the standards are summarized and presented based on test objectives, application targets, voltage conditions, duration, frequency, and waveform characteristics. In addition, the severity levels specified in each standard are organized into test profiles, and differences in voltage magnitude, duration, and waveform shape are visualized and analyzed. Through this approach, this study proposes qualitative findings that enable comparison of severity differences among standards with the same test purpose.
R7150 14:20-14:35	Accelerating Time-Censored Reliability Verification Test Plan Design via Spline Function and Projected Gradient Descent **Author(s):** Yunlei Tan, Ping Jiang, Minghao Li, Lunhao Ju **Presenter:** Yunlei Tan, National University of Defense Technology, China **Abstract:** In reliability verification testing, time-censored (Type-I censored) test plans must simultaneously satisfy the producer's risk and the consumer's risk while keeping the test duration as short as possible. Because the risk of a candidate plan is obtained by numerical integration over the prior distribution of the lifetime parameter, exhaustive grid search over the multidimensional plan space is computationally prohibitive. This paper proposes a surrogate-assisted framework that combines a cubic spline model with a projected gradient descent algorithm. A small set of numerically evaluated plans is first u sed t o fit continuous and differentiable surrogate models of the two risk surfaces as functions of the test time and the discrimination ratio. The trained surrogates then replace the expensive numerical integrator, and a projected gradient descent search locates the feasible plan with the shortest test time while the discrimination ratio is confined to a discrete grid. In a case study covering about 37,000 candidate plans, the spline surrogates achieve a coefficient of determination (R2) of 0.9959 and 0.9999 for the producer's and consumer's risk surfaces, respectively, and the proposed search returns a near-optimal plan within one second, compared with more than ten minutes required by exhaustive traversal.
R7080-A 14:35-14:50	A Comparative Study on the Severity of Random Vibration Environmental Test Standards **Author(s):** Jiyun Baek, Si-il Sung, Suyeon Kim, Donggeun Lee **Presenter:** Jiyun Baek, Kyonggi University, South Korea **Abstract:** Across various industries, products are exposed to diverse vibration environments

	during transportation and operation, which can lead to various reliability issues such as wire wear, loosening of fasteners, intermittent contact failure, electrical short circuits, and structural fatigue or failure. Since real- world vibration environments exhibit stochastic characteristics containing multiple frequency components simultaneously, random vibration environmental testing is widely utilized to realistically simulate these conditions. However, major random vibration testing standards exhibit variations in severity, as they apply diverse test procedures, power spectral densities (PSD), root-mean-square (RMS) values, and testing durations. Consequently, even for environmental tests sharing the same objective, discrepancies in severity exist among standards, yet research analyzing these differences remains scarce. Therefore, this study compares the procedures, objectives, and test conditions of random vibration testing across IEC 60068-2-64, ISO 16750-3, DEF STAN 00-035, RTCA DO-160G, AECTP 400, and MIL-STD- 810H. Furthermore, plotting test profiles from multiple industrial sectors on a single coordinate plane reduces visibility and complicates the comparison of severity across standards. To address this, this study categorizes the test subjects into rotary-wing aircraft, fixed-wing aircraft, ground vehicles, and onboard equipment, and visualizes the PSD profiles for each specific category to effectively compare severity across the standards. Additionally, by qualitatively analyzing the differences among major random vibration environmental testing standards, this research provides foundational data that can serve as a valuable reference for selecting test conditions and applying standards.
R7121 14:50-15:05	A Hierarchical Time-Stepped Monte Carlo Framework for Site-Level Reliability Forecasting of Gas Engine Power Plants **Author(s):** Ettore Rasca, Giovanni Brighenti, Sebastian Niedziela **Presenter:** Ettore Rasca, Ettore Rasca, INNIO, Austria **Abstract:** Data center applications require extremely high site availability, typically at or above 99.999%, which challenges the capabilities of traditional steady-state reliability methods. Such approaches cannot adequately capture engine-to-engine interactions, site and engine control logic, maintenance and service scheduling effects, environmental influences such as thermal dissipation, or the integration of heterogeneous model types within a single framework. To address this, this work presents a time-stepped Monte Carlo simulation framework with sub-minute resolution and a hierarchical state-machine architecture spanning component, engine, and site levels. The framework is primarily intended for offline pre commissioning studies to support site sizing, control strategy definition, and service planning, while its modular architecture is designed to enable future integration of digital twin models for live reliability forecasting. The method has been applied to the sizing of several large-scale sites and to the optimization of service strategies. Representative simulation results are presented to illustrate the capabilities of the framework, including engine-level distributions of availability and reliability, site-level demand availability, engine state trajectories, and failure mode classification. A sensitivity analysis is also included to demonstrate how fleet size influences site demand availability, illustrating the framework's utility for site sizing and redundancy evaluation.
R7153 15:05-15:20	Comparison of Bayesian Markov chain Monte Carlo models for zero-inflated failure data **Author(s):** G Harish Kaushik, Sampsa Pursiainen, Jaakko Peltonen **Presenter:** G Harish Kaushik, Tampere University, Finland

	Abstract: Reliability and Probabilistic Risk / Safety Assessment (PRA / PSA) of components in complex infrastructure systems is a major concern in disciplines including nuclear safety and civil engineering. In nuclear power plants a prominent modeling strategy, Bayes-Empirical-Bayes (BEB), models failures arising from a mixture of two Poisson processes. However, real-world failure count data is expected to suffer from zero-inflation and alternative models modeling the inflation have been suggested. In this work we study a Markov Chain Monte Carlo (MCMC) implementation of BEB and propose two zero-inflated variants -- Zero-Inflated Negative Binomial (ZINB) and Hurdle Negative Binomial (HNB). We characterise their ability to recover ground truth component failure rates and zero-inflation rates in a comprehensive controlled setting.
R7209 15:20-15:35	Modeling of Stress Relaxation for Compliant Contact Springs in Electrical Connectors **Author(s):** Chao Zhang, Hongcheng Chen, Sheng Le, Wanbin Ren **Presenter:** Chao Zhang, Harbin Institute of Technology, China **Abstract:** In this work, the stress relaxation behavior of compliant contact springs in electrical connectors were investigated experimentally using a self-designed test rig. A series of tests were conducted under different combinations of insertion depth, initial contact force, and environment temperature. A surrogate model considering mechanical assembly condition and a degradation model coupling insertion depth and environment temperature were established. The contact force surrogate model achieved an RMSE of 0.0169 N, while the degradation model yielded an average relative deviation of 6.32% under three additional validation conditions.
R7197 15:35-15:50	Influence of Crimp Geometry on the Electrical and Mechanical Reliability of Automotive Crimped Connections **Author(s):** Paula-Stefana Ferenczi, Florin Dragomir, Ildikó Péter **Presenter:** Paula Stefana Ferenczi, UMFST, Târgu Mureș, Romania **Abstract:** The electromechanical integrity of crimped connections is a critical determinant of long-term reliability in automotive wiring systems, yet the influence of anvil geometry on this integrity remains insufficiently characterized in the literature. This study quantifies the effect of anvil geometry (Standard, Radius and Flat) on the electrical contact resistance of automotive crimped connections, evaluated according to SAE/USCAR-21. A dataset comprising 25 test samples and 3 welded deduct samples per configuration was analyzed by boxplot comparison, graphical summary, individual-moving range (I-MR) process-stability assessment, tests of equal variances, variance-robust analysis of means (Welch ANOVA, Kruskal-Wallis and Games-Howell comparisons), and a comparison of standard deviations. Because variances differed significantly among geometries, the means were compared with variance-robust methods, which indicated a significant effect of anvil geometry on the mean deduct-corrected contact resistance: 0.189 milliohm for Flat, 0.231 milliohm for Radius and 0.273 milliohm for Standard. The effect on variability was also highly significant: the Flat geometry exhibited the lowest dispersion, and the standard deviation of Standard exceeded that of Flat by a factor of approximately 2.9. These findings indicate that anvil geometry governs both the level and the stability and repeatability of the electrical response, with direct implications for risk-based conformance assessment and process-capability evaluation in automotive crimped-connection manufacturing.

►Session 2

► Reliability in Critical Infrastructures and Transportation Systems

► Session Chair: Alba Sofi, University "Mediterranea" of Reggio Calabria, Italy

► 13:30-15:50 | November 24, 2026, Tuesday | RAFFAELLO

► R7055, R7072, R7118, R7123, R7125, R7205, R7096, R7171



Session Keynote Lecturer 13:30-13:50

Alba Sofi, University "Mediterranea" of Reggio Calabria, Italy

Speech Title: Reliability Sensitivity Analysis of Structures Subjected to Imprecise Stochastic Excitation

Abstract: Uncertainties affecting structural parameters and environmental excitations, such as earthquakes, sea waves, and gusty winds, play a crucial role in structural safety assessment. The well-established stochastic process model can capture the inherent randomness of environmental excitations. Epistemic uncertainties arising from the complexity of the underlying natural phenomena, measurement errors, limited or missing data, etc., can be effectively considered using the imprecise stochastic process model. The main purpose of this study is to perform reliability sensitivity analysis of seismically excited structures with respect to structural and loading parameters. Focusing on structures subjected to seismic excitation modelled as a zero-mean stationary Gaussian imprecise stochastic process, structural safety assessment is addressed within the framework of the first-passage theory by evaluating the reliability function for the extreme value response process of interest. By applying Vanmarcke's failure criterion, the reliability function is approximated by an explicit function of the first three spectral moments of the response process. Then, explicit analytical expressions of the sensitivities of the reliability function with respect to selected structural properties and the main parameters characterizing the power spectral density (PSD) function of the imprecise seismic excitation are derived by direct differentiation. Notably, the evaluation of reliability sensitivities involves the sensitivities of the first three spectral moments of the response process, which can be derived by direct differentiation as well. The proposed analytical expressions of reliability sensitivities may be useful for design sensitivity analysis of structures, as they allow a straightforward identification of the most influential parameters on the selected performance measure. Furthermore, these expressions can be effectively employed in reliability-based design optimization of structures subjected to imprecise seismic excitation. Numerical results are presented to investigate the relative importance of structural and loading parameters on the safety level of a frame structure controlled by external fractional viscoelastic dampers under seismic excitation.

R7055 13:50-14:05	A Pipeline for the Systematic Development of Hybrid Models: A Case Study of a Rubber-Metal Spring for Railway Applications **Author(s):** Jill Mercedes Linneweber, Nishant Bhardwaj, Meike Wohlleben, Walter Sextro, Rolf Naumann **Presenter:** Jill Mercedes Linneweber, University Paderborn, Germany **Abstract:** Accurate and reliable system models are a fundamental prerequisite for the analysis,

	design, and safety assessment of technical systems. In railway vehicle simulations, the quality of component models directly affects the credibility of system-level results and the reliability of subsequent engineering decisions. This is particularly relevant for components with nonlinear behaviour, where model simplifications may introduce uncertainties and inaccuracies into the predicted dynamic response. Hybrid modelling has emerged as a promising approach to improve model fidelity by combining physics-based simulation models with data-driven machine learning models. Hybrid models are increasingly being used in practice, but their development often depends on domain-specific expertise, in either physical modelling or data-driven methods and there is a lack of standardized and systematic methods. This limits transparency, transferability, and systematic validation, which are essential aspects in reliability- and safety-oriented engineering contexts. This paper proposes a structured hybrid modelling pipeline that standardizes and systematizes the development process of hybrid models. The pipeline starts with a system analysis to identify the available physical knowledge, relevant submodels, and modelling uncertainties. Based on this analysis, a suitable coupling strategy between physics-based and data-driven model components is selected. Machine learning elements are then integrated in a targeted manner to represent effects that are difficult to describe analytically, followed by a structured validation process to assess model accuracy and consistency. By providing a higher-level methodological framework, the approach enables a balanced integration of physics-based and data-driven elements, independent of the developer's primary modelling background.The proposed approach is demonstrated using a rubber-metal spring applied in railway vehicles. The hybrid model is implemented in the SIMPACK multibody simulation environment. The case study illustrates how the pipeline supports a transparent and reproducible integration of hybrid models into system-level simulations. The results highlight the potential of hybrid modelling to improve model accuracy and reduce representation errors for complex nonlinear components. By providing a systematic development procedure, the framework contributes to more reliable simulation models and supports future reliability-oriented system assessments.
R7072 14:05-14:20	Optimal SFC Throughput Distribution across Parallel Paths to Minimize the Cost to Comply with an SLA **Author(s):** Yasmany Prieto, Yaime Fernández, Yarelis Prieto **Presenter:** Yasmany Prieto Hernández, Universidad Católica de la Santísima Concepción, Chile **Abstract:** A Service-Level Agreement (SLA) is a contract between service providers and clients that specifies the expected Quality-of-Service (QoS), availability requirements, billing terms, and compensation for service failures. The providers face a trade-off between meeting expected QoS requirements and maximizing profit with limited network resources. In this work, we propose a method to optimally allocate resources within a Service Function Chain (SFC) to deliver a service that meets an SLA. We implement the SFC as multiple sub-SFCs operating in parallel, each carrying a fraction of the service's required throughput. We calculate the throughput distribution per sub-SFC by solving a Mixed Integer Linear Programming problem that minimizes the financial costs a service provider faces to comply with its SLA and implement the SFC. We evaluated our method for an SLA with three QoS intervals: high, medium, and low. Each interval corresponds to the delivered throughput, which can degrade due to sub-SFC failures. Results show that optimally

	distributing the service's provisioned throughput reduces average SLA compliance costs. Moreover, provisioning throughput beyond SLA requirements can reduce further SLA compliance costs. We compared our method using different levels of provisioned throughput with active/standby redundancy. Our method achieved lower average SLA costs while using fewer network resources.
R7118 14:20-14:35	Bet Prediction Selection for High-Cost Dynamic Optimization: A Controlled Empirical Benchmark in Non-Stationary Environments **Author(s):** Kerem Aytac, Omer Korcak **Presenter:** Kerem Aytac, Priva B.V., The Netherlands **Abstract:** Expensive objective-function evaluations can substantially limit the applicability of evolutionary algorithms in non-stationary optimization environments. In previous work, we introduced Bet Prediction Selection (BPS), a game-theoretic selection mechanism designed to reduce evaluation overhead through adaptive early withdrawal in static NP-hard domains. This study investigates the behavior of BPS in dynamic and computationally expensive settings using a simplified, controlled workforce-assignment benchmark designed to isolate adaptation and evaluation-efficiency characteristics. BPS is evaluated under a static baseline, step-wise environmental changes, smooth sinusoidal drift, and a non-linear heavy-penalty regime with simulated evaluation latency. It is compared with Elite, Tournament, Roulette Wheel, Random, and a static 50% Fixed Cutoff strategy. Both iteration-based and fixed gene-evaluation-budget experiments are conducted, with the latter using a primary budget of 50 million gene evaluations. Results show that BPS achieves internal evaluation-pruning rates exceeding 50% in several standard and dynamic regimes while obtaining lower solution costs than Elite selection under smooth environmental drift. The resulting evaluation savings also enable BPS to execute more evolutionary generations under fixed evaluation budgets. However, the HeavyPenalty regime reveals an important limitation, where lateemerging non-linear penalties reduce pruning effectiveness and degrade solution quality. Overall, the results indicate that adaptive game-theoretic withdrawal can improve evaluation efficiency and dynamic search performance, although its effectiveness depends on the structure of the fitness landscape.
R7123 14:35-14:50	Availability Challenges due to Faults Affecting FinFET Implemented RO-Based PUFs **Author(s):** Marco Grossi, Martin Omana, Cecilia Metra and Andrea Acquaviva **Presenter:** Marco Grossi, University of Bologna, Italy **Abstract:** Physical Unclonable Functions (PUFs) are frequently adopted in a wide variety of application fields to verify the identity of a user's access device before granting its access to a given resource. In this paper, considering the case of a standard ring oscillator (RO)-based PUF implemented by FinFET technology, we analyze the impact of likely FinFET faults on the PUF ability to authenticate correctly legal users, thus guaranteeing resource's availability. We will show that FinFET faults result in a variation up to 100% of the oscillation frequency of the RO containing the faulty transistor. Therefore, the probability of erroneous bits in the PUF response can increase by 54% with respect to the fault-free case, with consequent risks for resource's availability. Therefore, our analysis highlights the need of solutions to avoid that FinFET faults may compromise RO-based PUFs' ability to authenticate legitimate users. A solution of this kind is also

	introduced
R7125 14:50-15:05	How Field Events Are Impacting Oil&Gas Product Development **Author(s):** Gianni Mochi, Susanna Morelli **Presenter:** Susanna Morelli, Baker Hughes, Italy **Abstract:** In the entire life of the equipment the relevant fleet of similar machines can show problems or reliability relevant events so that product management will be to some extent impacted. Sometime the problems are generated by exogenous causes sometime by weakness, but the problems should be considered in any case and carefully processed to improve product reliability and robustness. The modern original equipment manufacturers are organized to manage site data collection and to investigate fleet events. In this paper the authors will summarize how the data flows into the product management system and how the events are later used to trigger improvements.
R7205 15:05-15:20	Reliability Modeling and Robustness Evaluation of Parallel Training Strategies via Resource-Layered Execution DAGs **Author(s):** Weijie Hong, Xiaochun Zhang, Linhao Zhuo, Xiao He, Chengxun Chen, Qingfeng Tong, Minghao Chen, Lei Jia **Presenter:** Qingfeng Tong, University of Electronic Science and Technology of China, China **Abstract:** Selecting a parallelization strategy for large-model training requires more than comparing peak memory, bandwidth, mean iteration time, or the longest profiled operators. These summaries omit temporal dependencies and do not show whether a duration perturbation propagates to the iteration makespan. We model an execution as a resource-layered directed acyclic graph (DAG) and define dimensionless finite-difference elasticity as the relative makespan response to a relative perturbation of a node or resource lane. Elasticities are computed through repeated replay of a resource-constrained FIFO list scheduler, and a controlled Monte Carlo layer reports makespan dispersion and tail amplification under explicit assumptions. Experiments cover ten Qwen3 parallel configurations on one 8-NPU Ascend server. Synthetic tests verify expected implementation behavior in the tested cases. On reconstructed real DAGs, HTA-style active-chain resource shares and normalized slowdown-elasticity shares agree within numerical tolerance in eight of thirteen cases; the five nonzero total-variation distances range from 2.07 to 10.55 percentage points. Across the evaluated windows, the model distinguishes launch-path-dominated forward execution from HCCL-sensitive data-parallel synchronization phases. Same-source replay reproduces four profiled executions within 5%. Leave-one-configuration-out clean-time correction yields absolute errors below 0.5% for the two data-parallel cases, but 34.19% for the PP-heavy case and 94.96% for the TP-heavy case; therefore, general absolute-time accuracy is not claimed. Interleaved clean measurements provide the principal external validation, with the overlap-aware model achieving Kendall =0.956 and Spearman =0.988 for strategy ordering. The framework can serve as a model-based tool for bottleneck diagnosis, optimization prioritization, and strategy ranking.
R7096 15:20-15:35	Soil-structure Interaction Affected by Artificial Water Recharge: A Data-Driven Scheme **Author(s):** Giovanni Franco Crosta

	Presenter: Giovanni Franco Crosta, University of Milan-Bicocca and Bibliotece Quadrelli-Crosta, Italy **Abstract:** This work is an attempt at understanding soil- structure interaction mediated by ground-water flow, from data which have been collected for the past 9 years. The case study was motivated by two phenomena observed late in 2015: a) onset of sub-millimetre fissures in the walls of a corner room on the 1st floor of a building; b) injection of water ("artificial recharge") under the building foundations through a well-intended solely for the seepage of rain-water, excavated a few metres away from the corner pile. Artificial recharge was suspected to alter "soil- structure interaction" and cause fissures. Investigation had to rely solely on observation i.e., on collection of data, hence the "data-driven" feature of the research Programme. The Site where the building is located is characterised by its physical properties (SECT. II). Two hydraulic plants at the Site are described (SECT. III). Programme Management (ISO 21503:2022) provides the main methodological framework (SECT. IV); PÉSTEL analysis is summarised. The account continues with SECTNS. V to VII: they describe the chain of Projects (ISO 21502:2020) belonging to the Programme, where a Deliverable or an Output (≡ Result) by a Project becomes a Resource (≡ Method, Material) for the next one. SECT. VIII is devoted to the main Outcome by the whole Programme: the hydro-geological and structure- mechanical interpretation of a runaway accident occurred to a hydraulic plant; the accident caused upconing at a well ≃ 35m away from the injection well and fissure response. SECT. IX discusses the accident by relating fissure dynamics to recharge-drainage cyclic uplift. SECT. X provides recently acquired evidence of structure evolution. SECT. XI concludes by emphasising the need to understand process interaction and by summarising Lessons learned.
R7171 15:35-15:50	Subset Simulation for the Resilience Analysis of Critical Energy Infrastructures Exposed to Extreme Natural Hazards **Author(s):** Santiago Taguado Menza, Francesco Di Maio, Enrico Zio **Presenter:** Santiago Taguado Menza, Politecnico Di Milano, Italy **Abstract:** We apply Subset Simulation (SS) to analyze the resilience of interdependent Critical Energy Infrastructures (CEIs) exposed to extreme natural hazards. A case study is shown with regards to an integrated power-and-gas network exposed to earthquakes. For the Sicilian CEI case study, SS estimates the probability of a large energy loss as 1.3×10^{-4}, in agreement with Monte Carlo (MC) simulation: SS is about eight times faster and allows mining ten times more failure scenarios with respect to MC.

►Session 3

► Agentic Artificial Intelligence and Large Language Models for Reliability and Safety

► Session Chair: Dario Valcamonico, Politecnico di Milano, Italy

► 13:30-15:35 | November 24, 2026, Tuesday | TIZIANO

► R7255, R7059, R7074, R7151, R7082, RS003, R7084



Session Keynote Lecturer 13:30-13:50

Jeroen Boydens, KU Leuven, Belgium

Speech Title: Dependable Embedded Software: Fault Tolerance, Variability and Safety-Security Co-Engineering

Abstract: Talk on current reseerach at KU Leuven, DistriNet, Bruges campus: Software-Implemented Hardware Fault Tolerance: Investigates how software-implemented redundancy can detect hardware errors and how to lower the imposed overhead, e.g. via custom RISC-V extensions. Optimizing Testing Strategies to deal with Software Variability: Researches how search-based sampling can decrease the cost and complexity to test highly variable software, while guaranteeing the quality of every individual variant. Co-Engineering Safety and Security: Aims to create a tool to address gaps in safety and security alignment, supporting the co-engineering process.

R7255 13:50-14:05	An Agentic AI Framework for Generating Failure Modes and Effects Analysis Tables **Author(s):** Dario Valcamonico, Piero Baraldi, Stefano Marchetti, Alessandro Righini, Enrico Zio **Presenter:** Dario Valcamonico, Department of Energy, Politecnico di Milano, Milan, Italy **Abstract:** Failure Mode and Effects Analysis (FMEA) is a method for supporting risk analysis in industrial systems. Its application is time-consuming, costly and strongly dependent on expert judgement. To address these challenges, this work proposes an agentic Artificial Intelligence (AI) framework for systematically generating FMEA tables. Each field of the table is generated and iteratively self-refined by dedicated triplets of AI agents. The proposed framework is applied to two safety-critical components (a hand valve and a centrifugal pump) of the water processing and supply functional group of a 1 MW Proton Exchange Membrane (PEM) electrolyzer. The results demonstrate that iterative agent refinement progressively improves the generated FMEA, increasing both the coverage of entries identified by human experts and the identification of additional safety-relevant entries that may be overlooked in manual analyses due to time and effort constraints.
R7059 14:05-14:20	Co-revAIse: A Multi-Agent Framework for Safety-Critical Development Lifecycles **Author(s):** Amel Jelidi, Amer Kajmakovic, Alexander Palmisano, Franz Sentobe, Daiana Demarcsek, Kay Römer **Presenter:** Amel Jelidi, Pro2Future GmbH, Graz University of Technology, Austria

	Abstract: Amid ever-evolving industrial automation systems, safety remains paramount through stringent regulations and standards. Industry 5.0 trends bring forth immense changes to industry, however, ranging from AI modules to distributed edge computing modules. Conversely, when such changes are implemented, safety regulations prompt manufacturers to reassess all related in-place Safety-related Control Systems (SCS). The development of such SCSs often follows a V-Model life cycle, along which multiple scrupulous processes arise, and may be revisited when an implemented change calls for reassessment and redevelopment. This work aims to examine the capabilities of emerging AI technologies to emulate and assist with time-consuming V-Model processes, alleviating some of the functional safety redevelopment costs associated with change-motivated SCS redevelopment. We therefore develop and evaluate four independent agents with dedicated safety tasks and specializations. The agents are deployed within the Co-revAIse framework in two distinct multi-agentic workflow candidates, which we assess and compare against an array of dedicated domain-specific benchmarks. The best-performing workflow, Co-revAIse-Parallel, passes official safety examination with 73.05%, yielding an Overall Safety Score of 73.88%
R7074 14:20-14:35	Reliability-Aware Legal Retrieval-Augmented Generation for Kazakh Legal Question Answering **Author(s):** Arailym Tleubayeva, Aigerim Mansurova, Zhansaya Makhambetova, Aday Shomanov **Presenter:** Arailym Tleubayeva, Astana IT University, Kazakhstan **Abstract:** Retrieval-augmented generation (RAG) can improve legal question answering by grounding responses in external legal evidence, but retrieval alone does not guarantee reliability. A system may retrieve incomplete evidence, misuse the retrieved context, or generate a fluent answer that is not fully supported by authoritative legal text. This problem is especially important for Kazakh legal question answering, where legal NLP resources are limited and morphological variation complicates retrieval and grounding. This paper investigates a post-hoc reliability layer for an unchanged Kazakh LegalRAG pipeline. The retriever, rank-fusion strategy, prompt, and generator are kept fixed; only generated answers are scored for reliability. We evaluate five post-hoc signals: three surface-level signals retrieval-score margin, embedding-based answer-context similarity, and generation consistency and two semantic signals: an LLM-based support audit and generator self-confidence. The signals are combined using interpretable logistic regression and evaluated with question-level splitting, cross-validation, calibration metrics, risk-coverage analysis, and abstention testing. Experiments are conducted on a Kazakh legal benchmark of 242 questions, including 182 answerable and 60 unanswerable questions, over 56,916 legal evidence chunks. The results show that surface-level signals are weak predictors of legal correctness, while semantic signals provide stronger discrimination. The two- signal semantic model achieves a cross-validated AUROC of 0.780 and a held-out AUROC of 0.873. Selective answering improves accuracy from 0.493 at full coverage to 0.806 at 50% coverage. However, reliability-based abstention is less effective than prompt-marker refusal for detecting fully unanswerable questions. These findings show that reliability estimation in Kazakh LegalRAG is feasible, but primarily through semantic grounding assessment rather than simple surface signals.
R7151 14:35-14:50	Towards Reliable LLM Aggregation: The MODEULAR Framework for Safe and Live Adaptive Routing in Mixture-of-Experts

	Author(s): Benjamin Joseph Spiteri, Alexiei Dingli **Presenter:** Benjamin Joseph Spiteri, University of Malta, Malta **Abstract:** Mixture-of-Experts (MoE) architectures have emerged as a critical paradigm for scaling Large Language Models (LLMs) through decoupling parameter capacity from per-token compute budgets. However, state-of-the-art MoE routing designs remain fundamentally static and closed-loop post-deployment, introducing severe reliability vulnerabilities when runtime modifications are required. Centralized under global SoftMax denominators, current frameworks suffer from severe architectural rigidity, attempting to assimilate novel external experts without computationally intensive offline retraining triggers catastrophic cold-start latencies and global probability theft, actively compromising systemic stability and established task performance. To address these operational hazards, this paper proposes the Mixture of Dynamic Experts Utilizing Live Adaptive Routing (MODEULAR) architecture, a framework engineered to ensure safe and stable dynamic MoE deployments. MODEULAR introduces a novel paradigm that structurally decouples the routing mechanism from the expert pool. By integrating an autonomous Expert Registry, acting as a critical safety ledger to authenticate security profiles and facilitate stateful execution masking, alongside a decentralized Live Adaptive Router (LAR), the framework successfully governs token activation to prevent the operational anarchy inherent in uncalibrated expert injection. By transforming parameter hot swapping into a governed administrative process, this work provides foundational roadmap for transitioning MoE systems towards continuously evolving architectures whilst maintaining strict quality control, latency predictability, and runtime reliability.
R7082 14:50-15:05	Knowledge-Graph-Guided Retrieval-Augmented LLMs for Explainable Root Cause Analysis in Automotive HiL Validation **Author(s):** Hamza Ouarrad, Mohammad Abboush, Andreas Rausch **Presenter:** Hamza Ouarrad, Technische Universität Clausthal, Germany **Abstract:** Hardware-in-the-Loop validation of automotive soft- ware systems generate large multivariate time-series recordings whose manual analysis is time-consuming and often limited to anomaly detection and fault classification rather than root- cause analysis. Although deep learning methods have shown strong performance in fault detection and classification, they usually require task-specific training or retraining when new fault locations, systems, or operating conditions are introduced. They also tend to treat localization as a classification task, without explicitly representing the spatial and functional relationships between fault locations, sensors, and downstream subsystem effects. This limits their generalizability and their usefulness for engineering root cause analysis and diagnosis. This paper proposes a knowledge-graph-guided retrieval-augmented large language model framework for RCA (root cause analysis) and fault localization in automotive HiL data. The method converts raw time-series recordings into compact diagnostic evidence, enriches this evidence with sensor-to-location and propagation knowledge, and retrieves similar historical cases to support the final reasoning step. The LLM is then used as a decision and explanation layer rather than as a direct time-series classifier, producing a ranked fault-location prediction together with an interpretable RCA explanation. The framework is evaluated on two automotive HiL case studies: an ASM gasoline engine and an electric vehicle

	system. The best-performing model achieves Top 1 accuracies of 90% and 94%, respectively, while recording- level aggregation reaches perfect file-level fault localization in the evaluated subset. These results demonstrate the potential of KG- guided RAG-LLM reasoning for explainable and generalizable HiL RCA.
RS003 15:05-15:20	From Competency Gaps to System Risk: A Data-Driven Human Reliability Framework Based on NLP Analysis of Procedures, Training Records and Incident Reports **Author(s):** Amanzhol Yelemessov, Aizhan Nazyrova, Madina Yelemessova, Tolebi Ermek **Presenter:** Amanzhol Yelemessov, Limited Liability Partnership "Tor Altai Nuclear Consulting", Astana, Kazakhstan **Abstract:** Human error remains a dominant contributor to accidents in process and energy facilities, yet established human reliability analysis methods represent workforce competency through a performance shaping factor assigned by expert judgement on a coarse ordinal scale and revised only at long intervals. As control rooms are digitalized and diagnostic work automated, the competencies that procedures demand drift away from those that training delivers, and a static factor cannot register that drift. This paper estimates the competency component of human error probability from evidence rather than judgement. Procedures, training records and incident reports are grounded in a shared competency taxonomy by a bi-encoder retriever with an ontology-constrained cross-encoder re-ranker. A bounded Competency Gap Index is computed from a criticality-weighted requirement intensity, a technological drift statistic and a coverage term discounting training by cognitive level and by retention decay since delivery. The index is mapped to a multiplicative shaping factor, propagated through the plant fault tree, and used to rank human basic events by Fussell–Vesely importance; an integer program then allocates a training budget to minimize top-event probability. On a gas-processing case study, grounding attains an F1 of 0.868, gap-conditioned probabilities rank observed task error frequencies at a Spearman coefficient of 0.79 against 0.55 for the expert-assigned factor, and exact allocation of a 480-hour budget cuts top-event probability by 46 % against 22 % for uniform allocation.
R7084 15:20-15:35	Sensor-Level Fault Diagnosis for Automotive Software Validation Using Large Language Models **Author(s):** Mohammad Abboush, Hamza Ouarrad and Andreas Rausch **Presenter:** Mohammad Abboush, TU Clausthal, Germany **Abstract:** Pre-series validation of automotive software on hardware-in-the-loop (HIL) platforms generates multivariate sensor recordings in volumes that manual review against functional safety requirements cannot sustain. Threshold-based tooling flags deviations without identifying their nature or source, whereas data-driven classifiers depend on large, labelled datasets and return opaque decisions difficult to reconcile with ISO 26262 traceability. This study investigates whether open-source instruction-tuned large language models (LLMs), supplied with a textual description of sensor behavior, can serve as data-efficient and interpretable engines for fault detection and diagnosis within the validation loop. In the proposed two-phase framework, automated requirement checking on ads PACE real-time platform first isolates recordings that violate a safety requirement; sliding signal windows are then reduced to statistical, relational, and contextual descriptors, embedded in a fixed prompt, and mapped by a 4-bit low-rank-adapted LLM to a fault location with a

	written justification. Four model families spanning two to eight billion parameters were evaluated on a gasoline-engine case study with six injected fault classes. The smallest model matched the largest at 81.6\% accuracy while a comparably sized model failed to converge, indicating that diagnostic competence under task-specific adaptation is governed by convergence rather than parameter count, and the full adapt-and-evaluate cycle fits on a single commodity accelerator.

