

33rd EUROPEAN SAFETY AND RELIABILITY CONFERENCE (ESREL 2023)

3 -7 September 2023

University of Southampton, United Kingdom



**EXTENDED
ABSTRACTS**

**20
23**
European Safety &
Reliability Conference

ESREL 2023

The 33rd European Safety and Reliability Conference (ESREL 2023)

The Future of Safety in the Reconnected World

— Extended Abstracts —

ESREL 2023

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Edited by

Mário P. Brito, Terje Aven, Piero Baraldi,
Marko Čepin and Enrico Zio



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Book of Extended Abstracts

Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

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Preface

ESREL (European Safety and Reliability) is an annual conference series ran under the auspices of the European Safety and Reliability Association (ESRA). The conference dates to 1989, but it was not referred to as ESREL until 1992. The conference has become well established in the international community, attracting a good mix of academics and industry participants that present and discuss subjects of interest and application across various industries.

This year the theme of the conference is “**The Future of Safety in a Re-Connected World**”. The conference covers several topics within safety, risk and reliability analysis methods, maintenance, optimisation, and risk management. Special focus has been placed on how technology developments and nature induced hazards impact societal safety in a world increasingly reconnected post Covid-19 pandemic. The conference addresses methodological solutions in prognostics and health management, mathematical methods, accelerated life testing, maintenance modelling, accident and incident modelling and reliability modelling. As with previous years, risk perception and communication also play a key role. The conference application areas range from aviation systems, oil and gas, nuclear energy, autonomous systems, Natech, security, transportation, health and medicine to safety and reliability of systems that will potentially enable the transition to net-zero emissions, for example hydrogen power generation systems.

The ESREL Conference returns to the United Kingdom after the 2016 event held in Glasgow. This time the Conference is held in the city of Southampton. The city of Southampton, a city at the centre of global connectivity, and which boasts a rich maritime history. Both the Mayflower and, centuries later, the Titanic, left Southampton dock towards very different fates, with the former signifying the irrepressible spirit of hope and the latter signifying hubris and disaster. These voyages offer lessons on the interplay of human and technological factors, both in optimising safety and reliability and in determining what risks should be considered in the first place. As such, the city of Southampton is a great location to host ESREL2023, one of the most prominent conferences in safety and reliability.

This year, the ESREL Conference includes 443 papers, 87 extended abstracts and 68 abstracts. The conference has received 739 abstracts. After a robust review process by the Technical Programme Committee, 443 papers have been accepted and are included in these proceedings. The work of peers, reviewers and Technical Panel Committee in helping the authors to improve their papers is greatly appreciated. Special thanks to the organisers of Special Sessions of the Conference, for their initiative and planning which has resulted in a broad spectrum of submissions and several interesting papers.

This book contains the extended abstracts accepted for ESREL2023 conference held at the University of Southampton from the 3rd of September 2023 to the 7th of September 2023.

The host of the ESREL2023 Conference is the University of Southampton, and its associated Centre of Risk Research. The conference is sponsored by the University, GrifTotalEnergies and VWay. Their support is greatly appreciated.

Finally, we would like to acknowledge the organising committee, and in particular the events team in the Faculty of Social Sciences in the University of Southampton for their careful planning of the conference events, registrations, and webpage. Thanks also to our PhD students Kaiqi Xu, Hanqin Zhang and Yujia Chang for their administrative help during the paper reviewing process.

Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio

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Speakers

Plenary Session Resilience analysis and optimization for interconnected or distributed systems: use cases and methodological contributions from the chair RRSC

Professor Anne Barros

*Professor in Reliability and Maintenance Modelling at Ecole CentraleSupélec,
University of Paris-Saclay*

Abstract

The R³ Group created in 2020 at CentraleSupélec, Université Paris-Saclay is developing research activities for risk, resilience and reliability analysis of complex engineered systems. Our models are mainly based on stochastic processes and data-driven approaches with a strong focus on optimization and uncertainties quantification for decision-making in design and operation. We are strongly connected to several industry partners with the chair Risk and Resilience of Complex Systems (RRCS), supported by the French national power supplier (Électricité de France - EDF), the French national Telecom supplier (Orange), and the French national Railway Company (Société nationale des chemins de fer français- SNCF). This is an arena to define study cases, share knowledge data and experiences, develop methods, and implement benchmarks and prototypes of tools. The objective of this keynote is to give you an overview of 4 years of activity within the R³ group and the RRSC chair in the field of resilience analysis and optimization. This overview will cover practical problems raised by the three industry partners, methodological contributions of the research group and implementation on use cases.

Biography



Anne Barros, PHD, is professor in reliability and maintenance modelling at Ecole CentraleSupélec, University of Paris-Saclay, France. Her research focus is on degradation modelling, prognostics, condition based and predictive maintenance. She got a PHD then a professorship position at University of Technology of Troyes, France (2003-2014) and spent five years as a full- time professor at NTNU, Norway (2014-2019). She is currently heading the Risk Resilience and Reliability Group (R³ Group – <http://r3.centralesupelec.fr/>) and holding an industrial Chair at CentraleSupélec (Chaire RRSC) with the ambition to improve resilience assessment and maintenance modelling methods for complex systems.

Plenary Talk

Early and effective safety/cybersecurity analysis – getting started with STPA

Stephen Porter

VP Americas/EMEA, at VWAY Corporation

Abstract

As safety and cybersecurity issues continue to surface, the methods used to design, develop, and operate safe & secure systems are evolving rapidly. STAMP and STPA are part of that change. Design failures continue to occur (at pace), despite the resultant systems having been thoroughly tested and validated. Conventional safety system approaches have proven to be incomplete. How can teams meet the needs of increasingly complex and autonomous software-enabled systems that must factor-in human interaction? Reliability engineering models and methods are no longer considered the principal or sole contributors to the safe operation of safety-critical and mission-critical systems. As the separation between engineering design and the organizations that deploy and operate these designs is being erased, a new paradigm is taking shape. STAMP and STPA are at the heart of that – as we discuss the belief that safety and security are really control problems, this session will also introduce the latest effective tooling framework to support this paradigm shift.

Biography



Stephen has over 30 years' experience in software product development, from deeply embedded safetycritical systems to large scale industrial operations. Currently focused on enabling improvements in the safe and (cyber) secure operation of complex systems in zero-emission smart-transportation, cleanenergy production, and 'patient-outcome driven' health solutions. Key to meeting this objective is providing design, development, and deployment tools needed to orchestrate operations, methods, and processes amongst relevant stakeholders. STPA has emerged as the new paradigm that underpins these efforts, helping innovators deliver safer, cleaner, and more secure solutions.

Stephen is a scale-up expert, having assisted many software product companies including Polarion (acquired by Siemens in 2016), Jama Software (acquired by Insight Partners in 2018) and more recently assisting Intland Codebeamer SDC, (Intland were acquired by PTC, 2022). In earlier years at Wind River (pre/post IPO), he led global activities in the instrumentation, communications, and controls sector; as well as having successfully founded, grown and divested several private companies along the way.

Plenary Session

Seismic risk and resilience of civil infrastructure: towards the reconciliation of time and space

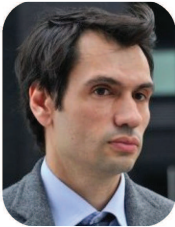
Professor Iunio Iervolino,

Professor of Structural Engineering at the University of Naples Federico II and at IUSS of Pavia

Abstract

Performance-based earthquake engineering (PBEE) is the state-of-the-art for the assessment of seismic reliability and risk. It relies on the separation between, hazard, vulnerability, and consequences. It has proven effective to provide a framework for research and industry practice, even beyond the earthquake peril. Nevertheless, its classical formulation applies to the analysis of single site assets, such as buildings, and it is meant for long-term assessment. On the other hand, the increasing complexity of civil infrastructure systems and the need to aid decision making in different contexts, has stimulated the development of declensions of PBEE for specific time (e.g., real-time, operational forecasting, and recovery) and space (spatially distributed infrastructure, and system of interconnected infrastructure) scales. However, each of these developments currently employs ad-hoc probabilistic models, with different input information, that do not necessarily reconcile with each other. It is the main current challenge of research to provide a holistic modelling of PBEE components applicable all time and space scales. The keynote will provide a review of the current declensions of PBEE and discuss whether the unifying goal is at reach given the current advances and what are the outstanding challenges.

Biography



Iunio Iervolino is full professor of Structural Engineering at the University of Naples Federico II and at IUSS of Pavia. He has a master in Management Engineering and a master and a Ph.D. in Seismic Risk. He has worked long time under the supervision of C. Allin Cornell. His research revolves around the fields of risk analysis of industrial and civil infrastructure systems, earthquake engineering, structural reliability, engineering seismology and probabilistic hazard analysis. Since his Ph.D. thesis, on the topic of seismic risk assessment of process industry facilities, he has authored more than three hundred publications. Among awards and honors, Iunio received the AXA research fund grant in 2011, and in 2014 he was appointed Fulbright visiting professor at Stanford University. He has advised about twenty Ph.D. theses so far, and his former Ph.D. students are employed in the industry of insurance and risk analysis or became university professors worldwide. He is editorial board member or associate editor of several scientific journals, such as Earthquake Engineering and Structural Dynamics, Soil Dynamics and Earthquake Engineering, Computer Aided Civil and Infrastructure Engineering, Sustainable and Resilient Infrastructure.

Engineering, Sustainable and Resilient Infrastructure.

Plenary Session

Risk-aware autonomous systems for safe and intelligent decision making

Professor Dr. Ingrid Bouwer Utne

Professor, Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Abstract

The technological advances in automation and autonomous systems enable new and challenging missions, processes, exploration and monitoring of areas on land and at sea. Higher autonomy in tedious operations may lead to safer and more efficient performance, supporting the human operator with respect to workload, supervision, and decision making. Advanced control systems introduce, however, new types of failures, due to increased system and mission complexity and unforeseen functional interactions. With reduced involvement by a human operator, early warnings and predictions of potential deviations are needed to enable system reconfiguration and provide the human operator with enough time to intervene when necessary.

Risk perception is an important part of human cognition which currently is not adequately implemented in the control and decision-making of autonomous systems. Supervisory risk control is a novel research area which couples risk assessment and modelling with control system design, i.e., bridging the disciplines of risk science, human factors, engineering cybernetics, and artificial intelligence (AI). Risk specialists need to be an integral part of the development of AI and control systems to improve safety and trust in these systems.

In this lecture, I claim that autonomous systems able to analyse and evaluate risks comprehensively would lead to highly intelligent system behaviours, safe interactions in challenging environments, and public trust and acceptance. I address challenges related to intelligent risk analysis and shared control, and promising solutions researched and tested using both simulation and field experiments with real robotic platforms. The focus is on marine systems due to the demanding challenges in that domain, and my experience as a researcher in the Centre of Excellence on Autonomous Marine Operations and Systems (NTNU AMOS), but the results should have relevance across different application areas.

Biography



Dr. Ingrid Bouwer Utne is a Professor at Department of Marine Technology at the Norwegian University of Science and Technology (NTNU). Her main research area is risk assessment and modeling of marine and maritime systems. Utne started her career in the marine domain as a young officer onboard two Norwegian frigates, and among other things she sailed with NATO's Immediate Reaction Force. Later, she has worked in the research institute SINTEF, in the industry, and she has been a visiting Scholar at UC Berkeley where she was a member of the Deepwater Horizon Study Group (DHSG) at the Center for Catastrophic Risk Management. The DHSG served as advisor to the US Presidential Commission, authorities, and the public on issues related to the Macondo blowout. In recent years she has specifically focused her research on improving the safety and intelligence of autonomous systems, as part of interdisciplinary work in the Center of Excellence on Autonomous Marine Operations and Systems (NTNU AMOS).

Plenary Session Effects of offshore safety case regulations on vessel/platform collision incidents

Professor Jin Wang

Professor in Maritime Technology at John Moores University of Liverpool

Abstract

An offshore installation is exposed to ship collision risk from both in-field and passing vessels. Both categories of collision have occurred on the United Kingdom Continental Shelf (UKCS) and both have the potential to result in catastrophic damage to the installation. World-wide, catastrophic collisions with installations have occurred resulting in severe damage to vessels and installations, leading to loss of life and environmental damage. This led the Health and safety Executive (HSE) to investigate the occurrence and reporting of ship to platform collisions on the UKCS. The research presented is an extension of the HSE's updated Ship/Platform Collision Incident Database. The database has been expanded in order to determine whether the fluctuations were a regular occurrence and, if so, what was the cause. This research analyses a large number of ship to platform collision incidents in terms of damage classification, the vessel type, month of occurrence and a comparison of the release of regulations with the fluctuation of incidents. Subsequently, this analysis has identified a key trend between the reporting of offshore collision incidents and the release and enforcement of offshore Safety Case regulations. Furthermore, how advanced risk modelling approaches are used to improve maritime safety is given with applications.

Biography



Prof. Jin Wang has served as Associate Dean (Research) in the Faculty of Engineering and Technology of LJMU since 2015 and also as Director of the LOOM Research Institute since 2003. Prof. Wang joined LJMU as a lecturer in 1995. He was promoted as Reader in Marine Engineering and Professor of Marine Technology in 1999 and 2002, respectively. His research interests are in risk-based design and operation of large maritime engineering systems. He has published extensively in this area, making him among top 70 in Civil Engineering in terms of publications and citations in the World Ranking of Scientists worldwide since 2020. He has authored or co-authored over 500 technical research outputs including 2 research monographs and 200 SCI-cited journal papers. Prof. Wang has led four EU funded projects as coordinator and 7 UK research council funded projects. He has participated in another four EU projects as LJMU's PI. He has won several awards for his research work including the 2017 RINA – Lloyd's Register Maritime Safety Award for Lifetime Achievement.

Prof. Wang has been a member of the Engineering sub-panel in the UK's Research Excellence Framework (REF) 2014 and 2021, assessing the quality of research in UK higher education institutions. He is Editor-in-Chief of Journal of Marine Engineering and Technology. He is Chair of the UK-Malaysia University Consortium (UK-MUC) of 16 UK and all 20 public Malaysian Universities to expand international higher education between the UK and Malaysia.

Plenary Talk

Launch Vehicle and Spacecraft Risk Analysis Applications

Dr. Todd Paulos

NASA Jet Propulsion Laboratory

Abstract

The United States space program for decades has primarily used coastal launch sites in California, Florida and Virginia as these locations offer less risk exposure to the public in case of an accident. With the push towards commercial launches, newer spaceports are being planned and developed as more accessible and affordable alternatives, such as Boca Chica Launch site in Texas, Mojave Air and Space Port inland California, and Corn Ranch Spaceport in Texas.

The Office of Commercial Space Transportation, part of the Federal Aviation Administration which administers the air traffic control over the United States, approves any commercial launch operation. As part of the launch approval process, the risk to the public is assessed. This talk presents a brief overview of a launch vehicle/spacecraft risk analysis from launch through landing, using the ill-fated, but trailblazing, X-33 as the example.

Biography



Dr. Todd Paulos has over 30 years of experience in the space, aviation and nuclear industries. He currently works at the NASA Jet Propulsion Laboratory in the Systems Reliability Group, and is the Probabilistic Risk Assessment Point of Contact for the laboratory, assessing the need for PRA across all JPL missions, and directly supporting programs such as Europa Clipper, Psyche, and Mars Sample Return. As part of the larger NASA wide community, Dr. Paulos is a main author of NASA's PRA Guidebook, NASA policy requirement document 8715.26 on nuclear flight safety, and has contributed to an international guidance document on post mission disposal risk assessment (along with the Japanese and European space agencies). Additionally, Dr. Paulos is a member of NASA's Reliability and Maintainability Technical Discipline Team. Dr. Paulos may be familiar to you as he has supported the International Association for Probabilistic Safety Assessment and Management (IAPSAM) organization since its inception, is the past President, current Treasurer, was the General Chair of PSAM 2014 in Honolulu, the Technical Chair of PSAM 2022 also in Honolulu, and has been to the joint

ESREL-PSAM meetings through the years, and is looking forward to our future collaborations.

Plenary Talk Reviewing 50 years' experience in Norwegian risk governance

Professor Jan Erik Vinnem

Emeritous Professor at NTNU on Maritime Safety

Abstract

2023 is the 50 years anniversary for systematic risk management in Norway, with the publication of a small book titled 'Risk analysis, description of hazards as input to decision-making' in 1973, 2years ahead of the US 'WASH-1400, which was a cornerstone for risk assessment in the nuclear power plants in US. The presentation will review the status of risk management in Norway, with emphasis on offshore petroleum, and look into the crystal ball with respect to upcoming offshore energy production, mainly from wind turbines.

Biography



Professor Jan Erik Vinnem has written over eight textbooks on systems safety. He has published over 200 research articles in high ranked journals such as Safety Science and Risk Analysis. His research interests are on risk-informed decision-making in offshore petroleum; barrier management & indicators in offshore petroleum; operational & on-line risk analysis; autonomous offshore petroleum production facilities.

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Optimization of Step-stress ADT following Tweedie Exponential Dispersion process

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In this study, we focus on the optimization of step-stress accelerated degradation test (SSADT) plan when the degradation process can be modelled by a stochastic Tweedie exponential dispersion (TED) process. In the context of an optimization based on the D-optimality and V-optimality criteria, with a prior transformation of stress, the equivalence between a multilevel SSADT plan and a simple SSADT plan using only the minimum and maximum stress levels can be shown. Thus optimal SSADT plans can be simply derived. An application example will be presented to assess the effectiveness of the proposed simple optimal SSADT plans.

Keywords: Accelerated Degradation Test, Optimization, Tweedie Exponential Dispersion Process.

1. Introduction

The Accelerated Degradation Test (ADT) is a powerful tool used to assess reliability and predict the lifetime of degrading products. In a Constant-Stress ADT (CSADT), products are divided into multiple groups and exposed to a constant and severe stress condition to collect degradation data. While CSADT is an efficient test, it requires numerous units to conduct the experiment, making Step-Stress ADT (SSADT) a more appropriate choice as it requires fewer test units. Two critical tasks must be addressed to carry out the optimal design of an SSADT plan. Firstly, the optimization criterion must be selected, and secondly, a suitable degradation model must be chosen for analysing the observed degradation data. Many studies have proposed using D-optimality to improve the estimation accuracy of unknown parameters of degradation models, and V-optimality for estimating reliability indices and specific p-quantiles of lifetime distribution as

optimization criteria. As for selecting the appropriate degradation model, the Tweedie exponential dispersion process (TED) process - a general class of degradation model, which includes some commonly used stochastic process (e.g., Wiener, Gamma, and Inverse Gaussian processes) as its special cases - can be used to describe more extensive degradation phenomena.

2. Model description

A stochastic process describing the evolution of a performance indicator over time is defined as an exponential dispersion (ED) process $\{Y(t), t \geq 0\}$, if satisfying the following three properties: (1) $Y(0)=0$ with probability one; (2) $\{Y(t), t \geq 0\}$ has statistically independent increments; (3) The increment follows ED distribution, i.e., $Y(t+\Delta t) - Y(t) \sim \text{ED}(\eta \Delta t, \lambda)$, for $\forall \Delta t > 0$, where the probability density function (PDF) of ED distribution $\text{ED}(\mu, \lambda)$ is expressed in Equation (1) hereafter.

$$f(y | t, \eta, \lambda) = c(y | t, \lambda) \cdot \exp\{\lambda[y\omega(\eta) - t\kappa(\omega(\eta))]\} \quad (1)$$

where η is the mean drift rate, λ is the dispersion parameter; $c(\cdot)$ is a canonical function, guaranteeing that the cumulative distribution function (CDF) of Equation (1) is normalized and equal to one; $\kappa(\cdot)$ is called the cumulant function, which is a twice differentiable function, and satisfying $\kappa'(\omega(\eta)) = \eta$, in which $\kappa'(\cdot)$ is the first derivative of $\kappa(\cdot)$.

An ED model can be characterized by its variance function within the class of all ED models. Furthermore, the TED process is an important class of ED process with power variance function:

$$V(\eta) = \eta^\rho, \rho \in (-\infty, 0] \cup [1, \infty) \quad (2)$$

where ρ is the power classification parameter.

3. Optimal SSADT plans under TED process

An SSADT is characterized by the total number of test units available n , the number γ of stress levels used in the test, as well as the stress value of each level, the allocation scheme of the measurements to each stress level, the test duration τ_γ , and the measurement time interval Δt . Here, we assumed that the number of units, the test duration τ_γ , and the measurement time interval Δt are given. Therefore, the objective of the SSADT planning is to determine the optimal stress levels, as well as the proportion of units allocated to each level. The foundations of our approach are based on the following theorem demonstrated by Yan *et al.* (2023).

Theorem 1 Based on the D and V-optimality criteria, if a test unit's degradation path follows the TED process and the relationship of drift parameter and stress satisfies $\eta_k = \alpha e^{\beta s_k}$, the optimal multi-level SSADT plan using stress levels $s_1 < s_2 < \dots < s_\gamma$ will degenerate to a simple SSADT plan using only the minimum and maximum stress levels, s_1 and s_γ .

Thus, the procedure of optimal design will follow:

Step 1: Derive the Fisher information matrix of the TED model, because many optimal SSADT design criteria are based on Fisher information matrix if the goal of conducting an experiment is to estimate the model parameters or their functions (e.g., lifetime percentiles).

Step 2: Derive that for D-optimality and V-optimality, a multi-level SSADT plan, when optimized, degenerates to a simple SSADT plan using only the minimum and maximum stress levels. This result establishes a rationale for considering a simple SSADT using only the minimum and maximum stress levels.

Step 3: We consider the design problem of a simple SSADT plan and present the optimal allocation of inspections at each stress level for different criteria.

Finally, a proof will be given that for the D-optimality and V-optimality criteria, when the total sample size n , inspection number M and the time interval Δt between inspections are given, the optimum SSADT plan based on TED process is given as follows:

(1) For **D-optimality**: the optimum plan assigns inspections: $(\frac{m_1}{M}, \frac{m_\gamma}{M}) = (p_1, p_\gamma) = (\frac{1}{2}, \frac{1}{2})$

(2) For **V-optimality**: the optimum plan assigns inspections:

$$(\frac{m_1}{M}, \frac{m_\gamma}{M}) = (p_1, p_\gamma) = (\frac{s_\gamma \sqrt{A_\gamma}}{s_1 \sqrt{A_1} + s_\gamma \sqrt{A_\gamma}}, \frac{s_1 \sqrt{A_1}}{s_1 \sqrt{A_1} + s_\gamma \sqrt{A_\gamma}}).$$

An application example based on actual data will be presented to compare the effectiveness of the proposed simple optimal SSADT plans and multi-level SSADT plans proposed in a previous study (Yan *et al.*, 2021). The results show that the efficiency is improved by using the optimum simple SSADT plan.

3. Major contribution and conclusion

Compared with the existing works, the major contribution of this study lies in the proof that, under the TED model with a drift parameter being an exponential function of the (transformed) stress level, a multi-level SSADT plan will degenerate to a simple SSADT plan using only the minimum and maximum stress levels under D-optimality and V-optimality criteria.

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Normal maritime accidents in the Navy – analyzing the collisions of US Navy J. S. McCain and US Navy Fitzgerald

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This paper explores two maritime accidents in 2017, based on the NTSB accident reports issued in 2019 and 2020. The two different collisions involved modern destroyers, i.e. the US Navy John S McCain and the US Navy Destroyer Fitzgerald. Based on a system approach, we have analysed design and Human Factors issues as described in the NTSB accident reports.

We have explored safety incidents, and have explored root causes based on a system perspective, i.e. exploring Man (Human Factors issues), Organizational issues, and Technology issues; abbreviated to MTO. In addition we have explored how the blunt end (Command and control in the Navy) and the sharp end (i.e. crew on the bridge) has been evaluated by key actors such as the Navy, courts and the investigation authority - NTSB. We have based our evaluation on an accident investigation model as used by the safety investigation authority. In addition we have performed a limited survey of maritime accidents investigations focusing on the technical equipment on the ship bridge and an exploration of best practices of bridge design. Design challenges has been a part of our analysis. We have tried to find the root causes leading to human errors, and we have tried to include the sensemaking of the involved actors from the sharp end. We have tried to identify the difference between work as imagined (procedures) and work as done (as documented by the accident investigation reports). The two specific accidents took place on a bridge, that were dependent on the use of modern technology. Both accidents happened during night time (where sensemaking is impacted by the circadian rhythm), at high speed (i.e. around 20 knots), with poor interaction with surrounding traffic - the AIS (automatic identification system) was turned off making communication with other ships challenging, the Navy's ineffective oversight in the areas of crew training and fatigue mitigation, loss of situational awareness/ ineffective communication and cooperation on the bridge. In addition our limited survey of maritime accidents, have highlighted the poor quality of situational awareness on the bridge, too many alarms, insufficient training, insufficient passage planning, poor work load assessment and poor (safety) management. The accident reports raise the issue of usability and user involvement from design through acceptance of the bridge systems, and raise the question "are the systems so poorly made that they are a challenge to use?" Based on the issues highlighted in the NTSB report, and our review of maritime accidents, it seems that the operation of the destroyers created the environment for

a Normal Accident – or an accident waiting to happen. However the John S McCain and the Fitzgerald case, the actors in the sharp end was blamed and punished for the accidents, thus indicating the need for a more “just culture” in the naval environment.

Keywords: Accidents, Accident investigations, Human Factors

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CFD Simulation and Experimental Study on Outgassing and Damage Characteristics of Multilayer Insulation During Ascent

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Multilayer insulation (MLI) is widely used on the outer surface of spacecrafts. In the ascent stage, the air pressure outside the spacecraft decreases rapidly from 1 atmosphere to 100 Pa within approximate 120 seconds. Hence, the inert gas of the spacecraft expands and then releases rapidly through the MLI, which may result in the damage of MLI. In this paper, a simplified geometrical model of MLI is established, and computational fluid dynamics (CFD) method is applied to simulate the outgassing process, the pressure contour and aerodynamic force of each MLI layer during ascent are calculated. The results show the pressure decreases gradually from the inside to outside layers, and the flow induced force generally rises from the inside to outside layers. The maximum aerodynamic force and stress occur at approximately the intermediate moment of the depressurization process. In addition, a test rig is designed to simulate the rapid depressurization process during ascent. MLI damage phenomena are observed in some geometric and fixation conditions. It is interesting that all the damage occurs at the outer layers of MLI firstly, and the maximum differential pressure between the upstream and downstream of MLI occurs at intermediate moment of the rapid depressurization process. These findings agree with the CFD results. Besides, the influence of layer number, fashion of outgassing holes and fixation on damage characteristics are discussed.

Keywords: Multilayer insulation; Ascent stage; CFD; Outgassing; Damage characteristics.

1. Background

Multi-Layer Insulation (MLI) is one of the most commonly used passive thermal control components for spacecraft due to its lightweight and outstanding radiation insulation performance. Referring to Figure 1, MLI components are generally composed of alternating spacer layers and reflecting layers.

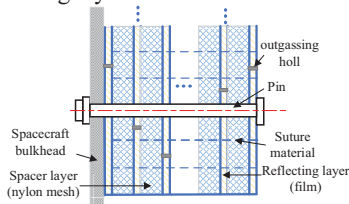


Fig. 1. Composition of MLI.

In the ascent stage of a flight, due to the rapid pressure decreasing, the gas inside the MLI components will rapidly discharge outward, which are prone to damage, tilting, or

detachment of MLI. The damage of MLI components directly affects thermal control, optical imaging, etc.

The researches on MLI components during ascent stage mainly focuses on heat transfer characteristics. Johnson et al. (2012) applied a vacuum chamber to simulate the launch and ascent environment, the boil-off and thermal characteristics of a liquid methane tank are studied. Liu et al. (2016) investigated the thermal performances of MLI during the ascent and on-orbit process. Therefore, it is urgent to study the flow and damage characteristics of MLI components in ascent stage.

2. CFD Model and Typical Results

As shown in Fig. 2, a simplified CFD model with area of 18mm×18mm, contains 5 nylon mesh layers and 6 insulation film layers. The area size is far smaller than actual size to simply the calculation. The nylon mesh is 0.2 mm in

diameter, and 0.1 mm in clearance from the adjacent films. The film is 10 μm in thickness with outgassing hole of 1mm in diameter. The grids have over 8 million elements in total with the least element size of 0.02mm. Transient-state model and SIMPLEX algorithm are applied.

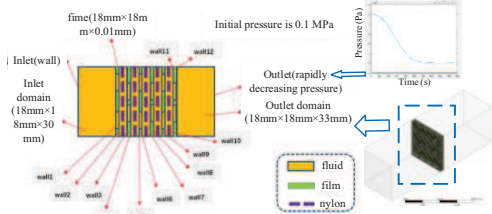


Fig. 2. CFD model.

The pressure results of typical interfaces at 58s when has the fastest outlet pressure decreasing rate are listed in Fig. 3. The calculated flow induced forces of each film are shown in Fig. 4.

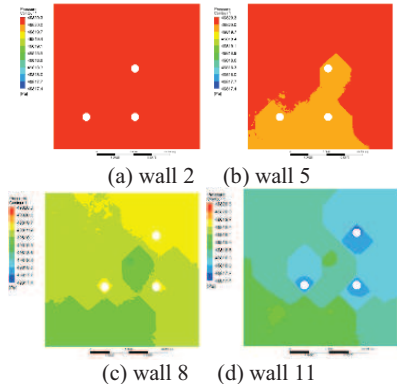


Fig. 3. Pressure contour at various interfaces.

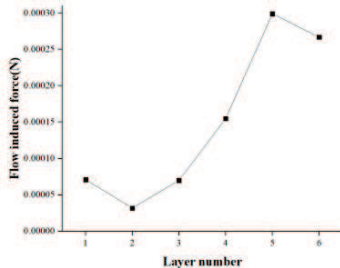


Fig. 4. Flow induced forces of each film.

As shown, the pressure decreases from the inside to outside layers. The pressure gradient near the outgassing holes is relatively large, indicating that the leakage through these holes is the main reason for pressure drop. Besides, the flow induced force of each layer generally rises from inside to outside, except for some fluctuations at both innermost and outermost layers. Hence the damage is more likely to occur at outer layers

3. Test Rig and Typical Results

As shown in Fig. 5, the test rig can simulate the rapid depressurization outside of the MLI. The MLI specimen is 240 mm in diameter. The differential pressure can be up to 70 kPa. Various number of layers, fashion of outgassing holes and fixation conditions are tested comparatively.

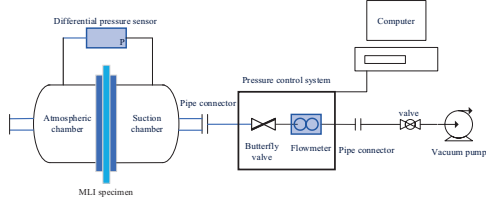


Fig. 5. Test rig and connections.

As shown in Fig. 6, the damage occurs at the outer layers of MLI, where has the larger aerodynamic force and stress than inner layers. The phenomenon agrees with the CFD results.