►Session 4

► Prognostics and System Health Management (I)

► Session Chair: Fabio Postiglione, University of Salerno, Italy

► 13:30-15:50 | November 24, 2026, Tuesday | BOTTICELLI

► R7256, R7138, R7191, R7029, R7051, R7053, R7066, R7112



Session Keynote Lecturer 13:30-13:50

Fabio Postiglione, University of Salerno, Italy

Speech Title: Statistical Modeling Approaches for Fuel Cell and Battery Degradation Data

Abstract: Many technological units experience progressive degradation throughout their operational life, which may eventually result in failure. Failure is typically defined as the condition in which the degradation level exceeds a predefined threshold. Therefore, accurately characterizing and predicting the evolution of degradation over time is essential for estimating the remaining useful life of these units and supporting effective maintenance planning. This talk presents statistical methods for the analysis of degradation data from two representative electrochemical energy systems: Solid Oxide Fuel Cells (SOFCs) and batteries. First, voltage measurements collected during long-term degradation tests of SOFC stacks are analyzed. The data exhibit a smooth voltage decay over time for each individual unit, together with variability in the degradation patterns across units. An empirical polynomial random-effects regression model is adopted to separately characterize these two sources of variability. Point and interval estimates are then obtained for selected performance and reliability measures. The proposed methodology is illustrated through two real-world case studies involving long-term degradation tests of SOFC stacks. Possible extensions based on Generalized Additive Mixed Models (GAMMs) are also briefly outlined. The second part of the talk focuses on battery degradation. A degradation model based on a Wiener process with change points is introduced, and its main properties are discussed. The reliability function and the conditional distribution of future degradation increments are derived, and maximum likelihood estimation of the model parameters, including the change-point locations, is addressed. The proposed model is then applied to a real degradation data set from Lithium-ion batteries, illustrating its practical potential and the feasibility of the adopted parameter estimation procedure.

R7256 13:50-14:05	A Data-Driven Methodology for Assessing Wind Turbine Reliability under Climate Change **Author(s):** Rita Pia Fares, Luca Pinciroli, Piero Baraldi, Enrico Zio, Giovanni De Matteo, Paolo Sterle **Presenter:** Rita Pia Fares, Edison Rinnovabili S.p.A., Italy **Abstract:** While wind energy is a cornerstone of the global climate transition, the reliability of wind energy assets is threatened by climate change. Specifically, this work considers the problem of rising ambient temperatures, which increase the frequency of temperature-induced alarms, leading to frequent unplanned downtime and significant energy losses. To address this issue, we develop a

	data-driven methodology to assess the impact of temperature-induced alarms on wind turbine reliability. The proposed methodology integrates: i) time-series clustering to identify characteristic patterns in operating conditions preceding alarms, ii) time-series classification to estimate exposure to critical conditions, and iii) Bayesian Gamma–Poisson modeling to predict alarm occurrences and quantify associated uncertainty. The methodology is validated using over a decade of SCADA data from an operating wind farm. Results show that the proposed approach can identify alarm-associated operating conditions, quantify their occurrence over time, and estimate the corresponding alarm rates and predictive uncertainty.
R7138 14:05-14:20	Sensor Health Monitoring: A KNN-Based Approach for Trustworthy Industrial Applications - Preliminary Results **Author(s):** Giacomo Veneri, Gianni Mochi, Francesco Ierardi, Matteo Liverani§ **Presenter:** Giacomo Veneri, Baker Hughes, Italy **Abstract:** As industrial systems increasingly rely on Artificial Intelligence (AI) for monitoring, optimization, and regulatory compliance, the trustworthiness of sensor data becomes a critical prerequisite for reliable decision-making. Sensor degradation, fouling, bias, and intermittent failures often develop gradually and remain undetected by conventional alarm systems, silently propagating errors into analytics, digital twins, and AI models. This paper presents a Digital Twin-based framework for continuous sensor health monitoring using a similarity-based approach implemented through the K-Nearest Neighbors (KNN) algorithm. Rather than attempting to predict absolute sensor values, the proposed digital twin evaluates whether a sensor behaves consistently with historical operating conditions exhibiting similar process states. The methodology is applied to a Continuous Emission Monitoring System (CEMS) for gas turbines, leveraging process variables such as load, fuel flow, temperatures, and oxygen concentration to identify comparable operating regimes. Expected sensor behavior is derived from neighboring historical observations, enabling the detection of drift, calibration issues, increased variability, and intermittent faults without requiring labeled failure data or redundant instrumentation. Results obtained from industrial deployments demonstrate that sensor degradation can be detected weeks before traditional alarms are triggered while maintaining full explainability through inspection of neighboring operating points. By transforming sensor health into a continuously monitored indicator, the proposed approach increases confidence in AI-driven predictions, improves regulatory robustness, and provides a foundation for autonomous and agentic industrial AI systems.
R7191 14:20-14:35	Design and Testing of a Flexible Array Sensor for Well-Control Manifolds Based on Metal Magnetic Memory **Author(s):** Kaizhe Wei, JIanchun Fan, Bingcai Sun, Hongtao Zhang, Shangyu Cao **Presenter:** Kaizhe Wei, China University of Petroleum, China **Abstract:** Early damage in well-control manifolds is difficult to identify, while their complex curved surfaces hinder synchronous multipoint monitoring. To address these problems, a flexible array sensor based on the metal magnetic memory principle is designed. Two-dimensional and finite-length three-dimensional magnetic dipole models are established, and the effects of defect length, width, and depth on the magnetic-field response are analyzed by the finite-element method. Based on the results, the array channel spacing is set to 10 mm, and a 64-channel array sensor is

	fabricated on a flexible substrate. Sensor characterization and defect-detection tests show a fitted sensitivity of 11.652 mV/Gs over −40 to 40 Gs. All three adjacent channels exhibit distinct responses to the defect and high interchannel correlations. The developed sensor therefore supports synchronous multichannel acquisition of defect-related signals, and the 10 mm array spacing is feasible under the present test conditions.
R7029 14:35-14:50	Error Propagation Mechanism for Online Ohmic Resistance Estimation in Large-Capacity Batteries **Author(s):** Daren Chen, Zekai Lin, Jingwen Wei, Guangzhong Dong **Presenter:** Guangzhong Dong, Harbin Institute of Technology, China **Abstract:** Online ohmic-resistance estimation supports thermal and power-margin management in large-capacity batteries, but recursive estimators usually report point coefficients without checking whether the resistance coefficient is identifiable under the current excitation. Finite-pulse reference mismatch omitted open-circuit-voltage dynamics, voltage and current errors-in-variables effects, and recursive least-squares covariance wind-up can therefore be absorbed into the estimated resistance. This paper presents a coefficient-level error-propagation framework for online ohmic-resistance estimation. The framework converts finite-pulse resistance into an instantaneous equivalent-circuit-model resistance reference by compensating polarization and open-circuit-voltage drift. It then propagates structural bias, sensor-noise bias, and covariance uncertainty to obtain a corrected resistance estimate, a 95\% confidence interval, and an excitation-aware validity gate. Informative updates are accepted, whereas invalid updates freeze the reported estimate. Validation on 150-Ah dynamic and low-excitation profiles shows that the framework preserves baseline accuracy under informative excitation while adding calibrated uncertainty. Under weak excitation and noisy measurements, the gate suppresses unreliable updates and prevents poorly conditioned coefficients from being reported as trustworthy resistance information. These results suggest that online resistance estimation should account for conditional identifiability rather than point-estimation accuracy alone.
R7051 14:50-15:05	Design and Experimental Study of Thread Detection Device for Drilling Tools **Author(s):** Zhitong Zhang, Jianchun Fan, Hao Jiang **Presenter:** Zhitong Zhang, China University of Petroleum, China **Abstract:** The threaded connections of ultra-long drill strings in 10,000-meter ultra-deep wells are highly susceptible to fatigue damage, wear, and corrosion under complex dynamic loading conditions, ultimately leading to tool failure. To address the challenge of fatigue fractures in drill tool threads in ultra-deep wells and overcome the limitations of existing nondestructive testing (NDT) technologies like ultrasound and magnetic particle inspection in field applications, the purpose of this study was to design a portable inspection device for internal and external threads based on the metal magnetic memory (MMM) technique. The device incorporates a mechanical structure with self-centering and variable-diameter capabilities, allowing it to adapt to various thread specifications and achieve stable scanning along the thread taper surface for high-resolution magnetic signal acquisition. Laboratory tests demonstrated that the device can effectively identify defects in both internal and external thread samples, with abnormal signal locations showing good agreement with actual defects, while flaw-free signals exhibited regular fluctuations corresponding

	to the thread profile. The research confirms that the device offers strong adaptability, high inspection efficiency, and user-friendly operation, meeting the field requirement for rapid and reliable assessment of drill tool thread integrity, which is significant for ensuring drilling safety.
R7053 15:05-15:20	Identification of Suspension Parameters in Rail Vehicles for Condition Monitoring Based on System Response to Local Track Irregularity **Author(s):** Max Kelber, Osarenren Aimiyekagbon, Walter Sextro **Presenter:** Max Kelber, Paderborn University, Germany **Abstract:** In the rail industry, preventive maintenance is still widely used. Vehicles and their components are manually inspected by qualified personnel at fixed time- or mileage-based intervals. This leads to high maintenance costs due to regular operational interruptions. Moreover, visual and manual inspection cannot reveal the dynamic characteristics of these components, so that their true health condition remains unknown. At the same time, the requirements for rail vehicles regarding safety, comfort and efficiency are constantly increasing. As one measure to ensure the safety and competitiveness of the rail sector, this work introduces a parameter identification scheme for model-based condition monitoring of bogie suspension components. Conical rubber-metal springs used in the primary suspension of rail vehicles are exemplarily considered to validate the parameter identification via simulations since they exhibit a complex dynamic material behavior. This approach allows the determination of the dynamic characteristics of individual rubber-metal springs based on vertical spring displacements, which are optically measured using a wayside Digital Image Correlation (DIC) system. At a speed of approximately 10 kilometers per hour, the vehicle is excited in the vertical direction as it passes a predefined local track irregularity. Measured vertical spring displacements are compared with corresponding simulated spring displacements of a multibody simulation (MBS) model of a vehicle implemented in SIMPACK. The parameters of the rubber-metal spring models in the vertical direction are identified using a surrogate optimization algorithm. The identified parameters of the nonlinear spring model are then used to calculate the dynamic stiffness as the condition indicator, with a relative error below 1.43 %. The identified dynamic stiffness can serve as a basis for diagnosing the condition of each spring by tracking its value over successive stages of operation.
R7066 15:20-15:35	Graph-Attentional Temporal Modeling for Rare Failure Detection in Industrial Sensor Streams **Author(s):** Mehdi Faraz, Asad Ullah Khan, Tuomas Ranti, Viktoriia Shubina, Tuomas Mäkilä, Jukka Heikkonen **Presenter:** Mehdi Faraz, Department of Computing University of Turku Turku, Finland **Abstract:** Detecting rare failure precursors in highly imbalanced industrial sensor streams requires models that jointly capture inter-sensor relational structure and temporal dynamics, capabilities that purely sequential architectures do not provide. To address this, a hybrid architecture is proposed that couples an edge-attribute-augmented Graph Attention Network (GAT) encoder with a Gated Recurrent Unit (GRU), enabling simultaneous relational encoding of sensor interdependencies and temporal modeling of their evolution over the observation window. To avoid relying directly on scarce failure labels, a robust subgraph warning analysis using only pre-failure evidence and NORMAL local baselines is first constructed. This analysis decomposed warning relevance into individual sensor deviation, disrupted sensor-pair relationships, and persistence under

	pseudo-event normal calibration. Then, a systematic window-length search from 4 to 20 time steps identify 13 as the optimal context length. Evaluated under Leave-One-Out Cross-Validation across 707 test windows on an industrial dataset, GAT-GRU correctly identifies six of the seven failure precursors, achieving a recall of 85.71%, a precision of 40.00%, a PR-AUC of 0.444, and a ROC-AUC of 0.988, outperforming five competing architectures across all detection and ranking metrics. A systematic encoder depth evaluation confirms that two graph attention layers best balance relational expressiveness and generalisation. Post-hoc analysis of the learned attention coefficients identifies two dominant inter-sensor coupling pairs whose mean attention increases from normal to pre-failure windows, ranking among the strongest attention shifts in six of the seven events. These findings provide interpretable, attention- based failure signatures to support decision-making in Industrial Internet of Things predictive maintenance systems.
R7112 15:35-15:50	Condition-Aware Residual Calibration and Sequential Alarm Decisions for Bearing Monitoring **Author(s):** Shiqi Zhang, Hangwei Yu, Yajie Dou, Haiyue Yu, Minghao Li, Ping Jiang **Presenter:** Minghao Li, National University of Defense Technology, China **Abstract:** bearing monitoring is affected by both operating-condition drift and fault-related drift. A fixed healthy distribution and a single global threshold may therefore interpret benign context changes as equipment degradation when healthy calibration data are limited. This paper presents Condition-aware Calibrated GCAD (GCAD-CCS), a decision-layer extension of a GCAD-inspired predictive-residual baseline. The method separates residual evidence from condition-support information, applies condition-aware residual calibration with finite-sample shrinkage, and combines EWMA-based sequential evidence with residual-consistency confirmation. We evaluate five bearing monitoring subsets under a fixed five-seed protocol. Under matched fixed persistence, fixed GCAD-CCS shows observed modest relative improvements over the GCAD-inspired baseline on Paderborn A and B. CWRU is unchanged under the matched fixed rule, while adaptive persistence is reported only as an operating-point sensitivity. XJTU-SY and MFPT do not show uniform gains. The primary transudative evaluation of the GCAD-inspired baseline and GCAD-CCS uses unlabeled sequence-level shared-prefix normalization; prefix-free processing is treated as a sensitivity analysis. The findings therefore support a bounded relative safety–sensitivity improvement under selected shifts, not a general online solution, universal superiority, or a state-of-the art claim.

►Session 5

► System-Theoretic Safety Analysis (STPA) and Resilience

► Session Chair: Yuantao Yao, Politecnico di Milano, Italy

► 13:30-15:20 | November 24, 2026, Tuesday | MASCAGNI

► R7058, R7037, R7041-A, R7099, R7049, R7015



Session Keynote Lecturer 13:30-13:50 | RS001

Yuantao Yao, Politecnico di Milano, Italy

Speech Title: Uncertainty-Aware Dynamic Causal Graph Ensemble for Root-Cause and Propagation Analysis of Nuclear Accident Transients (RS001)

Abstract: Root-cause and propagation analysis of nuclear accident transients requires interpretable causal evidence. This paper proposes an uncertainty-aware dynamic causal graph ensemble framework for root-cause and accident propagationpath analysis under limited samples, transient variability and ensemble-based structural uncertainty. The framework constructs time-lagged causal graphs from multivariate transient signals and generates a graph ensemble through repeated data perturbation and structure learning. Based on the ensemble, edgelevel support probability, uncertainty-weighted causal activation score, node-level upstream propagation evidence and path-level propagation metrics are derived. A simulation-based nuclear accident case study concerning loss-of-flow accident and powerstep scenarios shows that the proposed framework can provide analyst-oriented causal evidence for comparing accident severities, prioritizing possible upstream variables and evaluating physically meaningful propagation paths. The method is intended to providing additional support in accident interpretation and safety analysis rather than replacing expert judgement.

R7058 13:50-14:05	Towards Continuous Resilience Infrastructures: Machine Learning Tools for Dynamic Risk Assessment and Real-Time Safety Monitoring in Complex Industrial Systems **Author(s):** Tomaso Vairo, Simone Guarino, Mariangela Pinnelli, Paolo Bragatto, Roberto Setola **Presenter:** Tomaso Vairo, Campus Bio-Medico University of Rome, Italy **Abstract:** The growing integration of Machine Learning into industrial safety management enables a shift from static, point-in-time risk assessments to continuously updated, probabilistic risk solutions. This paper presents a unified pipeline for real-time safety monitoring and dynamic risk assessment comprising three complementary components: (i) an anomaly detection dashboard based on a one-class autoencoder with Monte Carlo Dropout uncertainty quantification; (ii) a hybrid digital twin coupling a physics-based thermal model with a Bayesian particle filter for continuous parameter estimation and predictive risk forecasting; and (iii) a Bayesian-updated dynamic risk matrix that tracks multi-hazard posterior probabilities in real time. The components share a common time base, a uniform normalized risk-signal interface, and an explicit score-normalization scheme, and are composed into an integrated event-driven pipeline. At each time step, the pipeline

	outputs a single dominant risk level by selecting the component with the highest categorical risk level. Computational experiments on a unified synthetic process-plant scenario show that the integrated infrastructure can detect incipient degradation, quantify uncertainty about system parameters, and escalate actionable risk signals to operators. Results are discussed with caveats concerning the synthetic and preliminary nature of the evaluation, the distributional assumptions underlying MC-Dropout uncertainty estimates, and the behavior of percentile-based thresholds under temporal autocorrelation.
R7037 14:05-14:20	The Role of the Design for Testability as System Resilience Function **Author(s):** Carlo Vitucci, Anders Järleholm, Daniel Sundmark, Thomas Nolte **Presenter:** Carlo Vitucci, Ericsson AB, Sweden **Abstract:** Design for Testability (DFT) has traditionally been seen as a manufacturing quality metric, primarily aimed at maximizing fault coverage during production testing. Yet increasing hardware complexity makes this outlook insufficient. DFT now needs a broader perspective. It acts as a structural enabler of system resilience, influencing the entire product lifecycle, from hardware design to runtime fault management. This analysis uses a service-centric dependability model, which recognizes the value of maintaining system services in a timely manner. It applies a revised resilience triangle, a well-known quantitative resilience model, showing that reducing Mean Time To Detection is crucial to minimizing service loss. The paper defines strategic DFT principles and ties them to measurable resilience outcomes. It also describes a hardware compliance vision, an approach to ensure hardware meets reliability and testability standards. These contributions establish DFT as a structural system property rather than merely a verification activity and lay the foundation for its integration into resilience engineering for embedded systems in the Radio Access Network (RAN) domain.
R7041-A 14:20-14:35	Machine-Learning Surrogates Trained on PyPSA-Eur Synthetic Data **Author(s):** Federico Ferretti, Isabel Asensio Bermejo, Vytis Kopustinskas **Presenter:** Federico Ferretti, Joint Research Centre of the European Commission, Italy **Abstract:** Assessing the resilience of power systems against outages is a central task of transmission system operators, yet underlying security-constrained optimization studies are computationally expensive: a single contingency redispatch simulation of the full European model can take up to days to complete even on high-performance hardware, while comprehensive screening may involve thousands of scenarios–location combinations. This paper proposes a different use of open energy-system optimization models as synthetic-data sources for training machine-learning surrogates that can replace the optimization step and offer a valuable path to the development of pre-screening tools that limit the number of full contingency redispatch simulations required. We present a case study using the open sector-coupled model PyPSA-Eur, with a dataset of 328,328 contingency-victim pairs that cover, one by one, the loss of the entire generation fleet of each of the 287 European NUTS-2 zones across four seasonal regimes. A two-step surrogate detects HILP (high-impact-low-probability) pairs on unseen network zones with 0.90 accuracy. Inference takes milliseconds per pair, enabling a full continental generation-loss screen in under a second. Strict group-wise validation, identity-only baselines and cross-season transfer tests confirm that the surrogate learns transferable electrical structure. The workflow

	(network construction, feature extraction at the pre-contingency state, HPC data generation, leakage-aware validation) is generic and applicable to other prediction targets such as energy not served or congestion risk, offering system operators a practical path to near-real-time resilience pre-screening.
R7099 14:35-14:50	Simulation on Assessment of Power System Absorptive Capacity under Sequential High-Impact Physical Disruptions **Author(s):** Tetiana Biloborodova, Vadym Shkarupylo, Volodymyr Artemchuk, Amir Sanhinov, Kyrylo Vasyliev, Oleksandr Chemerys **Presenter:** Tetiana Biloborodova, Pukhov Institute for Modelling in Energy Engineering of the NASU, Ukraine **Abstract:** This study proposes a simulation-based methodology to quantify a power system's absorptive capacity under high-impact sequential, cumulative events. The methodology evaluates how the steady-state operating condition changes after each additional component deactivation and identifies the cumulative disturbance level beyond which the predefined operational acceptability criteria are no longer satisfied. The methodology is demonstrated using a pre-war model of the Electric Power System of Ukraine. Power system operating-state indicators are normalized to the intact baseline state to quantify operating-state degradation. The results show progressive degradation under cumulative component loss. The proposed methodology provides a framework for tracing power system degradation and quantifying absorptive capacity under cumulative high-impact physical disruption
R7049 14:50-15:05	Configuration-based Analysis of Overreliance in Human–Artificial Intelligence Interaction **Author(s):** Julieth Patricia Castellanos Ardila, Marjorie Pettersson **Presenter:** Julieth Patricia Castellanos Ardila, Mälardalen University, Sweden **Abstract:** Artificial Intelligence (AI) increasingly supports human decision-making, but accepting incorrect AI outputs, known as overreliance, may contribute to unsafe outcomes, particularly in high-risk systems. Existing guidance provides limited support for analyzing how human--AI interaction structures create conditions for such overreliance. This paper proposes Human--AI Configuration-based Overreliance Analysis (HACO), an STPA-grounded method that uses generic interaction configurations to represent human and AI functions, decision context, information access, decision authority, and interaction sequence. HACO treats overreliance as a control problem by identifying overreliance-related control actions (OrCAs), developing causal scenarios, and formulating safeguards. An illustrative human-approval configuration demonstrates traceability from the decision situation to safeguards, which can support the derivation of safety constraints and design requirements for human--AI systems.
R7015 15:05-15:20	Self-Erosion of Safety Barriers: Concepts, Mechanisms, and a Full-Life-Cycle Health Management Paradigm **Author(s):** Yanyan Wang, Jinqiu Hu, Yueting Hu, Mingjie Xv, Chongwen Zhu **Presenter:** Yanyan Wang, China University of Petroleum, China **Abstract:** Safety barriers may satisfy design and acceptance requirements at commissioning, yet

	their intended functions can gradually deteriorate during long-term service. To explain this time-dependent weakening process, this paper develops the concept of safety barrier self-erosion and proposes a full life cycle health management paradigm. Safety barrier self-erosion is defined as the gradual decline of intended safety functions under the combined influence of physical and technical degradation, deviations in human performance, and delays in institutional and managerial adaptation, through which latent hazard factors may eventually develop into observable hazards. The paper clarifies the conceptual boundaries and evolutionary characteristics of self-erosion, analyzes its multidimensional manifestations and four principal driving mechanisms, and establishes a closed-loop framework comprising multisource evidence acquisition, health state characterization, dynamic trend inference, intervention optimization, and verification and updating. To provide a more operational illustration, a well-control scenario is used to map key functions, including formation fluid control, early kick detection, wellhead isolation and choke and kill operations, personnel response, and management support, to corresponding evidence, health indicators, weakening signals, and intervention and verification measures. The proposed paradigm shifts barrier governance from isolated correction after failure toward continuous health state management and proactive intervention throughout design, operation, life extension, and decommissioning.

►Session 6

► Balancing AI-Driven Safety and AI-Induced Risks in Integrated Nuclear Systems

► Session Chair: Ruixue Li, University of Maryland, United States

► 16:00-18:35 | November 24, 2026, Tuesday | TINTORETTO

► R7249, R7239, R7248, R7098, R7116, R7200, R7203, R7179, R7092



Session Keynote Lecturer 16:00-16:20

Xi-Wei Wang, City University of Hong Kong, Hong Kong

Speech Title: Risk-Averse Assembly Point Planning for Nuclear Emergency Evacuation

Abstract: Current off-site evacuation planning fails to account for the high uncertainty and spatiotemporal dynamics of radiological threats. This oversight results in the selection of suboptimal or hazardous assembly points (APs), which compromise urban safety and exacerbate risk perception during severe nuclear accidents. In this study, we propose a risk-averse, dynamic AP selection framework driven by quantum-inspired multi-objective optimization to adapt to time-dependent radiological risks and uncertainties. First, multiple time-dependent gridded dose fields are used to establish time-dependent risk maps by comparing the Conditional Value-at-Risk (CVaR) of gridded dose against thresholds. Then, these maps dynamically adjust AP availability and establish a dynamic selection model to optimize the population-weighted cumulative evacuation time and radiological risk while accounting for transportation logistics as a boundary condition. Finally, an improved QNSGA-II algorithm is proposed to adapt to multi-decision problems and optimize AP selections. The framework is applied to Daya Bay Nuclear Power Plant (DBNPP), and its feasibility is validated by comparing the performance of AP selection results obtained using the fixed emergency area and the time-dependent risk map, with the framework reducing the risk and time objectives, bus waiting time, and resident waiting time.