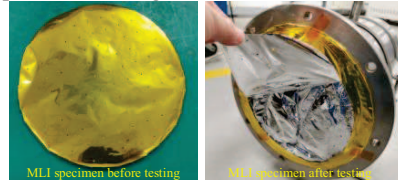


Fig. 6. Damage phenomenon of a 5-layer MLI.

4. Conclusions

The pressure of MLI decreases from the inside to outside layers. Besides, the flow induced force generally rises from the inside to outside layers in general. In addition, a test rig is designed to simulate the rapid depressurization process during ascent. MLI damage phenomena are observed in some conditions. All the damage occurs at the outside layers of MLI firstly, which agree with the CFD results.

Acknowledgement

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MBSA model to evaluate and analyse the production availability of an offshore wind farm

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Estimating the production availability of an offshore wind farm is a new challenge. In order to perform these calculations as well as possible, work is carried out within TotalEnergies using the GRIF software suite. A synthesis is proposed in this article and will be presented at ESREL 2023.

Keywords: Wind, Offshore, Petri nets, Monte-Carlo simulation, MBSA, Maintenance, O&M, Production availability, Weather, GRIF

1. Introduction

Preparing for the energy transition is one of the major concerns of the French government, which enacted the Energy Transition Law for Green Growth (LTECV) on 17 August 2015 to limit global warming effects (ecologie.gouv.fr., 2017). To meet this challenge, the French energy supermajor Total became TotalEnergies in 2021 to make the group a major player in the energy transition and to achieve, jointly with society, carbon neutrality by 2050. To achieve this, the company has set itself the following objectives:

- (i) Reduce greenhouse gas emissions as much as possible, primarily on its different sites operated in Europe and elsewhere in the world that are under its direct responsibility
- (ii) Offset all remaining emissions, for example through CO₂ capture projects
- (iii) At the same time, propose an energy mix that is less and less carbon intensive with the development of renewable energies (solar, hydrogen, onshore and offshore wind, etc.).

To enhance energy mix, from 2022 onwards, new offshore wind farm projects will emerge close

to consumption grids and raise new questions which the Offshore Wind industry is preparing to meet the objectives of the LTECV law. To this end, Reliability Availability Maintainability (RAM) studies can provide decision-aid support to define the best Operation and Maintenance (O&M) strategy, i.e. the one allowing to obtain the optimum between OPERating EXpenditure (OPEX) and production availability (ISO 20815:2018) for a given farm.

2. Issues

The complexity of the O&M model of an offshore wind farm relies on the accuracy of the simulation model, especially on the way the weather impact and the maintenance strategy are to be considered. Indeed, all effects induced on intervention vessel mobilization times, power of turbines and logistic delays are to be addressed properly as they can have a significant impact on final results. By simply considering the wind speed and wave height, it quickly becomes clear that the availability and accessibility of human resources and maritime transport are variable. Moreover, the structures, machines and technologies present in an offshore wind farm are continuously increasing in size. This makes it difficult to access reliability data and feedback on different O&M strategies.

Faced with such constraints and following a benchmark of existing software and methods, it appears that a Model Based Safety Assessment (MBSA) modelling technique is the best solution. By definition, in the context of system safety analysis, MBSA is an approach that consists of building high-level models that are closer to the descriptions of functional and physical architectures of systems, while remaining assessable by the tools for calculating safety indicators (Batteux, 2017).

This type of methodology has already been conducted for oil & gas industry through Petro module of the GRIF software suite (GRIF, 2023), technology of TotalEnergies, which supports the MBSA approach (Batteux, 2016). However, this module does not properly address all offshore wind market specificities, and that is why it is needed to propose an alternative with the Flex module also available in the GRIF simulation package based on Petri nets with predicates and assertions associated to Monte-Carlo Simulation.

3. Methodology

The purpose of this new tool is to consider in a same integrated model (non-exhaustive list):

- Curative maintenance interventions further to random failures
- Planned events (inspection, preventive maintenance, testing, etc.)
- Weather impact (wind and wave) and all associated effects on the system
- System architecture and design capacities
- Logistics (maintenance resources, intervention vessels, mobilization times, spare part strategy, procurement times, etc.).

To do so, the Flex methodology put in place consists in:

- (i) In GRIF-Petri12 (dedicated graphical interface for the realization of Petri nets with Predictions and Assertions)
 - (a) Create a library of generic Petri nets (components, resources)
 - (b) Define flow propagation for generic components
- (ii) In GRIF-Flex
 - (a) Model the system from its definition by assigning the corresponding generic Petri nets for each block created

- (b) Enter a source and a target of the flow (mono or multi) that will circulate through the system components according to flow definitions.

To illustrate the use of Flex module, the figure below allows to see a simple model composed of two turbines and an offshore sub-station).

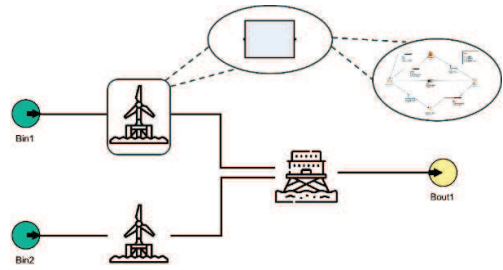


Fig. 1. Flex model and methodology illustration

4. Perspectives

The aim of the research is to create a MBSA model with Flex according to a test case. Further results will be provided during the presentation at ESREL 2023.

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Requirements for quantitative risk assessment of hydrogen facilities: An Irish use case

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The present work summarises the requirements for a Quantitative Risk Assessment (QRA) of a hydrogen facility. This is done within a framework of the recently announced National Hydrogen Strategy in the Republic of Ireland. The proposed framework for risk assessment is based on a probabilistic method called Bayesian networks. This framework is expected to provide permitting authorities with a decision support system and guidance for QRA hydrogen facilities.

Keywords: Quantitative Risk assessment, Hydrogen safety, Bayesian Networks, Hydrogen Economy, Uncertainty Quantification.

1. The Hydrogen Strategy in Ireland

In the summer of 2023, a recently formulated National Hydrogen Strategy has been unveiled in Ireland. This strategy stands as a pivotal point of reference intended to facilitate the advancement of the nation's hydrogen economy, predicated upon key objectives encompassing decarbonisation, energy security and growing industrial opportunities. The Government of Ireland: Department of the Environment, Climate and Communications (2023). In effect, this strategic framework offers a viable trajectory, particularly for corporate entities like the Electricity Supply Board (ESB), which has already embarked on ventures geared towards establishing robust hydrogen infrastructure. This infrastructure plays a crucial role in the overarching endeavour to effectuate the decarbonisation agenda for the country ESB-press (2022); RTE news (2023). While the strategy is congruent with existing European legislative provisions, it is pointed out that standards and the hydrogen safety framework should be revised and further developed due to the early stage of the sector. Given this context, it is of paramount importance to devise methodological frameworks designed to underpin the decision-making process within the hydrogen safety sector.

Safety is a central concern in hydrogen production, often pivotal for securing regulatory approval and public acceptance. This challenge arises from hydrogen's physical traits, including high leakage susceptibility, broad flammability limits, elevated laminar burning velocity, and low minimum ignition energy (Cashdollar et al. (2000)). Consequently, ensuring safe large-scale hydrogen production needs adept risk management and trustworthy risk analysis methodologies.

Authorisation of hydrogen systems, akin to other energy production systems, hinges on adherence to safety codes and standards. Currently, several safety standards derive from established natural gas safety frameworks and, in the case of Ireland, this is regulated by the Commission for Regulation of Utilities. Emerging standards (e.g., ISO-15916, and ISO-22734:2019, ISO (International Organization of Standardization) (2015, 2019)), are informed by recent system experience and tailored to hydrogen safety. Incorporating Quantitative Risk Assessment (QRA) methodologies into safety codes and standards offers a consistent reference for designing and operating hydrogen facilities.

2. Quantitative Risk Assessment for hydrogen systems

QRA is a systematic tool to identify individual risk contributions and to calculate the overall risk of a system or a process. According to West et al. (2022), the standard process for a QRA starts with risk identification, then risk analysis, and finally, risk assessment. The first step, involves scope definition, system description and initiating event identification. The analysis consists of scenario identification, consequence analysis, and risk quantification. The final step of QRA is made of uncertainty analysis and risk evaluation.

The QRA for hydrogen systems involves various methods for modelling and computing the risks. However, the study of different scenarios is limited due to the lack of sources listing the failure modes for all hydrogen fuelling station components or related systems.

3. Proposed method for Quantitative Risk Assessment

Bayesian Networks (BN), have been proposed in recent years as a methodology for enhanced accuracy, transparency, and dynamism Estrada-Lugo et al. (2019). A BN is a probabilistic model that models events as random variables, each of them described by a probability distribution. BNs can accept a wide range of data, from expert knowledge, to experimental data and historical records. The proposed work will need to gather data and information specific to hazardous scenarios relevant to hydrogen installations and the human factors involved. The data required for this study will be collected from experts in the hydrogen industry (e.g., ESB), hydrogen safety, as well as international standards and technical reports (ISO/TR 15916:2015; ISO 16110-1:2007; ISO 22734-1:2008) using structured risk assessment techniques such as HAZID and HAZOP. The information gathered will be used as input for the Bayesian model to compute the likelihood of the study scenarios.

4. Remarks

The Irish National Hydrogen Strategy explicitly suggests: *it may be more appropriate to develop*

a hydrogen safety strategy or framework which could initially be applied on a voluntary basis, which would then be used as a test case for early projects to assess its suitability and identify where improvements can be made, before ultimately progressing to establish it as a legally binding regulatory framework. The objective of this study is to enhance the advancement of this safety strategy by employing a rigorously formulated methodology supported by explainable artificial intelligence methods like Bayesian Belief Networks. The proposed approach will facilitate the aggregation of existing information and enable model updates as needed on an actual hydrogen facility case study.

Acknowledgement

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Risk Assessment and Reliability in the implementation of Urban Electric Mobility Projects

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The study's objective is to conduct a risk assessment to identify opportunities, risks, and impacts in implementing urban electric mobility projects and evaluate the perceptions of state secretaries and government, Mayors, Manufacturers, service providers, and other stakeholders on the risks. As part of the study, it was necessary to identify technical barrier and/or financial barriers worldwide, define how to use the advantage of renewable energy technologies to bring more reliability to the project, and categorize the risks considering hardware (buses, batteries, material national vs. imported, chargers, electrical centers).

Currently, it is observed an increase in pollution, the emergence of the pandemic scenario covid-19, the opportunity for the emergence of new technologies, the ever-increasing application of the concept of recycling/reusing, the need to contribute to reducing emissions of CO₂, the need to optimize costs and resources, the increased reliability, the need for resilience and the need for integration. This scenario shows it is necessary to administer and manage the risks in implementing a project that involves using renewable technologies for mobility as a solution in urban areas, such as electric buses with energy supplied from renewable sources. The study focus on the identification of these risks.

As a methodological approach, qualitative and quantitative data will be obtained from an in-depth literature review on the topic and from stakeholders, such as secretaries and government, Mayors, Manufacturers, service providers, and other stakeholders. FMEA will be used to identify risks and barriers. It will consider the vision of the main stakeholders in the Brazilian market, which can be expanded to the world scenario.

As a result, the authors propose a matrix with opportunities, risks, and impacts and a model that can be implemented to meet current regulations. The model brings the whole concept of sustainability to the center of the solution.

The conclusion is that by working proactively on risks to meeting regulations, digitalization concepts associated with using renewable sources and solutions that contribute to decarbonization can be effective, and cities can be transformed and have a promising future for future generations.

As a contribution, the proposed analysis will demonstrate the existing risks and some of the best responses and possibilities to make this transition contribute to decarbonization and transforming the planet in a better way. The present study augments the knowledge of the engineers/managers and professionals involved with Urban Electric Mobility Projects. Although conducted in Brazil, it can be generalized to other projects, whose safety is affected by lack of risk assessment. The study can change the practice and thoughts of professionals dealing with Mobility Projects.

Keywords: Smart city, resilient cities, net zero, , risk assessment, risk management urban electric mobility

1. Introduction

With time, with the increase in pollution, with the emergence of the pandemic scenario covid-19, with the opportunity for the emergence of new technologies, with the ever-increasing application of the concept of recycling/reusing, with the need to contribute to reducing emissions of CO₂, with the need to optimize costs and resources, increase reliability, the need for resilience and the need for integration, it is necessary to administer and manage the risks in the implementation of a project that involves the use of renewable technologies for Mobility as a solution urban areas, such as electric buses with energy supplied from a renewable source. By bringing digitalization concepts associated with the use of renewable sources and solutions that contribute to decarbonization, we can transform cities and have a promising future for future generations.

Currently, one of the biggest offenders in the effects is CO₂ emissions and when we analyze a city, we can highlight that one of the biggest offenders are diesel-powered buses and trucks that, even with the evolution of technologies over time, still

represent more 70% of CO₂ emissions. When we talk about a resilient smart city, we can bring the pillar of urban mobility as fundamental and when we apply the transformation to an electric technology with the use of renewable sources, we have the way to start the scenario of this scenario reversal. Another point to highlight is that research related to the subject shows that 60% of people will live in cities and it is increasingly important to change the current scenario.

Thinking of an energy matrix migration methodology for urban electric mobility, we can consider an assessment of the main risks and mitigation actions that can be explored in this process, where throughout this work we hope to demonstrate through risk management and FMEA methodologies: 1- Matrix based on the main points of risks and barriers considering the vision of the main stakeholders in the Brazilian market and which can be expanded to the world scenario. The proposal is to evaluate the perceptions with state secretaries and government, Mayors, Manufacturers, service providers, in addition to the teams responsible for implementing this process. 2 Identification and direction of the main points raised worldwide as a technical barrier and/or financial barrier, 3- How to use the advantage of

renewable energy technologies to bring more reliability to the project, 4- Categorization of risks considering hardware (buses, batteries, material national vs imported, chargers, electrical centers), risks and management of guarantees, cyber security risks since it is necessary to make the best use of platforms and connectivity, quality risks in the provision of services and operation where we must have a very strong focus on management of the people responsible for the execution and implementation of the project in addition to the people who will take care of the day-to-day, risks of changing legislation and regulation, risks in quality and cost of the necessary inputs, in addition to the risk of demand and/or revenue adequate to profitability minimum to investors, cost reduction and benefits to citizens.

The proposed analysis will demonstrate the existing risks and some of the best possibilities to make this transition contributing to decarbonization and transforming the planet in a better way. As expected results, we have the proposal of a matrix with the identification of opportunities, risks and impacts with the proposal of a model that can be implemented in the light of current regulations and bringing the whole concept of sustainability to the center of the solution, contributing with the other benefits already highlighted and financially viable in a replicable model.

Preliminary Risk Analysis and Mitigation Actions

We can highlight that one of the main risk points in the implementation of an intelligent city concept with the implementation of urban electric mobility technologies is the clear mapping of the needs and opportunities of each project. We can highlight: 1- Business Model: Where the best business model should be sought to be implemented, whether it is in an integral solution that includes electric bus technology, recharge infrastructure, substations, systems to manage design, maintenance and power solution in a single scope. Based on the integral solution, we may have variations that fragment scopes to enhance the final solution to the customer. 2- Preliminary Mapping of the necessary technology, such as vehicle size, quantity of passengers, time availability for recharge during the day or consider the concept of night recharge. 3- Recharge infrastructure at storage sites, whether in garages, terminals or specific locations. 4- Reliability in batteries considering performance, minimal autonomy with a complete recharge cycle and technology availability after the manufacturer guaranteed cycle (currently around 8 years with a maximum depreciation of 20% of battery performance). 5- Solution for battery use in projects that may integrate Storage Solutions or that can be reused battery banks in the application of a second cycle in part with manufacturers. 6- Clear definition of the scope of technical assistance, preventive, predictive and corrective maintenance, aiming at agility in maintenance making the vehicles stop as little as possible, in addition to the maintenance of the warranty provided by the manufacturers.

Considering the preliminary points explored, the vast experience in the management of the largest fleet of urban vehicles outside China, the methodology provides for work with specific groups involving bus operators representatives, manufacturers representing both domestic and international manufacturers, involvement of the municipalities and/or states responsible for the granting of services, investors and financing agents and class entities that act as ambassadors of urban electromobility.

Detailing a little more about the methodology, the proposal is at first to evaluate the risks, barriers and opportunities found through the evaluation of the project to implement a new electric bus technology considering the expert groups of the main stakeholders. The proposed groups are: 1- Specialists in Diesel Bus Operation; 2- Experts who work in the manufacture of electric buses, both being manufactured in Brazil and imported; 3- Experts in the Public Power Optics considering the main projects in progress in Brazil; 4- Experts from leading investors and business models developers. Based on the analysis of the sessions of the sessions with these 4 groups, using the risk management methodology, the proposal is the consolidation of the points of attention found, creation of a prioritization matrix considering the relevance score of each of the items worked. From this priority, we return to the groups formed and validate the results of prioritization and worked with the proposal of mitigating the risks found and documentation and registration of steps made to contribute to the success in the implementation of an urban electric mobility project.

In preliminary analyzes we can highlight: A- Risks related to the technical part, such as maximum route, amount of routes, type of pavement, slope of the route, availability of hours for refilling, preventive maintenance, predictive maintenance, corrective maintenance time, availability of Infrastructure in both garage or terminals, in the distribution system; B- Hardware risks: availability of spare parts over vehicle life, battery technology to maintain or optimize vehicle autonomy, type of bus considering maximum size and autonomy with a single recharge cycle; C- Software Risks: Ensure the efficiency of the entire system monitoring software considering vehicles and porters, as well as ensuring proper and safe communication against possible cyber attacks that compromise the operation; D- Power supply-related risks: availability of redundancy in the different feeder and substitution distribution system, renewable energy generation assessment with solar panels in conjunction with storage systems; E- Business Model Risks: Use and apply business models appropriate to each location considering fees received from users, financial subsidies applied by the municipalities and states, 100% integrated business model or made by strategic blocks, duration time of contract and financing origin, besides highlighting the encouraged lines.

Considering the proposed scope and defined steps, we hope to answer the questions described in this paper, as well as generate documentation that can be used for success in the implementation of urban electromobility projects.

The Procedure Performance Predictor (P3): Application of the HUNTER Dynamic Human Reliability Analysis Software to Inform the Development of New Procedures

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The Human Unimodel for Nuclear Technology to Enhance Reliability (HUNTER) software has been designed to provide a simplified framework for modelling dynamic human reliability analysis (HRA). HUNTER essentially creates a virtual operator (i.e., a digital human twin) that controls and responds to a virtual power plant (i.e., a digital twin or full-scope simulator) according to a procedural script. HUNTER has successfully modelled control room operator performance for nuclear power plant incidents, producing realistic human error probabilities, courses of actions, and time durations. Recent engagement with U.S. nuclear industry stakeholders has identified uses for HUNTER and dynamic HRA beyond traditional probabilistic safety assessment. As nuclear power plants upgrade to new digital control rooms, or as control rooms are built for advanced reactors like small modular reactors, there emerges a unique situation for the operating procedures at plants. Existing procedures for legacy plants have been vetted and validated across numerous iterations. Yet, as new technologies emerge in control rooms, there is often little operating experience to inform the development of the new procedures. A Revision Null operating procedure is of concern for both procedure writers and plant safety personnel. Building on HUNTER's handling of procedures, a special variant of HUNTER is being developed, called the Procedure Performance Predictor (P3). HUNTER-P3 allows procedure writers to script a novel procedure to simulate operator and plant performance in the use of that procedure. HUNTER-P3 identifies potential error traps with the novel procedure, thereby creating a way to screen procedures for suitability and safety. HUNTER-P3 also includes consideration for deviations from the procedures to flag potential disparities between work as imagined vs. work as done.

Keywords: HUNTER, human reliability analysis, dynamic, procedure, work as imagined, work as done

1. Review of HUNTER

The Human Unimodel for Nuclear Technology to Enhance Reliability (HUNTER; Boring et al., 2022) is a dynamic human reliability analysis (HRA) tool designed to be simple to use. Initially based on an effort to create a dynamic implementation of the Standard Plant Analysis Risk-Human (SPAR-H; Gertman et al., 2005) HRA method, HUNTER grew to become a standalone software package that allows analysts to use procedures and a linked nuclear power plant model to create a realistic simulation of human performance that can be considered a virtual operator. The basic structure of HUNTER includes three functional modules:

- *Task*—which is driven by plant operating procedures

- *Individual*—which is those factors, specifically performance shaping factors (PSFs), that affect the operator
- *Environment*—which is a model of the virtual world of the simulation, typically a simulator

The software implementation of HUNTER includes additional modules necessary to execute HUNTER as standalone software. These include software modules such as a scheduler, which coordinates the interface between the task, individual, and environment, and coordinates Monte Carlo runs to produce distributions of performance outcomes.

Recent versions of HUNTER (Lew et al., 2022) include the use of the Rancor Microworld

Simulator (Rancor; Ulrich et al., 2017), a simplified pressurized water reactor simulator that has been used in a variety of studies with student and licensed reactor operators (e.g., Park et al., 2023). The advantages of Rancor center on its simplicity, which allows it to be more readily used than a full-scope and full-scale simulator for studies to collect operator-in-the-loop data, and which features a reduced number of parameters compared to full-scope training simulators. In other words, Rancor is easier to interface with HUNTER than conventional simulators for proofs of concept while also allowing ready collection of empirical data to validate HRA models.

2. Introducing HUNTER-P3

HUNTER includes a procedure authoring system that makes it straightforward to input procedures to drive the Task Module. A prototype tool called HUNTER-Gatherer uses natural language processing to automate the process of inputting procedures from existing libraries.

In recent industry forums to discuss uses of HUNTER, a strong use case has emerged outside traditional applications in HRA for risk assessment. Given the focus in HUNTER on running procedures with a plant simulator, there is a much-needed application of HUNTER to evaluate new procedures. Existing operating procedures at plants benefit from extensive operating experience, industry benchmarking and lessons learned sharing such as through the Pressurized Water Reactor Owners Group (PWROG), and continuous improvement through procedure revisions. However, two new situations challenge this process:

- Plant upgrades that introduce new digital systems in the main control room that require new procedures
- New plants that feature entirely neoteric main control rooms that likewise require new procedures.

These Version Null procedures present potential safety and efficiency concerns for operator performance.

To address this challenge, HUNTER is incorporating a new function called Procedure Performance Predictor (P3). HUNTER-P3 uses

HUNTER's built-in Monte Carlo tools with human performance variability to identify where in procedures there might be error traps. In this manner, HUNTER-P3 can be used to flag deviations between work as intended and work as done. HUNTER-P3 will serve as a screening tool for novel procedures to help iterate and refine them prior to deployment. Identified error traps serve to prioritize scenarios where empirical evaluation is warranted. HUNTER-P3 is being validated using historic version histories of procedures from a nuclear power plant.

Disclaimer

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Quantum Machine Learning for Drowsiness Detection with EEG Signals

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Human reliability is increasingly important in accident prevention, and monitoring biological parameters can help detect patterns indicating behaviors that may lead to accidents. Electroencephalogram (EEG) data has been used to identify drowsiness, a major cause of fatigue in machine operators in the oil and gas industry. While classic machine learning methods like Multilayer Perceptron (MLP) have been used with EEG data, quantum computing has shown promise in solving complex problems efficiently. Variational Quantum Algorithms are one example of quantum concepts applied to classical structures for data training. This study aims to classify operator drowsiness using Quantum Machine Learning (QML) models. EEG signals are preprocessed to extract relevant features such as Higuchi Fractal Dimension, Complexity, and Mobility, as well as statistical features. QML models are trained with various quantum circuit layers, rotation, and entanglement gates. Results will be compared with classical MLP models. This work contributes to exploring the context of drowsiness in QML, which has not been extensively studied in the literature. It serves as a proof of concept that QML models are suitable for this type of data and can be further improved as Quantum Computing continues to evolve.

Keywords: EEG. Quantum Machine Learning. Drowsiness Detection. Diagnosis. Variational Quantum Algorithm.

1. Introduction

Quantum mechanics presents a new paradigm for solving computational problems, sometimes with a significant advantage over classical methods, such as in prime factorization or quantum system simulation (Maior et al., 2023). In this study, we utilize Quantum Machine Learning (QML) through Variational Quantum Algorithms (VQA) to analyze a practical issue - detecting drowsiness using real-world electroencephalography (EEG) time series data. We analyze in this extended abstract the subject #8 from the ULg multimodality sleepiness database, also known as DROZY (Massoz et al., 2016).

Accurate detection of drowsiness from EEG data is critical for ensuring safety in industries and critical processes. Fatigued workers can pose significant risks in workplaces, particularly in industries involving hazardous operations and

equipment. Drowsiness can impair operators' judgment, concentration, and productivity, leading to errors and decreased work quality, as well as an increased risk of accidents. Utilizing a drowsiness detection model based on EEG data can provide valuable insights into operators' wakefulness, enabling the implementation of preventive measures to avert serious incidents (Ramos et al., 2022).

2. Methodology overview

The VQAs models are based on the methodology used by (Maior et al., 2023). These models were developed using the TensorFlow Quantum library and were executed on the Cirq quantum simulator without consider the quantum noise. The algorithms are constructed through four main steps. Firstly, the classical data is preprocessed by normalizing and extracting features due to the qubit limitation (30 qubits consume 8 GB of RAM). We consider three

features related to EEG specifically (Higuchi Fractal Dimension, Complexity, Mobility), and five statistical (Mean, Variance, Root Mean Square, Peak-to-peak, Kurtosis, and Maximum amplitude). Subsequently, the data is encoded into qubits using the angle encoding method, where N qubits are initialized in a $|0\rangle$ state.

Secondly, we define Parameterized Quantum Circuits (PQC) using different architectures. The first architecture includes only rotation gates (R_y, R_z, R_y) for each qubit with parameterized angles. Additionally, we explore a circuit configuration with the same Euler rotation (R_y, R_z, R_y) followed by nearest-neighbor qubit couplings using a single type of entanglement gates per circuit. In this study we use three: CNOT, CZ, and i SWAP. PQCs with different numbers of layers (1, 5, and 10) are constructed, with a maximum of 10 layers due to computational limitations.

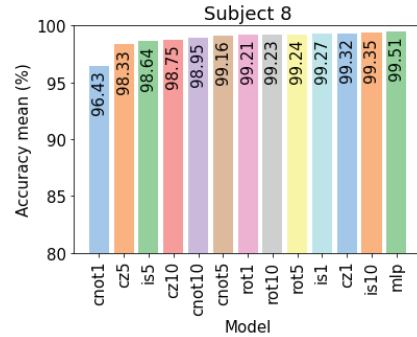
Thirdly we perform the measurements resulting in processed quantum data that is converted back into classical data. Finally, the extracted features from the quantum measurements are collected and fed into a classical neural network (with a dense layer composed by 100 neurons). Error backpropagation and classification analyses are performed, where we can assess if the subject is awake or drowsy.

3. Results

Our results were generated based on the aforementioned architectures, which gave 12 different quantum models. Furthermore, we used a classical Multilayer Perceptron (MLP) with the same configuration of the neural network inserted in the QML models. We ran each model 10 times and extracted the mean value of the accuracy for comparison purpose.

In Figure 1, we can observe an increasing visualization of the average accuracy results. As a positive highlight, the classical model still outperforms the quantum models, with an average accuracy of 99.51%, while the lowest accuracy was observed for the CNOT entangling gate configuration with one layer (96.43%). The quantum model with the highest result was the i SWAP gate (99.35%) with 10 layers, which was very close to the classical MLP, followed by the CZ gate with one layer (99.32%).

Figure 1. Subject 8 accuracy mean by model.



We used a Kruskal-Wallis statistical test to assess whether there was a significant difference in accuracies among the 13 models studied. The test was conducted at a significance level of 0.05, and we obtained a p-value lower than 0.01 and a test statistic of 98.60, indicating that there were significant differences among the models.

4. Conclusion

In this study, we applied QML models to test their applicability on EEG drowsiness data. For subject 8, we found that the MLP model performed better on average than the quantum models, although the i SWAP gate with 10 layers of circuit also showed promising results. As quantum computing advances, it is important for experts to stay informed about the potential improvements these technologies can offer. Our future research will expand to include more subjects and different QML models to further investigate their performance in this context.

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A new maintenance efficiency model and inference method for interval censored failure data

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1. A new maintenance model

GRTgaz owns and operates the longest high-pressure natural gas transmission network in France. Its industrial assets include more than 32,500 kms of pipeline and 26 compressor stations. The R&D center (RICE) of GRTgaz is developing tools to model these assets for optimizing their management, particularly in terms of maintenance policies. These tools are based on reliability distributions that consider equipment aging and maintenance models. Intrinsic ageing is modeled using probability distributions (Weibull with parameters α and β) for the operating time of an unmaintained system. Effect of maintenance is between minimal and perfect, this is known as imperfect maintenance.

The assessment of the system requires the application of probabilistic models and the statistical estimation of their parameters from the observation of field data. The considered imperfect maintenance models are the virtual age models of type ARA (Arithmetic Reduction of Age). Virtual age models consider that each maintenance rejuvenates the system, so that, at time t , the maintained system is equivalent to a new unmaintained system of age $V(t)$ smaller than t . $V(t)$ is the virtual age of the system at time t . Among the virtual age models, the ARA models

assume that, between two maintenances, virtual age evolves like the calendar time.

An industrial asset from GRTgaz is put into service at time 0. It undergoes failures, PM and CM actions. PM are planned at deterministic times. $\forall i \geq 1$, τ_i is the time to the i^{th} maintenance. When a failure occurs (at a random time), the associated CM is delayed to the time of the next PM. Even if it is failed, the system continues to deteriorate until the next PM. Maintenances durations are assumed to be negligible. Therefore, there are two types of PM. The first type (simply denoted PM hereafter) is PM such that no failure has occurred since the last maintenance. The effect of these PMs is that which was planned by the initial maintenance plan. The second type (denoted PCM hereafter) is PM such that at least one failure has occurred since the last maintenance. The effect of these PMs cumulates the effect of the initial PM and the effect of the CM associated to the previous failures. Therefore, the failure and maintenance process consists of a sequence of recurrent events of 3 types, failures and two types of PM (PM and PCM).

We propose a stochastic model for this process, in which the maintenances are imperfect, of the ARA type. Since at failures times no maintenance is performed, this is equivalent to assume that a minimal as bad as old (ABAO) repair is

performed. Let M1 be the imperfect maintenance model associated with PMs and M2 the imperfect maintenance model associated with PCMs. Then, the new model is written F ABAO-PM M1-PCM M2. We tested all the combinations corresponding to PM and PCM effects of type ARA_1 and ARA_∞ which are sub-models of ARA models. Depending on the combination, the virtual age will be different.

2. Statistical inference for censored data

In the GRTgaz case, failure times are not observed, they are detected at the time of next PM. Therefore, the data are interval censored. Two situations are considered: the Poisson case, for which the number of failures in each interval is known, and the Bernoulli case, for which we only know if at least one failure has occurred in each interval. In order to estimate the model parameters, we compute the likelihood associated to both censored observations situations.