R7249 16:20-16:35	Knowledge-Based Functional Reasoning for Cryogenic Hydrogen Pump Failure Diagnosis under Limited Failure Data **Author(s):** Ruixue Li, Katrina M. Groth **Presenter:** Ruixue Li, University of Maryland, United States **Abstract:** Cryogenic reciprocating hydrogen pumps are critical components of liquid hydrogen fueling infrastructure. However, failure diagnosis is complicated by limited verified failure evidence and coupled thermal-hydraulic processes. This paper presents a knowledge-based functional reasoning approach using Multilevel Flow Modeling (MFM). A pump-centered functional model represents liquid and vapor hydrogen transport, pumping energy conversion, pressure support, thermal interactions, and phase-change dependencies. Qualitative causal reasoning is applied to identify candidate pathways leading to reduced pump discharge pressure, illustrating how deviations propagate across interconnected functional domains. The inferred pathways are assessed against historical operational measurements to examine the consistency and

	observability of expected functional states. A selected operational interval exhibits a reduction in discharge pressure, while evidence for the predicted upstream hydraulic and phase-change mechanisms remains inconclusive. The results demonstrate how structured functional knowledge can organize interpretable failure hypotheses, guide evidence assessment, and identify diagnostic limitations under limited verified failure data.
R7239 16:35-16:50	Physics-Informed LSTM for Predicting Operator Action Consequences in Small Modular Reactors **Author(s):** Stefano Marchetti, Katrina M. Groth **Presenter:** Stefano Marchetti, University of Maryland, United States **Abstract:** Operator actions are critical for mitigating accidents in nuclear power plants. Assessing alternative actions requires predicting how their timing affects accident progression, but the computational cost of system thermal-hydraulic simulations can limit rapid consequence evaluation. This study proposes a physics-informed long short-term memory network (PI-LSTM) for predicting the consequences of operator actions. The training objective combines trajectory and action-effect losses with a local cladding energy-balance constraint. Fixed, training-derived diagonal scaling of the physical residual is additionally evaluated to improve the balance between physical regularization and predictive accuracy. An additional action-equivalence penalty is also proposed to suppress predicted differences between requests that produce equivalent simulated responses, while retaining sensitivity to actions with distinct consequences. The framework is applied to manual emergency core cooling system initiation at different times during loss of coolant accidents in a representative integral small modular reactor modeled with RELAP5-3D. Evaluation considers peak cladding temperature and inlet pressure trajectories, together with differences between matched actions in previously unseen accident scenarios. Results show that the physical constraint improves prediction accuracy, allowing the PI-LSTM to predict the effects of operator actions accurately and efficiently, enabling informed decision-making on real-time operator actions during accident scenarios.
R7248 16:50-17:05	Feature Selection and Model Explainability Under Temporal Aggregation for Cryogenic Hydrogen Pump Diagnostics **Author(s):** Rocco Cassandro, Mehdi Amiri Darehbidi, Katrina M. Groth **Presenter:** Rocco Cassandro, Rocco Cassandro, University of Maryland, United States **Abstract:** Condition monitoring of complex energy systems using multivariate, nonstationary data requires suitable temporal representations and informative features for effective diagnostics. However, features selected for predictive performance may differ from those identified by model explanation methods, raising questions about the consistency of feature relevance. This paper presents a comparative evaluation of temporal aggregation, feature selection, and explainability for health state classification of reciprocating liquid-hydrogen pumps operating in hydrogen fueling stations. Healthy, Incipient, and Degraded states are retrospectively identified for three failure modes using a Bayesian change-point detection approach. A common set of 15 physically interpretable features is evaluated across different aggregation windows of consecutive operating runs. Four conventional feature selection methods are compared using an ensemble classifier, while SHAP and LIME are employed to assess agreement between feature selection and post-hoc

	explanations. Results show that preferred window configurations vary across failure modes, achieving balanced accuracies ranging from 0.921 to 0.980. Reducing the feature set from 15 to 5 descriptors largely preserves classification performance, with an average balanced accuracy reduction as low as 0.006. SHAP and LIME identify identical top five feature sets, although their agreement with conventional feature-selection methods varies across failure modes. These findings highlight the complementary roles of predictive feature selection and model explainability in developing compact and interpretable diagnostic models.
R7098 17:05-17:20	Beyond Explainability: Why Explainable AI Alone is Insufficient for Safety Assurance of Nuclear Power Plants **Author(s):** Mengchu Song, Wenlin Wang, Guohua Wu **Presenter:** Mengchu Song, Shenzhen Technology University, China **Abstract:** Explainable artificial intelligence (XAI) has recently emerged as a promising approach to support the integration of artificial intelligence (AI) into the operation and maintenance (O\&M) of nuclear power plants (NPPs) by improving transparency for human oversight and regulatory acceptance. This paper examines whether explainability alone is sufficient to assure the safety of AI applications in NPPs, as XAI is often intended to support. Existing applications of XAI in nuclear systems are reviewed, demonstrating its potential to improve the interpretability of AI-based decisions and support human evaluation of AI outputs. However, this paper argues that explainability should not be regarded as a sufficient condition for nuclear safety assurance. Several challenges that may limit the effectiveness of XAI are identified, including technical constraints, human factors challenges, regulatory uncertainties, and cybersecurity risks associated with increased transparency. To enable the safe and reliable deployment of AI in nuclear applications, future research should move beyond explanation-centered approaches toward a multidimensional safety assurance framework that integrates XAI with human factors engineering, physics-informed intelligence, standardized validation methodologies, and cybersecurity protection.
R7116 17:20-17:35	A Hybrid CNN-LSTM-Attention Network for Bearing Health State Prediction Integrating Multi-Domain Feature Fusion **Author(s):** Jun Yang **Presenter:** Jun Yang, South China University of Technology, China **Abstract:** Epistemic uncertainty is difficult to quantify reasonably in small-sample degradation testing, while existing uncertain differential equation-based degradation models do not account for initial state uncertainty in a performance characteristic (PC). To address these issues, this paper proposes an uncertain differential equation-based degradation model with initial state uncertainty (UDEDMI). The proposed model separately characterizes the initial state uncertainty of a PC and the epistemic uncertainty arising during the degradation process. Based on the model, belief reliability and belief reliable life are further derived. Considering the characteristics of different model parameters, corresponding estimation methods are adopted for parameter estimation. Results from a simulation study and a permanent magnet brake case study demonstrate that the proposed model can reasonably estimate the deterministic degradation law and quantify epistemic uncertainty, thereby providing more reasonable reliability evaluation results.

R7200 17:35-17:50	Boundary-Informed Gaussian Process Reconstruction for Sparse Radiation Monitoring in Shielded Nuclear Environments **Author(s):** Tengjie Chen, Jipu Wang, Zhenwen Wei, Ziyang Lin, Haoyuan Song, Sijuan Chen, Ming Yang, Yong Liu, Jingting Luo **Presenter:** Tengjie Chen, Shenzhen University, China **Abstract:** To reconstruct gamma dose-rate fields in shielded nuclear environments under limited measurement availability, this paper proposes a boundary-informed Gaussian process correction framework. The point-kernel (PK) field is retained in directly visible regions. In detector-visible shadow regions, a data-driven background is constructed from neighboring illuminated boundaries and sparse observations, and zonal Gaussian process regression (GPR) is used to correct the remaining bias. To address systematic overprediction in remote shadow regions, wall-path-dependent optical-thickness attenuation is further introduced at the prior level. Results on a two-dimensional Co-60 development benchmark show that, in regions where the reference dose rate exceeds 10 mSv/h, the unclipped RMSRE decreases from 183.27% for the raw PK field to 15.53% for the core D-BSP method. Wall-path information mainly improves errors in remote low-dose shadow regions rather than providing uniform gains across the full field. The results indicate that, in physics-ML hybrid reconstruction for nuclear safety monitoring, the physical spatial structure encoded in the background field can strongly affect the extrapolation behavior of sparse GPR correction.
R7203 17:50-18:05	Neuro-Symbolic Hazard Identification for Safe Design of Autonomous Mobile Robots **Author(s):** Jing Wu **Presenter:** Jing Wu, Technical University of Denmark (DTU), Denmark **Abstract:** Large language models (LLMs) offer new opportunities for AI-assisted hazard identification in autonomous robotics, but their ungrounded reasoning may lack the structured causal relationships and traceability required for safety-critical applications. This paper proposes a neuro-symbolic approach that integrates a semantic Knowledge Graph (KG) with Function-Centric Hazard Identification Approach (F-CHIA) to ground LLM-based hazard reasoning in structured safety knowledge. F-CHIA knowledge is transformed into an RDF-based KG representing relationships between system functions, guidewords, deviations, causes, consequences, and safety requirements. The approach is evaluated using an autonomous mobile robot for inspection during the decommissioning of a nuclear research facility, comparing LLM-only hazard generation with KG-grounded reasoning and examining cross-domain knowledge transfer from an agricultural autonomous system. Within the evaluated reference set, the KG preserved 100% of the reference F-CHIA reasoning paths and achieved full traceability. While the LLM-only approach reproduced several hazards captured by the F-CHIA knowledge graph, it also identified five additional hazard themes beyond the current knowledge-based coverage, revealing opportunities for domain-specific knowledge extension. Cross-domain evaluation demonstrates that general perception-related safety knowledge can be transferred across robotic applications, while domain-specific hazards, remain undetected when absent from the KG. The findings support a hybrid architecture in which LLMs provide exploratory hazard reasoning while knowledge graphs provide structured safety knowledge, contextual grounding, and traceability. The approach demonstrates the potential of

	combining generative and symbolic AI for early-stage, auditable hazard identification in autonomous robotics.
R7179 18:05-18:20	I-131 Dispersion and Population Overlap from Hypothetical Accident Releases at Daya Bay: Effects of Meteorology and Iodine Form **Author(s):** Ziyang Lin, Tengjie Chen, Haoyuan Song, Zihan Wei, Zhenwen Wei, Sijuan Chen, Ming Yang, Yong Liu, Jingting Luo, Jipu Wang **Presenter:** Ziyang Lin, Shenzhen University, China **Abstract:** Off-site assessment after a nuclear accident needs to identify plume intensity, affected area, and the population potentially exposed. Changing winds and boundary-layer conditions alter plume transport, while iodine form influences atmospheric removal. We used CALMET-CALPUFF to simulate four hypothetical 48-h I-131 releases at the Daya Bay Nuclear Power Plant under a fixed source term. Two screened January and July 2024 meteorological episodes were paired with gaseous and particulate I-131 parameterizations. Model performance was evaluated against 49 airborne I-131 observations from the Fukushima accident, and Daya Bay concentration fields were combined with a 1-km population grid. For gaseous I-131, July produced a slightly higher maximum 1-h concentration, whereas January had a larger lower-threshold footprint. Particulate I-131 enlarged threshold-exceedance area on every modeled date at both thresholds, by up to 70.8%, while barely changing the maximum 24-h mean concentration. Plume extent and population overlap did not always identify the same emergency priorities. Within the modeled hypothetical scenarios, these findings support multi-metric, population-oriented emergency screening rather than reliance on peak concentration alone.
R7092 18:20-18:35	Commit Before Act: A Qualified Residual Ledger for AI-Assisted Evacuation Planning in a Radiological Emergency—Preventing Stale Replay and Auditing Suppressed Plans **Author(s):** Se Hoon Son, Younhee Kim **Presenter:** Younhee Kim, Dong-Eui University, South Korea **Abstract:** AI-assisted emergency planning can hide qualified alternatives and later tempt reuse of a plan produced under an obsolete state. We present a Qualified Residual Ledger (QRL), a tamper-evident commit-before-act architecture. Before display, QRL fixes the generated set, display membership, and machine-suppressed residuals; after human disposition, it appends human-nonelected residuals; before release, it binds the durable commitment, current qualification, freshness, and authorization to the same candidate and version. A public-data-seeded harness instantiated 40 plans from ten Ulu radiological-emergency routes and four disclosed control modes. Across 600 primary fault episodes, QRL answered eight audit questions and detected every tested single-record alteration or deletion. At display width k=3, a post-event reference plan had been suppressed before display in 19.8% of all episodes and 22.6% of episodes with an eligible reference; a wind-shift sweep moved this rate from 0% to 67%. In restorative events, retained QRL payloads covered 0% of newly eligible reference plans, fresh regeneration covered 100%, and stubs preserved prior-exclusion evidence in 100%. QRL therefore neither improves evacuation performance nor replaces regeneration. Its contribution is a stale-replay barrier and reconstruct able evidence of what the machine generated, displayed, suppressed, and authorized within the stated prototype and threat model.

►Session 7

► Belief Reliability for Complex Systems: Uncertainty Management and Safety Assurance; Trustworthy Agentic Intelligence for PHM-Oriented Industrial Reliability and Safety

► Session Chair: Xiaoyang Li, Beihang University, China

► 16:00-18:50 | November 24, 2026, Tuesday | RAFFAELLO

► R7108, R7143, R7100, R7238, R7140, R7127, R7254, R7133, R7194



Session Keynote Lecturer 16:00-16:20 | R7158

Sylwia Werbinska-Wojciechowska, Wroclaw University of Science and Technology, Poland

Speech Title: A Reliability-Oriented Asset State-Based Criticality Assessment Framework for Physical Asset Management (R7158)

Abstract: Effective Physical Asset Management (PAM) requires reliable identification and prioritization of critical assets. Conventional asset criticality assessment approaches commonly rely on failure consequences, risk, reliability, or multi-criteria evaluation, but often treat criticality as a relatively stable asset characteristic. This may not adequately reflect changes in asset condition and maintenance performance throughout the asset lifecycle. This paper proposes a Reliability-Oriented Asset State-Based Criticality Assessment Framework for Physical Asset Management, distinguishing between two complementary layers: a Static Layer, representing asset importance through consequence- and safety-related factors, and an Asset State Layer, representing current reliability and maintenance condition. The proposed approach treats criticality as a state-dependent property that changes when the underlying asset state changes rather than simply as a function of elapsed time. An illustrative case study demonstrates the application of the framework and its potential to support more adaptive reliability-oriented maintenance prioritization.

R7108 16:20-16:35	Optimal Design of Reliability Qualification Test Plans Based on Multi-Source Information Fusion **Author(s):** Ping Jiang, Yunyan Xing, Yajie Dou, Yunlei Tan, Minghao Li, Haiyue Yu **Presenter:** Ping Jiang, National University of Defense Technology, China **Abstract:** Reliability qualification test (RQT) is essential for verifying that products meet specified reliability requirements. But traditional RQT methods usually require large sample size for high-reliability products. This paper proposes an optimal design method for RQT plans based on multi-source information fusion. A nonlinear Wiener process is employed to model degradation trajectories and compute failure probabilities from degradation data. An inverse-variance weighting framework fuses degradation-based estimates with small-sample prior test data, reducing the coefficient of variation of the failure probability estimate. A Bayesian expected-risk design method is proposed to explicitly integrate estimation uncertainty into producer's and consumer's risk calculations through posterior probability density functions. A case study from an

	electromechanical servo actuator for satellite attitude control demonstrates that the fusion method requires only 17 test samples compared to 33 for conventional Bayesian plans, which is a 48.5% reduction, while satisfying risk constraints. The method converges to classical plans as prior information becomes sufficient.
R7143 16:35-16:50	Software for Reliability Evaluation of Drone Swarm/Fleet **Author(s):** Eyüp Durgun, Özgür Kabak **Presenter:** Eyüp Durgun, Istanbul Technical University, Turkey **Abstract:** This study proposes a conflict- and reliability-aware maintenance health assessment framework based on the Cumulative Belief Degree (CBD) approach. Expert uncertainty is quantified using an entropy-based measure, while the consistency among expert assessments is evaluated based on the degree of similarity between their belief distributions. These two dimensions are jointly incorporated into a reliability-adjusted weighting scheme to refine expert contributions and enhance the reliability of subsystem-level health assessments. The aggregated CBD values are then used to determine maintenance criticality levels, and alternative threshold scenarios are investigated through a case study conducted in an aircraft production facility. The results indicate that the proposed framework produces more consistent maintenance decisions by limiting the influence of uncertain and conflicting expert judgments. Overall, the framework provides a systematic approach for incorporating expert reliability and consensus into maintenance health assessment and decision-making.
R7100 16:50-17:05	An Uncertain Differential Equation Based Degradation Model with Initial State Uncertainty **Author(s):** Hongshuo Zhu, Fuqiang Sun **Presenter:** Hongshuo Zhu, Beihang University, China **Abstract:** Epistemic uncertainty is difficult to quantify reasonably in small-sample degradation testing, while existing uncertain differential equation-based degradation models do not account for initial state uncertainty in a performance characteristic (PC). To address these issues, this paper proposes an uncertain differential equation-based degradation model with initial state uncertainty (UDEDMI). The proposed model separately characterizes the initial state uncertainty of a PC and the epistemic uncertainty arising during the degradation process. Based on the model, belief reliability and belief reliable life are further derived. Considering the characteristics of different model parameters, corresponding estimation methods are adopted for parameter estimation. Results from a simulation study and a permanent magnet brake case study demonstrate that the proposed model can reasonably estimate the deterministic degradation law and quantify epistemic uncertainty, thereby providing more reasonable reliability evaluation results.
R7238 17:05-17:20	Performance-Margin-Guided Magnetic-Field Recovery of Flexible Magnetic Cilia Sensors **Author(s):** Yangqianhui Zhang, Dong Han, Huayong Yang, Qingyuan Zhang **Presenter:** Yangqianhui Zhang, Zhejiang University, China **Abstract:** Flexible magnetic cilia sensors accumulate residual bending after prolonged loading. The bent cilium shifts its zero-force Hall reading and the sensor falls out of specification although its structure is intact. This paper treats the recovery of such a sensor by an external magnetic field

	as a maintenance action and uses a deterministic performance margin, the reading error against a 5% full-scale tolerance, to select the field magnitude and exposure time and to assess the retained sensing response. The study uses a coupled COMSOL–Hall model of an NdFeB–PDMS cilium and judges' retention only after the field has been removed. Among the tested treatments, an aligned field of 25 MT applied for 60 s has the lowest field dose that meets the margin requirement. It reduces a 14.1° residual bend to 0.06° and returns the zero-force reading to within 12% of its tolerance. In the residual-bend state the sensitivity changes by about 2%, so the margin is governed by the zero-force reading. The field has to be aligned with the cilium to better than 5°, and a cilium whose modulus has degraded receives a negative margin although its geometry recovers.
R7140 17:20-17:35	Enhancing Automated Warranty Repair Reports Analysis with AI Generative Technologies **Author(s):** Nan Yang, Qingyuan Zhang, Rui Kang **Presenter:** Nan Yang, Beihang University, China **Abstract:** Risk control is an important guarantee for the safe operation of complex safety-critical systems. With the increasing complexity of system structures, system risks exhibit more pronounced characteristics of continuous evolution. Existing risk control methods mainly focus on risk identification and probability calculation, lacking real-time feedback and closed-loop regulation of risk states. To address this issue, this paper proposes a risk control method based on the integration of Markov chains and PID control. In this method, the probability of risk state occurrence is abstracted as the controlled variable, and a risk control system composed of a controller, actuator, and sensor is constructed. Risk and economic terms are introduced to determine the target risk value. The controller outputs control signals based on the deviation between the target risk, actual risk, and disturbances. The actuator converts the signals into the intensity of safety interventions, while the sensor perceives and feeds back the system risk state through a Markov state transition model, forming a closed-loop risk control mechanism. Finally, the aircraft landing gear retraction/extension system is taken as an example for validation, and the results show that the reliability of the system converging within 1500h is approximately 75.58%. This method provides a new modeling approach for closed-loop risk control of complex safety-critical systems.
R7127 17:35-17:50	Belief Reliability Modeling of GaN HEMTs Considering Small Signal Performance Degradation **Author(s):** Yang Miao, Xiaoyang Li, Fuqiang Sun **Presenter:** Yang Miao, Beihang University, China **Abstract:** Gallium nitride high electron mobility transistors are key active devices in radio frequency power amplifiers, and their broadband small signal gain is critical to maintaining the required amplification function. During long term operation, electrical and thermal stresses cause device parameter degradation and uncertainty, which further reduce the performance margin and reliability. However, existing studies have not fully characterized the quantitative relationship among device parameters, operating conditions, degradation, broadband performance, and functional reliability. In this work, small signal equivalent circuit modeling and reliability science principles are combined to develop a belief reliability model for gallium nitride high electron mobility transistors. First, an equivalent circuit with 15 parameters is used to establish the broadband gain and performance margin equations. Then, temperature effects and parameter degradation are

	incorporated to construct the performance degradation equation. Finally, uncertainties in device parameters and degradation processes are quantified to obtain the reliability function. The proposed model is applied to a numerical case. The results show that junction temperature significantly affects performance degradation and reliability, while sensitivity analysis identifies transconductance, gate to source capacitance, and gate to drain capacitance as the main parameters affecting broadband performance. The proposed method provides a quantitative basis for reliability-oriented design of gallium nitride high electron mobility transistors.
R7254 17:50-18:05	Agent-Assisted Fault Investigation for Robotic Manipulators **Author(s):** Wenxin Jiang, Enrico Zio **Presenter:** Wenxin Jiang, Politecnico di Milano, Italy **Abstract:** Reliable operation of robotic manipulators requires not only detecting abnormal behavior but also investigating its possible causes. Such investigations may involve comparing historical observations, obtaining additional diagnostic measurements, and assessing whether the available evidence supports a particular explanation. This paper presents an agent-assisted framework that coordinates these activities through dedicated prognostics and health management (PHM) tools. A language model investigator organizes site inspection, historical evidence retrieval, and targeted diagnostic checks, while the PHM tools perform the numerical analyses. An independent evidence audit evaluates proposed interpretations against calibrated response criteria and constrains conclusions when the evidence is insufficient. The framework is evaluated on a simulated Franka Panda manipulator performing pick-and-place tasks under controlled joint and gripper abnormalities. Across 22 investigations, the system obtained qualified historical comparisons and completed the corresponding diagnostic checks. Correct specific response interpretations were obtained in 17 of 20 joint cases, while broader or unresolved findings were retained when necessary. Representative cases show how measured evidence supports the reported interpretations.
R7133 18:05-18:20	P2-VMAR: Cross-Condition Bearing Remaining Useful Life Prediction for Trustworthy PHM Agents **Author(s):** Zhengduo Zhao, Junru Sun, Xuanyuan Su, Bohao Huang, Zhixuan Lian, Laifa Tao **Presenter:** Zhengduo Zhao, Beihang University, China **Abstract:** Reliable remaining useful life (RUL) prediction is a prerequisite for trustworthy prognostics and health-management agents, yet bearing degradation representations learned under one operating condition often transfer poorly to another due to shifts in global trends, periodic signatures, and transient impulses. Existing predictors either entangle these degradation factors within a single latent sequence or rely on high-capacity backbone fine-tuning, resulting in high parameter costs and instability under scarce target-condition data. This paper proposes P2-VMAR, a frozen GPT-2-based large language model (LLM) framework for cross-condition bearing RUL prediction. Multiscale decomposition and tokenization (MDT) first separates vibration signals into global trend, quasi-periodic, and residual components, and converts them into patch-level degradation tokens. A condition- and scale-aware prefix pool (P2) then introduces lightweight prompts into the key–value streams of a frozen Transformer, enabling adaptive representation transfer without updating backbone parameters. Furthermore, a prefix-coupled

	volume-minimization objective (P-VMAR) jointly aligns health-state-consistent embeddings across operating conditions with a non-redundancy constraint. Experiments on three cross-condition transfer tasks of the XJTU-SY dataset demonstrate that P2-VMAR achieves a mean task-wise relative score reduction of 20.51% compared with the strongest baseline. The results indicate that structured degradation encoding and geometry-aware lightweight adaptation provide an efficient prognostic inference framework for reliable PHM decision support under operating-condition shifts.
R7194 18:20-18:35	Orchestrative RAG as a Workflow-Contract Layer for Replayable PHM-Oriented Manufacturing Workflows **Author(s):** Chunzhou Zhao, Jinsong Yu, Diyin Tang, Jinhan Zhou, Lipu Zhou, Zhenzhong Wei, Hao Liu **Presenter:** Chunzhou Zhao, Beihang University, China **Abstract:** Reusing a manufacturing diagnostic procedure requires explicit step requirements, resource assignments, and input dependencies. A broad-goal component query can leave intermediate operations unspecified, while repeated language-model planning can change the selected procedure. This paper presents Orchestrative RAG, a workflow-contract layer for prognostics and health management (PHM)-oriented manufacturing tasks. A blueprint declares step requirements; a workflow contract records the assigned components and supporting knowledge; and an executor follows the selected path and records the values consumed and produced by each step. We evaluated component binding over a fixed catalog of 23 components, then examined planning and execution separately. Across three predefined scenarios, step-specific queries recovered all 11 required components, compared with 7 for broad-goal queries, when both used capability aliases and type rules. Planner calls varied across repeats, so the executor test fixed the path: a three-step workflow with deterministic components reproduced its outputs and dependency records across 30 runs. The results support step-specific component selection under an aligned catalog vocabulary and show that retaining a selected path preserves an inspectable record of repeated execution in this prototype.

►Session 8

► Artificial Intelligence for Reliability and Safety

► Session Chair: Elena Zaitseva, University of Zilina, Slovakia

► 16:00-18:50 | November 24, 2026, Tuesday | TIZIANO

► R7056, R7144, R7077, R7067, R7181, R7187-A, R7201, R7215, R7216-A, R7093



Session Keynote Lecturer 16:00-16:20

Elena Zaitseva, University of Zilina, Slovakia

Speech Title: Importance Analysis in Machine Learning

Abstract: Importance Analysis, originating in reliability engineering, can provide a complementary perspective on the analysis of machine learning classifiers. The first direction applies Structural Importance as a feature importance measure. By interpreting a classifier as a structure function, it evaluates the influence of individual input features on classification outcomes and supports feature ranking and selection. Experiments with Decision Tree, Random Forest, SVM, and Multi-Layer Perceptron classifiers demonstrate performance comparable to, and in some cases better than, established feature selection methods. The second direction addresses classifier reliability under uncertain input conditions. Feature observation errors are modelled probabilistically, while classifier availability measures the probability of preserving the original classification result despite these errors. Binary Decision Diagrams enable its efficient and exact computation.

R7056 16:20-16:35	Liquid Neural Networks for Side-Channel Security Assessment of Embedded Cryptographic Implementations **Author(s):** Kexin Li, Mariagrazia Fugini, Ernesto Damiani **Presenter:** Kexin Li, Politecnico di Milano, Italy **Abstract:** The security of embedded cryptographic implementations is an important component of system reliability in resource-constrained environments such as IoT devices, smart cards, or automotive controllers. Side-channel analysis provides an effective means of assessing whether secret-dependent information can be inferred from physical leakages, thereby exposing hardware implementations to vulnerabilities. In this paper, we investigate the application of Liquid Neural Networks (LNNs), specifically architectures based on Closed-form Continuous-time (CfC) cells, to deep learning-based side-channel security assessment. LNNs are selected because their adaptive continuous-time dynamics provide a compact architecture with enhanced robustness to noisy measurements, making them well suited for practical side-channel analysis. We evaluate the proposed LNN-SCA model on the ASCAD benchmark dataset. As CNN-based models represent the dominant baseline for deep learning side-channel analysis, we compare LNN-SCA with the widely adopted Convolutional Neural Network (CNN)_best reference implementation. Experimental results show that LNN-SCA, with a substantially smaller number of trainable parameters, achieves

	key-rank convergence to zero using fewer attack traces than the CNN best baseline, representing a significant reduction in model complexity. To evaluate robustness under realistic measurement conditions, additive Gaussian noise is introduced into the attack traces as a standard model of acquisition noise. Under additive Gaussian noise conditions, LNN-SCA maintains successful key recovery across the tested noise levels, while the baseline model fails to reach rank zero within the evaluated trace budget. These results suggest that CfC-based liquid neural networks offer a lightweight, parameter-efficient, and noise-resilient framework for reliability-oriented side-channel security assessment of embedded cryptographic implementations.
R7144 16:35-16:50	A Multi-Source Information Game Approach for UAV Fault Diagnosis **Author(s):** Yanchen Dong, Suo Mingliang, Qiuxian He, Yuexuan Yuan **Presenter:** Yanchen Dong, Beihang University, China **Abstract:** To address the conflict and redundancy of multi-source sensor information in unmanned aerial vehicle (UAV) fault diagnosis, a multi-source information game method is proposed. First, each information source is modeled as a game player, and payoff functions balancing fault identification capability against inter-source redundancy are constructed based on information entropy theory, yielding a game model for multi-source information selection. Second, the Nash equilibrium of the game is solved to obtain the optimal information combination strategy under information conflict and redundancy. Finally, a support vector machine (SVM) is employed to verify the diagnostic performance of the equilibrium information combination. Case studies on real UAV flight data demonstrate that the proposed method significantly improves diagnostic performance over the fixed strategy while effectively reducing inter-source redundancy, achieving a reasonable trade-off between fault identification capability and information redundancy.
R7077 16:50-17:05	Experimental Identification of ODD Factors for AI-based Inductive Safety Sensors **Author(s):** Mark Locherer, Michael Kordovan, Bernd Buxbaum, Thorsten Kever **Presenter:** Mark Locherer, DHBW Ravensburg, Germany **Abstract:** The operating context of AI systems is given by the operational design domain or short ODD. Current revisions in proximity switching norm IEC 60947-5-2 intend to incorporate aspects for AI technology. While this offers new possibilities, ODD integrity and consistency are a key requisite for a valid assurance argument and hence, potential certification for data- driven safety-critical systems. This is key when placing products to the market. This paper offers insights in defining the ODD for AI-driven inductive safety sensors, frequently used across different industries. We outline several measurements and ex- pediments to achieve an understanding of the influencing factors of such sensors, which are critical in the ODD definition. The results not only indicate a frequency drift due to temperature but also a decision region shift between initial and repeated measurements and suggest thermal hysteresis associated with heating and cooling cycles. Additionally, we demonstrate our findings by implementing two auto encoders. First, with complete ODD assumptions based on our results and second, without these insights. In a nutshell, to fulfill functional and safety requirements, the ODD must comprise these effects to obtain sound technical perspective. This paper can be seen as an initial step to present details on ODD integrity for data-driven inductive safety sensors and motivates further research.