2.1. The Poisson case

For k maintenances, the observations are the realizations $\Delta n_1, \dots, \Delta n_k$ of the random variables $\Delta N_1, \dots, \Delta N_k$ where for all $i \geq 1$, ΔN_i is the number of failures between the $(i-1)$ -th and i -th maintenance. At the failure times, no maintenance is performed. Thus, a non homogeneous Poisson process (NHPP) is observed between two successive maintenances. The properties of NHPPs lead that the likelihood function is written :

$$\mathcal{L}(\theta; \Delta n_1, \dots, \Delta n_k) = \left[\prod_{i=1}^k \frac{\alpha^{\Delta n_i} [V_{i-1} + \Delta \tau_i]^\beta - V_{i-1}^\beta}{\Delta n_i!} \right] \exp \left[-\alpha \sum_{i=1}^k [V_{i-1} + \Delta \tau_i]^\beta - V_{i-1}^\beta \right]$$

where V_i is the virtual age at the i^{th} maintenance.

2.2. The Bernoulli case

For k maintenances, the observations are the realizations b_1, \dots, b_k of the random variables B_1, \dots, B_k . $\forall i \geq 1$, B_i equals to 1 if there has been

at least one failure in $[\tau_i, \tau_{i+1}[$, and 0 otherwise. Therefore, the likelihood function is:

$$\mathcal{L}(\theta; b_1, \dots, b_k) = \prod_{i=1}^k \left(1 - \exp \left[-\alpha [V_{i-1} + \Delta \tau_i]^\beta - V_{i-1}^\beta \right] \right)^{b_i} \exp \left[-\alpha [V_{i-1} + \Delta \tau_i]^\beta - V_{i-1}^\beta \right]^{1-b_i}$$

3. Résultats and conclusion

The quality of the proposed estimators has been assessed through an extensive simulation study. Of course, the more data (systems and failures), the better the estimates. Unsurprisingly, the results are better in the Poisson case than in the Bernoulli case, due to the amount of information in each case.

Finally, the method is used to assess the ageing and maintenance efficiency of real system from GRTgaz.

Acknowledgement

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MAINTENANCE METHODE EVALUATION OF CASING ALIGNMENT USING LASER MEASUREMENT TECHNIQUE: A CASE STUDY OF GAS TURBINE GENERATOR 100 MW CLASS

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In the asset management system, the management of maintenance activities includes both preventive and corrective maintenance management methodologies. It is defined as maintenance specifications and schedules, procedures for maintenance execution and missed maintenance, inspection measurements and results. During the Major Inspection Overhaul the casing alignment activity on rotating equipment, especially the gas turbine generator (GTG) is a form of maintenance activity that is grouped into life cycle delivery. This is a follow-up on asset performance and health monitoring. This activity involves aligning or leveling the turbine casing in the X and Y axes so that the GTG unit can operate reliably. The concept of aligning the turbine casing on the X and Y axes as can be seen in Fig. 1 (a).

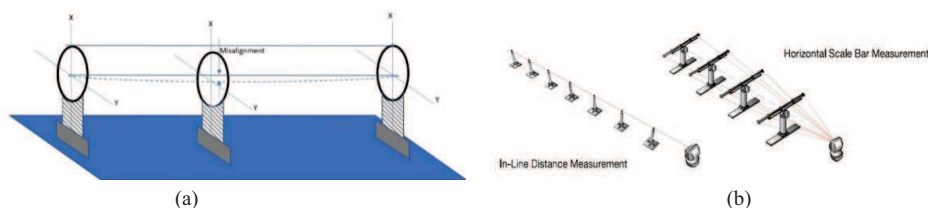


Fig. 1. (a)The concept of aligning the turbine casing on the X and Y axes. (b) How to measure casing alignment data using a laser alignment tool

During the life cycle of an asset from the construction stage to operation, there will be a change in the structural characteristics of the GTG foundation resulting in a change in the position of the turbine casing, both the internal casing and the external casing. Changes in casing position and casing deformation can result in misalignment and vibration when the unit is operating. This work aims to provide an understanding of the effectiveness of using laser alignment on the GTG casing. The measurement casing alignment data using a laser alignment tool as shown in Figure 1 (b).

The method used is taking points on all compressor casing, compressor discharge casing (CDC), inner barrel, turbine casing, turbine shrouds, inlet casing, exhaust casing, and all pedestal bearings as illustrated by Fig. 2.

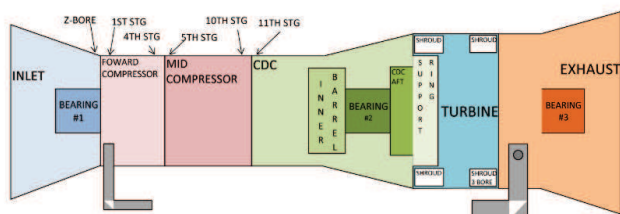


Fig. 2. Parts of the 100MW class gas turbine casing that can be performed casing alignment

In case alignment work is generally done by 2 methods, top on and top off as seen in Fig. 3. Top On is done by attaching the upper casing to the lower casing, while the top-off is done without installing the upper casing, both methods are carried out without the rotor being attached to the turbine casing.



Fig. 3. casing alignment data collection process (a) Top off with piano wire (b) Top On with laser alignment tool.

Based on the case study of the GTG 100 MW class has been proven to be able to speed up measurement time compared to the piano wire method for 1 days with a time comparison that can be seen in Table 1.

Table 1. Comparison of casing alignment time using piano wire and laser alignment tools

Work Item	Piano wire (hours)	Laser alignment tools (hours)
Tools installation and calibration	4	1
Initial alignment reading	6	0.5
Data validation	4	0.5
Tools removing	1	0.5
Correction move for alignment	16	16
Tools installation and calibration after corection movement	4	1
Casing alignment reading	6	0.5
Data validation	4	0.5
Total	45	20.5

In Table 1 we can see that the use of laser alignment tools took a total of 20.5 hours compared to the use of piano wire which took a total of 45 hours. The use of laser alignment tools is proven to speed up the time in the process of installing tools, calibrating, reading and validating data and get accurate results where the measurement results can reach 0.001mm in carrying out casing alignment on GTG. This method benefits unit owners with reduced maintenance time and increased unit performance.

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A Bayesian inference and metaheuristics model for estimating maritime accidents: the case of Fernando de Noronha

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Toxic spills that arise from maritime accidents can lead to catastrophic environmental damage to animals. The numerous oil tankers that travel the planet raise the risk of potential oil spills that can affect sensitive ecosystems such as oceanic islands. To evaluate those risks, frequency estimation is an essential step. However, dealing with events with low frequency and high consequence poses a challenge, since classical statistical approaches strongly relies on data, which are scarce in this case. To overcome this shortcoming, a Bayesian population variability-based method is proposed to assess the accident rates considering accident data from various databases combined with the expertise of professionals such as academics, captains, pilots, and chief officers. As a real case application, we used this framework to estimate the frequency of accidents near Fernando de Noronha Archipelago. The results can support decision-making regarding measures to prevent accidents or reduce risks.

Keywords: Bayesian analysis, Maritime accidents, Frequency assessment, Quantitative risk assessment, Oil spills.

1. Introduction

The maritime traffic accentuates the risk of potential oil spills. Fernando de Noronha Archipelago (FNA), located in the Brazilian northeast region, is home to endemic species and it has a Conservation Unit's status to protect it. Since it constitutes a fragile ecosystem, the consequences of a spill can be even aggravated since FNA lacks infrastructure and mitigation plans for such accidents and it is located near maritime routes (Siqueira et al., 2023).

Assessing accidents such as oil spills is very challenging, due to data scarcity and to inconsistencies in the available databases (Siqueira et al., 2022). This drawback is circumvented here by using Bayesian-based methods to address the lack of specific data by complementing the information available with specific data, such as expert opinions. Therefore, this work aims to estimate the accident rates that lead to oil spills in FNA using a Bayesian-based method, the Bayesian Population Variability Analysis (BPVA) (Siqueira et al., 2022), to estimate maritime accident frequency occurrence from databases and expert opinions.

2. Methodology

We have an integrated framework to perform the BPVA (Fig. 1). First, we need to fit the data regarding the prior knowledge regarding accident rate λ to a continuous prior distribution. Next, we define the likelihood function according to parameters found via Particle Swarm Optimization to incorporate the specific data. Finally, we obtain the non-parametric posterior distributions.

We use exposure data, considering the number of events within a time, to formulate the likelihood estimation. The National Technical University of Athens Ship Design Laboratory database, the Annual Overview of Marine Casualties and Incidents 2020 and the Statistics of Marine Accidents of the Japan Transport Safety Board databases were considered (EMSA, 2020; JTSB, 2021). The expert opinion data was collected via questionnaires, answered by academics, pilots, ship authorities and other waterway professionals, assigning a weight according to the respondent category and navigation experience.

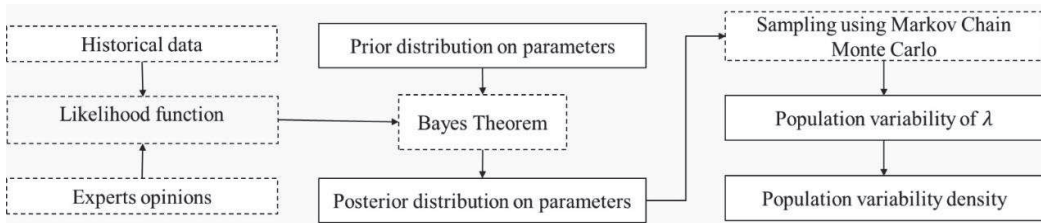


Figure 1. Methodology flowchart.

3. Results

Fig. 2 depicts the prior and posterior distribution of the accident rate. The prior (blue) is obtained via probability distribution over the model parameters, while the non-parametric posterior (green), is obtained via Markov Chain Monte Carlo methods. Note how the distribution shift to the right, moving away from the initial estimate and overestimating the rate.

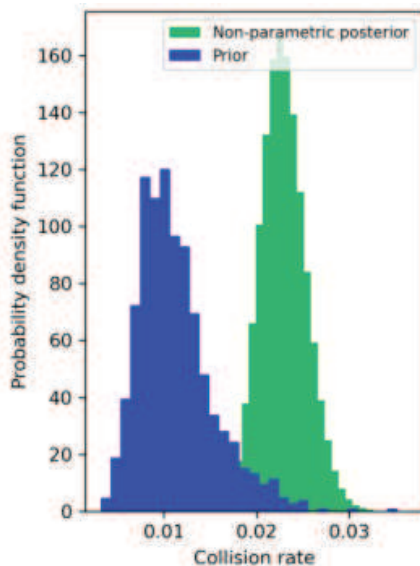


Figure 2. Population variability density for collision rate.

4. Conclusion

The main capability of our model is that it can incorporate different kinds of information in a context of data scarcity, as we did here in the oil spill context. We can also assess the underlying variability of the relevant data available to our

problem (i.e., maritime accident databases). Thus, we can improve the robustness of our prior estimates. We suggest as a future step to include in our assessment the evaluation of the normalized root mean squared error, in which we simulate the accident data with these hyperparameters and compare the deviation from the real data. Moreover, the outcomes of this article can aid risk assessments, as it is a sophisticated tool to estimate the frequencies of infrequent accidents such as oil spills.

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Agent-based modelling and analysis of search and rescue (SAR) operations in the Barents Sea

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Despite the significant increase in maritime activities in recent years in the Barents Sea, maritime search and rescue (SAR) modelling and simulation in the Arctic waters, including in the Barents Sea is a relatively less researched area. The present study proposes an agent-based modelling framework, which models and simulates different SAR scenarios and evaluates the performance of the SAR system under various operating conditions, while considering the dynamicity and uncertainties of the weather and sea conditions.

Keywords: Agent based modelling, Arctic offshore, Search and rescue operations, Barents Sea

1. Introduction and problem statement

Remoteness of the Arctic offshore environment, combined with harsh meteorological and oceanographic conditions can hinder search and rescue (SAR) operations. Additionally, there is a scarcity of port infrastructure along the Arctic coastline that may negatively affect the SAR operations (Naseri, Barabady 2016). While different studies have been conducted on maritime SAR modelling and simulation (Ai et al. 2019; Norrington et al. 2008; Siljander et al. 2015), the research focused on the Arctic waters and the Barents Sea is still limited.

Agent-Based Modelling (ABM) (Van Dam, Nikolic, and Lukszo 2012), has been applied extensively to model complex systems, whose behaviour evolves from the interactions of system agents with one another and with the environment. The aim of this paper is to develop an agent-based modelling framework to analyse the SAR operations in the Arctic waters. It considers the dynamicity and uncertainties related to met-ocean parameters and constrains related to the SAR infrastructure. Different rescue scenarios are simulated and the performance of the SAR system under different conditions are evaluated.

2. Model description

Let a geographical region in the Barents Sea be divided into cells ω_{jk} , $j = 1, \dots, v$, $k = 1, \dots, w$. Each cell is characterised by some weather and

sea parameters including temperature, wind speed, significant wave height, and wind chill index, denoted by, $wind^{\omega_{jk}}$, $wave^{\omega_{jk}}$, $temp^{\omega_{jk}}$, and $wci^{\omega_{jk}}$ respectively. The ABM consists of different agents, including rescue vessels, rescue helicopters, and evacuees, who need to be rescued. For a generic SAR operation, we can consider below activities:

- i. vessels and helicopters depart from the base and arrive at the location of the distressed ship (i.e., a_1 and a_2),
- ii. once the rescue crew are at the location, the evacuees are embarked on the vessel or the helicopter (i.e., a_3 and a_4),
- iii. the vessel or the helicopter should travel back to the rescue base (i.e., a_5 and a_6), and
- iv. the evacuees are disembarked from vessels and helicopters (i.e., a_7 and a_8).

These activities are performed in the Barents Sea, modelled by defining an overall severity level, $Z^{a_i} \in [\zeta_n]$, $i = 1, \dots, 8$, $n = 1, \dots, N$ with N being the total number of the severity levels, as a function of the severity levels of met-ocean parameters.

The agents perform the activities until all of the evacuees are rescued and transported to either of the rescue bases. The time required to complete each activity, τ_{a_i} , is dependent on the type of the activity and the severity of the operating conditions $\tau_{a_i} = g_i(a_i, L^{a_i})$, $i = 1, \dots, 8$, with

$g_i(\cdot)$ being the expert-based mapping function to estimate τ_{a_i} for activity a_i performed under operating conditions with severity L^{a_i} . The value of L^{a_i} is conditional on the location of the agent, ω_{jk} , and calendar time, t , which is introduced to consider the dynamicity of the weather and sea conditions.

In this modelling framework, the refuelling time of helicopters and vessels are included as a random variable. Also, note that, τ_{a_i} , $i = 1, 2, 5, 6$ (i.e., sailing and flying activities), depends on the speed of vessels and helicopters, which are dependent on the severity level of the operating conditions. Finally, the total time to rescue all the evacuees can be considered as the SAR system performance measure.

3. Results and Discussion

The ABM is developed for a hypothetical SAR operation. The study area and SAR bases for vessels and helicopters are shown in Fig. 1a. The distressed ship has 500 people onboard. In total, there are 10 vessels and 4 helicopters contributing to the SAR operation (see Fig. 1)



Fig. 1 The study area and the location of SAR bases

To estimate the total rescue time in different months of the year, 50 simulations were run for each respective month. The model parameters are obtained in consultation with SAR field operators and experts, and are elicited in the form of probability distributions to account for the uncertainties associated with expert data. Meteorological parameters are NORA10 modelled data, collected from the repository of Meteorological Institute of Norway (3-hourly data from 1980 – 2012). As illustrated by the box plot of the total rescue time in each month in Fig. 2, there is a clear seasonality in total rescue time, where the longest and shortest rescue times occurring during Nov – Feb and Jun – Aug, respectively.

4. Conclusion

The proposed ABM framework can model the SAR operations in the Barents Sea considering its severe operating conditions, while considering their dynamicity. The results of the simulations of the paper shows a clear seasonality in total time of rescue operation, with longest rescue operations taking place in wintertime (Nov–Feb). The flexibility and scalability of the agent-based models allow us to run a variety of SAR scenarios. The proposed framework can be used to inform decision-makers and improve the effectiveness of SAR operations in the Arctic waters.

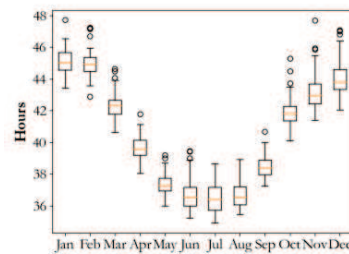


Fig. 2. The time of rescue for each month in hours

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Importance analysis in the evaluation of input attributes of classifiers

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Most often, the techniques of Machine learning are used for the decision of problems in Reliability Analysis. In this study, we propose to consider the application of the Reliability Analysis based method application for the decision problem in Machine Learning, in particular, the analysis of the influence of input attributes on the classification result. Some attributes are most important for the classification because they significantly influence the classification result than others. A new method for the determination of the most important attributes is proposed. This method is developed based on the approach of Importance Analysis, which is widely used in Reliability Analysis. The attribute's importance is evaluated by structural importance.

Keywords: Classification, Importance analysis, Multi-state system, Structure function, attributes selection.

1. Introduction

Classification is one of the principal approaches in machine learning. The classification efficiency depends on many factors. One of the factors affecting classification is the quality of the initial data. The initial data used for the classifier induction assumes sufficient training samples, their balances among specified classes, acceptable data dimension, authenticity, and absence of redundant data or noise. The choice of the input attributes that have the maximum impact on the result is one of the tasks of the data pre-processing. This problem is known as feature extraction/selection (Bolon-Canedo et al, 2013). The feature selection/extraction, on the one hand, reduces the dimensions of the studied data sets, on the other hand, the required classification accuracy is of paramount importance and must be maintained despite the reduction of attributes. There are many approaches to feature selection/extraction. As a result of feature extraction, a new set of attributes from the original set is formed (Bruni et al., 2022). The often-used methods for feature extraction are based on techniques of Linear Discriminant Analysis, Principal Component

Analysis and Independent Component Analysis. As a result of feature selection, an acceptable set of attributes from the original dataset is selected without any transformation (Naheed et al., 2020). Feature selection methods can be divided into filter, wrapper, and embedded methods. Filters are independent of an algorithm of the classifier induction and choose attributes based on the characteristics of initial data. The wrapper methods depend on the algorithm of classifier induction. A classification algorithm evaluates a subset of selected attributes according to a classification measure. These methods have high performance but require much computation time to execute. Embedded methods perform attribute selection in the process of the classifier induction and depend on the classifier and algorithm of its induction. This study proposes a new method for attribute selection based on the importance analysis of the initial data set of attributes.

2. Method

A new method for analysis of the influence of the classification factors (input attributes) on the result is proposed. It allows for studying the

sensitivity of decision making. This method can be thought of as a feature selection method that combines the advantages of filter and wrapper based methods. The proposed method has the universality of filters. Attributes are evaluated and quantified by Structural Importance (SI) (Zaitseva et al., 2023).

The proposed method consists of two steps (Fig. 1). The construction of the mathematical model acceptable for reliability analysis is implemented in the first step. This step is implemented based on the classifier induction. The result of this step is a decision table of the classification, which is interpreted as the structure function of a system (mathematical model of a system for its reliability analysis). The analysis of important components (attributes) is performed in the second step based on reliability engineering based methods. The result of this step is a quantification of all attribute importance for the result of classification.

The proposed method has been used for the induction of a Fuzzy Decision Tree (FDT). The analysis of input attributes' importance based on the proposed method is considered by the example of the analysis of the factor of the timing of tracheostomy in COVID-19 patients (Zaitseva et al., 2023). The attributes with the biggest or non-zero value of SI are selected for the induction of the final classifier (Fig.2). The classification performance in this case study is not changed after eliminating non-important attributes with SI=0. Therefore, if we omit attributes with zero or small values of SI, the classification model can be simplified, the time for training will be shorter, we can avoid large dimensional, and also the data

compatibility with the input model can be improved.

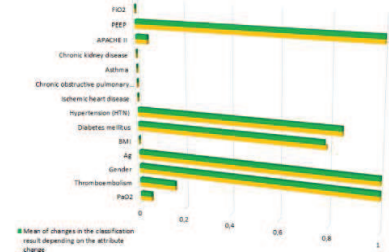


Fig. 2. The evaluation of attributes' importance

3. Conclusion

The advantages of the proposed method are (a) evaluation and selection of attributes depending on the classification result (similar to wrapper methods) and (b) can be used for any classifier without fundamental changes similarly to filters. At the same time, the application of the proposed method for the analysis of big data or data drift will need additional modification. The present version of the method can be effective for minor changes in attribute importance since the uncertainty arising, in this case, can be covered by the use of a fuzzy classifier.

Acknowledgment

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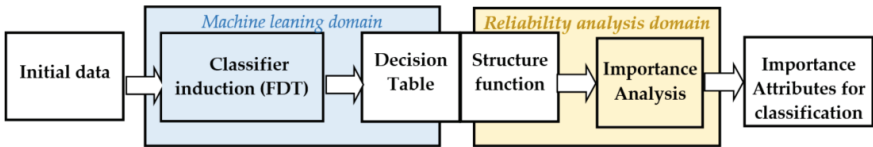


Fig. 1. The method for quantification of input attributes' importance.

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From Fault Trees to Piping and Instrumentation Diagrams

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Piping and Instrumentation Diagrams (P&IDs) are a graphical representation of the design of industrial plants. While images of P&IDs for a given system exist, a formal representation of a P&ID containing safety-relevant information is often missing. Such a formal P&ID model (1) provides a high-level representation of the system including its safety and reliability properties which is easier to understand for non-experts, and (2) enables automatic generation of fault trees by tools like RISK SPECTRUM MODEL BUILDER, which allows for systematic updates of the safety model after system modifications.

In this work, we aim to automatically infer a formal representation of (the safety-relevant part of) a P&ID from a given set of fault trees. Fault trees (FTs) are manually created from P&IDs and capture the safety-relevant part of the system. We present an automatic translation from FTs to P&IDs. The transformation starts by creating the P&ID components from the labels of basic events in the FTs. In a second step, the topology of the P&ID – including the pipe connections – is inferred from the structure of the FTs and their minimal cut sets.

Keywords: Piping and Instrumentation Diagrams, Fault Trees, Automatic translation, Safety analysis, Formalisation

1. Introduction

Piping and Instrumentation Diagrams (P&IDs) are a graphical representation of the design of industrial plants Toghraei (2019), for instance nuclear power plants. P&IDs describe, among other things, the mechanical components, the process control instrumentation and the process piping. For a safety assessment of a plant, P&IDs serve as one of the inputs and a starting point.

When performing a probabilistic safety assessment (PSA), P&IDs are often translated into fault trees. *Fault trees (FTs)* are a graphical model that provides a comprehensive understanding of risks and mitigation strategies in the modelled system Ruijters and Stoelinga (2015). Typically, reliability experts create and update FTs manually. The link between the system description and the safety model stays in the expertise of safety analysts. Interpreting reliability results or updating FTs after a design change depends fully on their knowledge.

An alternative to this manual process is the automatic generation of FTs from a formal representation of a P&ID Renault et al. (1999), as supported by tools such as RISK SPECTRUM MODEL BUILDER or KB3 Bouissou (2005). This approach maintains the connection between the system description and the safety analysis.

However, in most cases, a formal P&ID model does not exist because FTs were created manually. In these cases, we still want to obtain a *formal*

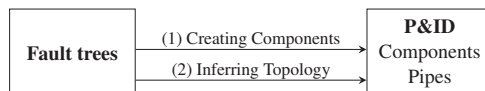


Figure 1. Inference process from fault trees to P&ID

P&ID model, because (1) it is easier to communicate results of the safety assessment to non-specialists, and (2) automatic generation of FTs from possibly updated formal P&ID models helps to keep FTs consistent with the system description after modifications.

We present a method (see Fig. 1) to infer the safety-relevant part of P&IDs from manually built FTs, given definitions of P&ID components with their reliability information in a Knowledge Base in RISK SPECTRUM MODEL BUILDER. While existing approaches commonly use image recognition to infer formal P&ID models from existing P&ID images Arroyo et al. (2016), these pictures do not contain all safety-relevant information – whereas the FTs we use as input do.

2. Fault tree to P&ID

Formalising P&IDs We formalise P&IDs based on Bayer and Sinha (2020) as a graph $D=(C, P)$. The vertices C represent P&ID *components* associated with a label and type. The edges P represent *pipes* (with an optional label) connecting two components. The example P&ID in Fig. 3 depicts parts of a Residual Heat Removal System (RHS).

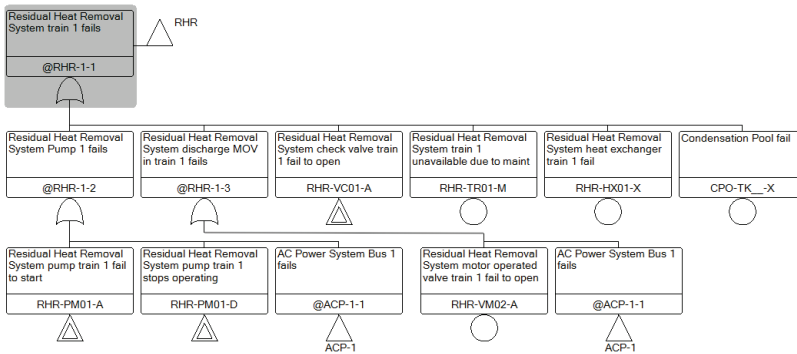


Figure 2. FT modelling RHS train 1 failure

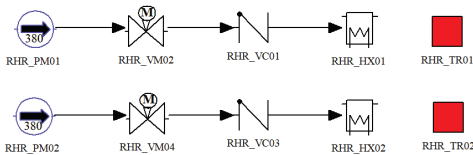


Figure 3. P&ID of a Residual Heat Remove System (RHS). Each redundant part consists of a pump, an RHS-specific valve, a check valve, a heat exchanger and an event representing a failure due to maintenance.

Approach We infer P&IDs from FTs as outlined in Fig. 1. The approach takes as input FTs in .rsa files from RISK SPECTRUM PSA. We create a P&ID from these FTs by (1) creating the P&ID components from the basic events in the FTs, and (2) inferring the pipe connections between the FT structures. The resulting P&ID is exported into .kbi files for import by RISK SPECTRUM MODEL-BUILDER. We show the translation by example of the RHS, using the FT in Fig. 2 as input.

Creating P&ID components From the FTs, we first create the P&ID components, i.e., vertices C in the graph. As basic events in the FT represent failures in system components, we can deduce the component names (and their types) from the labels of the basic events. Here, we exploit a systematic naming schema in the FTs present in large studies – especially in nuclear power plant PSAs.

From the basic event labels in the FT in Fig. 2, we identify five component labels RHR-PM01, RHR-VM02, RHR-VC01, RHR-HX01, RHR-TR01. We obtain the type of component from the labels based on the two characters after the dash.

Inferring P&ID topology We infer the topology of the P&ID – particularly the pipe connections P – based on the structure of the FTs and their minimal cut sets. For instance, basic events in the same cut set indicate that the corresponding components belong to trains in parallel. Note that the FTs alone might not suffice to fully infer the P&ID topology, e.g., the order of components in series.

Post-processing can be employed using domain-specific knowledge or manual expert intervention.

Continuing the example, the pipe connections between the P&ID components are inferred, resulting in the P&ID in Fig. 3. Components within one train of RHS are connected by an OR-gate. Failure of any of them will fail the whole train. Thus, these components are in series. Their order in the P&ID can follow the order of the basic events in the FT, it can be determined by additional domain knowledge, or is manually edited by an expert. The two trains of RHS are connected by an AND-gate. Thus, both trains are in parallel.

3. Conclusion

We presented an automatic translation from FTs to formal P&ID models. The approach is implemented in a prototypical Python tool and creates P&IDs for import in RISK SPECTRUM MODEL-BUILDER. We will validate our approach on several P&IDs from industrial case studies.

Acknowledgement

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Segmenting without Annotating: Crack Segmentation and Monitoring via Post-hoc Classifier Explanations

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Monitoring the cracks in walls, roads and other types of infrastructure is essential to ensure the safety of a structure, and plays an important role in structural health monitoring. Automatic visual inspection allows an efficient, cost-effective and safe health monitoring, especially in hard-to-reach locations. To this aim, data-driven approaches based on machine learning have demonstrated their effectiveness, at the expense of annotating large sets of images for supervised training. Once a damage has been detected, one also needs to monitor the evolution of its severity, in order to trigger a timely maintenance operation and avoid any catastrophic consequence. This evaluation requires a precise segmentation of the damage. However, pixel-level annotation of images for segmentation is labor-intensive. On the other hand, labeling images for a classification task is relatively cheap in comparison. To circumvent the cost of annotating images for segmentation, recent works inspired by explainable AI (XAI) have proposed to use the post-hoc explanations of a classifier to obtain a segmentation of the input image. In this work, we study the application of XAI techniques to the detection and monitoring of cracks in masonry wall surfaces. We benchmark different post-hoc explainability methods in terms of segmentation quality and accuracy of the damage severity quantification (for example, the width of a crack), thus enabling timely decision-making.

Keywords: Crack detection, Image classification, Segmentation, Explainable AI, Attribution maps.

1. Introduction

The automated detection and segmentation of cracks in images is challenging due to the variety of crack aspects, the complexity and diversity of materials, and irregular illumination. Various approaches have been developed for this task, mainly based on image processing Yamaguchi et al. (2008); Hoang (2018). Data-driven approaches based on supervised learning have shown great performance, often using the popular U-Net neural network architecture Augustauskas and Lipnickas (2020). However, they require to label large amounts of images at pixel-level.

Post-hoc explainability methods aim at explaining the decisions of black-box models such as deep neural networks (see Arrieta et al. (2019) for a review). In particular, in this work, we focus on attribution methods, that associate a relevance to each feature in the input. The authors of Seibold et al. (2022) proposed to leverage the explanations of a classifier to segment damages in magnetic tiles and sewer pipe images, motivated by the fact that while annotating images for supervised segmentation is tedious, classification labels can be

obtained at a fraction of the cost. In this work, we benchmark the ability of several post-hoc explainability methods, as well as post-processing steps, to generate high-quality segmentation masks for cracks in masonry building wall surfaces.

A major concern is the development and propagation of cracks over time, leading to increased stress and subsequent failure of the structure. The severity of a crack can be quantified, for instance, through width measurement Carrasco et al. (2021). Thus, we also study if these methods are usable to quantify damage severity and monitor its evolution, thus enabling timely decision-making.

2. From Classification to Segmentation

We propose the following methodology to generate crack segmentation masks:

- (i) Train a binary classifier on positive (cracked) and negative (non-cracked) training images.
- (ii) Perform inference on unseen test images. For each positive prediction, extract post-hoc explanations of the classifier and produce attribution maps for the positive class.
- (iii) Post-process the resulting attribution maps:

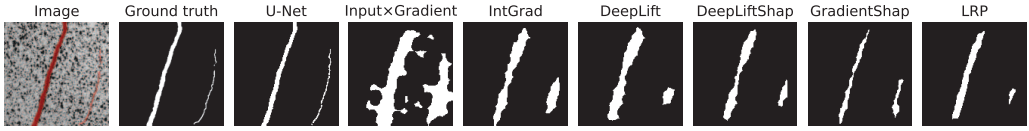


Fig. 1.: Visualization of crack segmentations obtained via post-hoc explainability methods and post-processing.