R7067 17:05-17:20	A Lightweight Channel Pruning Method for Intermittent Fault Diagnosis of Analog Circuits **Author(s):** Junyou Shi, Huidong Zhou, Zhilin Yang, Shuqiang Liu **Presenter:** Huidong Zhou, Beihang University, China **Abstract:** Intermittent faults in analog circuits are difficult to diagnose because their signatures are brief and easily affected by disturbances. This paper proposes CRR-Pruning, a structured channel pruning method combining classification contribution, perturbation robustness, and channel non-redundancy. A compact one-dimensional convolutional neural network is first trained, after which its channels are scored and pruned. The resulting network is then fine-tuned. On a Sallen-Key band-pass filter dataset, a target channel pruning rate of 30% reduces the parameter count and floating-point operations (FLOPs) by 49.00% and 49.63%, respectively, with 97.17% accuracy and 96.79% macro-F1. Although pruning based on batch normalization (BN) scaling factors performs better under the original test conditions, CRR-Pruning achieves higher mean accuracy under four tested additive Gaussian noise levels. These results show that CRR-Pruning reduces model complexity while retaining high diagnostic accuracy on the evaluated circuit, with performance that depends on the type of disturbance.
R7181 17:20-17:35	Contagious Memories: Measuring Error Propagation and Recovery in Multi-Agent Memory Systems **Author(s):** Olamide Faroun, Chioma Tagbo, Elizabeth Osanyinro, Godswill Chukwu, Oluwole Fagbohun, Toluwalase Emmanuel Oludipe, **Presenter:** Godswill Chukwu, Independent Researcher, United Kingdom **Abstract:** Teams of language-model agents increasingly read from and write to a common memory. If one agent writes one false fact, what happens next? This is a simulation study: eight programmatic agents share one fact through seven memory architectures (private, shared, provenance, confidence-weighted, consensus, decaying, verifier-gated) and a provenance-and-verifier combination. No language model is executed; every behavioral assumption is a named parameter anchored to published measurements of how models resolve conflicts and swept across the measured range. We plant one false entry and measure contamination over 5 to 200 interactions with two metrics borrowed from epidemiology, a memory reproduction number estimated from ordinary logs and a memory half-life. Across 1,000 runs per architecture, the false entry is still held by someone in 85% of plain-shared-memory runs at 50 interactions and leaves 0.759 of the team wrong at 200, although contradicting evidence arrives by interaction six in the median run. Confidence weighting, write-by-consensus and refresh-on-use decay are indistinguishable from plain shared memory, and strict majority confirmation is worse (persistence 91% against 85%). Provenance with lineage retraction cuts contamination at 50 interactions by 96% with a half-life of five interactions, degrades gracefully when one observation in five is wrong, and survives noisy correction signals and heterogeneous teams; a write verifier covers lost lineage. A late-injection test shows the reading rule matters as much as the store, and the reproduction number estimated from the first 50 interactions predicts the team's state at 200 with 81% accuracy when a stationarity check computed from the same window passes; every configuration it placed below one had persistence of at most 0.09 at 200.

R7187-A 17:35-17:50	Vision-Language Change Detection for Safety and Environmental Monitoring of Open-Pit Mines **Author(s):** Wanyun Chen, Changhe Li, Yong Xu, Qun Fang **Presenter:** Wanyun Chen, Anhui University of Science & Technology, China **Abstract:** Open-pit mines are dynamic, high-risk sites where waste-dump growth, tailings-dam expansion, slope excavation and unplanned land disturbance must be detected early to support safety governance and environmental compliance. Satellite change detection offers site-wide coverage, but conventional pixel level methods return only a binary mask and cannot tell operators what changed, where, or whether a detected change is a genuine mining activity rather than seasonal vegetation, shadow or dust. This talk presents a multimodal monitoring framework, recently published in IEEE Internet of Things Journal, that couples change masks with grounded natural-language descriptions. It is built on a benchmark of over 70,000 bi-temporal image pairs from 100 mining sites on six continents, each annotated with pixel level masks, expert-verified change descriptions and bounding boxes. A 7B vision-language model is trained with reinforcement learning to refine its own descriptions and localizations, and the resulting text guides the change detector through a change-aware cross-attention. Across twelve detectors, language guidance raises F1 from 71.8 to 76.6, mainly by suppressing false alarms, so that alerts reach safety staff with an explanation of the hazard and its location. We discuss deployment in IoT-based mine monitoring and open directions for risk-informed decision support.
R7201 17:50-18:05	Learning-Based Ticket Transition Delay Prediction for Improving Reliability in IT Support Workflows **Author(s):** Björn Norén, Stefan Forsström, Qing He **Presenter:** Björn Norén, Mid Sweden University, Sweden **Abstract:** Delays in IT support workflows are difficult to anticipate because they may arise from team handovers, technical integrations, and ambiguous ownership states. This paper studies event-level prediction of long-delay transitions in historical IT support ticket workflows. Each transition is treated as a prediction point, and the task is formulated as binary classification of whether the next transition delay exceeds 24 hours. We compare current-state tabular baseline models with a sequence-aware LSTM model, where the baselines use only the current event representation and the LSTM additionally uses historical ticket context. Experiments on real-world industrial ticket data show that the task is learnable and that the LSTM achieves the strongest overall performance. The LSTM reached a balanced accuracy of 75.9%, indicating that sequence-aware prediction may provide practical value for proactive management of IT support workflows.
R7215 18:05-18:20	Do We Need Balanced Classes for Data-Driven Intrusion Detection? **Author(s):** Yasemin Demirkaya, Mehmet Tahir Sandıkkaya **Presenter:** Yasemin Demirkaya, Istanbul Technical University, Turkey **Abstract:** Oversampling methods from the SMOTE family are widely applied to address class imbalance in network intrusion datasets. These methods assume that the confusion between classes stems from lack of samples; however, this assumption has not been systematically tested

	for network traffic, where different types of attacks can produce similar flows. This paper investigates what oversampling actually contributes to performance metrics by tracking the shift of misclassified samples at the class level. The SMOTE, Borderline-SMOTE, and ADASYN methods are evaluated on the BCCC-CSE-CIC-IDS2018 dataset in both binary and multiclass tasks using Random Forest, XGBoost, Deep Neural Networks, Convolutional Neural Networks, and FT-Transformer. The results indicate that oversampling should not be applied as a default solution in intrusion detection, and its impact should not be evaluated solely based on aggregate metrics.
R7216-A 18:20-18:35	Reliability-Aware Dispatch and Charging Decisions for Battery-Electric Mine Trucks under Travel-Time Uncertainty **Author(s):** Ting Guo, Changhe Li, Guoyu Chen **Presenter:** Ting Guo, Anhui University of Science & Technology, China **Abstract:** Battery-electric mine haulage couples truck dispatching, battery state of charge (SOC), charging resources, and operational queues. Small travel-time forecast errors can change vehicle arrival order, trigger queues, cross SOC reachability thresholds, and reduce shift production. This study examines how such errors propagate through discrete operational boundaries. We develop a stochastic, resource-constrained discrete-event simulation (DES) of an all-electric shovel–truck–dump system. A next-event calendar advances loading, travel, dumping, waiting, and charging events, while first-come-first-served queues form endogenously at shovels, dumps, and chargers. Realized travel times are generated by a dynamic speed model conditioned on weather and surface states. At decision time, forecasts are reconstructed from observable states as quantile predictive distributions; controlled relative perturbations of 5–20% emulate forecast errors. The simulator also represents traction, idle, and auxiliary energy consumption, battery health, piecewise charging behavior, and time-of-use electricity prices. On top of the DES, we propose DB-CFL, a boundary-aware counterfactual delta-value model. A heterogeneous graph transformer encodes the truck–shovel–dump–charger–road state graph, and a shared potential network produces signed changes in production, grade deviation, and energy cost by contrasting candidate and baseline actions. A four-logit head predicts arrival-order reversal, queue-state transition, SOC-reachability violation, and production-deadline crossing. Monte Carlo dropout uncertainty and boundary margins guide a limited budget of high-fidelity simulations, while the final action is selected from simulator outcomes. We evaluate DB-CFL with common-random-number counterfactual rollouts under controlled perturbations and compare it with rule-based, rolling-horizon, uniform-search, absolute-value, and pairwise-ranking baselines. This framework is designed to identify when small forecast errors become decision-relevant in coordinated dispatch and charging.
R7093 18:35-18:50	Graph-Based Machine Learning for Bottleneck Analysis to Improve Workflow Reliability in IT Support **Author(s):** Björn Norén, Stefan Forsström, Qing He **Presenter:** Björn Norén, Mid Sweden University, Sweden **Abstract:** Identifying bottlenecks in IT support workflows is difficult because delays in ticket handling may arise not only from team handovers, but also from technical integrations, and ambiguous ownership states. This paper performs bottleneck analysis in real-world IT support

	ticket data by representing recurring ticket state transitions as an aggregated workflow-entity graph. Using this representation, we analyze bottleneck-prone routes and show that delays are concentrated in a limited subset of transitions. We then compare Graph Neural Networks with simpler baseline models for bottleneck-route classification. The results show that while the task is learnable, the more advanced models do not provide a clear advantage over the simpler baselines evaluated in this study, including logistic regression, multilayer perceptron, and tree-based models. However, our findings suggest that graph-based representations remain valuable for structural bottleneck description and interpretation, although the present classification setting should be interpreted as retrospective analysis rather than forward prediction.

►Session 9

► Industrial Reliability Analysis and Optimization under Limited Data

► Session Chair: Cheng Liu, City University of Hong Kong, China

► 16:00-18:35 | November 24, 2026, Tuesday | BOTTICELLI

► R7211, R7164-A, R7161-A, R7183, R7184-A, R7222-A, R7180, R7234-A, R7198-A



Session Keynote Lecturer 16:00-16:20

He Li, Liverpool John Moores University, UK

Speech Title: Reliability and Maintenance of Floating Offshore Wind Systems

Abstract: This talk will highlight key aspects of the reliability and maintenance of floating offshore wind systems, including turbines and wind farms. It will begin with an overview of the development of a failure dataset, AI-based data analysis methods, and new insights into failure modes and maintenance characteristics of floating offshore wind turbines. The presentation will cover failure analysis and prevention strategies, along with the design of a health monitoring system tailored for floating wind turbines. Transformation-based reliability analysis methodologies will also be introduced to predict reliability characteristics, especially in the context of limited domain knowledge about these emerging systems. Furthermore, real-time, risk-based opportunistic maintenance strategies for floating wind turbines and farms will be presented. The session will conclude with an availability estimation, demonstrating how maintenance scheduling performance can be evaluated. Together, these insights aim to improve the cost-effectiveness and safety of operations in floating offshore wind farms.

R7211 16:20-16:35	Distributionally Robust Resilience Optimization for Interdependent Infrastructure Systems with Individual Rationality and Distributed Coordination **Author(s):** Kai Wang, Yiping Fang **Presenter:** Kai Wang, Université Paris-Saclay, France **Abstract:** Pre-disaster protection of interdependent infrastructure can sustain system service levels during disasters, but a centralized optimization model may reduce the service benefits for individual operators. This article develops a distributionally robust optimization (DRO) model with individual rationality constraints to jointly account for system resilience and individual network resilience. Individual rationality in this article requires that, under any probability distribution, no network's expected resilience falls below its non-cooperative baseline. Disaster uncertainty is represented by joint damage scenarios and a finite-support probability ambiguity set. A column-generation method based on Dantzig--Wolfe decomposition is developed, where each network generates protection--operation plans locally and exchanges only interface values and scenario losses. A case study on interdependent power--water networks shows that the unconstrained DRO solution achieves the highest worst-case expected system resilience (85.323\%) but yields a negative expected improvement for the water network under some

	admissible distributions. With individual rationality constraints, sacrificing only a small the optimal objective (0.133\%) suffices to guarantee that both networks improve their expected resilience over the score-based baseline under any distribution.
R7164-A 16:35-16:50	Physics-guided Deep Learning for Damage Detection in Aerospace Composite Structures **Author(s):** Cheng Liu, Xuebing Xu **Presenter:** Cheng Liu, City University of Hong Kong, China **Abstract:** Deep-learning-based structural health monitoring methods have shown strong potential for detecting fatigue damage in carbon fiber reinforced polymer (CFRP) composites. Nevertheless, their performance often deteriorates when applied to structures with material configurations or mechanical properties that differ from those represented in the training data. To improve model transferability across composite layups, this study develops a physics-guided convolutional neural network that incorporates stiffness degradation and guided-wave characteristics into the learning process. A damage evolution model is first established to relate axial stiffness degradation to variations in the power spectral density of Lamb-wave signals. The resulting physics-based damage information is then combined with experimentally observed signal features through a hybrid network architecture. In addition, a physics-consistency loss is introduced to constrain the predicted damage states according to the expected degradation trend. The proposed approach is evaluated using the NASA CFRP dataset under a cross-layup testing setting, in which the model is trained on data from a single composite configuration and subsequently applied to other layup configurations. The results show that the proposed model achieves damage detection accuracies above 90% across the evaluated CFRP layups, demonstrating improved generalization under variations in structural configuration. These findings indicate that integrating degradation physics with data-driven feature learning provides an effective strategy for transferable guided-wave-based damage detection in composite structures.
R7161-A 16:50-17:05	An Efficient Network Reliability Analysis Approach **Author(s):** Yan Shi, Cheng Liu **Presenter:** Yan Shi, City University of Hong Kong, China **Abstract:** Real-world systems, such as manufacturing [1], computing [2], and transportation [3] systems, can be effectively represented as network models comprising nodes and links. This modeling approach enables managers to better understand system architectures. As the demand for reliable services grows, reliability analysis has become essential in the planning, design, and operational phases of many systems [4]. In numerous networks, links exhibit varying capacities, and the networks themselves must transmit a specified flow from a source node to a terminal node. Therefore, network performance depends not only on connectivity but also on the capacity to sustain maximum flow. Capacitated Network Reliability (CNR), defined as the probability of successfully transmitting a given flow between source and terminal nodes, thus plays a critical role in evaluating network reliability [5]. However, analyzing CNR is an NP-hard problem, limiting exact computations to small networks due to the infeasibility of exhaustive exploration. While numerous methods have been developed for small- and medium-sized networks, estimating CNR for large-scale networks remains a significant challenge. This difficulty is exacerbated in dynamic real-world scenarios where network topologies may change abruptly, such as traffic networks

	affected by road closures or accidents. In such cases, traditional non-machine learning approaches must be re-executed for each topology change, often falling short of practical requirements for speed and adaptability. To address these challenges, we propose a novel graph-based neural network, the Response Flow Graph Neural Network (RFGNN) [6], specifically designed for CNR analysis. The innovation of RFGNN lies in three key components: (1) an iterative mechanism to update link weights by identifying flow obstruction nodes during propagation, (2) a new formulation that integrates local neighborhood information using updated link weights to construct the RFGNN, and (3) an adaptive framework to improve prediction accuracy for CNR problems. Once constructed, the RFGNN demonstrates exceptional computational accuracy in estimating CNR across various sub-networks, outperforming traditional methods, particularly in scenarios involving dynamic topology changes. This study highlights the potential of RFGNN as a powerful tool for addressing complex CNR problems in large-scale and evolving networks.
R7183 17:05-17:20	Physics-Grounded Conformal Assessment of Actuator-Demand Headroom under Multicopper Motor Degradation **Author(s):** Hira Ambreen, MD Monjur A Alahi Atib, Shuang Liang, Diyin Tang **Presenter:** Hira Ambreen, Beihang University, China **Abstract:** Closed-loop compensation can mask multicopper motor degradation, making flight tracking alone insufficient to quantify remaining actuator authority. This paper proposes a physics-grounded conformal framework separating modeled actuator-demand feasibility from mission-conditioned temporal conformity. Reconstructed controller demand and degradation-dependent motor effectiveness define headroom and its flight-level minimum over a fixed 10-s post-onset horizon; negative minimum headroom is equivalent to at least one requested motor effect exceeding modeled availability. For modeled-feasible flights, a robust amplitude–persistence score of downward headroom deviations is calibrated by groupwise split conformal prediction, with minimum-headroom scoring as a matched scalar baseline. On a fixed 354-flight SIL/HIL evaluation partition inspected during score development, decisions were non-nested (four trajectory-only and ten scalar-only atypical cases); these counts are descriptive. Post-development 100-repeat same-dataset resampling with the frozen score yielded mean empirical conformity of 0.9603 (empirical 5th–95th percentiles: 0.9347–0.9802), with mean trajectory-only and scalar-only counts of 6.19 and 5.78. Real-X450 provides only secondary model-based stress evidence (13 modeled feasibility crossings among 147 evaluable flights), not formal conformal validation. Modeled feasibility, temporal conformity, and operational safety remain distinct.
R7184-A 17:20-17:35	Probabilistic Prognostics for Pricing and Operational Control of Battery Swapping Systems under Reliability Constraints **Author(s):** Ting Yu, Dacheng Zhang, Huixing Meng, Wei Wang **Presenter:** Ting Yu, City University of Hong Kong, China **Abstract:** In battery swapping systems, batteries with heterogeneous usage histories circulate among users and stations, linking current service decisions to the future service capability of a shared fleet. Probabilistic prognostics can characterize degradation and thermal risk, but these estimates do not directly determine the economic consequences or admissibility of further battery use. We develop a framework that connects probabilistic battery health assessment to joint pricing

	and operational control under explicit reliability constraints. An upstream Kriging-assisted dynamic Bayesian network supplies degradation and thermal risk trajectories with their predictive uncertainty. A lifecycle reserve assigns a shadow cost to additional battery use by integrating increases in expected risk, exposure above risk thresholds and posterior uncertainty over a common physical use increment. A fused risk indicator modifies exposure severity and informs battery eligibility without adding another monetary term. The reserve enters service prices and the reward of a reinforcement learning controller trained with proximal policy optimization. The controller coordinates price adjustment with charging, grid discharge and battery relocation. Prospective reserves are calculated from eligible inventory at the start of each interval. Before demand is realized, policy proposals are projected onto the feasible set and the resulting prices are posted. Deterministic allocation enforces the modeled instantaneous reliability and physical constraints during execution. Energy dynamics and throughput accounting link executed actions to lifecycle consumption and realized reserves. A comparative simulation study is designed to examine the interaction between risk valuation and operational flexibility. The evaluation varies the uncertainty charge independently of the reliability margin to distinguish their effects on service fulfillment, economic return and lifecycle consumption. The formulation extends probabilistic prognostics to operational health management by reflecting the consequences of battery use in economic decisions while retaining reliability requirements as independent limits on admissibility.
R7222-A 17:35-17:50	Lightweight Physics-Consistent Probabilistic Remaining Useful Life Prediction for Cutting Tools via Causal State-Space Representation **Author(s):** Ting Wang, Jiali Cheng, Rongze Li, Luca Bernini, Paolo Albertelli, Zhiqiang Cai **Presenter:** Ting Wang, Northwestern Polytechnical University, China **Abstract:** Reliable cutting-tool remaining useful life (RUL) prediction is essential for risk-aware replacement, yet indirect sensing, few run-to-failure tools, and distribution shifts hinder accurate degradation tracking and trustworthy uncertainty. Existing methods often separate wear forecasting from threshold-crossing inference, producing inconsistent trajectories or poorly calibrated intervals. This paper proposes Causal State-space Probabilistic Estimation of RUL (CaSPER), a lightweight framework that learns long-term degradation through input-adaptive causal recursions and joint current--future wear supervision. Nonnegative stochastic increments and model-path pooling generate monotone trajectories and a coherent first-passage RUL distribution. CaSPER achieves the best overall point and probabilistic performance among seven methods on PHM2010 and remains competitive under the stronger shifts of Hannover. Ablations confirm the complementary roles of causal representation, monotone evolution, and path pooling. The method supports uncertainty-aware maintenance, with current evidence limited to cross-tool PHM evaluation and within-machine Hannover adaptation.
R7180 17:50-18:05	Bearing Fault Diagnosis Method with Limited Samples: A TabPFN Framework with Fast Adaptation for Novel Fault Types **Author(s):** Tonglin Luo, Jian Ma, Jinsong Zhao, Junjie Huang, Minghui Zhang **Presenter:** Tonglin Luo, Beihang University, China **Abstract:** The dual scarcity of fault sample quantities and types widely existing severely limits the application of data-driven fault diagnosis models. The training cost of existing few shot bearing fault

	diagnosis models is generally very high, making it difficult to quickly respond to newly emerged fault types. This paper proposes a robust few-shot fault diagnosis method framework named TabPFN-FD based on the new Tabular Prior-Data Fit Network (TabPFN), which includes signal feature extraction methods and fine-tuning methods. Experiments based on public bearing datasets show that TabPFN-FD can perform domain adaptation using just 2-10 samples per known sample type as fine-tuning data. Furthermore, TabPFN-FD obtains good diagnostic capability for new fault using only 4-9 samples of unseen types, with diagnostic accuracy of up to 91.21%. This represents an improvement of up to 14% over existing models. The results of this paper demonstrate the feasibility of using new TabPFN, which features an architecture distinct from traditional machine learning methods, to address few-shot fault diagnosis problems characterized by a lack of both sample quantity and diversity. Additionally, it provides a foundational framework for such research.
R7234-A 18:05-18:20	Coordinated Maintenance Optimization for Heterogeneous Systems of Systems with Limited Maintenance Resources **Author(s):** Qin Zhang, Tong Chen, Yu Liu **Presenter:** Qin Zhang, University of Electronic Science and Technology of China, China **Abstract:** A system of systems (SoS) integrates heterogeneous systems that provide complementary functions and collaborate to accomplish complex missions. Mission success depends on whether the functions available across its constituent systems collectively satisfy mission requirements. During operation, component failures may render some functions unavailable, while retained functions can still contribute to mission execution. Maintenance can restore lost functions, but limited maintenance resources often prevent the full restoration of all degraded systems. Maintenance activities must therefore be selected and coordinated across systems to recover the functional capabilities required for the next mission and increase the probability of mission success. This study proposes a coordinated maintenance optimization framework for heterogeneous SoSs. The framework represents each constituent system by its retained functions and links component restoration to system functionality and SoS mission success. It accounts for both the functional configurations required within individual systems and the coordinated functional contributions across systems. A mission reliability model based on an aggregated Markov chain is developed to assess the probability that the SoS successfully completes the next mission. The resulting mission success probability is incorporated into a selective maintenance optimization model to determine a component restoration scheme that maximizes SoS mission reliability under maintenance resource constraints. An illustrative example of a manned-unmanned cooperative aircraft SoS demonstrates the proposed framework. The results show that accounting for retained functions and their coordination enables more effective allocation of limited maintenance resources and improves the SoS mission success probability.
R7198-A 18:20-18:35	Maintenance Decision-Making for Offshore Wind Farms: Demand Prediction, Opportunistic Maintenance, and Fleet Scheduling **Author(s):** Hongxu Ye, He Li, Huanhuan Li **Presenter:** Hongxu Ye, University of Southampton, United Kingdom **Abstract:** Offshore wind farm maintenance involves several interconnected decision problems,

	including the prediction of maintenance demand, the identification and utilization of maintenance opportunities, and the scheduling of maintenance resources under offshore operational constraints. This study investigates these aspects through three related maintenance approaches. First, a reliability-based model incorporating component failure dependencies and maintenance effects is developed to predict failures and maintenance actions over the wind farm lifecycle. Second, SCADA-based failure warning is combined with statistical reliability information to support opportunistic maintenance decisions, where warning- or failure-triggered tasks are coordinated with preventive tasks selected according to their maintenance value. Third, a maintenance fleet scheduling model considering diverse weather windows and constrained maintenance resources is developed, with dynamic failure risk assessment used to support task prioritization and scheduling. Case studies demonstrate the effects of failure dependencies on predicted maintenance demand, the capability of condition-aware warning to provide useful lead time for maintenance intervention, and the importance of weather conditions, failure risk, and resource availability in maintenance scheduling. Together, these studies support informed maintenance planning, resource allocation, and lifecycle management of offshore wind farms, thereby contributing to more effective operation and maintenance.

►Session 10

► Safety Analysis (I)

► Session Chair: Jeroen Boydens, KU Leuven, Belgium

► 16:00-18:20 | November 24, 2026, Tuesday | MASCAGNI

► R7028, R7141, R7208, R7073, R7069, R7039, R7052, R7232



Session Keynote Lecturer 16:00-16:20

Yanhua Zou, Wuxi University, China

Speech Title: AI for Human Reliability Analysis of Nuclear Power Plants

Abstract: The increasing digitalization, automation, and intelligent operation of nuclear power plants are reshaping operator responsibilities, cognitive demands, and human-system interactions, posing new challenges to the scope, analytical methods, and risk quantification capabilities of human reliability analysis (HRA). Advances in artificial intelligence (AI) provide new opportunities to address these challenges and enhance HRA methodologies. This presentation reviews recent research progress in AI-enabled HRA, focusing on operator state and performance prediction, performance shaping factor (PSF) analysis and human error probability (HEP) estimation, dynamic HRA and virtual operator modeling, and the application of large language models and intelligent agents to HRA. Existing studies have demonstrated progress in operator state recognition, cognitive failure prediction, dynamic human risk assessment, and cognitive-behavioral simulation. However, significant challenges remain in ensuring the fidelity of operator cognition and behavior models, establishing quantitative relationships between operator states and human error probabilities, improving model generalization across complex accident scenarios, assessing the joint reliability of human operators, automation, and AI, and validating model credibility. Future research directions are discussed, with particular emphasis on data-enhanced dynamic HRA, virtual operators and cognitive-behavioral simulation, joint reliability analysis of human operators, automation, and AI, and online human risk monitoring and decision support. Key scientific challenges, implementation requirements, and potential capability development pathways are further examined, highlighting the importance of empirical validation, uncertainty quantification, and nuclear safety constraints for the trustworthy application of AI in HRA.