Table 1.: Crack segmentation quality for different explainability and post-processing methods (F1 score in %).

Post-processing thresh.	morph.	Baseline	Input×Grad	IntGrad	DeepLift	DeepLiftShap	GradientShap	LRP	U-Net (oracle)
simple	✗	12.18	14.64	18.91	22.58	24.03	13.88	22.17	83.67
	✓	4.73	23.30	27.74	34.44	38.19	20.61	37.43	
GMM	✗	18.05	21.54	28.92	31.70	37.07	19.78	28.39	
	✓	7.88	20.76	25.96	29.55	33.10	21.27	36.16	

- (a) Thresholding using the *simple* or *GMM* strategies as in Seibold et al. (2022).
- (b) Morphological closing and area opening operations, in order to close gaps in the mask and remove noisy attributions (see Figure 1).

We conducted experiments on the Experimental DIC (digital image correlation) cracks data set Rezaie et al. (2020), consisting in 256×256 image patches from stone masonry walls damaged in a shear-compression loading experiment. We complemented this data set with 874 additional negative patches coming from the same walls.

The crack classifier network is a VGG11 with 128 neurons in the fully-connected layers. In this study, we evaluated following post-hoc XAI techniques: Input×Gradient, Integrated Gradients (IntGrad), DeepLift, DeepLiftShap, GradientShap and Layer-wise Relevance Propagation (LRP). We also include a simple baseline where the image is just converted to gray-scale before the post-processing. As an oracle, we trained a U-Net11 on the segmentation labels of the training set.

The segmentation quality is evaluated by the F1 score on the test set. For each method, we report the results using combinations of thresholding and morphological post-processing in Table 1.

3. Crack Severity Monitoring

To assess the severity of cracks, we computed the number of cracks per patch (CPP) Pantoja-Rosero et al. (2022), the total crack area per patch, and the maximum crack width, using the width estimation

method from Carrasco et al. (2021). We report the mean absolute error (MAE) or mean absolute percentage error (MAPE, in %) with the ground-truth measure for two of the methods in Table 2.

Table 2.: Crack severity assessment results.

Method	Post-processing thresh.	CPP morph.	MAE	Area MAPE	Width MAPE
DeepLift	simple	✓	0.81	146.0	264.6
	GMM	✓	0.72	352.1	374.2
LRP	simple	✓	0.90	91.0	163.1
	GMM	✓	0.82	261.8	257.6
U-Net (oracle)			0.74	20.1	20.8

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Assessment of fault detection and monitoring techniques for effective digitalization

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As a result of digitalization, data is collected at every level of production as an enhancer for decision-making. However, including more sensors to collect additional information does not directly contribute to increasing the system reliability but instead raises challenges for optimal data utilization. This work presents an evaluation approach based on FMSA (Failure mode and symptoms analysis) combined with FMECA (Failure mode, effects and criticality analysis) prioritization methods. The different methods are applied to a feed-drive system to evaluate the suitability of the currently implemented detection and monitoring techniques. The recommendations derived from the evaluation can be utilized to maximize confidence in the monitoring and to minimize the sensors utilization and data collection. Since the FMEA family of assessment tools present shortcomings such as bias and uncertainty associated with their results, this work also aims at mitigating these effects in obtaining the monitoring priority numbers and their respective categorization and prioritization.

Keywords: Digitalization, monitoring, system reliability, FMSA, MPN, FMECA, Fuzzy logic

1. Introduction

Industrial digitalization aims to enhance operational efficiency and equipment reliability, which can only be obtained through proper maintenance supported by data-driven decision-making. For any system, effective monitoring techniques are vital for detecting, diagnosing, and prognosing faults and defining critical maintenance items (Murad et al. 2020). However, extensive digitalization does not co-exist with sustainability; contrariwise, it could imply increased cost and complexity and potentially lower reliability. Thus, it is crucial to uncover unleveraged monitoring potentials within the existing system capabilities or to improve them with minimal resource addition.

Among the detection and monitoring analysis tools, the FMSA was selected due to its focus on fault identification and degradation rather than occurrence. The implementation of this tool is exemplified through a case study of a feed-drive system. Additionally, the study compares different methods to calculate the MPN (Monitoring Priority Number) and its prioritization. These methods are evaluated for their ability to provide relevant information and recommendations to effectively utilize data resources, consider critical functions, and avoid unnecessary equipment deployment.

2. FMSA and FMECA assessment methods

FMSA is an extension of the FMECA, focussing on selecting the appropriate detection and monitoring techniques for different failure mode symptoms (ISO 2015). Each FM (Failure Mode) has one or multiple root causes and associated symptoms, which are detected at specific locations and frequencies. These inputs determine ratings for the likelihood of detection, diagnosis and prognosis accuracy, and the degree of severity of the FMs.

The MPN is the product of the mentioned factors. A high MPN indicates a suitable detection and monitoring for the associated FM (ISO 2015). A lower MPN may signify low severity or deficient detection, diagnosis, or prognosis. The MPN threshold is user-defined, and its ranking does not directly suggest improvement actions. This study applies various existing methods to calculate and categorize MPNs linking them to linguistically described recommended actions. These actions provide concrete improvement directions, reducing the bias associated with FMEA tools. Methods used include standard MPN calculation (ISO 2015), Pareto, Boxplot (Catelani et al. 2020), and Bluvband approach (Bluvband et al. 2004), k-means clustering, and Fuzzy-FMSA (Murad et al. 2020).

Table 1. Resulting MPN calculation, prioritization and recommended actions derived with different methods.

Methods	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	FM12	FM13	FM14	FM15	FM16	FM17	FM18	FM19	FM20	#C modes	C modes threshold	#NC modes	Review region																							
Standard MPN	R	20	R	12	R	8	R	8	I	36	I	48	R	18	I	36	R	18	R	24	I	36	I	32	R	18	NC	135	R	18	R	24	R	24	I	48	I	54	NC	90	7	[80-25]	2	Yes			
Pareto (inv. MPN)	C	20 (123)	C	12 (131)	C	8 (135)	C	8 (135)	NC	36 (95)	C	18 (125)	NC	36 (107)	C	18 (138)	C	18 (119)	NC	36 (107)	C	32 (111)	C	32 (125)	NC	135 (8)	C	18 (123)	C	18 (119)	C	24 (119)	NC	48 (95)	NC	54 (89)	NC	90 (53)	12	<36	8	No					
Boxplot	R	20	R	12	R	8	R	8	I	36	NC	48	R	18	I	36	R	18	I	24	I	36	I	32	R	18	NC	135	R	18	I	24	I	24	NC	48	NC	54	NC	90	7	[95-24]	5	Yes			
Bluyband	C	20	C	12	C	8	C	8	C	36	NC	48	C	18	C	36	C	18	C	24	C	36	C	32	C	18	NC	135	C	18	C	24	C	24	NC	48	NC	54	NC	90	13	<48	5	No			
Clustering (3 groups)	NC	N/A	I	N/A	I	N/A	I	N/A	I	N/A	I	N/A	I	N/A	R	N/A	R	N/A	R	N/A	R	N/A	I	N/A	I	N/A	NC	N/A	R	N/A	R	N/A	R	N/A	I	N/A	R	N/A	NC	N/A	10	N/A	3	No			
FMSA (4 out)	R	100	I	50	R	100	R	100	I	50	I	50	I	50	I	50	R	100	R	100	I	50	I	50	I	50	NC	327	R	100	R	100	R	100	I	50	I	50	R	100	10	Memb. [20-80]	1	Yes			
FMSA (6 out)	R-R	200	LH	60	R-A	175	R-A	175	LH	60	LH	60	LH	60	LH	60	R-A	175	R-A	175	LH	60	LH	60	LH	60	NC	413	R-A	175	R-A	175	R-A	175	LH	60	LH	110	R-R	200	10	Memb. [20-150]	1	Yes			
Code		I		R		C		NC		LH		LH		LH		R-A		R-A		R-R																											
Description of the recommended action		Improve		Review		Critical		Non-critical (Satisfactory monitoring)		Improve monitoring high priority		Improve monitoring low priority		Review monitoring (consider adding monitoring level)		Review monitoring (consider reducing monitoring level)																															

3. Case study: Results and discussion

Figure 1 displays the feed-drive system analyzed. Positioning accuracy, response time and load-carrying capacity are considered as the system’s key performance indicators (KPI). The system has a current sensor and a rotational encoder for functional (control) and monitoring (detection) purposes.

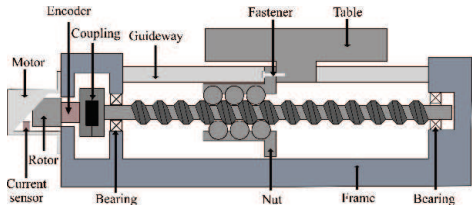


Figure 1. Schematic of a feed-drive system.

Initially, functional analysis (VDI 1996) helped establish the system’s functions. Then, FMs for each function were detailed, and the FMSA criteria were graded by panel of experts. MPNs, their prioritization, and recommendations are presented in Table 1.

The first four methods (rows 1-4 in Table 1) used the standard MPN calculation, testing various FM prioritization methods derived from FMECA.

Three prioritization categories with associated improvement recommendations were found using defined thresholds and the boxplot method. The former results in case-dependent FM prioritization categories, while the latter is generalizable but underestimates FMs requiring improvement.

Pareto and Bluyband methods classify 60% and 75% of FMs as critical but lack information on monitoring improvement actions. Clustering results in three categories and an average of FMs needing monitoring improvement. However, the association

between prioritization groups and the selection of the number of groups can be ambiguous.

Integrating expert knowledge into prioritization-recommendation through fuzzy logic yields four and six output categories, depending on recommendation specificity and discretization of edge categories to minimize algorithm bias. This approach aims to reduce uncertainty in FM prioritization by providing a clear directive for improvement. The case study’s results highlight the need for monitoring improvements in FMs related to position estimation and mechanical coupling. For instance, adding a linear encoder and accelerometer can enhance system monitoring and contribute to achieving KPIs. The assumption in action-oriented FMSA is that once the rule base is created it is used in multiple systems. Further evaluation in industrial cases will determine the suitability of the approach for effective digitalization.

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Confidence intervals for RUL: a new approach based on time transformation and reliability theory

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Abstract

This work describes a new analytical approach to derive confidence intervals on Remaining Useful Life (RUL) estimators. The new method applies a time transformation to make the Mean Residual Life (MRL) a linearly decreasing function of the transformed time. Then, explicit confidence bounds for the RUL are derived in the linear MRL case and mapped back to the physical space with the inverse time transformation. A reliability assessment problem of Light-emitting diodes (LEDs) that have undergone accelerated degradation tests, and for which confidence bound and RUL must be provided, demonstrates the new approach. LEDs fail when the luminous flux depreciation exceeds a maximum threshold and the time to failure corresponds to the first hitting time. In this case, Weibull distributed first hitting time is a realistic assumption, which allows the above time transformation method to be carried out explicitly. It is then shown that, if an alternative model (a Gamma distribution, with an appropriate shape factor) had been adopted instead, the results would be quite close to those obtained initially. The key parameter is the slope of the MRL in the transformed time; that parameter can be explicitly related to the shape factor of the Weibull or Gamma distribution. Comprised between 0 and 1, it is used to build the confidence interval; the larger its value (the steeper the slope, i.e., the faster the degradation), the lower the variance of the RUL is, and the narrower the confidence interval. Similar results can be obtained with a Wiener or a Gamma process, which suggests a distributional robustness of this approach. We believe this time transformation approach to be advantageous when the computational efficiency and robustness of the RUL estimation are of primary importance. It also provides useful insights into the dynamics of RUL, which are linked to the ageing characteristics.

Keywords: RUL, Time Transformation, Confidence Interval, Mean Residual Life, LED, Degradation.

1. Background

Remaining useful life (RUL) estimation is a critical need for predictive maintenance and system health management. RUL is inherently uncertain due to operational and environmental conditions and different ageing and wear-out speeds, Dersin (2023). Uncertainty quantification (UQ) is therefore essential for reliable RUL estimation. Despite the increasing interest in UQ for RUL, most existing approaches are based on simplifying assumptions and fail to account sufficiently for epistemic and aleatory uncertainties in RUL estimation. This work introduces a new framework for RUL estimation and UQ. By applying a time-warping function, we can linearize the average loss of RUL over time and formally analyse its natural variability and statistical uncertainty analytically. We demonstrate the efficiency of the proposed method on an RUL estimation problem for LEDs, Van Driel et al

(2012). The proposed method enables quantification of uncertainty for the RUL by means of closed-form expressions for confidence bounds, functions of time. This can provide invaluable support for predictive maintenance, e.g., a risk reduction regarding system failures, and data collection decision-making.

2. The method

In Dersin (2023), a time transformation $\tau = g(t)$ is introduced to map the lifetime variable (t) to a warped lifetime (τ) so that the MRL linearly decreases in the transformed domain. Formally, the transformed MRL is defined as, $v(\tau) = m - k\tau = m - kg(t)$, where m is the mean time to failure and k is the angular coefficient determining the speed of ageing (loss of mean residual life) in the transformed space.

The transformation $g(t)$ is given in terms of the reliability function $R(t)$ by,

$$g(t) = \frac{m}{k} [1 - R(t)^{\frac{k}{1-k}}] \quad (1)$$

and the parameter k is expressed in terms of the coefficient of variation σ/m by,

$$k = \frac{1 - (\sigma/m)^2}{1 + (\sigma/m)^2} \quad (2)$$

Eq. (2) shows that, the smaller σ/m , the steeper the slope k . In other words, a faster degradation corresponds to less uncertainty. Also, at the limit $t \rightarrow \infty$, the transformed time $\tau \rightarrow \frac{m}{k}$. The $g(t)$ function is usually S-shaped and has an inflection point t^* where d^2g/dt^2 vanishes. The time derivative can be seen as a metric for the speed of ageing, and t^* marks the transition from fast to slow ageing. Before the inflection point, $g(t)$ is convex (faster ageing) whilst after the inflection point it is concave (slower ageing). The parameter k turns out to be an upper bound on the time derivative of the MRL after the inflection point:

$$|\frac{dv}{dt}| \leq k \quad \text{for } t > t^* \quad (3)$$

For 2-parameter Weibull (W) and Gamma (G) distributed lifetimes the value for k can be explicitly derived as $k = \frac{2\Gamma^2(1+\beta^{-1})}{\Gamma(1+2\beta^{-1})} - 1$, and $k = \frac{\beta-1}{\beta+1}$, where β is the shape parameter for the W and G, respectively. Also note that, for Weibull distributed lifetimes, the inflection point t^* can be formally derived as follows:

$$t^* = \eta \left(\frac{\beta-1}{\beta} \frac{1-k}{k} \right)^{\frac{1}{\beta}} \quad (4)$$

3. Application and results

The method presented in Section 2 is applied to a LED durability assessment problem. The run-to-failure data, flux degradation trajectories $\phi(t)$, of 100 LEDs have been gathered with 4 combinations of accelerated current and temperature. For each combination, 25 LEDs are available, and $\phi(t)$ collected till 9072 hours with a monthly sampling frequency. A LED failure occurs when the luminous flux depreciation exceeds a 2% threshold, i.e., $\phi(t) < 0.98\phi(0)$. This failure threshold, relatively harsh compared to the most common industry best practice of 50 to 90 %, was selected to reduce the high number of right-censored failures. Table 1 presents the results of the lifetime and RUL analysis, and an example for the time transformation $g(t)$ and its derivative dg/dt are plotted in Fig. 1 for the stress level $I=0.7$ A and $T=85^\circ\text{C}$. Note that for the lower stress levels ($I=0.35$ A), $t^*=4455$ h, which indicates that $|dv/dt| \leq 0.749$ for $t > 4455$ h. On the other hand, for the same temperature but higher current 0.7 A, see Fig. 1, $k=0.84$ and change from fast to slow ageing occurs at $t^*=2940$ h, which indicates the flux degradation stabilizes earlier: $|dv/dt| \leq 0.84$ for $t > 2940$ h

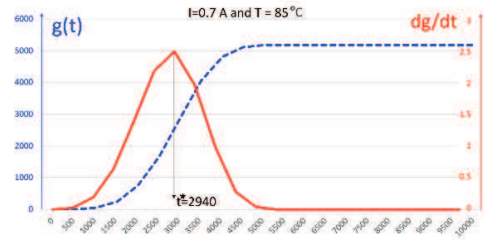


Fig. 1. The warping function $g(t)$, dashed line, and $\frac{dg}{dt}$, solid line, for $(T, I) = (85^\circ\text{C}, 0.7\text{ A})$.