R7028 16:20-16:35	Co-Analysis of Failure Modes and Threat Modes with Failure Effect in Safety and Security **Author(s):** Marzana Khatun, Sebastian Fischer **Presenter:** Marzana Khatun, Robert Bosch GmbH, Germany **Abstract:** Failure mode and effect analysis is widely used in automotive for risk assessment- However, systematic approaches often lack holistic support for analysing interactions among failure modes, threat modes, and their resulting effects, particularly in complex system. Safety analysis alone is insufficient to cover critical gaps in complex systems, where security aspects play a crucial role. Therefore, understanding the interaction between safety-related failure modes and cybersecurity threats is essential. This paper presents a co-analysis approach based on correlation

	coefficients to support the understanding of interactions among failure modes, threat modes, and failure effects within the Failure-Threat Mode and Effects Analysis (FTMEA) framework. In addition, the relationships among the failure modes, threat modes, and their overall system-level effects are analysed to provide a more comprehensive representation of these interactions. Furthermore, exemplary cases are described to illustrate proposed approaches in a simple communication interface applicable for automotive domain.
R7141 16:35-16:50	Simulation-Driven FMEA through a SysML Workflow **Author(s):** Samuel García Lorente, Daniel Villafañe Delgado, Pedro Rubio Martín **Presenter:** Daniel Villafane, Anzen Engineering, Spain **Abstract:** Model-Based Safety Assessment (MBSA) aims to improve the consistency and traceability of safety analyses by integrating them with model-based systems engineering practices. However, failure-propagation relationships required by safety analysis are often defined manually and maintained separately from the physical system representation. This paper presents an integrated workflow in which a SysML model provides the system architecture and operating context, while an explicit analysis configuration file maps externally developed LTspice subsystem netlists to SysML parts and ports and defines simulation-specific fault and effect criteria. Individual component failures are injected into the mapped executable representations, and the resulting responses are evaluated to generate traceable Failure Modes and Effects Analysis (FMEA) records. These relationships are subsequently consolidated through a Failure Modes and Effects Summary (FMES). The approach is demonstrated on an electrical auxiliary power supply comprising a current limiter, input filter, and power-conversion stage. A campaign of 456 single component failure cases across two operating modes was executed, of which 449 (98.5%) were successfully evaluated. A no exhaustive expert review verified the configured measurement points, failure-mode evaluation thresholds, and local-to-end-effect relationships for this pilot use case. The results demonstrate an expert-reviewed proof of concept for deriving traceable failure effect relationships under the configured conditions; independent validation of classification accuracy remains future work.
R7208 16:50-17:05	A Structured FMEA Methodology for Early Safety Analysis of RTL IP Cores **Author(s):** Francesco Capone, Giuseppe Panariello, Giovanni Spinelli, Rosalba Liguori, Luigi Di Benedetto, Alfredo Rubino, Gian Domenico Licciardo **Presenter:** Francesco Capone, University of Salerno, Italy **Abstract:** The pervasive adoption of Systems-on Programmable Chip (SoPC) in critical scenarios is moving increasingly complex Hardware (HW) modules onto Field Programmable Gate Arrays (FPGA). In this context, using Failure Mode and Effects Analysis (FMEA) as an early design-analysis tool is particularly valuable, since failures associated with an HW architecture can be identified before synthesis and technology-dependent implementation. This work presents a structured methodology for applying FMEA directly in register-transfer-level (RTL) descriptions and functional specifications. The proposed approach divides the RTL-based IP into sub-blocks using a structural and functional stopping criterion, derives the analysis elements from the specified interfaces and requirements, and failure modes from the element's contract. This methodology is demonstrated on a proprietary railway IP targeted to a Zynq Ultra Scale+ MSc. The procedure

	identifies 293 failure-mode instances, 55.6% of which produce erroneous completed outputs, 35.2% prevent output completion, 9.2% may still produce a correct output.
R7073 17:05-17:20	A Failure-Mode Criticality Grading Method Based on Combined-Weight Fuzzy Evaluation **Author(s):** Junyou Shi, Zhilin Yang, Huidong Zhou, Zezhong Niu **Presenter:** Zhilin Yang, Beihang University, China **Abstract:** Grading failure modes in complex equipment is difficult when failure consequences are uncertain and field data are sparse, as often occurs during early design. Failure mode, effects and criticality analysis (FMECA) commonly uses a risk priority number based on occurrence, severity, and detection; however, tied RPN values, implicit equal treatment of the risk factors, and crisp expert scores can obscure maintenance priorities. This paper proposes a failure-mode criticality grading method based on combined-weight fuzzy evaluation. The method extends FMECA by introducing five factors: occurrence probability, severity, detection difficulty, maintenance difficulty, and life-cycle impact. Subjective and objective weights are integrated to reflect both engineering judgement and information dispersion in the scoring matrix. A fuzzy evaluation matrix with adjacent-grade membership is then used to preserve uncertainty in expert scores. The resulting comprehensive criticality value is mapped to four fault grades and corresponding maintenance strategies. An electric drive system is used as an illustrative case.
R7069 17:20-17:35	A Hybrid Probabilistic Bow-tie Model for European Wildfire Risk Analysis **Author(s):** Linna Li, Jing Wu, Fredrik Asplund, Lazaros Nalpantidis **Presenter:** Linna Li, Technical University of Denmark, Denmark **Abstract:** Wildfire risk varies considerably across European countries due to differences in ignition conditions, environmental factors, and fire management capabilities. This paper proposes a bow-tie framework for country-level wildfire risk analysis in Europe. In the framework, the fault tree side is used to analyses wildfire ignition-related factors, while the event tree side is used to assess post-ignition wildfire consequences. The bow-tie structure is further converted into a Bayesian Network (BN) for probabilistic modelling. Using the proposed framework, a comparative analysis of wildfire ignition characteristics is carried out for multiple European countries, and fire consequence risk is evaluated through consequence-state probabilities and an expected wildfire consequence risk index. The results show clear cross-country differences in both ignition probability and fire consequence risk, highlighting substantial variation in ignition-related factors, consequence-state distributions, and overall fire consequence risk levels across countries. The framework can be used for preliminary cross-country wildfire risk assessment and comparison in Europe.
R7039 17:35-17:50	Formal Modelling and Verification of Usage Restriction Area Management in Railway Operations **Author(s):** Baran Önen, Bilal Üyümez, Werner Iberl, Andreas Oetting **Presenter:** Baran Önen, Technical University of Darmstadt, Germany **Abstract:** The Usage Restriction Area (URA) concept protects hazardous areas and work zones in railway operations by restricting the use of bounded parts of the railway infrastructure. Managing these areas requires the coordinated interaction of several system components, including the

	Advanced Protection System (APS). This work considers URA management in an APS-based architecture, including the integration of trackside sensors for hazard detection. The behavior is formally modelled and verified in UPPAAL, a tool suite for automatic verification of real-time systems modelled as networks of timed automata. The model covers URA creation and removal, sensor inhibition, degraded-mode handling, and the propagation of restrictions into movement permissions. Verification includes general consistency properties and safety properties derived from failure modes identified in a reduced-scope Failure Mode and Effects Analysis (FMEA). The verification results show that all consistency and safety properties are satisfied within the considered scope. However, state-space explosion remains a relevant limitation as model complexity increases.
R7052 17:50-18:05	Exploring Digital Twin State Spaces: A MBSA approach for Automated System Safety Analysis **Author(s):** Emanuele Dini, Paolo Maggiore, Emanuele De Paola, Giuseppe Maria Garraffo **Presenter:** Emanuele De Paola, Leonardo S.p.A, Italy **Abstract:** This paper presents a novel black-box methodology for extracting Minimal Cut Sets and Safety Performance Indicators directly from a general-purpose Digital-Twin (known as Single Source of Truth), leveraging its systematic state-space exploration and thereby avoiding model reengineering into discipline-specific safety languages. The approach is evaluated on an avionic case study developed within the MathWorks environment, where the extracted quantitative safety metrics are compared with those obtained through a traditional Fault Tree Analysis. Both result accuracy and computational effort are examined, with particular attention to the latter. Preliminary strategies to mitigate computational time are investigated and discussed, highlighting the potential of the proposed method for scalable, model-based safety assessment.
R7232 18:05-18:20	A Novel Digital Twin (DT) Platform for Electrical Distribution Networks Compatible with Turkish Smart Grids **Author(s):** Erol Yumuk, Beytullah Topcu, Alper Kerem, Alper Emin Yardimci **Presenter:** Alper Kerem, Kahramanmaras Sutcu Imam University, Turkey **Abstract:** Electricity distribution systems constitute one of the fundamental pillars of sustainability, reliability and efficiency in the modern world. Conventional grids are increasingly strained by rising energy demand, by the need to accommodate renewable generation and by volatile market conditions, which together make digital transformation unavoidable. In this context, Digital Twin (DT) technology offers considerable potential for grid management by creating virtual and dynamically updated replicas of physical systems. The present study addresses the reduction of outage durations, the improvement of grid efficiency, the reduction of operating costs and the strengthening of sustainability through DT technology. To this end, a comprehensive and vendor-agnostic DT platform for electricity distribution networks has been developed that is fully aligned with Turkiye's national smart grid targets (TAS2023) and national smart metering programmed (MASS-2021), and that fuses seven heterogeneous data sources — SCADA, automatic meter reading (AMR), GIS, OMS, field readings, the call center and meteorological services — into a single canonical model in real time. The proposed model comprises three stages. In the first stage, reliable data transfer over the existing communication infrastructure is provided

	by a quad-extension database built on PostgreSQL with Postages, Timescale DB and Apache AGE, together with a Kafka-based event-driven microservice architecture. In the second stage, grid components such as meters, transformers and lighting circuits are modelled, and panda power power-flow physics is combined with machine learning models (XGBoost, LSTM and Isolation Forest) to disaggregate technical and non-technical losses. In the third stage, a probabilistic outage correlation engine targeting a detection time below 60 s is integrated, and a 65-screen user interface covering more than 10 000 network elements is developed to enable scenario-based analysis. The platform is demonstrated on a realistic synthetic dataset representative of the Ankara distribution network.

►Session 11

► AI-Augmented Predictive Maintenance for Complex Industrial Systems

► Session Chair: Bin Wang, Politecnico di Milano, Italy

► 9:00-11:10 | November 25, 2026, Wednesday | TINTORETTO

► R7235, R7090, R7147, R7091, R7213, R7245, R7257



Session Keynote Lecturer 9:00-9:20 | R7252

Umberto Alibrandi, National University of Singapore, Singapore

Speech Title: Simulating Physics of Sediment Transport and Erosion with Scientific Digital Twins (R7252)

Abstract: Coastal erosion and sediment transport represent major challenges for the safety and resilience of coastal infrastructure. Their prediction requires computational models capable of representing complex fluid–sediment interactions, evolving bed morphology, and the underlying physical mechanisms. This paper presents a Scientific Digital Twin (Sci-DT) framework for sediment transport and erosion, integrating holistically scientific modelling, computational modelling, and epistemic reconstruction driven by observations. The Sci-DT distinguishes four complementary processes: (i) ontological evolution of the physical system, (ii) scientific modelling, (iii) computational modelling, and (iv) epistemic reconstruction. Scientific modelling is organized through a hierarchy of representations connected by coarse-graining, from microscopic interactions to macroscopic conservation laws governing fluid motion, sediment transport, and morphological evolution. The Consistent Particle Method (CPM) provides a particle-based computational representation in which physical fields are carried by discrete particles while differential operators are reconstructed through polynomial consistency. The resulting Physical World Model (PWM) of Sci-DT combines the reconstructed physical state with its physically admissible evolution laws (“physical field”), while observations provide information for updating uncertain states and model parameters (“informational field”). Attention is given to predictive reliability, distinguishing numerical consistency and convergence, physical admissibility, and agreement with observations. The proposed framework establishes a foundation for integrating physics-based particle simulations with coastal monitoring data, and it supports future applications in erosion prediction, coastal protection, and flood resilience.



Session Keynote Lecturer 9:20-9:40 | R7235

Bin Wang, Politecnico di Milano, Italy

Speech Title: Depassivation-Informed Residual Learning for Cross-Domain Remaining-Capacity Estimation of Li/$SOCl_2$ Batteries (R7235)

Abstract: This study proposes a depassivation-informed residual learning method for remaining-capacity estimation of lithium–thionyl chloride (Li/$SOCl_2$) primary batteries under varying discharge conditions. A pulse-voltage branch provides a baseline capacity estimate, while a gated, bounded residual branch incorporates slope- and curvature-based descriptors of depassivation transients to refine the prediction. Training and model selection use source-domain data only, without access to target-domain data. In cross-domain experiments transferring from 10 to 2 mA and from 10+20 to 2 mA, the proposed method achieves mean absolute errors of 82.41 and 87.17 mAh, respectively, representing reductions of 9.3% and 25.5% compared with its pulse-only configuration. These results demonstrate that integrating depassivation information through bounded residual learning improves cross-domain capacity estimation, supporting condition assessment and maintenance of primary-battery backup systems.

R7090 9:40-9:55	Zero-Shot Railway Fastener Anomaly Detection Based on Large-Scale Vision Language Models **Author(s):** Bo Tang, Ran Bi,Wubin Peng, Zhanwei Yang, Jingsong Xie, Zhibin Guo **Presenter:** Bo Tang, Central South University, China **Abstract:** Ensuring the operational safety of railway sys tems demands rigorous fastener inspection. However, tradi tional vision-based approaches rely heavily on large-scale anno tations, while standard Vision-Language Models (VLMs) like CLIP struggle with semantic misalignment in complex indus trial backgrounds. To address these limitations without requir ing target domain training data,this study proposes LPA-CLIP (Low-rank Prompt Adaptation CLIP), a specialized framework for zero-shot anomaly detection. We introduce a transfer learning paradigm that constructs a generalized anomaly per ception foundation using public industrial datasets. Central to this architecture is the Low-rank Prompt Adapter (LoR PA), a lightweight module designed to dynamically calibrate semantic prompts via cross-modal interaction. This mechanism effectively suppresses background noise and aligns visual repre sentations with defect descriptions. Experimental evaluations on a railway fastener dataset demonstrate that LPA-CLIP significantly outperforms state-of-the-art baselines in zero-shot settings,attaining an image-level AUROC of 74 .4%and a pixel level AUROC of 91.1%, validating its robust generalization capability for intelligent railway inspection.
R7147 9:55-10:10	A Causal-Guided Graph Transfer Learning Method for Aircraft Engine Remaining Useful Life Prediction **Author(s):** An Zhou, Yi Chang, Yujie Cheng, Chen Lu **Presenter:** An Zhou, Beihang University, China

	Abstract: Accurate remaining useful life (RUL) prediction of aircraft engines is essential for condition-based maintenance and operational reliability. However, multi-sensor monitoring data usually contain redundant or weakly degradation-related information, while historical engines may provide different levels of transferable knowledge for a specific target engine. To address these issues, this paper proposes a causal-guided graph transfer learning method for aircraft engine RUL prediction. First, DAG-GNN is employed to identify degradation-sensitive sensor variables and learn their directed structural relationships with RUL. Based on the learned causal topology, a window-level degradation graph representation model combining one-dimensional convolution and graph attention is developed to capture temporal degradation characteristics and inter-sensor structural dependencies. Subsequently, time-domain moving and dynamic time warping are introduced to retrieve historical engines with similar degradation trajectories, and an engine-level graph attention mechanism is utilized to adaptively transfer their degradation knowledge to the target engine. Experiments on the C-MAPSS dataset demonstrate the effectiveness of the proposed method for aircraft engine RUL prediction. The proposed framework improves RUL prediction performance by integrating causal-guided degradation representation and similarity-guided historical knowledge transfer.
R7091 10:10-10:25	Interpretable Fault Diagnosis for Train Transmission System based on Virtual-Node-Augmented Physical Graph under Sparse-Sensor Conditions **Author(s):** Wubin Peng, Bo Tang, Ran Bi, Jingsong Xie, Zhibin Guo **Presenter:** Wubin Peng, Central South University, China **Abstract:** Reliable fault diagnosis for high-speed train drivetrains under sparse sensor conditions is hindered by topological degradation and lack of physical interpretability. To address this, this paper proposes the Physical-Topology-Aware Graph Neural Network (PTA-GNN). First, a fixed physical graph augmented with virtual nodes is constructed to act as structural aggregators, maintaining topological integrity even during sensor failure. A dynamic structure learner with relation-type bias is then introduced to adaptively refine physical prior weights and model time-varying fault propagation intensities. Furthermore, a dual-stream inference mechanism fuses physical and semantic information to ensure the diagnosis is physically auditable while capturing subtle fault features. Evaluations on the BJTU-RAO dataset demonstrate that PTA-GNN achieves superior robustness against sensor loss and generates diagnostic evidence packs containing node contributions and propagation paths for maintenance decision support.
R7213 10:25-10:40	FL-SS-PMD: A Prefix-Conditioned Smooth-State PMDformer for Lithium-Ion Battery Degradation Forecasting **Author(s):** Mengwei Li, Leyan Wang, Kunyang Li, Yiting Zhou, Zehan Liu, Jian Ma **Presenter:** Mengwei Li, International Innovation Institute, Beihang University, China **Abstract:** Accurate forecasting of lithium-ion battery degradation trajectories is important for predictive maintenance and reliability management. This paper proposes a prefix-conditioned Full-Life Smooth-State PMDformer (FL-SS-PMD) for battery capacity degradation forecasting. The model retains the Transformer-based temporal encoder of PMDformer and introduces a structured smooth-state decoder to represent the dominant degradation trend and local capacity variations. A

	prefix-conditioning module further adapts the predicted trajectory to the current observation stage, while prediction-feedback recursive training is used to reduce error accumulation in multi-block forecasting. Experiments on 100 pouch lithium-ion cells under four observed-prefix settings show that FL-SS-PMD achieves a mean absolute error (MAE) of 0.028714 and a root mean square error (RMSE) of 0.040857, reducing the corresponding errors by 57.09 percent and 60.04 percent compared with PMDformer. The results demonstrate the effectiveness of FL-SS-PMD for stable battery capacity degradation forecasting.
R7245 10:40-10:55	Diagnosing and Correcting Calibration-Distribution Mismatch in Conformal Prediction for Remaining Useful Life Estimation **Author(s):** Sonali Gangwar, MD Ariful Islam Mozumder, Hee Cheol Kim **Presenter:** Sonali Gangwar, Inje University, South Korea **Abstract:** Conformal prediction is supposed to give 90% coverage. On a widely used NASA turbofan engine benchmark we obtained only 26–47% across its four subsets, and 37% on a newer NASA dataset simulated under real flight conditions. The cause lies in how calibration data is built. Training engines run until failure, so holding some back for calibration measures prediction error at the very end of engine life, where error is small (about five cycles). Test engines are observed at unknown mid-life points, where error is about 20 cycles. The conformal quantile is set on easy cases and applied to hard ones. We call this the calibration-distribution mismatch. Our fix samples each calibration engine at a random mid-life point instead of its last cycle, so calibration errors come from the same part of the lifecycle as deployment. Coverage rises to 85–94% on the benchmark and 78–81% on the flight-condition dataset, with no change to the underlying model, although the latter stays below the target. On three of four benchmark subsets, the corrected intervals match the coverage of conformalized quantile regression while being 26–38% narrower. For engines with a predicted remaining useful life below 50 cycles, random-cutoff calibration keeps 93–100% coverage, while conformalized quantile regression falls to 84% and 73% on the two six-condition subsets.
R7257 10:55-11:10	Analysis of Road Traffic Operational Degradation under Hazardous Driving States **Author(s):** Bo Yao, Enrico Zio, Junhua Wang, Ting Fu, Qiangqiang Shangguan, Yaxuan Li, Wenyi Liao **Presenter:** Bo Yao, Politecnico di Milano, Italy **Abstract:** Drivers are the important component of road traffic systems, and hazardous driving states can impair traffic system operation. However, the risk levels associated with different hazardous behaviors relative to the driver population remain unclear. Vehicle trajectories capture the interaction between road infrastructure and driver behavior and provide an observable representation of traffic operation. This study uses a generative inference method to simulate the trajectory distribution of the driver population. A driving simulator records trajectories during distraction involving phone viewing or water intake, alcohol-impaired driving, and drunkenness driving. Within a human reliability analysis framework, equivalent quantile levels and extreme-value extrapolation of lane-boundary margins are used to estimate human error probabilities, performance shaping factors, and spatial failure rates. These measures locate hazardous-state trajectories within the population distribution and quantify operational degradation. Application to a

	simulated reconstruction of an actual road showed that the generated population distribution encompassed all observed hazardous-state trajectories. Lane-departure risk depended strongly on the road environment, and predicted operational failures closely agreed with observed boundary encroachments. The framework differentiated the population-relative risk levels of multiple hazardous driving states and provides an analytical basis for improving the operational safety of road infrastructure.

►Session 12

► System Reliability

► Session Chair: Qingyuan Zhang, Hangzhou International Innovation Institute of Beihang University, China

► 9:00-11:20 | November 25, 2026, Wednesday | RAFFAELLO

► R7207, R7042-A, R7086, R7128, R7154-A, R7188, R7240, R7045



Session Keynote Lecturer 9:00-9:20

Qingyuan Zhang, Hangzhou International Innovation Institute of Beihang University, China

Speech Title: System Reliability Evolution and Risk Assessment under Discrete-Continuous Process Coupling

Abstract: Many aerospace systems are dynamic hybrid systems in which discrete state transitions and continuous physical processes interact, making reliability evolution and risk difficult to predict. Existing methods often model discrete and continuous processes separately, so the causal links among component degradation, system performance loss, and mission risk remain difficult to quantify. This talk presents a unified framework based on the thoughts of performance margin, in which the effect of both processes are described in a stochastic hybrid automata model or a multilayer information-substance-energy network. Three case studies will be introduced to demonstrate the framework: a UAV parachute system, an A320 environmental control system, and an aircraft landing gear system. The results show that the framework can support reliability prediction, safety design, and risk-informed maintenance of complex systems.

R7207 9:20-9:35	Auditable Simulation Evidence for Reliability and Safety Assessment: Provenance of Multi-Level Simulation Runs **Author(s):** Sebastian Weber, Max Scheerer, Robert Heinrich **Presenter:** Max Scheerer, FZI Research Center for Information Technology, Germany **Abstract:** Multi-level simulation (MLS) executes one scenario on models of different abstraction levels and switches between them at runtime. Switches are triggered by policies and admitted or rejected by validation gates, and each carries the behavioral state across simulator boundaries. Whether a result segment can serve as evidence in a reliability or safety assessment therefore also depends on a decision and validation history that conventional outputs do not record. A rejected or aborted switch leaves no trace in the result files, and a commit on a level whose validity check failed leaves at most a flag. We map a compact, simulator-independent run-time model of MLS switching, including declared gate failure semantics, onto the W3C PROV data model and implement a deterministic PROV-JSON exporter with four audit queries that supply the switching-related part of the records required by the simulation-credibility standard NASA-STD-7009B, among them "why did segment X run at level L?" and "which results depend on degraded segments?". On 51 runs of a deterministic MLS harness, the answers computed from the exported documents alone agree with the harness's event log for all 8,537 switched segments and

	all 64 rejected, aborted, or degraded switches. Every document parse and re-serializes with standard PROV tooling. Graphs grow linearly with the number of switches, and answering each query once takes under a millisecond for typical runs.
R7042-A 9:35-9:50	Stability of the Reliability of the System against Fluctuations in Component Reliabilities **Author(s):** Kiyori Shindo **Presenter:** Masahro Hayashi, Tokyo City University, Japan **Abstract:** System reliability is affected by two factors. One is the component reliabilities, and the other is the system structure. Therefore, a natural question arises: “How much does each factor affect the system reliability?” When the former factor has a great effect, then collecting data for accurate estimations of the component reliabilities becomes especially important, while the work needed to collect such data may be intractably long. On the other hand, when the latter factor has the greater effect, then the work needed to collect such data would be less because high accuracy would not be needed. Here, we propose an approach to answer this question. The key idea is to construct a polynomial (reliability polynomial) expressing the system reliability in terms of component reliabilities while assuming every component reliability is the same value p. It is true that by varying the value of p from 0 to 1 the reliability polynomial outputs a curve that is unique for each system structure. However, this curve fluctuates if we input values different from p into the parameters expressing the component reliabilities. If the curve fluctuates largely with inputs different from p, then we can say that the component reliabilities have a great effect on system reliability; else if the curve fluctuates only a little, we can say that the system structure has a greater effect. The numerical results suggest that the latter is true except for the case that the component reliabilities are unrealistically low.
R7086 9:50-10:05	Structural Importance as a Feature Importance Measure for Machine Learning **Author(s):** Elena Zaitseva, Vitaly Levashenko, Kristina Dostalova, Alexandra Cizmarova **Presenter:** Vitaly Levashenko, University of Žilina, Slovakia **Abstract:** Feature importance assessment plays an important role in machine learning, supporting model interpretation, feature selection, and dimensionality reduction. Existing feature importance measures are primarily derived from statistics, information theory, and machine learning methodologies, while concepts from reliability analysis remain largely unexplored in this context. This paper proposes applying Structural Importance, a well-established importance measure from reliability engineering, as a feature importance measure for machine learning. The proposed approach treats a classifier as a structure function and evaluates the influence of input attributes by observing changes in classification outcomes. A correspondence between reliability analysis concepts and feature importance analysis is established, enabling the computation of feature importance scores using Structural Importance. The resulting values provide a ranking of attributes according to their influence on classifier behavior and can be used for feature importance assessment and feature selection. The proposed method was evaluated on the Breast Cancer Wisconsin and Fetal Cardiotocography datasets using Decision Tree, Random Forest, Support Vector Machine, and Multi-Layer Perceptron classifiers. Experimental results demonstrate that the proposed approach achieves classification performance comparable to, and in several cases better than, traditional filter-based and wrapper-based feature selection methods, confirming the

	potential of reliability-based importance analysis for machine learning applications.
R7128 10:05-10:20	Analysis and Detection Method for Random Hardware Faults Based on Markov Chains and Dynamic Fault Trees **Author(s):** Xinhua Luo, Cuiping Shao, Huiyun Li, Zhimin Tang, Yihan Chen **Presenter:** Cuiping Shao, Shenzhen University of Advanced Technology, China, and Guangdong Provincial Key Laboratory of Computility Microelectronics, China **Abstract:** Safety-oriented testing benefits from detecting faults associated with critical functions early in a constrained test sequence. This paper presents a workflow that links a selected safety goal to register-level test prioritization. Functional-dependency (FDEP) paths in a dynamic fault tree are mapped to local continuous-time Markov chain models. The resulting transition weights are combined with register fault probabilities to quantify relative register importance. A greedy algorithm then uses these importance values to reorder an existing Tessent-generated pattern set. In an automotive microcontroller case study comprising 11 safety-related registers and 589 patterns, the reordered sequence increased modeled-fault coverage by 21.90 percentage points within the first 10\% of patterns. The corresponding importance contribution increased by 0.231. The top 20\% of the reordered sequence achieved an importance contribution of 93.4\%, and the average relative reduction in fault-detection position was 82.71\%. Final modeled-fault coverage remained unchanged when all patterns were applied. The case study therefore demonstrates that the workflow can be operationalized with existing tooling and simple quantitative metrics, providing a practical means of prioritizing safety-relevant faults when the available pattern budget is limited.
R7154-A 10:20-10:35	First-Order Reliability Assessment of Singly Reinforced Concrete Flexural Structural Elements by Statistical Linearization **Author(s):** Zhmagul Nuguzhinov, Serik Akhmediyev, Valentin Mikhailov, Gulnara Nuguzhinova, Assemkhan Nuguzhinova, Nazerke Kopbalina **Presenter:** Zhmagul Nuguzhinov, Abylkas Saginov Karaganda Technical University, Karaganda **Abstract:** Partial-factor design conceals the scatter of material strengths, geometry and actions behind a single set of characteristic values. For a simply supported reinforced-concrete (RC) flexural member this paper reconstructs the flexural limit-state function from the rectangular-stress-block model and treats the governing parameters as random variables. A first order second-moment (statistically linearized) expansion supplies the mean and variance of the safety margin, from which the reliability index and the Gaussian probability of failure-free operation are obtained. A companion finite-element check in ANSYS is used only to confirm the deterministic moment capacity. Parametric variation of the tensile reinforcement ratio between 0.20% and 0.25% shows that a target survival probability of 0.98 is reached at $\mu \approx 0.24\%$ ($A_s \approx 5.8$ cm²), whereas the equivalent deterministic calculation recommends $\mu \approx 0.215\%$. The increment is modest in steel consumption but systematic in reliability. The same numbers are then compared with the EN 1990 target index for ultimate limit states ($\beta_t = 3.8$ for reliability class RC2 and a 50-year reference period), which makes explicit that a survival probability of 0.98 is a service-oriented, not a standard ULS, requirement. The procedure is intended as a design-stage screening tool rather than a substitute for a full FORM/SORM or Monte Carlo study.

R7188 10:35-10:50	First-Order Reliability Assessment of Singly Reinforced Concrete Flexural Structural Elements by Statistical Linearization **Author(s):** Zhmagul Nuguzhinov, Serik Akhmediyev, Valentin Mikhailov, Gulnara Nuguzhinova, Assemkhan Nuguzhinova, Nazerke Kopbalina **Presenter:** Zhmagul Nuguzhinov, Abylkas Saginov Karaganda Technical University, Karaganda **Abstract:** Partial-factor design conceals the scatter of material strengths, geometry and actions behind a single set of characteristic values. For a simply supported reinforced-concrete (RC) flexural member this paper reconstructs the flexural limit-state function from the rectangular-stress-block model and treats the governing parameters as random variables. A first order second-moment (statistically linearized) expansion supplies the mean and variance of the safety margin, from which the reliability index and the Gaussian probability of failure-free operation are obtained. A companion finite-element check in ANSYS is used only to confirm the deterministic moment capacity. Parametric variation of the tensile reinforcement ratio between 0.20% and 0.25% shows that a target survival probability of 0.98 is reached at $\mu \approx 0.24\%$ ($A_s \approx 5.8$ cm²), whereas the equivalent deterministic calculation recommends $\mu \approx 0.215\%$. The increment is modest in steel consumption but systematic in reliability. The same numbers are then compared with the EN 1990 target index for ultimate limit states ($\beta_t = 3.8$ for reliability class RC2 and a 50-year reference period), which makes explicit that a survival probability of 0.98 is a service-oriented, not a standard ULS, requirement. The procedure is intended as a design-stage screening tool rather than a substitute for a full FORM/SORM or Monte Carlo study.
R7240 10:50-11:05	Predictable or Reliable? An Information-Theoretic Robustness Metric for Networks under Random Failures **Author(s):** Robert Adamovski, Robert E. Kooij **Presenter:** Robert Adamovski, TU Delft, The Netherlands **Abstract:** In this paper, an information-theoretic robustness metric is proposed. Random link (node) failures transform a fixed network observable, in this case the effective resistance between two nodes, into a random variable. We consider the event that no path remains between the two nodes (a disconnection) a separate catastrophic failure state. The metric includes the probability of catastrophic failure as well as the Shannon entropy of the response among the surviving states. A network gets a high score if it rarely fails and its response stays stable or predictable. Given that the response is real-valued, we define a resolution at which two responses are treated as different. We prove that the metric is scale invariant, decomposes by the chain rule, does not decrease when the resolution parameter is increased, and reduces to two-terminal reliability in the coarse limit. This paper also shows that the resolution acts as a tuning parameter. At finer resolution, the metric is strongly anti-correlated with reliability, algebraic connectivity and link count: redundancy makes networks more reliable but less predictable. At coarse resolution it largely agrees with the legacy metrics. Monte Carlo experiments on five families of 50-node networks show this trade-off.
R7045 11:05-11:20	An AI Agent-Based Framework for Co-Analysis of Functional Safety and Cybersecurity **Author(s):** Antonino Armato, Farhan Rasheed, Cristiano Novello, Alessandro Catasta, Francesco Lertora, Brian Taylor **Presenter:** Alessandro Catasta, Cadence Design Systems, Italy

Abstract: The convergence of functional safety and cybersecurity in safety-critical automotive semiconductor systems poses a fundamental challenge to traditional analysis methods. Existing co-analysis frameworks, including Failure and Threat Modes and Effects Analysis (FTMEA) and related approaches, rely on manual identification of common effects and expert-driven evaluation of countermeasures, resulting in high effort, limited reproducibility, and potential oversight in complex designs. This paper introduces a novel AI Agent-based framework for the automated co-analysis of functional safety and cybersecurity. The proposed agent autonomously processes Failure Mode and Effects Analysis (FMEA) artifacts and Threat Analysis and Risk Assessment (TARA) outputs, identifies common effects resulting from both hardware faults and cyberattacks, and evaluates the mutual influence of safety mechanisms and cybersecurity countermeasures. A case study on the OpenRISC processor core proves that the AI agent effectively identifies four groups of common effects and achieves an average Risk Priority Number (RPN) reduction of 25.8% through cross-domain countermeasure reuse and completes the full analysis in few minutes. The results indicate that AI-assisted co-analysis can systematically uncover previously undetected cross-domain risks and provide a transparent, reproducible basis for countermeasure evaluation.

►Session 13

► Maintenance

Session Chair: Yiliu Liu, Norwegian University of Science and Technology, Norway; Masoud Naseri , UiT The Arctic University of Tromsø, Norway

► 9:00-10:50 | November 25, 2026, Wednesday | TIZIANO

► R7050, R7054, R7063, R7033, R7167, R7258



Session Keynote Lecturer 9:00-9:20

Masoud Naseri, UiT he Arctic University of Tromsø, Norway

Speech Title: Deep Reinforcement Learning Optimisation of Maintenance and Logistics Planning for Offshore Oil and Gas Processing Plants

Abstract: Offshore oil and gas (O&G) processing facilities operate under harsh conditions in which components degrade by various dependent mechanisms Maintenance plans are, then, defined to ensure high production availability. However, these maintenance plans are constrained by a number of factors, including number of maintenance teams available, spare-part logistics, and storage, etc. This work proposes a DRL-based framework for maintenance and logistics planning optimisation. Components degradation is modelled by a compound degradation process consisting of a continuous wear process and damage-dependent random shocks which, in turn, affect the continuous wear process. Maintenance interventions are considered possibly imperfect, implemented by a limited number of maintenance teams and constrained by the availability of spare parts. The maintenance optimisation, then, integrates the logistics planning. This is mathematically formulated as a Markov decision process, which is solved using the Proximal Policy Optimization algorithm coupled to a logistics and work-permit scheduler, with a forward simulation engine predicting the components' remaining useful life. The stochastic repair and lead times introduce delayed-reward and credit-assignment problems that challenge the learning process. To address these technical challenges, a state-augmentation-based approach is proposed embedding spare parts in transit, warehouse availability, ongoing maintenance interventions pending work-permit requests. The proposed optimisation framework is applied to an O&G production plant of literature.

R7050 9:20-9:35	Using Life Cycle Cost Monitoring to Optimise Maintenance **Author(s):** Zdenek Vintr, Michal Vintr **Presenter:** Zdenek Vintr, University of Defence, Czech Republic **Abstract:** This paper presents a method for optimising preventive replacement intervals of degradable components using Life Cycle Cost analysis and operational maintenance data. The proposed mathematical model combines acquisition, replacement, and corrective maintenance costs to identify the preventive replacement interval that minimises the unit life cycle cost. Unlike approaches based solely on predictive analyses, the proposed method utilises operational data to validate and refine maintenance programmes under real operating conditions. A railway vehicle

	case study demonstrates the application of the model and shows that extending the originally prescribed replacement interval can reduce total unit costs while maintaining acceptable operational performance.
R7054 9:35-9:50	A Metrology-Based Methodology for Gear Refurbishment and Residual Life Assessment **Author(s):** Edoardo Gianolio, Sandro Marta, Andrea Mura **Presenter:** Andrea Mura, Politecnico di Torino, Italy **Abstract:** Gears are essential mechanical components for power transmission but are naturally subject to wear that can compromise their functional integrity. While complete replacement is the common industrial practice, functional restoration represents a sustainable and efficient alternative for large or high value components. This research presents a methodology for gear repair through subtractive machining based on an integrated decision-making process. The approach utilizes non-contact laser scanning to quantify damage even on complex surfaces. Based on measured wear, a specific material removal thickness is defined to preserve the hardened surface layer, followed by a recalculation of the profile shift coefficient. The strategy includes the manufacturing of a new mating pinion to ensure proper kinematics and structural integrity. The validity of the repair is confirmed through structural verification according to international standards evaluating both bending and contact stress. By applying an inverse linear damage rule, it is possible to estimate the residual operational life of the refurbished gear set ensuring the restoration of the original load capacity.
R7063 9:50-10:05	Neighborhood-Aware Optimization for Smart Building Predictive Maintenance **Author(s):** Anas Hossini, Leïla Kloul, Maël Guiraud, Benjamin Cohen Boulakia **Presenter:** Anas HOSSINI, Paris Saclay University, France **Abstract:** Predictive maintenance of smart buildings must keep the Quality of Service (QoS) above its required level at minimal long-term cost. This constrained optimization problem is commonly tackled with neighborhood-based metaheuristics such as Simulated Annealing (SA), yet the neighborhood itself—how candidate solutions are generated at each iteration—is rarely studied. We show that this choice strongly impacts the quality of the resulting strategies. We build a reliability model that captures component aging and inter-system fault propagation, and derive three problem-aware neighborhoods from it, which we compare under identical conditions on the lighting system of a real smart building. The neighborhood alone shifts performance as much as changing the optimization algorithm, and a poorly designed one can bias the very signal used to evaluate the strategies. A hybrid reinforcement learning–SA algorithm inherits these gains.
R7033 10:05-10:20	A KG-BN-Based Three-in-One Operation and Maintenance Risk Assessment Method for Salt Cavern Compressed Air Energy Storage Systems **Author(s):** Mingjie Xu, Jinqiu Hu, Yanyan Wang, Tianyu Wang **Presenter:** Mingjie Xu, China University of Petroleum, China **Abstract:** Salt cavern compressed air energy storage (CAES) couples surface facilities, wellbore structures, and geological bodies, which makes operation and maintenance risk assessment difficult using isolated methods. This study proposes a three-in-one risk-assessment method

	integrating a knowledge graph (KG) with a Bayesian network (BN), hereafter termed KG-BN. The KG organizes engineering objects, monitoring evidence, risk factors, abnormal states, and accident consequences. Event-specific local subgraphs are extracted from abnormal field evidence and mapped to a BN for posterior inference, sensitivity analysis, scenario analysis, and control-measure deduction. In the case study, the high-risk probability of serious accident consequences increases from 0.184 to 0.460. Removing abnormal gas-concentration and annulus-pressure evidence reduces this probability by 0.10 and 0.09, respectively. Layer-wise ablation shows that the wellbore-structure layer accounts for 60.7% of the total reduction, identifying wellbore integrity and leakage as the dominant risk sources.
R7167 10:20-10:35	A Systems-Based Modular Framework for Network Risk-Aware Infrastructure Renewal Planning **Author(s):** Sungin Cho, Ajith Parlikad **Presenter:** Sungin Cho, University of Cambridge, UK **Abstract:** Infrastructure renewal planning is often asset-centric, with decisions informed by condition, failure likelihood, and consequence measures that may capture local failure effects. However, the wider consequences and renewal significance of an asset depend on the response of the interconnected assets in the network, including topology, redundancy, and system state, which are not always systematically incorporated into renewal decisions. This paper proposes a systems-based and modular framework for network risk-aware infrastructure renewal planning that integrates asset deterioration, network level consequences, renewal policies, planning constraints, and uncertainty within a common simulation environment. The framework comprises three layers. The system representation layer maps individual assets to infrastructure networks through topology and governing flow models, enabling failure consequences and renewal actions to be evaluated in network level. The decision modelling layer combines asset level failure likelihoods with network consequences to formulate risk-informed renewal criteria and alternative policies. The planning layer uses stochastic simulation to represent uncertain asset failures, evolving network states, and subsequent renewal actions over the planning horizon. The framework is demonstrated on the IEEE 118-bus model, where direct and conditional network risk indicators are used to formulate and compare alternative renewal policies over a planning horizon. The framework aims to provide a flexible decision-support approach for more system-informed and evidence-based renewal planning.
R7258 10:35-10:50	An Integrated Stochastic Petri Net and Bayesian Network Approach to Reliability Assessment of Industrial Process Systems **Author(s):** Mei Chen, Seyed Ali Hosseini, Thomas Potthast, Dario Valcamonico **Presenter:** Thomas Potthast, Leibniz University Hannover, Germany **Abstract:** Reliability assessment of industrial process systems requires models capable of representing both the physical evolution of the process under component faults and the uncertainty associated with the probabilistic characterization of system health. To address these two aspects, this work proposes a method that combines stochastic Petri nets (PNs) and dynamic Bayesian networks (DBNs). The PN represents component-state transitions and process dynamics and is used as a physics-based generative model. A set of N Monte Carlo realizations over T time steps is

	generated and converted into discrete state trajectories describing the evolution of component and process variables. These trajectories are then used to learn the conditional probability tables (CPTs) of a DBN representing the health state of the system. The network structure reflects the physical dependencies in the process. CPT entries are estimated from simulated state counts, with a uniform distribution assigned to parent configurations absent from the data. Exact inference yields the probability that the system is in an unsafe state at each time step. The framework is applied to the DAMADICS benchmark, considering the thin-juice inlet actuator, its bypass valve and the first evaporator.

►Session 14

► Prognostics and System Health Management (II)

Session Chair: Hao Rong, Liverpool John Moores University, UK; Matteo Davide Lorenzo Dalla Vedova, Politecnico di Torino, Italy

► 9:00-10:50 | November 25, 2026, Wednesday | BOTTICELLI

► R7253, R7129, R7186, R7061, R7078



Session Keynote Lecturer 9:00-9:20

Hao Rong, Liverpool John Moores University, UK

Speech Title: Data-Driven Scenario Generation for Autonomous Shipping: Methods and Applications

Abstract: The development and evaluation of autonomous ship collision avoidance systems require representative and diverse encounter scenarios. However, generating realistic scenarios that reflect actual ship navigation behaviours remains a significant challenge. This presentation will introduce a data-driven framework for generating ship encounter scenarios based on historical Automatic Identification System (AIS) data. The framework begins with the identification and extraction of near-collision encounters from historical ship trajectories. These encounters are subsequently characterised using parameters describing the relative motion and interactions between vessels. A clustering-based approach is employed to identify representative encounter patterns, providing a foundation for understanding the diversity of real-world navigational situations. Building on these patterns, a scenario generation methodology is developed to produce encounter scenarios that preserve characteristics observed in historical maritime traffic. The presentation will discuss the framework's methodology, scenario representation, and evaluation, highlighting its potential to support systematic testing and assessment of autonomous ship collision avoidance systems. This research contributes to developing more realistic and representative testing environments for Maritime Autonomous Surface Ships (MASS).

R7253 9:20-9:35	Per-Phase Electro-Thermal Modelling of a BLDC-Driven Electromechanical Actuator for Model-Based Fault Identification: A Simulation Study **Author(s):** Matteo Costarelli, Leonardo Baldo, Paolo Maggiore, Matteo Davide Lorenzo Dalla Vedova **Presenter:** Matteo Davide Lorenzo Dalla Vedova, Politecnico di Torino, Italy **Abstract:** The adoption of electromechanical actuators (EMAs) in aircraft systems is increasing, but their application to flight-critical functions remains limited by reliability concerns and potentially critical failure modes. Model-based health monitoring can support their safe operation by estimating fault-related parameters from measured actuator responses. However, these estimates depend on the ability of reference models to account for operating conditions affecting the monitored signals. Unmodelled variations may otherwise be attributed to degradation, leading to incorrect health assessments. Winding temperature is particularly relevant, as it modifies motor

	resistance and the electrical signals used for fault identification. This paper examines the thermal response of a brushless DC motor within a high-fidelity EMA simulation model. A lumped thermal network represents the three phase windings separately and connects them to a common stator-housing node. Instantaneous Joule losses heat the windings, whose temperature-dependent resistances feed back into the electrical model. Thermal parameters combine manufacturer specifications, modelling assumptions and finite-element estimates of thermal masses. Four nominal simulation cases, comprising step and chirp commands with and without external load, show temperature rises below 1 K without load and approximately 20 K over 2 s under load. During loaded position holding, the fixed commutation state produces a phase-temperature imbalance of several kelvin, which a common winding-temperature model cannot resolve. The resulting resistance asymmetry is discussed in relation to fault-identification signatures, providing a basis for thermally aware EMA health monitoring and prognostics.
R7129 9:35-9:50	Certifiability-Aware Remaining Useful Life Prediction under Operating-Condition Shift via Condition-Aware Weighted Conformal Calibration **Author(s):** Lunhao Ju, Haiyue Yu, Yajie Dou, Ping Jiang **Presenter:** Lunhao Ju, National University of Defense Technology, China **Abstract:** Remaining useful life (RUL) prediction under changing operating conditions requires more than accurate point estimates: available calibration data may not support a finite uncertainty certificate for the target distribution. This paper develops condition-aware weighted conformalized quantile regression (CA-WCQR) for RUL interval calibration, finite-certifiability assessment, and conservative abstention. A condition descriptor enables exact or estimated calibration-to-target density-ratio weighting; the construction includes the normalized target mass and returns \nocert{} when support is insufficient or this mass exceeds the miscoverage level. Experiments on the variable-condition NASA C-MAPSS FD002 and FD004 subsets use five seeds and engine-disjoint splits. The official test distributions exhibit weak natural shifts, under which weighted and pooled calibration closely agree. Under controlled shifts, coverage-error variations remain small and uncertain, while severe evidence scarcity substantially reduces finite certifiability. A secondary risk analysis illustrates the consequences for abstention, inspection, and cost, but is interpreted descriptively because failure events are sparse.
R7186 9:50-10:05	Longitudinal Ball-Screw Monitoring Using Regional Reconstruction Error from a Nominally Trained Convolutional Denoising Autoencoder **Author(s):** Rodrigo Stockler Tognetti, Francesco Morgan Bono, Simone Cinquemani **Presenter:** Rodrigo Stockler Tognetti, Politecnico di Milano, Italy **Abstract:** study evaluates whether regional reconstruction-error (RE) features from a nominally trained and frozen convolutional denoising autoencoder (CDAE) retain longitudinal sensitivity in a chronologically later portion of a ball-screw life test. The CDAE was trained only on nominal-condition data from campaigns separate from the 166-acquisition CATE life test. The 163 post-commissioning acquisitions were retrospectively divided into a development interval (9–170 h, n = 105) and a final temporal holdout (171–228 h, n = 58). Regional definitions were fixed before holdout evaluation. In development, the Y-axis low-frequency and Z-axis high-frequency regional scores yielded Spearman coefficients of 0.807 and 0.669, respectively. In the holdout, these

	decreased to −0.174 and 0.308 and moving-block bootstrap intervals included zero. Simple baselines performed better on the same holdout, including raw Y/Z RMS (ρS = 0.946), Y-band spectral power (ρS = 0.715), and Z-band spectral power (ρS = 0.630). The results show that strong development-set associations do not establish temporal transferability. Within this single campaign, the evaluated regional CDAE RE features did not outperform simpler vibration baselines and are therefore interpreted as anomaly-sensitive features rather than calibrated measures of wear, preload loss, or formal health indicators.
R7061 10:05-10:20	Reliability-Aware Bearing RUL Prediction via Late-Life Weighted Evidential Learning and Conformal Calibration **Author(s):** Siyu Zhu, Qianqian Zhang, Yuening Zhu, Lu Wei, Zheng Qian **Presenter:** Siyu Zhu, Beihang University, China **Abstract:** Bearing remaining useful life (RUL) prediction in rotating machinery is a data-driven reliability assessment task rather than pure point regression. Reliable prognostics therefore require joint consideration of prediction error, uncertainty calibration, and late-life overestimation risk, particularly because optimistic predictions near failure may delay maintenance intervention. This paper proposes a reliability-aware RUL prediction framework that integrates late-life weighted evidential learning with source-validation conformal calibration under a strict same-condition, bearing-level holdout protocol. A deep temporal sequence network is used to model degradation dynamics, while the evidential objective assigns larger penalties to near-failure samples and unsupported evidence under large residuals, reducing over-confident and over-optimistic predictions in the maintenance-critical region. Source-validation conformal calibration then constructs calibrated prediction intervals without using test-bearing labels, lifetime statistics, or normalization information. Experiments on the XJTU-SY bearing dataset show that the proposed method achieves an MAE of 0.1921, an RMSE of 0.2813, a PICP of 0.9681 at the 95\% nominal coverage level, a PINAW of 0.7864, a calibrated NLL of 0.2974, an uncertainty-error Spearman correlation of 0.2954, and an overall SROE of 0.0840. These results demonstrate that combining uncertainty quantification, conformal calibration, and late-life risk control provides a more dependable basis for data-driven reliability assessment and risk-aware bearing prognostics.
R7078 10:20-10:35	Continual Degradation Trajectory Prediction for Lithium-Ion Batteries under Nonstationary Conditions Using Elastic Weight Consolidation **Author(s):** Junjie Huang, Jian Ma, Tonglin Luo, Xiangyu Jin, Mengwei Li **Presenter:** Junjie Huang, Beihang University, China **Abstract:** Data-driven performance degradation prediction supports proactive maintenance, but monitoring streams in industrial applications are often nonstationary because operating conditions, device heterogeneity, and product designs change over time. These shifts create a stability-plasticity dilemma: models must adapt to new degradation patterns without forgetting previously learned ones. To address this problem, this paper proposes an Attention-based Memory-Augmented Continual Learning (AM-CL) framework for lithium-ion battery degradation trajectory forecasting. AM-CL combines a degradation trajectory prediction network based on one-dimensional convolution and gated recurrent units (DTP-GRUC), which uses an attention mechanism to capture critical temporal features and nonlinear turning points in long

	health-indicator sequences, with Elastic Weight Consolidation (EWC), which protects parameters important to historical degradation modes through the Fisher Information Matrix. Experiments on a lithium-ion battery dataset provided by Contemporary Amperex Technology Co., Limited (CATL) evaluate AM-CL under four dynamic scenarios: temporal, unit, feature/type, and domain expansion. In the temporal expansion scenario, AM-CL reduces average prediction root mean square error (APRMSE) by 12% relative to Covering Data Training (CDT). Across the remaining scenarios, AM-CL improves historical-knowledge retention relative to CDT while avoiding the computational cost of full dataset retraining

►Session 15

► Safety Analysis (II)

► Session Chair: Rui He, University of Electronic Science and Technology of China, China

► 9:00-11:05 | November 25, 2026, Wednesday | MASCAGNI

► R7020, R7126, R7135, R7237, R7145, R7142, R7148



Session Keynote Lecturer 9:00-9:20

Rui He, University of Electronic Science and Technology of China, China

Speech Title: Human–Machine Collaboration for Dynamic Fault Root Cause Tracing in Complex Mechanical Systems

Abstract: The process of root cause tracing in large-scale mechanical systems is iterative. Initial symptom observations may not provide sufficient evidence to identify the root cause of a fault. Maintenance engineers therefore conduct further diagnostic actions and use new findings to update their understanding of the fault and determine subsequent diagnostic or corrective actions. This process involves human–machine collaboration, in which maintenance engineers perform diagnostic actions and provide the findings to a model. The model then rules out unlikely candidate root causes and recommends the next action. An important decision is which diagnostic action to perform next, as different action sequences may lead to different costs. This talk first considers fault root cause tracing when symptom variables and candidate root causes are predefined. We formulate the root cause tracing process as a Markov decision process. To describe the relationships between symptoms and root causes, we construct a Markov logic network. The parameters of this probabilistic graphical model are estimated using a variational expectation-maximization algorithm. Based on the constructed model, the posterior probabilities of candidate root causes are updated as new diagnostic findings become available. We further integrate the model with reinforcement learning to optimize the sequence of diagnostic actions and reduce expected diagnostic costs. A real-world case study involving starting air system failures of harbor tug engines is presented to illustrate the performance of the proposed method. The talk then considers a more general, open-ended root cause tracing problem, where neither symptom variables nor candidate root causes are predefined. We discuss how large language models can identify potential root causes from symptom observations, recommend subsequent diagnostic actions, and update their assessments based on new findings. The talk concludes with a discussion of open research challenges.

R7020 9:20-9:35	A Structured Dataset for Human and Organizational Factors Analysis in Nuclear Power Plants: Evidence from NRC HFIS Reports (1998-2010) **Author(s):** Xingyu Xiao, Jiale Chen, Ben Qi, Jingang Liang, Jiejuan Tong, Haitao Wang **Presenter:** Xingyu Xiao, Tsinghua Univeristy, China **Abstract:** Human factors events are a leading contributor to safety-significant incidents at nuclear power plants, yet no machine-readable, longitudinal dataset has previously existed to enable

	systematic quantitative analysis at scale. This paper fills that gap by introducing the first structured, publicly released dataset derived from the NRC Human Factors Information System, covering 104 plant units across 13 years (1998–2010) and comprising 58,935 event records. We developed an automated PDF parsing pipeline capable of resolving multi-page record spans, recovering truncated subcategory descriptions through a curated 99-code mapping, and achieving a 96.6% exact-match validation rate against source report totals, a level of fidelity previously unattainable through manual extraction. The resulting dataset enables longitudinal trend analysis, cross-plant and PWR/BWR comparative studies, probabilistic risk assessment, and machine learning applications that were simply out of reach before. Released under CC BY 4.0, this resource is positioned to become a foundational benchmark for quantitative human reliability research in the nuclear industry.
R7126 9:35-9:50	An Accident-Evidence-Based Framework for Human Reliability Assessment in Intelligent Shipping **Author(s):** Zhe Hu, Yangang Sun, Hao Hu, XingZhi Yang, Lei Dai, Yi Hu, Zhipeng Zhang, He Huang **Presenter:** Xingzhi Yang, Shanghai Jiao Tong University, China **Abstract:** The increasing integration of automation and autonomous functions into maritime operations is transforming seafarers from direct operators into supervisory decision makers. Under such conditions, human reliability risks arise not only from individual errors but also from the interaction among human cognitive states, operational processes, environmental constraints, and task demands. Existing human reliability analysis (HRA) approaches have limited capability in representing dynamic transitions between supervision and manual intervention in intelligent shipping environments. This paper proposes a Human–Operation–Environment–Task (HOET)-based human reliability assessment framework for intelligent shipping, which derives human failure modes from historical accident evidence and integrates accident records, experimental observations, and expert knowledge through a reliability-aware evidence fusion mechanism. A total of 457 accident-related records were coded from investigated maritime casualties and safety reports. Fault tree analysis (FTA) and event tree analysis (ETA) were applied to identify recurrent human failure modes and reconstruct the barrier degradation process. Based on the identified mechanisms, a HOET indicator system was established, and a Bayesian Network (BN) model was developed to support probabilistic reasoning of human reliability vulnerabilities. Two documented grounding cases, MV Wakashio and MV Ever Given, were retrospectively analyzed to examine the diagnostic capability of the proposed framework. The results indicate that control transition and manual takeover represent critical vulnerability points in intelligent shipping operations. The proposed framework provides a structured approach for identifying critical human reliability factors, tracing risk propagation pathways, and supporting safety improvement strategies for future human–autonomy collaboration in maritime systems.
R7135 9:50-10:05	KAMP4AS: Architecture-Based Change Propagation Analysis for Safety-Critical Automotive E/E Systems **Author(s):** Max Scheerer, Sebastian Weber, Robert Heinrich **Presenter:** Max Scheerer, FZI Research Center for Information Technology, Germany

	Abstract: Changes to automotive electrical/electronic (E/E) architectures rarely stay local: replacing an electronic control unit (ECU), migrating a bus, or modifying a signal propagates across hardware, software, wiring harness, power supply, and the safety argumentation required by ISO~26262. The impact of such changes is still assessed largely by hand, which is slow and prone to omissions. This paper presents KAMP4AS, an automotive extension of the KAMP framework for architecture-based change impact analysis. KAMP4AS adds (i) a dedicated E/E hardware metamodel covering nodes, buses, gateways, signals, power rails, wiring harness, and services; (ii) an explicit deployment bridge that maps software components onto this hardware; and (iii) an automated change propagation analysis, iterated until no further impacts emerge, that combines structural propagation rules with quantitative constraint analyses for bus load, power budgets, end-to-end timing, cybersecurity (ISO/SAE~21434), and, as a first-class concern, ASIL consistency of safety-critical signal paths. Detected violations such as ASIL mismatch, power overload, or timing violation are turned into concrete, role-annotated work plan tasks.
R7237 10:05-10:20	A Method-Neutral Library for Human Reliability Analysis Method Evaluation **Author(s):** Zdenko Simic, Luca Podofillini, Vinh Dang **Presenter:** Zdenko Simic, PSI, Switzerland **Abstract:** Human Reliability Analysis (HRA) is an important element of Probabilistic Safety Assessment (PSA) for nuclear power plants, with several methods currently in use. A consistent comparison and, more generally, evaluation of these methods requires a common interpretation of the scope and boundaries of the Human Failure Events (HFEs), as well as of the associated performance conditions, typically translated into Performance Shaping Factors (PSFs). Achieving such consistency is challenging because guidance for qualitative analysis, when present, varies considerably across HRA methods in quality and level of detail. Building on earlier work by the authors on method-neutral Qualitative Analysis (QA) and reference human error probabilities (HEPs), this paper presents the motivation, framework, and pilot implementation of an HFE Library, as a transparent, reusable framework for applying, comparing, and reviewing HRA methods against a controlled qualitative basis. The library organizes each HFE entry into four components: HFE Description, method-neutral QA, Evidence and Reference HEP, and HRA Method Applications. This architecture separates factual scenario information, method-neutral interpretation, evidence-informed benchmarking, and method-specific quantification. The library uses linked spreadsheet workbooks for the shared HFE basis, the evidence and Reference HEP record, and applications of NARA, EPRI CDBT/THERP, and IDHEAS-ECA.
R7145 10:20-10:35	Introducing Configurational Analysis into Product Safety Engineering: A Connector-Fire Case **Author(s):** Shun Zhang, Haiwen Lu **Presenter:** Shun Zhang, Cisco, China **Abstract:** Safeguard architectures in product-safety standards embody technical propositions rarely available as reusable cross- case models. This paper asks when fuzzy-set qualitative comparative analysis (fsQCA) can complement safety research involving equifinality and causal asymmetry, and answers with an applicability screen. IEC 62368-1 specifies what must be demonstrated and how conformity is judged; fsQCA asks only which calibrated configurations accompany an outcome in a declared case universe. A fully disclosed N = 32, k = 5 matrix of

	connector-fire cases executes calibration, necessity, truth-table minimization, and robustness checks. It is a benchmark, not empirical evidence: empirical claims require preregistered fault insertion or case-complete field data with pre-outcome measurement.
R7142 10:35-10:50	Integration Technology and Applications of PHM and PSA for Operational Risk Management and Control in Nuclear Power Plants **Author(s):** Zeng Yu **Presenter:** Zeng Yu, Shenzhen University, China **Abstract:** Existing Living Probabilistic Safety Assessment (Living PSA) approaches rely on static failure probabilities and cannot adequately capture the effects of equipment degradation on evolving nuclear power plant risk. Meanwhile, Prognostics and Health Management (PHM) lacks effective support for system-level risk assessment. This paper proposes an integrated PHM–Living PSA framework for time-dependent risk prediction. An equipment degradation model is established, and Bayesian inference combined with adaptive fitting is used to generate Remaining Useful Life (RUL) samples. The cumulative density function of the RUL distribution is then used to estimate cumulative failure probabilities, with mission-window POFs calculated from differences at the interval boundaries and mapped to corresponding Living PSA basic events. Furthermore, a discrete-event–continuous-state architecture enables continuous degradation information to update equipment POFs and discrete plant configuration changes to update the PSA logic structure, supporting dynamic system-level risk assessment and prediction.
R7148 10:50-11:05	Domino Risk Analysis of Cylindrical FPSO Explosion Accident Based on Bayesian Network **Author(s):** Congbao Huang, Yuntao Li, Qi Jing **Presenter:** Congbao Huang, China University of Petroleum Beijing, China **Abstract:** Global natural gas exploitation is shifting from shallow to deep water. Owing to their axisymmetric configuration, cylindrical FPSOs exhibit favorable stability and adaptability, making them key facilities for deepwater gas development. However, as exploitation activities intensify, the risk of gas leakage and explosion increases. The complex, compact and highly integrated layout of these platforms renders their fire and explosion hazards prone to triggering domino effects, which can cause severe damage to surrounding equipment and the entire platform. This study employed fault tree analysis to identify the key risk factors and developed a probabilistic model of natural gas leakage–explosion accidents for cylindrical FPSOs based on Bayesian network theory, through which the accident probability was quantified, and critical hazard-contributing factors were identified. The explosion overpressure on equipment surfaces induced by gas leakage was then simulated numerically, and the overpressure results were used in the domino effect analysis. The results revealed that the domino effect exhibits an accelerating propagation characteristic, providing a theoretical basis for predicting accident escalation pathways.

►Online Session A

► Machine Learning and Data Analysis in Reliable Engineering; Engineering Reliability Maintenance and Safety Management

► Session Chair: Waichon Lio, Beihang University, China

► 9:00-11:50 | November 25, 2026, Wednesday | Room A

► R7040, R7177, R7250, R7204, R7247, R7057, R7233, R7104, R7173, RS004



Session Keynote Lecturer 9:00-9:20 | R7236

Waichon Lio, Beihang University, China

Speech Title: A Belief Reliability Analysis Method Based on Bayesian Residual to Characterize Epistemic Uncertainty (R7236)

Abstract: This paper introduces an integrated normal uncertainty distribution to characterize epistemic uncertainty in battery degradation residuals. Inspired by the uncertain Bayesian posterior construction, it combines two normal uncertainty distribution branches with distinct centers and scales. Least squares fits the linear trend and estimates the four distribution parameters from 67 battery degradation observations. Compared with a normal uncertainty model fitted by least squares, it reduces the distribution function squared error by 72.6045% and lowers KS distance. The uncertain hypothesis test does not reject the model at the 0.05 significance level. These results support the integrated normal uncertainty distribution as a residual model for belief reliability analysis of battery degradation.

R7040 9:20-9:35	A Study on Multi-Objective Optimization of Turning Parameters for Low Carbon Emissions and High Surface Quality **Author(s):** Zhidong Zhang, Shengkui Zheng, Dechao Wang, Shengjie Jin, Shuai Lu, Chengdao Piao, Jianhai Zhang, Hailong Tian **Presenter:** Zhidong Zhang, Yanbian University, China **Abstract:** To address the trade-off between minimizing carbon emissions and ensuring superior surface quality in low-carbon turning processes, this paper proposes a multi-objective optimization method that concurrently considers both carbon emissions and surface roughness. A mathematical model for carbon emissions is first established based on the quantitative relationship between cutting parameters and power consumption during turning. Subsequently, a surface roughness prediction model is developed using a GA-BP neural network—an enhanced backpropagation network optimized by a genetic algorithm. The two individual objective models are then transformed into a single integrated objective function that aims to reduce carbon emissions and improve surface quality simultaneously. Subsequently, the two independent objective models are transformed into a comprehensive objective function, aiming to simultaneously reduce carbon emissions and improve surface quality. Based on this objective function, the sparrow search

	algorithm (SSA) is adopted to obtain the process parameter combination with low carbon emission and high surface quality.
R7177 9:35-9:50	Predictive Triviality in Manufacturing Productivity Modeling: A Framework for Detecting Temporal Leakage and Shortcut Features **Author(s):** Huong Thao Nguyen, Thanh Nam Nguyen, Gia Huy Tran, Dinh Huy Nguyen, Thu Huong Nguyen, Dinh Van Nguyen, Anh Vang Tran **Presenter:** Huong Thao Nguyen, Hanoi University of Science and Technology, Vietnam **Abstract:** Accurate labor productivity forecasting is essential for production planning and resource optimization in the labor-intensive garment industry. However, previous studies on a widely used garment productivity benchmark often report high predictive performance without sufficiently controlling for data integrity, potentially allowing data leakage and shortcut features to produce predictive triviality. This study introduces a Temporal and Structural Integrity (TSI) Framework to identify data leakage, isolate shortcut variables, and evaluate model dependency through systematic feature ablation across multiple machine learning models. Under a strictly controlled, leakage free and non-trivial feature setting using the UCI garment productivity dataset, XGBoost achieved an MAE of 0.097 and an R2 of 0.338. Discretizing the shortcut variable maintained these constraints while improving performance to an MAE of 0.090 and an R2 of 0.406, whereas an exploratory scenario simulating pre-shift planning features further improved the results to an MAE of 0.084 and an R2 of 0.454. The findings demonstrate that predictive performance alone may be insufficient for evaluating industrial forecasting models and highlight the importance of data integrity and structural dependency analysis for reliable machine learning-based decision support in manufacturing.
R7250 9:50-10:05	Residual-Driven Interaction Learning for System-Level Risk-Informed Decision Support in Industrial Energy Systems **Author(s):** József Szeles, Tamás Ruppert **Presenter:** József Szeles, University of Pannonia, Hungary **Abstract:** Industrial energy systems couple production, com- pressed air, cooling and power, so a decision that is sound for one subsystem can push another past its limit. Digital twins (DTs) capture these couplings only in part, and querying them before every decision is costly. We propose an architecture in which a reinforcement learning (RL) agent uses the DT as a scaffold rather than as a permanent safety check. Besides its policy, the agent learns the system-level risk of each action, the probability that at least one hard limit is violated, together with an epistemic credible range for this risk. It acts alone when the range lies below the risk limit and requests a DT simulation when the range crosses the limit or outcomes contradict its estimate. Residuals between DT and plant reveal missing interactions, which are learned only under explicit attribution conditions. The approach is studied in a hypothetical simulation of a pneumatic production line, with a one-step policy over a single decision variable. Over a 120-day season (10 runs), the agent needed 76% fewer DT requests than checking every decision with the DT (68–78% across coupling strengths), with comparable violations (11.8 vs. 12.5 hours per season) and 95.5% vs. 97.4% of the ideal output. A data-driven safety filter without a DT had 2.0 more controllable violation hours per season; fixed safety margins had 1.2 fewer, at 5.2 points lower output. Acting alone, the agent

	underestimated its risk about threefold, and its range gives no worst-case guarantee.
R7204 10:05-10:20	A Candidate Reliability-Calibrated Convolutional Framework for Online Lithium-Ion Battery Health Monitoring and Maintenance Decision Support **Author(s):** Syed Touqeer Hussain, Zi Xuan Gao, Muhammad Obaid, Juan Chen **Presenter:** Syed Touqeer Hussain, Beihang University Beijing, China **Abstract:** Online tracking of the state of health (SOH) of lithium-ion batteries supports safe operation and maintenance planning of electric vehicles, but a battery management system (BMS) in service rarely records laboratory capacity tests, and a point estimate alone does not show how far it can be trusted near the end of life (EOL). This paper examines a candidate reliability-calibrated framework in which a compact convolutional and temporal convolutional network (CNN-TCN) tracks the capacity from BMS-available inputs, Monte Carlo dropout and a Gaussian mixture describe the distribution of each estimate, and a conformal step calibrates its interval online. The calibrated distribution yields maintenance states and a cost-based replacement signal. On four NASA cells, evaluated within each cell and on cells left out of training, the average RMSE is 0.0144 and 0.0169, and the calibrated 95 % intervals reach an empirical coverage of 95.4 % and 97.4 %. Comparisons with simple baselines, ablations and perturbed sensor inputs indicate where the framework helps and where its benefit is small. On the cells that reach the EOL threshold, an alarm preceded the EOL in 14 of 15 runs.
R7247 10:20-10:35	Temporal Modeling of Integrity Drift in Industrial Data Pipelines: A Graph-Aware Reliability Framework for Detecting Generative-AI-Induced Degradation **Author(s):** Chalapathi Koneni **Presenter:** Chalapathi Koneni, Independent Researcher, United States **Abstract:** GenAI-assisted data processing can produce structurally valid values that alter downstream analyses. We present IDI-TDM, a temporal and graph-aware integrity framework that combines bidirectional-LSTM reconstruction, KL divergence, entropy shift, and Isolation Forest evidence with a weighted pipeline dependency graph. The framework produces bounded stage-level exposure scores and an Integrity Drift Index (IDI) for pipeline-wide monitoring. We derive a finite-path interpretation of propagation and prove ancestor non-interference, which keeps unrelated branches from changing a monitored stage's score. On the electricity-load benchmark with controlled GenAI-inspired perturbations, IDI-TDM achieves precision 0.9313, recall 0.9401, F1 0.9357, ROC-AUC 0.9854, and PR-AUC 0.9747. We separately evaluate stage-dependency behavior across 250 seeded graph simulations per scenario. For a constructed upstream fault chain, propagation improves downstream ROC-AUC from 0.7523 to 0.9608. Under branch-specific faults, graph scoring achieves 0.9509 ROC-AUC with no sustained unrelated-branch alerts, compared with 0.4421 for global averaging. Ancestor-only pooling achieves 0.9578, emphasizing the value of selecting relevant dependency paths. The combined results support dependency-aware integrity monitoring and stage-specific operational triage.
R7057 10:35-10:50	Decision Support System for Cyber-Resilient Railway Fallback Operations **Author(s):** Lóránt Meszlényi, Xingming Bi, Bilal Üyümez, Andreas Oetting, Stefan Katzenbeisser **Presenter:** Lóránt Meszlényi, University of Passau, Germany

	Abstract: Modern railway operations face vulnerabilities from cyberattacks that can compromise signaling system integrity. This paper presents a decision support system for fallback level operations that augments train dispatcher displays with multi-modal sensor data from cameras, acoustic sensors and GPS sources to provide independent verification capabilities. Our approach presents redundant data streams to enable detection of discrepancies between systems. The human operator maintains final decision authority, serving as a critical safety layer that can identify potential system compromise. Through experimental scenarios at a railway test facility, we demonstrate that independent verification through multi-modal sensing supports effective dispatcher decision-making and enhances cyberresilience by requiring attackers to compromise multiple independent systems simultaneously.
R7233 10:50-11:05	Systemic Failures in Mega Cyber Breaches: Towards an Enterprise-Wide Model of Information Security Governance and Cyber Resilience **Author(s):** Sarfraz Iqbal, Lars Magnusson **Presenter:** Sarfraz Iqbal, Linnaeus University, Sweden **Abstract:** Mega cyber breaches persist despite substantial investment in security technology and compliance, suggesting a governance problem beyond isolated technical faults. This study analyzes six breaches documented in scholarly sources: Target, Equifax, Capital One, SolarWinds, British Airways, and Yahoo through a two-pass comparative qualitative design. First, documented failures are coded inductively across operational, access, monitoring, coordination, governance, learning, capability, supply-chain, and strategic categories. Second, the evidence is mapped to Stafford Beer's Viable System Model (VSM): Operations (System 1), Coordination (System 2), Control (System 3), Intelligence (System 4), and Policy (System 5). Across the cases, System 1 weaknesses consistently co-occur with System 3 assurance failures; coordination and adaptation gaps can allow local weaknesses to persist or propagate, while policy failures become decisive where priorities suppress corrective action. The paper develops the mechanism of cascading viability failure and a VSM-based governance model centered on recursion, feedback, requisite variety, and distributed responsibility.
R7104 11:05-11:20	Risk Budgets for AI Products: Safe Experimentation and Progressive Delivery of Generative and Agentic Features **Author(s):** Olusegun Akinfenwa, Desmond Ezo-Ojile, Jesutofunmi Onuoha, Temitope Kadri, Christian Chimezie, Toyese Oloyede **Presenter:** Olusegun Akinfenwa, Independent Researcher, United Kingdom **Abstract:** AI product teams improve generative and agentic systems through rapid experimentation and A/B testing, but these loops optimise product metrics and do not adequately control security, safety, or governance risks. We introduce AI risk budgets: per-category, per-quarter allowances of expected risk covering adversarial vulnerability, harmful outputs, privacy, autonomy, fairness, and regulatory obligations. Each release is charged against the budget according to its severity, exposure, and measurement uncertainty. We pair these budgets with a progressive delivery pipeline comprising offline and adversarial gates, shadow deployment, canary and ramp stages, runtime monitoring with automated rollback, and a decision rule that promotes a

	release only when product evidence, risk gates, and budget constraints all agree. In a seeded release-pipeline simulation involving three product archetypes—a retrieval-augmented assistant, a multilingual agent, and an autonomous workflow agent—thirty paired runs per configuration show that risk-budgeted delivery reduces user-facing incidents by approximately twentyfold, high-risk exposure by two to three orders of magnitude, and rollback latency from twelve hours to less than one hour, at the cost of increased evaluation expenditure and slower release cycles. A budget sweep demonstrates that the risk budget operates as a control parameter along a monotonic risk–return frontier, from which conventional A/B testing deviates substantially. The pipeline's decision ledger also serves as auditable governance evidence.
R7173 11:20-11:35	Causal Agent Bench: Reliability-Aware Benchmarking of Causal Reasoning, Coordination and Explainability in Multi-Agent Consumer Intelligence **Author(s):** Olufemi Taiwo, Brain Aboze, Oluwole Fagbohun, Victor Omoboye, Chinomso Okere, Adefisayo Adejumo Oreoluwa **Presenter:** Olufemi Taiwo, Independent researcher, United Kingdom **Abstract:** Consumer intelligence systems increasingly answer causal questions with pipelines of specialised components: one proposes a causal graph, another chooses what to control for, a third estimates the effect and a fourth explains it. When one handoff is wrong, the pipeline still returns a confident number. Reliable causal decision making in modular and agentic AI systems therefore depends on three properties that existing benchmarks do not measure: error propagation between components, detection of and recovery from corrupted handoffs, and abstention when no valid causal answer exists. Causal Agent Bench is a reproducible benchmark and evaluation harness that scores these reliability properties together with causal structure recovery, intervention effect estimation, unit level counterfactual prediction, causal driver attribution and an identifiability audit with abstention. Its structural causal model environments retain exogenous noise, so structural, interventional and counterfactual ground truth is exact under latent dependence, latent treatment and outcome confounding, outcome selection, delayed effects, nonlinear non-additive mechanisms, real covariate distributions and distribution shift. Handoffs are first class corruptible artefacts, with a formal back-door adjustment interface, a data driven verifier with fallback recovery, ensemble graph reconciliation and systematic corruption response curves. Across twenty seeds, correctly adjusted pipelines cut naive effect error by up to two orders of magnitude where identification holds; discovery error propagates into downstream estimates, and deleting three edges from a graph handoff raises effect error from 0.085 to 0.20 while verifier recovery restores it to 0.034 under every corruption tested; a dispersion based audit separates identifiable from non-identifiable environments with accuracy 0.95; and bootstrap intervals that are well calibrated under identification cover the truth in no seed under latent treatment and outcome confounding. The evaluated pipelines are statistical instantiations of the agent roles; a documented language model harness with structured output validation and cost logging is released with the code.
RS004 11:35-11:50	Minimizing Unscheduled Maintenance from an Aircraft and Rolling Stock Maintenance Perspective: Preventive Cost Model **Author(s):** Adel A Ghobbar **Presenter:** Adel A Ghobbar, Prince Sultan University, Saudi Arabia

	Abstract: This paper addresses the practical problem of unscheduled maintenance. Unscheduled maintenance needs may arise either due to natural reasons, inadequate/improper maintenance, or a lack of support resources needed to turn around an asset. One of the possible solutions to this problem is to adopt or improve preventive maintenance strategies. This paper uses the concept of delay time modeling (DTM) to address the practical problem mentioned earlier. An extension of the basic DTM has been used, and downtime and cost models have been developed to factor in supportability requirements. The TOPSIS multi-criteria decision model has been used to refine the inspection interval results of the cost and downtime models to obtain the ideal inspection interval in line with an organization's preference. Finally, the 'risk' element has been factored in to validate the computed ideal inspection interval and make the model acceptable to other industries
R7137 11:50-12:05	A Physics-Informed Dual-Factor Health Indicator for Quantitative Condition Monitoring of Rolling Bearings **Author(s):** Wenchang Song, Liang Guo, Ao Cao, Huiying Yin and Hongli Gao **Presenter:** Wenchang Song, Southwest Jiaotong University, China **Abstract:** Conventional bearing health indicators are commonly extracted from vibration statistics and therefore provide limited physical interpretability and can fluctuate under noise and operating-condition changes. This paper proposes a physics-informed dual-factor health indicator (PIDHI) for quantitative condition monitoring of rolling bearings. A parameter-interactive degradation twin (PIDT) combines a nonlinear bearing dynamic model with extended Kalman filtering to identify time-varying contact stiffness and local-defect geometry under model-based response and feasibility constraints. These physically interpretable variables form a global stiffness-degradation factor and a localized-defect factor. After normalization, the two factors are transformed by nonlinear penalty functions and fused into a scalar score bounded in [0,1]. The score links health loss to distributed stiffness degradation and localized defect growth and is mapped to four engineering state levels. Run-to-failure studies on the public XJTU-SY Bearing1-1 record and the in-house SWJTU-SY Test-3 record compare PIDHI with RMS, Gini index, crest factor, and envelope entropy. In both records, PIDHI maintains a stable high-value plateau before a distinct decline at the accelerated-degradation transition, whereas the conventional indicators show stronger fluctuation, premature drift, or late-stage saturation. The proposed method therefore provides an interpretable route from vibration measurements to continuous state assessment and threshold-based warning.

►Online Session B

► AI-Augmented Predictive Maintenance for Complex Industrial Systems

Session Chair: Yasi Shen, Powerchina Zhongnan Engineering Corporation Limited, China

► 10:00-12:05 | November 25, 2026, Wednesday | Room B

► R7065, R7122, R7124, R7241, R7159, R7223, R7131

R7065 10:00-10:15	Research on Pricing of an Innovative Grouting Processs under Complex Geological Conditions **Author(s):** Yasi Shen, Guanjun Li, Longbing Xiong **Presenter:** Yasi Shen, Powerchina Zhongnan Engineering Corporation Limited, China **Abstract:** Complex geological conditions are a major constraint in the construction of water resources and hydropower projects. Conventional curtain grouting cannot fully adapt to highly weathered rock masses, fracture zones, Cretaceous red beds, and other unfavorable strata. To address this limitation, an innovative “integrated drilling-and-grouting, in situ flushing-and-compaction” process has been developed to improve seepage control and foundation reinforcement reliability. This paper proposes a preliminary pricing strategy based on measured construction resource consumption, structured as process breakdown, field observation, market price inquiry, and reasonable allocation. The technical principles of the process and the resource-consumption-based pricing method are first summarized. A case study is then conducted on the left and right abutment grouting works of the upper reservoir dam at the Pingjiang Pumped Storage Power Station. The calculated civil works unit cost is CNY 812 per meter. The results provide a practical basis for cost accounting of innovative grouting processes and support reliability assessment and economic optimization under complex geological conditions.
R7122 10:15-10:30	A Simulation-Testing Fusion Method and Analysis Platform for Thermal-Fatigue Reliability Assessment of PCBs in Reactor Protection Systems **Author(s):** Chenyu Jiang, Guangze Pan, Baimao Lei, Qian Li, Qiang Chen **Presenter:** Chenyu Jiang, China Electronic Product Reliability and Environmental Testing Research Institute (China CEPREI Laboratory) **Abstract:** The paper proposed a simulation-testing fusion based thermal-fatigue reliability assessment method for reactor protection system (RPS) printed circuit boards (PCBs), aiming to reduce the test cost and cycle of conventional accelerated-aging-test verification, enable rapid assessment of PCB thermal-fatigue reliability indices, and facilitate rapid product iteration. For the proposed method, the acceleration factor of a PCB is predicted firstly via its thermal simulation model. Then, based on the predicted acceleration factor, PCB accelerated aging tests are designed and conducted, and different types of reliability models are established according to the distinct life distribution characteristics of different products and failure modes. Furthermore, the proposed method is encapsulated into a software platform that handles the simulation modeling and reliability assessment involved in the method, thus advancing its engineering application. Finally, a simplified protection system analog input (AI) board is adopted as a case study to verify

	and demonstrate the feasibility of the proposed method.
R7124 10:30-10:45	Reason Transition Safety for LLM-Assisted Decision Systems: A Before-Reason-After Framework for Pre-Action Safety Assessment **Author(s):** Masao Hirofuji, Masatoshi Hirofuji **Presenter:** Masao Hirofuji, Insight & Growth AI Material Lab, Japan **Abstract:** LLM-assisted decision systems increasingly generate recommendations, plans, messages, tool-use proposals, and other outputs that may lead to consequential actions. Existing safety approaches commonly assess final outputs, runtime constraints, tool permissions, pre-execution gates, or human approval. However, a proposed action may appear acceptable while the observable transition leading to it omits a context-relevant reason, overweights a narrow reason category, or moves directly from context to action without an inspectable reason stage. This paper proposes Reason Transition Safety (RTS) as a pre-action safety assessment perspective for LLM-assisted decision systems. RTS uses Before-Reason-After (BRA) as a minimal representation of the observable transition from prior context, through reasons, to a proposed decision or action. We define three observable reason-transition problems—Missing Reasoning, Biased Reasoning, and Direct-to-Action Reasoning—and associate them with Proceed, Confirm, Stop, and Human Handoff. A pilot feasibility study applied exploratory rubrics to ten decision-support trials under three heterogeneous ChatGPT configurations. Observed mean Reason Generation Scores were 11.5, 15.5, and 17.0 out of 18, and mean Reason-Constraining Scores were 2.40, 2.49, and 2.90. These values are descriptive only because the configurations differed in instruction, ChatGPT environment, and external knowledge. No between-configuration or causal inference is drawn. The pilot shows that observable Reason-to-After relations can be structured and assessed, but does not establish reduced unsafe actions, real-world safety improvement, or superiority of any configuration.
R7241 10:45-11:00	ProbeGuard: Generalizable Detection of Indirect Prompt Injection in RAG via Semantic Reasoning and Structured Evidence **Author(s):** Md. Aurongojeb Lishad, Md. Deniad Alam, Md. Eftekhar Rahman **Presenter:** Md. Aurongojeb Lishad, North South University, Bangladesh **Abstract:** Retrieval-augmented generation (RAG) enables large language models (LLMs) to answer questions using external documents, but hidden instructions in retrieved documents can override the model's intended behavior. Most existing detectors for indirect prompt injection are trained on a single benchmark, require access to model internals, or give no explanation for their decisions. We present ProbeGuard, a training-free, black-box detector that examines each retrieved document before it reaches the LLM. ProbeGuard operates in two stages. In the first stage, an LLM thinks step by step about whether the document contains instructions aimed at the model and produces a risk score with a rationale. In the second stage, the same LLM answers six structured questions to identify whether an instruction is present, whom it targets, and how it would change the model's behavior. Then an evidence-tiered fusion rule, with no learned weights, combines the signals of both stages into an explained decision. ProbeGuard is evaluated against embedding classifiers trained on 30,000 BIPIA samples and a naive LLM judge. On the BIPIA test set, ProbeGuard matches the strongest trained baseline in macro F1 (0.9012) and detects more

	attacks (95.04% vs. 90.76%), at a moderately higher false-positive rate. Under obfuscation attacks, it detects 97.00% of 999 attacks, compared with at most 89.19% for the baselines. On an unseen set of 200 documents with new attack styles, it detects 80.00% of attacks with no false positives, while the best trained baseline detects only 45.00%. These results suggest that structured LLM reasoning generalizes beyond the training distribution.
R7159 11:00-11:15	Research on Construction Scheme and Effectiveness Evaluation Method of Civil-Aircraft Safety Work System **Author(s):** Wenzao Zhou, Haosong He, Wentao Liu, Zhonghao Wu **Presenter:** Wenzao Zhou, Nanjing Engineering Institute of Aircraft Systems, avic, China **Abstract:** In the development process of civil aircraft, safety assessment serves as the core support for guaranteeing aircraft safety, airworthiness compliance and economic performance. A sound safety work system is the fundamental guarantee for implementing relevant assessment activities. Guided by full-life-cycle systems engineering and airworthiness compliance requirements, this paper sorts out the current status and prominent problems in the construction of civil-aircraft safety systems. To address drawbacks of conventional system evaluation, including one-sided static scoring, difficulty in characterizing engineering uncertainties of parameters, and challenges in quantitatively identifying key risk factors, this paper investigates system construction schemes and effectiveness evaluation methods. An evaluation-verification framework integrating IFAHP-entropy weight-optimized weight fusion-lightweight uncertainty validation is established, which provides implementation suggestions for the construction and assessment of safety systems.
R7223 11:15-11:30	Reliability Stress Testing of RAG Retrieval under Query-Relevant Corpus Poisoning **Author(s):** Janet Sung, Kainan Zhou, Gangzhen Qian, Hang Xiao **Presenter:** Janet Sung, Google LLC, USA **Abstract:** External text can affect a retrieval-augmented generation (RAG) system only after the retriever admits it to the model context. We stress this admission step while varying document content, attacker query information, per-target poison budget, and contamination scope. Across 623 BEIR queries from SciFact and NFCorpus, five query-targeted documents per query reduce classical-retriever nDCG@10 by 40.2–61.5% in isolated-target stress. Full-query anchoring explains most BM25 degradation, whereas appended text also shifts LSA and Hybrid rankings. A pretrained BGE-small validation reaches 100% target exposure for query-only P = 5 on both datasets; adding the injection payload changes SciFact nDCG only from 0.269 to 0.271 and lowers NFCorpus exposure slightly to 98.8%, indicating that query anchoring remains the dominant retrieval-side factor for this dense model. Query length materially changes the interpretation of partial-information attacks: on 162 long SciFact queries, two random terms cover 19.9% of eligible terms and still yield 39.5% Hybrid target exposure. Multi-target contamination adds cross-target interference. Overlap-based admission can remove full-query poisons but may sharply reduce clean retrieval utility, and MMR leaves exposure unchanged under the tested configuration. The study measures retrieval-layer failures, not downstream instruction following.
R7131	An Interface-Driven Method for Identifying Initiating Events in Probabilistic Risk Assessment

11:30-11:45	**Author(s):** Thinh Q. Nguyen, Vincent P. Paglioni **Presenter:** Thinh Nguyen, Colorado State University, USA **Abstract:** In this paper, we propose an interface-driven method (IDM) for systematically identifying initiating events (IEs) in accident scenarios. The method adapts systems-oriented concepts from Carson's System Requirements Analysis (SRA) for identifying anomalous interface conditions and Levenson's Systems Theoretic Process Analysis (STPA) for identifying unsafe control actions (UCAs) and integrates them into the Probabilistic Risk Assessment (PRA) process as potential IEs. The IDM applies an inductive analysis to the operational conditions and output interfaces of the system within a scope defined by one or more undesirable end states. Deviations from nominal outputs and indications observable to a control entity, including out-of- range outputs, incorrect outputs, untimely outputs, and missing outputs, are evaluated to identify relevant IEs. This bottom-up perspective complements the traditional top-down Master Logic Diagram (MLD) and provides an additional means of assessing IE coverage. The IDM is demonstrated through its application to a passenger aerial vehicle (PAV) to illustrate how the method is performed in practice. The resulting IEs are qualitatively compared with those derived from an MLD to illustrate areas of overlap and the complementary insights provided by the two approaches.
R7199 11:45-12:0**0**	Verifying Architectural Decisions Prior To Implementation: Detecting Harmful Interactions in an Event-Driven Production Control System **Author(s):** Leonardo Zanoni, Anders Sindberg Nissum, Aljaz Knific, Eun-Young Kang, Torben Worm **Presenter:** Leonardo Zanoni, University of Southern Denmark (SDU), Denmark **Abstract:** Architectural mitigation tactics for system reliability are frequently selected and evaluated in isolation. While individual design decisions may satisfy localized constraints, their integration can inadvertently violate end-to-end performance and availability requirements. This paper investigates this vulnerability through a case study of an event-driven control system for an industrial pasta-production line, which relies on heartbeat-based machine failure detection and a warm-spare scheduler. We formally specify the critical architectural components using the UPPAAL model checker, translating availability requirements into temporal logic queries to verify system correctness prior to implementation. Although individual tactics satisfy their respective local timing bounds, an overlap of a scheduler failure with the handling of a machine failure forces the standby scheduler to restart detection. Consequently, system recovery latency increases from 16 to 38 seconds, as the standby component is forced to reinitiate the complete detection and decision pipeline. Guided by the resulting diagnostic traces, we introduce a Redis-based architectural refinement that establishes a shared detection state and accelerated failover mechanisms. Subsequent verification confirms that the refined model satisfies all temporal constraints, including a strict 25-second end-to-end recovery bound, demonstrating the critical role of formal modeling in assessing architectural integration prior to deployment.

►Online Session C

► System Design and Modeling Based on Reliability

► Session Chair: Emmanuel Fragniere, School of Management Valais-Wallis (HES-SO), Switzerland

► 13:30-16:35 | November 25, 2026, Wednesday | Room A

► R7106, R7023, R7062, R7206, R7060, R7157, R7244, R7220, R7064, R7175, R7083



Session Keynote Lecturer 13:30-13:50

Emmanuel Fragniere, School of Management Valais-Wallis (HES-SO), Switzerland

Speech Title: Human-in-the-Loop Reliability: Designing Accountable Decision Gates for AI-Enabled Safety Systems

Abstract: As artificial intelligence becomes embedded in reliability assessment, risk analysis, maintenance and safety management, the presence of a human operator is frequently presented as a sufficient safeguard. However, a human-in-the-loop architecture may remain unreliable when the human merely confirms an automated recommendation, lacks the information required to challenge it, has insufficient intervention time, or does not hold clear decision authority. This presentation develops a socio-technical model of human-in-the-loop reliability based on bounded rationality, automation bias, tacit knowledge, collective intelligence and human agency. It conceptualizes reliable decision-making as a five-stage chain connecting signal perception, contextual interpretation, knowledge sharing, AI-supported recommendation and accountable action. Four design requirements are proposed: authority to pause or override, observability of evidence and uncertainty, retained human competence, and explicit decision ownership. The model is illustrated through a credit-risk case in which sequential approval by several experts produced apparent assurance while diluting individual responsibility. The introduction of a clearly accountable risk owner changed decision behaviour and increased scrutiny before approval. The presentation concludes that human-in-the-loop should not be treated as a procedural add-on. It should be engineered and evaluated as an accountable reliability function within the complete socio-technical system.

R7106 13:50-14:05	GovAgent: Runtime Constitutional Governance for Autonomous Multi-Agent Systems **Author(s):** Kemisola Adalumo, Samuel Datubo Jaja, Desmond Ezo-Ojile, Jesutofunmi Onuoha, Oluwole Fagbohun, Victor Omoboye **Presenter:** Kemisola Adalumo, Independent researcher **Abstract:** Autonomous AI agents act on digital environments at machine speed with limited human supervision, while the instruments of AI governance act on documents and organisations, leaving an enforcement gap at runtime. We propose GovAgent, runtime constitutional governance for multi-agent systems: machine-checkable regulatory and organisational controls are represented as executable policies evaluated before each consequential action, combining capability-scoped identity, compiled policy checks, adaptive escalation, tamper-evident logging, recovery and a

	governance-aware learning signal. We evaluate it in GovSim, a discrete-event testbed of public-administration, financial and healthcare workflows under parameterised attack, against five baselines over 390,000 scenario executions, with twenty seeds for the principal comparison. In the simulated settings studied, GovAgent blocks 98.4 per cent of attempted severe violations with microsecond decisions and cuts the share of scenarios with a severe violation from 47.1 to 0.76 per cent, against 5.3 per cent for a rules-only policy engine. Equivalence testing shows task success matches unrestricted agents inside a pre-specified two-point margin, 0.02 per cent of benign actions are hard-blocked, and the result is stable under perturbation of the principal risk constants. A held-out attack suite of five unanticipated families breaches the frozen policies where the design predicts: aggregate-level harm, audit-substrate tampering and missing attributes, delimiting what an action-level runtime governs. Runtime governance can convert principles into enforceable behaviour without giving up the benefits of autonomy, provided its scope, trusted components and residual failure modes are stated precisely. Index Terms— AI governance, autonomous agents, multi-agent systems, runtime enforcement, AI safety, access control, audit.
R7023 14:05-14:20	Fault Tree Analysis of Self-Locking Handwheel for Ship Distribution Box Based on Fuzzy Theory **Author(s):** Zhuang Tan, Fengrui Liu **Presenter:** Zhuang Tan, Jiangsu Automation Research, China **Abstract:** Aiming at the problem of missing basic data in traditional fault tree analysis of complex systems, this study proposes a fuzzy the-ory-based fault tree analysis method for self-locking handwheels used in ship distribution boxes. Taking a self-locking handwheel for ship distribution boxes as an example, a fault tree is first es tablished. Expert evaluations of basic events are collected and converted into fuzzy numbers, which are then transformed into precise fuzzy probability values. Finally, the system-level failure probability and the importance indicators of each basic event are calculated through computation. The quantitative analysis identifies key failure factors affecting system reliability, providing a basis for subsequent targeted improvements and reliability analysis work.
R7062 14:20-14:35	Component Reinforcement Method for Power Systems Based on Shapley Value Responsibility Allocation **Author(s):** Dezheng Kong, Yuxiong Huang, Qingqiu Liu **Presenter:** Dezheng Kong, Xi'an Jiaotong University, China **Abstract:** The reliability tracing calculation of power systems has high computational complexity and is difficult to embed into power system optimization models. To achieve power system component reinforcement considering reliability tracing, a power system component reinforcement method based on Shapley value reliability responsibility allocation is proposed. First, a source-grid-load-storage responsibility allocation model based on the Shapley value is established, and linear expressions of the Shapley value and Expected Energy Not Supplied (EENS) are obtained. A risk attribution table is then used to analyze the risk-driving factors. Second, a power system component reinforcement planning model with the dual objectives of minimizing the variance of Shapley values and minimizing system EENS is established, so as to obtain an optimal solution that considers both system risk reduction and balanced responsibility allocation. Finally,

	case studies on the RTS-79 system show that the proposed method can obtain the optimal reinforcement scheme and effectively reduce reliability indices such as system EENS.
R7206 14:35-14:50	A Review of Reliability Indicator Systems for Networked Equipment **Author(s):** Yuna Zhang, Lei Niu, Xiaojian Yi, Yaru Hao, Bing Han, Jie He **Presenter:** Yuna Zhang, Yangtze Delta Region Academy of Beijing Institute of Technology (Jiaxing), China **Abstract:** Networked equipment consists of functional nodes, communication links, and mission coordination relationships. Its reliability is jointly affected by node states, network topology, mission logic, and dynamic reconfiguration. Conventional reliability indicators developed for individual equipment are therefore insufficient to fully characterize reliable mission operation under networked and system-of-systems conditions. This paper review reliability indicator systems for networked equipment and clarifies the conceptual boundaries among reliability, availability, robustness, survivability, resilience, mission reliability, and system-of-systems contribution. A three-level evaluation framework is organized around the node-and-link level, network level, and clues-ter/system-of-systems level. From a systems engineering perspective, the resource, capability, and mission levels are further introduced to examine the relationships between the two hierarchical structures. Methods for constructing reliability indicator systems are then summarized in terms of indicator generation, screening and reduction, probabilistic aggregation, uncertainty treatment, and cross-level propagation. The cross-level relationships among nodes, networks, and missions are further classified into four mapping mechanisms: structural logic mapping, state probability mapping, network performance mapping, and mission-loop mapping. The applications of the indicator system across the concept development, design, and service stages are also discussed, covering indicator definition and verification requirements, reliability modeling and design, and in-service tracking and feedback. Finally, major challenges in reliability evaluation under dynamic topology, heterogeneous interdependence, cascading failures, and uncertainty are analyzed.
R7060 14:50-15:05	Ontology-Assisted Signal Temporal Logic Monitoring for Explainable Safety Assurance of Industrial Control Systems **Author(s):** Chidi Agbo **Presenter:** Chibuzo Ukegbu, Milwaukee School of Engineering, Milwaukee, USA **Abstract:** Industrial control systems (ICS) require monitoring mechanisms that not only detect safety-critical deviations but also provide engineers with actionable, system-level explanations of their causes and impacts. While Signal Temporal Logic (STL) supports formal specification and runtime verification of temporal safety properties, existing STL-based monitors typically report violations without sufficient contextual information about affected components, dependencies, or propagation effects within the system. This paper presents an Ontology-Assisted Signal Temporal Logic (OA-STL) framework for explainable safety assurance in ICS. The framework combines STL monitoring patterns with a semantic knowledge layer that bridges formal runtime monitoring and system-level operational knowledge. Temporal violation evidence and robustness traces generated by STL monitoring are translated into ontology-aligned representations describing process variables, system assets, and dependency relationships. This enables automated generation of

	semantically grounded diagnostic explanations that identify candidate causes, affected components, and downstream impact pathways associated with detected violations. The proposed framework is evaluated on a MATLAB/Simulink Tennessee Eastman Chemical Plant Process using multiple representative fault scenarios across subsystems. Results demonstrate that OA-STL not only detects safety violations but also systematically enriches formal monitoring outputs with ontology-driven causal explanations, enabling a unified monitoring-to-diagnosis pipeline for explainable safety assurance in industrial control systems.
R7157 15:05-15:20	Data-Driven Optimization of Weibull–Arrhenius Accelerated Life Testing for EPDM Sealing Rings **Author(s):** Ziqi Liu, Guosheng Xu, Haiqing Liu, Jihong Yan **Presenter:** Ziqi Liu, Harbin Institute of Technology, China **Abstract:** Accelerated life tests are commonly conducted at several elevated temperatures and continued until most or all specimens fail, which may lead to inefficient use of test resources. This study proposes a data-driven framework for evaluating temperature-cell importance and optimizing the termination time of a Weibull–Arrhenius accelerated life test. After excluding one documented anomalous result, 79 valid failure-time observations collected at multiple temperature levels are first analyzed using a leave-one-temperature-cell-out procedure. A composite influence index is constructed from changes in the extrapolated use-condition scale parameter, the temperature–lifetime relationship, and the common Weibull shape parameter. The complete data are then retrospectively converted into Type-I right-censored data under different candidate stopping times. Each censored data set is refitted by joint maximum likelihood estimation, while a paired nonparametric bootstrap is used to quantify the prediction loss caused by early termination. Finally, a constrained cost-minimization model determines the least-cost stopping time that satisfies specified requirements for failure information, fitting validity, lifetime-prediction accuracy, reliability accuracy, and low-quantile-life accuracy. The proposed framework provides a practical basis for assessing marginal temperature-cell influence and planning test duration and can improve accelerated-test efficiency while preserving explicitly specified prediction-accuracy requirements.
R7244 15:20-15:35	Reliability-Aware V2G Scheduling for Port Renewable Energy Systems Under Grid-Capacity and Renewable-Output Stress Scenarios **Author(s):** Zhihao Yu, Daogui Tang, Jorge De La Cruz, Hongping Wang, Yazhou Nie **Presenter:** Zhihao Yu, Wuhan University of Technology, China **Abstract:** This paper develops a reliability-aware vehicle-to-grid (V2G) scheduling and deterministic ex-post stress-test framework for port renewable-energy systems. It first solves an economic electric-yard-truck schedule under state-of-charge (SOC), departure, and degradation constraints, then evaluates energy not supplied (ENS) under R0-R4 grid-capacity and renewable-output stress scenarios. A 31-day case study with 76 trucks, 2408 dwell records, and 5-min prices shows that a 2 h dwell extension raises monthly net profit to CNY 328,920.60. R0-R3 retain a 100% disturbance-window supply rate, whereas islanding with 30% renewable output yields 38.85 MWh ENS and a 9.44% supply rate. V2G provides fast resilience support but cannot replace fixed backup during prolonged islanding.

R7220 15:35-15:50	Floating-Point Precision Limits in Computing Small Failure Probabilities: Error Bounds and Stable Formulations for Reliability Assessment **Author(s):** Taras Starushenko, Eugene Machusky **Presenter:** Taras Starushenko, Eugene Machusky, Taras Starushenko, Kyiv Polytechnic Institute, Ukraine **Abstract:** Safety targets routinely demand failure probabilities between one in a million and one in a billion, yet these are often computed as the complement of a reliability value very close to one. In floating-point arithmetic this complement suffers catastrophic cancellation, which destroys significant digits. This paper quantifies the consequences for reliability computations in the formats now used in reliability software and hardware. We derive a forward error bound and a precision-adequacy criterion for series systems and evaluate four benchmark models (a 1000-component series system, parallel redundancy, exponential mission unreliability and a 100-component m-out-of-n system) in bfloat16, binary16, binary32, binary64 and 80-bit extended precision against a 60-digit reference. With the naive formulation, binary32 returns no correct digits once the failure probability falls below one in ten million, and binary64 keeps only three correct digits at about two in ten trillion. Stable formulations based on log1p, expm1 and direct tail summation keep the relative error below two parts per million in binary32 and near the limit of double precision in binary64. In bfloat16 they still err by about 20 percent unless sums are accumulated in binary32, which brings the error below 0.4 percent. Log-domain storage avoids underflow but loses relative accuracy as probabilities shrink. We compare these errors with the uncertainty of industry failure data and give practical guidelines for reliability software.
R7064 15:50-16:05	Improving Adversarial Reliability: from Design to Operation using Security Twins **Author(s):** Vincenzo Sammartino, Fabrizio Baiardi **Presenter:** Vincenzo Sammartino, Università di Pisa - Dipartimento di Informatica, Italy **Abstract:** Adversarial reliability is the expected time before a rational attacker first compromises a critical asset of a system. We show how a single probabilistic object – the distribution of attack paths through a system – can drive the quantitative evaluation and optimization of adversarial reliability throughout the system life cycle. Our solution separates three functional layers. A security twin enriches an infrastructure digital twin with vulnerability information, assigning each exploitable transition a success probability. Monte Carlo simulation of individual intrusions on this twin, each driven by an attacker strategy, yields reliability statistics such as mean time to compromise and time-dependent breach probability. The simulated intrusions can be represented as an intrusion graph over attacker states, whose traversal frequencies rank assets by the realized risk. This shared substrate supports the solution of four defensive optimization problems: patch scheduling, denial-of-service exposure, sensor placement, and decoy placement. A fifth retrospective problem reconstructs the attacker's most probable path in a successful intrusion, drives log-retention budget toward the assets that most improve future reconstruct ability, and flags attacker transitions that do not match the predicted intrusions as candidate undocumented vulnerabilities. Because the ST can be instantiated from architectural specifications alone, the same pipeline can assess a system before it is built, turning adversarial reliability into a verifiable design requirement. Experiments on two operational security twins (126 and 202 assets) and synthetic topologies up to 104 nodes show

	that joint allocation increases the mean time to compromise by up to 3.9× over an undefended baseline and that design-time predictions match post-deployment measurements within 8%.
R7175 16:05-16:20	Adversarial Causal Deliberation among Autonomous Agents for Reliable Consumer Behaviour Explanation **Author(s):** Linda Oraegbunam, Jacob Sanni, Chinomso Okere, Brain Aboze **Presenter:** Linda Oraegbunam, Independent researcher **Abstract:** Autonomous agents can generate plausible explanations of consumer behaviour even when the available evidence does not support a causal conclusion. This paper proposes adversarial causal deliberation (ACD), a framework in which agents are assigned competing roles and are required to challenge one another before any causal claim is accepted. A hypothesis agent proposes candidate causal mechanisms, a confounder critic searches for alternative explanations, an evidence verifier runs adjusted estimates, falsification tests and refuters, and a causal judge applies explicit identification criteria. Every exchange is logged in a structured causal argument graph. We evaluate ACD in a controlled simulation with programmatic agent policies over six consumer scenarios with known ground truth, covering confounding, spurious correlation, mediation, collider bias, reverse causation and hidden confounding. Across fifty seeded replications, ACD reaches a claim F1 of 0.906 against 0.533 to 0.559 for single-agent reasoning, majority voting, cooperative debate and an adjust-for-everything analyst (Holm-corrected $p \leq 8.9 \times 10^{-10}$), while cutting the false-positive rate from 0.35 to 0.04 and roughly halving calibration error. Ablations show that the critic protects recall, falsification protects against hidden confounding, and temporal reasoning prevents bad controls. We also identify an honest failure mode: confounding weak enough to evade both the critic and the falsification gate.
R7083 16:20-16:35	Evaluation of Passive Radiative Cooling Film for Thermal Stress Reduction and Reliability Oriented Energy Performance in Hot Climates **Author(s):** Abdulmajeed Almohnna, Ahmed A. Alzahrani **Presenter:** Ahmed A. Alzahrani, Aramco, Saudi Arabia **Abstract:** High ambient temperature, intense solar irradiance, and airborne dust create persistent thermal stress for buildings and heat-exposed industrial assets in hot climates. Elevated surface and enclosure temperatures increase cooling demand and may contribute to equipment derating, nuisance trips, accelerated aging, and reduced operating margin. This paper evaluates a passive radiative cooling (PRC) film using a field pilot, first-principles simulation, accelerated laboratory testing, and long-term soiling assessment. The film was installed on a small one-story building at an industrial facility in the eastern region of Saudi Arabia and compared with an uncovered reference roof area. Field measurements showed up to 20 °C roof surface temperature reduction and 20.1% energy reduction during the pilot period. A validated thermodynamic model was then used to estimate annual performance, indicating 14.1% annual cooling-energy savings and sustained daytime roof temperature reduction. Laboratory ultraviolet and solar light-soaking tests showed that the film maintained high reflectance after accelerated exposure. Long-term outdoor testing showed that accumulated soiling can degrade temperature reduction performance over time, while cleaning restored the film response close to its original condition. These results indicate that PRC films can reduce building cooling loads and provide a reliability relevant passive

	thermal-management pathway for selected industrial applications.

►Online Session D

► Product Reliability Assessment and Management

► Session Chair: Huixing Meng, Beijing Institute of Technology, China

► 13:30-16:05 | November 25, 2026, Wednesday | Room B

► R7120-A, R7170, RS002, R7168, R7246, R7097, R7221, R7196, R7103



Session Keynote Lecturer 13:30-13:50

Huixing Meng, Beijing Institute of Technology, China

Speech Title: Some Advances on Data-driven Risk Assessment in the era of AI

Abstract: While conventional risk assessment is often constrained by subjective expert judgment, the integration of artificial intelligence (AI) and probabilistic graphical models (PGMs) provides an emerging alternative. This convergence effectively advances the domain of data-driven risk assessment by boosting both analytical capability and scope. This presentation will first detail the techniques used to integrate and utilize diverse inputs of data-driven risk assessment, which include structured accident report statistics, explicit domain knowledge, virtual reality-generated data, outputs from deep generative models, and large language models. This talk begins with a review of these analytical methods and concludes by outlining several directions that deserve further research.

R7120-A 13:50-14:05	Construction and Practice of Training System for Human Error Prevention in Nuclear Power Plant Based on Simulator Dynamic Error Implantation **Author(s):** Xiliang Tao, Guoqiang Li, Zhihui Xu, Wenqiang Peng **Presenter:** Xiliang Tao, Taishan Nuclear Power Joint Venture Co. LTD, China **Abstract:** A third-generation nuclear plant conducted anti-human error training for main control room operators over three years by dynamically implanting error scenarios into simulator retraining. Meanwhile, actual human error events also occurred on-site. To address this, the study proposes an active error implantation training method. Using a dynamic error implantation model and technology-organization coupled training, high-frequency error scenarios are simulated, and trainee performance is observed and statistically analyzed. Results are compared with actual human error events. Based on this comparison, optimization suggestions are proposed: enhancing scenario realism and strengthening the adaptability of human error prevention tools, in order to bridge the gap between training and actual work and improve human reliability of third-generation nuclear units.
R7170 14:05-14:20	Research on Robustness of IEEE 118-Bus Power Network Based on Cascading Failure Model of Complex Network Theory **Author(s):** Chunchao Zhu, Dong Wu, Rong Ding, Huan Zhao **Presenter:** Chunchao Zhu, The Fifth Electronic Research Institute of Ministry of Industry and

	Information Technology, China **Abstract:** The robustness of power networks is essential to guarantee the safe and stable operation of power systems. This paper takes the IEEE 118-bus power network as the research object and constructs a load-capacity cascading failure model. The impacts of five attack strategies on the network robustness are systematically explored. Simulation results are summarized as follows. Firstly, degree-based attack and betweenness-based attack pose the highest threat. The IEEE 118-bus power network shows strong robustness against random failures. However, it is highly vulnerable to intentional attacks on critical nodes. Secondly, degree attack produces the maximum cascading failure steps in the power network. The number of additional failed nodes reaches 9. Degree attack directly damages the topological structure of the power network. It also induces remarkable cascading failure effects. Thirdly, full-range simulations of node removal ratio and multi-dimensional indicators are performed to analyze the attack efficiency of the IEEE 118-bus power network. The propagation mechanism of cascading failures under different attack strategies is uncovered.
RS002 14:20-14:35	Estimation of Parametric Geometric Degradation of a Wedge-Shaped Rock-Cutting Tool Using FE–SPH Dynamic Responses and LSTM **Author(s):** Yaqi Shen, Jing Zou, Hanhua Zhu, Zhaolin Cheng, Bin Wang, Zihan Zhang, Wei Wei **Presenter:** Yaqi Shen, Wuhan University of Technology, China **Abstract:** This study investigates whether short-duration cutting responses can estimate the parametric geometric state of a wedge-shaped rock-cutting tool. A controlled finite element smoothed particle hydrodynamics (FE–SPH) dataset was generated, with the three cutting-force components and global internal energy used to estimate a normalized geometric index. A long short-term memory (LSTM) network performed state estimation; a statistics-based multilayer perceptron (Statistics MLP) and feature-ablation tests assessed temporal modeling and response-source contributions. On the validation subset of six development states, the LSTM-Force+Energy model achieved an RMSE of 0.0680 and R2 = 0.9586. For the fully held-out D06 and D10 states, the absolute errors of the trajectory-mean predictions were 0.0311 and 0.1056. Combining force and energy outperformed source alone, indicating complementary information. Cutting-velocity perturbations shifted the predictions, limiting the present conclusions to interpolation among geometric states under controlled FE–SPH conditions.
R7168 14:35-14:50	Attention-Enhanced Cascaded Representation Learning for Aeroengine Bearing Fault Diagnosis **Author(s):** Yilin Zhao, Danhuai Guo, Jiaxin Zhu, Xuan Huang **Presenter:** Yilin Zhao, Beijing University of Chemical Technology, China **Abstract:** Fault diagnosis of inter-shaft bearings in aeroengines is crucial for ensuring flight safety. In real-world scenarios, aero-engine vibration signals typically exhibit complex and intertwined characteristics. Specifically, bearing vibration data inherently contain multi-scale features, where transient local fluctuations and long-term operational trends are tightly coupled. In addition, the signals are often contaminated with substantial interference noise. To address these challenges, we propose an attention-enhanced cascaded representation learning model, which cascades

	multiple Transformer-CNN feature extraction blocks with attention-guided fusion mechanism. By integrating local and global representations, the model effectively captures short-term data fluctuations while understanding long-term trends and cyclical characteristics of bearing operation. Experimental validations on an aero-engine bearing dataset demonstrate that the proposed method achieves a diagnostic accuracy of 99.79\%. Comparative analysis further indicates that Transformer-CNN-AFF (TCAFF) consistently outperforms benchmark methods under severe noise and diverse operating conditions, highlighting its effectiveness and robustness in reliable detection of inter-shaft bearing faults in aero-engines.
R7246 14:50-15:05	AI-Augmented Predictive Maintenance for Multi-Zone Industrial Data-Processing Systems: A Hybrid Generative-Discriminative Framework **Author(s):** Chalapathi Koneni **Presenter:** Chalapathi Koneni, Independent Researcher, United States **Abstract:** Multi-zone industrial data-processing systems need early failure detection and reliable decisions about where to intervene. We present the Generative AI-Assisted Predictive Failure Detection Pipeline (GAI-PFDP), integrating a temporal multivariate encoder, contextual graph embeddings, a conditional variational autoencoder, and probabilistic anomaly ranking. The six-zone evaluation covers 90 days of telemetry and 412 labeled historical and injected fault events. On the 30-day held-out test period, the full configuration achieved 94.6% detection accuracy, 0.925 macro-F1, and 48.3-ms per-window inference latency. Its alert-to-restoration interval was 67.4% lower than threshold-based monitoring. We extend the study with intervention-aware allocation, ranking alerts by incident likelihood, downstream exposure, mitigation actionability, and preventable recovery time. Across 12,000 matched synthetic alert batches, the policy reduced severity-weighted recovery burden by 21.38%, versus 18.52% for probability-only ranking and 20.13% for graph-weighted risk. Paired recovery experiments link actionable warning time to restoration outcomes. Together, the studies show how cross-zone detection can inform capacity-limited recovery decisions, with separate evaluation endpoints for alert detection and intervention outcomes.
R7097 15:05-15:20	Fault Diagnosis of Marine Diesel Engines Based on Spatio Temporal Graph Attention Network **Author(s):** Tao Yu, Yunan Yao, Wenqiang Li **Presenter:** Tao Yu, Wuhan University of Technology, China **Abstract:** To address the issue of the insufficient extraction of deep spatio-temporal features from multi sensor long-sequence monitoring data of marine diesel engines, as well as the vulnerability of weak fault features to background noise, a fault diagnosis method based on a spatio-temporal graph attention network (STGAT) is proposed. Multisource signals including thermodynamic, lubricating oil, and vibration data from marine diesel engines are collected and preprocessed. A temporal attention mechanism is employed to adaptively capture global temporal dependencies, and a deep residual shrinkage network (DRSN) is introduced to suppress noise in high-dimensional data. Meanwhile, a graph attention network (GAT) and a convolutional neural network (CNN) are utilized to capture spatial dependencies among sensors and local temporal features, respectively. The fault diagnosis results are then output through a fully connected layer. Experimental results show that the STGAT model can effectively extract deep spatio-temporal

	features from multi-sensor long sequences and overcome background noise interference. On the test set, the classification accuracy reaches 98.90%, outperforming support vector machine (SVM), CNN, GAT and spatio-temporal graph convolutional network (STGCN). Noise robustness experiments further verify the effectiveness and robustness of the model under noisy conditions. The proposed model synergistically mines spatio temporal dependencies while suppressing noise, significantly improving the fault diagnosis accuracy for marine diesel engines, and demonstrates strong potential for engineering applications.
R7221 15:20-15:35	Uncertainty-aware Predictive Maintenance for Two-Stage Degradation Under Monitoring Noise **Author(s):** Chenning Liu, Jiantai Wang, Yu Zhao, Haodi Ji **Presenter:** Jiantai Wang, Beihang University, China **Abstract:** Predictive maintenance decisions for degrading systems are based on predicted health indicators. Under practical noisy condition monitoring, however, directly using degradation observations may lead to inappropriate maintenance decisions. This paper develops an uncertainty-aware predictive maintenance model for a two-stage degrading component. The normal and defective stages are characterized by Wiener processes, with defect occurrence modeled independently of the degradation evolution. Periodic manual inspections identify the discrete state, while a scalar Kalman filter estimates the degradation level from noisy observations. Once a defect is confirmed, the posterior uncertainty of the estimated degradation level is propagated into the Wiener first-passage reliability for predictive maintenance. The inspection interval and reliability threshold are jointly optimized by minimizing the long-run average cost rate. A numerical example demonstrates the proposed approach and illustrates the effect of degradation-level uncertainty propagation on maintenance decisions.
R7196 15:35-15:50	Digital Twin for Crack and Life Prediction of Fixed-Wing Aircraft Structures: A Feasibility Study **Author(s):** JingYing Liu, Jia Ning Chen **Presenter:** Jingying Liu, The Fifth Research Institute of the Ministry of Industry and Information Technology, China **Abstract:** The structural reliability of aerospace vehicles is a crucial factor affecting flight reliability and mission completion. Among them, the fixed wing, as the component of the aerospace vehicle that bears the most concentrated aerodynamic loads, relies on scheduled ground inspections, long-term life tests, and equivalent estimation to ensure structural integrity. This traditional approach makes it challenging to achieve real-time awareness of structural conditions and to meet the urgent engineering requirement for modern aerospace vehicles to predict and prevent failures in advance. To address these issues, this paper focuses on the 2024-T3 aluminium alloy fixed-wing skin and proposes a hybrid digital twin architecture driven by both physical mechanisms and data. Firstly, a physical layer is constructed based on the classical Forman crack growth equation to deduce the evolution patterns of cracks during the stable and unstable propagation stages. A long short-term memory network is introduced as the data layer to learn and refine the local fluctuation characteristics of the crack growth time series, and a residual correction mechanism is used to achieve fusion of the two layers. Simulation results demonstrate that, compared with a single model, the proposed research framework performs better in predicting crack growth trends and

	estimating remaining life. This method provides a physics–data hybrid modelling basis for future digital-twin development in aerospace structural health monitoring, effectively alleviates engineering challenges related to the limited sample size of fixed-wing specimens and the difficulty of large-scale testing, and offers a generalizable technical pathway for structural health monitoring modelling when physical test conditions are lacking in engineering practice.
R7103 15:50-16:05	ConformAI: Continuous Conformity Assessment and Governance Drift Detection for Generative AI **Author(s):** Ayomipo Solaja, Brain Aboze, Chioma Tagbo, Chimaoge Okezie Chukwueke and Ikenna Onyeama **Presenter:** Ayomipo Solaja, Independent Researcher, United Kingdom **Abstract:** AI systems are usually assessed for conformity once, before deployment, yet generative AI applications keep changing afterwards: model versions, system prompts, retrieval corpora, tool permissions and user populations all move. A system that was compliant on the day of certification can quietly stop being compliant without tripping conventional monitoring. We present ConformAI, a framework that treats conformity as a continuously measured property of the running system. It maps governance requirements to executable test suites in seven categories, runs a sampled slice daily together with near-boundary metamorphic probes, monitors the resulting behavioural fingerprint with calibrated CUSUM and MEWMA charts, attributes each alarm to the responsible change using a change-point gated change log, and gates every release with a full pre-and-post suite comparison. On a simulation testbed with six injected drifts of known onset and cause, over thirty seeds, ConformAI detects all 180 drift episodes with a mean latency of 10.7 days, 0.10 false alarms per 240-day run and correct attribution in every case. Quarterly red teaming with the same test battery detects 33 percent, aggregate MLOps monitoring 70 percent with no attribution, and a static checklist none. Release gates block 97.8 percent of unsafe releases and falsely block 3.8 percent of benign ones.

▶About Rome, Italy

Rome, the capital of Italy, is one of the most historically rich cities in the world. Known as the “Eternal City”, it has been a center of culture, politics and religion for nearly three millennia, and its historic center is listed as a UNESCO World Heritage Site. Rome combines ancient monuments, Renaissance palaces and vibrant contemporary life, making it an inspiring venue for an international academic conference.

November is a pleasant time to visit Rome: daytime temperatures are mild, the summer crowds have gone, and the city can be explored comfortably on foot. The conference venue, NHOW Roma, is located at Corso d’Italia 1, close to the historic center and well connected by public transport.

Attractions in Rome

- Colosseum: the iconic Amphitheatre of ancient Rome and the symbol of the city.
- Vatican Museums and St. Peter's Basilica: masterpieces of art and architecture in the smallest state in the world.
- Trevi Fountain: the famous baroque fountain where visitors toss a coin to ensure their return to Rome.
- Pantheon: a remarkably preserved temple of all the gods, with its celebrated concrete dome.
- Roman Forum and Palatine Hill: the heart of political and social life in ancient Rome.
- Piazza Navona: a lively square built on the site of a Roman stadium, famous for its fountains.
- Spanish Steps and Via die Condotta: a favorite area for shopping and evening walks.
- Villa Borghese: a large landscape garden housing the Galleria Borghese art collection.

Transportation Options in Rome

- Metro: Lines A, B and C connect the main railway stations and the historic center.
- Public Transport: an extensive network of buses and trams operated by ATAC.
- Roma Termini: the main railway station, connected to the airport by the Leonardo Express.
- Fiumicino Airport (FCO): Rome's main international airport, about 30 km from the city center.
- Taxi and ride-hailing services are available throughout the city; official white taxis are recommended.
- Walking: most of the historic center, including the conference venue surroundings, is best explored on foot.