The method enables the derivation of confidence intervals for the RUL (see Table 2 in the Weibull case for the same stress combinations), which can support risk-based maintenance optimization. Note that a Gamma model (for the same value of k) would lead to very close results as the warping function would be very close.

Table 1 Result of the lifetime analysis and resulting best-fitting distributions according to the AIC.

T [°C]	85		105	
I [A]	0.35		0.7	
Best-fit	G	W	G	W
η	6.89	7581	7.04	4934
β	6.98	2.86	3.88	3.85
m [kh]	6.8	6.7	4.4	4.4
k	0.749	0.75	0.59	0.84
t^* [kh]	-	4.4	-	2.9

Table 2: RUL bounds for 80% confidence level (h)

t	3000	4000	5000
RUL+	3227	2342	1757
RUL-	451	213	125

Also, under continuous monitoring conditions, the k parameter could be updated with time, leading to narrower confidence intervals as increased degradation would result in higher values of k over time. The degradation (loss of LED luminous flux) could also be modelled by a Gamma or a Wiener process.

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Cutting Tool Degradation Monitoring in Turning with Artificial Neural Network

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Keywords: reliability, artificial intelligence, monitoring, degradation, turning, cutting tools

1. Extended Abstract

During machining, the cutting tool is subjected to mechanical, thermal, and chemical stresses that lead to its degradation [1]. Consequently, both the quality of the machined surface and the compliance with manufacturing tolerances are reduced. Under nominal turning conditions, the tool is predominantly worn on its flank face. The size of this degradation is characterized by a value called V_b and defined by the ISO 3685 standard [2]. This standard defines the End Of Life (EOL) of the tool at V_b equal to 300 μm . Industrial practice is to replace the tool before its EOL, which wastes time, materials and increases production costs. Therefore, tool management is an important issue as the cost of tools can represent a significant proportion of production costs [3].

Most cutting tool replacement policies are based on knowledge of the condition of the tool. This step of monitoring and determining the condition of a tool is a growing area of research as there are many approaches to monitoring the degradation of cutting tools. These approaches can be divided into two categories: direct and

indirect monitoring. Direct monitoring consists of directly measuring the degradation on the tool. This direct analysis makes it possible to accurately observe tool degradation but requires the machining operations to be stopped to carry out the measurement, which increases the downtime of the machines and consequently the production cost. To avoid having to stop the machining process to perform a tool degradation measurement, existing approaches mainly focus on indirect monitoring, which consists of estimating the tool condition from signals collected during machining. Recently, with the emergence of the industry 4.0 and the growing generation of data by machine tools, data-driven models have been implemented to this task. These machine learning approaches use different techniques such as: fuzzy logic, support vector machines, self-organizing map, neural network, ... and can monitor the state of the tool with less error than conventional empirical and statistical approaches [4].

The approach presented describes the use of neural networks to monitor tool wear from data collected during instrumented turning tests.

These data consist of the cutting forces collected during the life of the tool for different cutting conditions. The database is composed of the degradation of 30 tools whose wear was measured on average every 2.8 minutes. From the temporal signals of the cutting force, several indicators are calculated. These indicators, either statistical or frequency, are not all correlated with tool wear. To identify those most correlated with the wear, a Spearman correlation analyses is performed. The most correlated data are used as input to the neural network. In our database, the root mean squared value of the feed force as well as the cutting force are used together with the machining time and the total machine length as they are most correlated with tool wear.

The choice of neural networks is based on their ability to achieve better classification results compared to other classical artificial intelligence approaches [5]. In this case, the objective of the neural network is to monitor the value of the tool's degradation (V_b). The input to the neural network is therefore the correlated indicators identified by the correlation analysis and the output is the size of the flank wear (V_b).

A neural network is defined by several parameters that control its architecture and learning method, these parameters are identified by comparing what is done in the literature and adapting these trends to the database presented above. The performance of the network is evaluated by computing the mean squared error between the value estimated by the neural network and the value measured during the tests. The best performance is achieved with neural networks with 2 hidden layers. The first layer is composed of 6 neurons and has a hyperbolic tangent activation function. The second layer is also composed of 6 neurons with a rectified linear unit activation function. This architecture optimizes the mean squared error loss with an "Adam" optimizer. Network learning is monitored to avoid overfitting. This is achieved by stopping the training when the network no

longer improves its results on a validation sample. Compared to other ANN approaches that use only one activation function, this network obtains 40% better performance.

The network is evaluated on degradation trajectories with variations in cutting speed between 2 measurement points to verify that the network can generalize its results to variations in cutting conditions. After training, the proposed network can correctly track the degradation and timely detect the EOL of the tool. The results show that the network correctly estimates degradation to an average error of less than 40 μm . Consequently, the network detects the EOL with an error of about one minute. In practice, these errors have no impact on the machining process. The model also tends to give conservative results by slightly overestimating tool degradation. The approach shows that this type of simple model can obtain satisfactory results for monitoring tool degradation. This method requires the instrumentation of the machine tools, but with the rise of Industry 4.0 this is increasingly common.

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Data Driven Approach for Diagnostic and Prognostic of Vertical Motor-Driven Pump

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This paper will present on data architecture that is used to collect heterogeneous data from vertical motor-driven pumps and how the collected data is used by the feature engineering module to extract salient features associated with different faults. Once fault signatures are developed, diagnostics models like eXtreme Gradient Boosting are used for automating the fault classification process. Given the diagnostic outcome, a prognostic model like autoregression integrated moving average is used to forecast the health condition of the motor-driven pump. Along with prediction horizons for 12, 24, and 48 hours, uncertainty bounds are also computed. This allows nuclear power plants to achieve condition-based maintenance and reduce unnecessary downtime, achieving significant cost-savings.

Keywords: diagnosis, prognosis, autoregression integrated moving average, uncertainty bounds, classification, condition-based maintenance.

1. Introduction

Operations and maintenance (O&M) activities are key aspects of ensuring the availability and reliability of energy generated by nuclear power plants (NPPs) Ngarayana et al. (2019). O&M costs—including activities such as inspection, calibration, testing, and replacement—are some of the major non-capital costs contributing to the overall operation costs of these energy-generating sources. The energy industry employs three main maintenance strategies to ensure availability, reliability, and safety. These maintenance strategies are (1) time-based periodic maintenance, (2) failure-based maintenance, and (3) condition-based maintenance (CBM). Each energy plant, based on their regulatory and safety requirements, deploys these maintenance strategies at various levels across their structures, systems, and components.

This paper focuses on a CBM approach for a vertical motor-driven pump (MDP) which is part of a circulating water system (CWS) in an NPP. For details on CWS, refer to Agarwal et al. (2021). The rest of the paper is organized as follows. First, data-to-decision architecture is presented in Section 2. Diagnostic and prognostic model results for a diffuser fault mode observed in a vertical MDP are presented in Section 3. Finally, conclusions are presented in Section 4.

2. Data-to-Decision Architecture

The CBM approach in this paper (see Fig. 1) utilizes heterogeneous data from vertical MDPs and how the collected data is used by the feature engineering module to extract salient features associated with different faults. Once fault signatures are developed, diagnostics models are used to automate the fault classification process. Given the diagnostic outcome, a prognostic model is used to forecast the health condition of the MDP. In the architecture, prognostic outcomes are integrated with generation risk and economic models (which is outside the scope of this paper).

3. Diagnostic and Prognostic Models

The diagnostic model, using eXtreme Gradient Boosting (XGBoost), was developed to estimate the condition of the vertical MDP, based on the features extracted from the vibration and plant process data. In this case study, the diffuser fault in vertical MDP and associated measurements were the focus. A total of 502 input features extracted from vibration and process data were used for diagnosis of diffuser fault. The input feature space was split into 336, 108, and 46 for training, validation, and testing of XGBoost. The training, validation, and testing accuracy (i.e., correct diagnosis is presented in Table 1. Given the diagnostic outcome of the diffuser fault the

Rotating machinery health state diagnosis through Quantum Machine Learning

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Academia and enterprises have explored Prognostic and Health Management (PHM) to perform the diagnosis of failure modes via several traditional Machine and Deep Learning methods. However, the computation scenario is heading toward new advances, which include Quantum Processing Units. Due to its promising results in terms of speed and scalability, research centers worldwide began experimenting with models that lay at the intersection of machine learning and quantum computing. In this sense, a new technique that has already been applied in different scenarios is Quantum Machine Learning (QML), which aims to improve conventional methods in terms of performance and results. This work aims to apply QML models for the fault diagnosis of bearings, an important rotating machinery component, by vibration signals. We apply hybrid models involving the encoding and construction of parameterized quantum circuits connected to a classical neural network. The study uses rotation gates and different entanglement gates (CNOT, CZ and iSWAP), and explores the impact of varying the number of the quantum circuits layers. We perform a classical Multilayer Perceptron model for comparisons purposes. We use the database Case Western Reserve University with 10 failure modes. The obtained results suggest that, despite the current limitations of quantum environments, QML models are promising tools to be further investigated in PHM activities.

Keywords: Quantum Machine Learning. Rotating Machinery. Health State Diagnosis. Variational Quantum Algorithm.

1. Introduction

Rotating machinery is a critical industry equipment that operates in complex environments subject to high temperatures, fatigue, and large loads (Song et al., 2018). Vibration analysis has become the industry standard for evaluating the condition of this type of equipment. Traditional methods for diagnosing failure modes, in the context of Prognostic and Health Management (PHM), include feature extraction using signal processing methods and defect classification adopting Machine Learning (ML) and Deep Learning (DL) approaches.

A field that has been gaining space in the literature is Quantum Computing, as well as the algorithms developed within this framework with the aim of promoting improvements in problem solving, such as PHM (Maior et al., 2023). The so-called Quantum Machine Learning (QML) combines quantum computing techniques to the

classical ML models. Among these, the concept of qubits, or quantum bits, which are the smallest quantum units, is highlighted. The qubits can admit the states "0", "1", or a linear combination of both, called superposition (Correa-jullian et al., 2022). Furthermore, entanglement operations allow strong correlations to be established between qubits regardless of the distance between them (Correa-jullian et al., 2022). Therefore, the objective of this work is to investigate and adapt QML models to perform PHM, through the diagnosis of failure modes, of bearings as the rotating equipment components.

2. Methodology overview

Our QML models were constructed via TensorFlow Quantum library and runned in the Cirq quantum simulator without consider noise. The framework to develop the QML models is divided in four main steps, as follows:

(1) Prepare Quantum Dataset: we preprocess the classical data by normalizing and extracting features – in this case, mean, variance, root mean square (RMS), peak to peak, kurtosis, maximum amplitude, skewness, and crest factor. Then, the data is encoded into qubits via angle encoding method where N qubits defined in a $|0\rangle$ state.

(2) Evaluate quantum model: after encoding the data, PQC is created with different architectures. The first one consists only of rotation gates over y , x , and z , for each qubit with parameterized angles. In addition, we considered a circuit configuration with a Euler (composed by R_y, R_z, R_y) followed by a nearest-neighbor qubit coupling using the different entanglement gates (CNOT, CZ, and i SWAP). PQCs were built with different numbers of layers (1, 5, and 10). The maximum number of layers was 10 due to computational limitations.

(3) Sample: measurements are performed, returning the processed quantum data to classical data. For this work, a measurement operation was defined through the Pauli Z-gate ($Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$) in each of the qubits.

(4) Evaluate classical model: it collects the built features that are fed to the neural network. Error backpropagation and diagnosis are performed.

4. Results

In Table 1, we can observe the results for the thirteen models performed in this study. The metric analyzed is the Recall. The classic MLP has the worst recall (91.95%). The best result consists of the configuration of PQC with CZ and five layers (98.47%), which is approximately six percentage points greater than MLP. The CNOT configurations, among all the QML structures applied in this research, have the lowers results.

Table 1. Recall results.

Category	Quantum gates	# of circuit layers	Recall
Classic MLP	-	-	91.95
QML	Ry, Rx, Rz	1	97.32
		5	95.02
		10	96.93
	Ry, Rz, Ry + CNOT	1	94.25
		5	95.02
		10	95.79
	Ry, Rz, Ry + CZ	1	96.93
		5	98.47

	10	96.55
Ry, Rz, Ry +	1	96.93
i SWAP	5	95.79
	10	96.93

We performed the Kruskal-Wallis statistical test to evaluate the null hypothesis that “the medians of the balanced accuracies of the models are equal”. In other words, we want to assess whether the balanced accuracy scores vary based on the “model” factor. As shown in Table 2, the null hypotheses were rejected since the statistics exceed the critical value (21.0261). Thus, we can infer that, statistically, at least two medians among the models differ and the balanced accuracy scores vary based on the model factor. Certain models consistently demonstrate suboptimal performance, particularly those utilizing CNOT. On the other hand, some models, such as the architecture with CZ, exhibit superior results.

Table 2. CWRU: Kruskal-Wallis test results.

Metrics	CWRU
	8 features
H_{obs}	47.9495
$pvalue$	3.19e-06

5. Conclusion

There are now a lot of restrictions on how much computing power quantum programs have. Nonetheless, this is a potential route that frequently gains ground in businesses and academia. For example: another metrics can be compared, such as precision and accuracy; different PQC and Neural Networks structures; other backpropagation and encoding methods; and, run the models in a real quantum hardware.

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Developing risk models that are resilient and responsive to rapid change

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One of the key challenges that risk models face is being resilient and responsive to rapid change. This is particularly challenging when such models consider relatively rare events and/or are based on exposure rates as rapid changes can in some circumstance start to break down the key assumptions that these models are based on. The Rail Safety and Standards Board Safety Risk Model estimates the underlying risk from the operation and maintenance of the Great British mainline railway. The use of normalizers in the model is key, as it enables comparisons across years and apportioning of the risk to more granular levels (such as train operator or geographic region). Such localization of estimates is not without challenges and recent experience of how the Great British rail network reacted to the COVID-19 pandemic has led to a need to better understand how best to normalise risk and performance indicator models such as the Safety Risk Model. The aim being to make them more adaptable and responsive, and therefore more representative of the risk as it changes.

Keywords: railway safety, resilience, risk modelling, normalization, train accidents.

1. Introduction

The Safety Risk Model (SRM), owned and managed by the Rail Safety and Standards Board (RSSB), is one of the most mature and well-established risk models in the EU railway sector according to a survey (ERA, 2015). The main objective of the SRM is to estimate the underlying risk arising from the operation and maintenance of the Great British mainline railway (Gilchrist & Harrison, 2021).

The risk outputs from the model are normalized so that they can be used as a tool by railway stakeholders to understand their risk profile and manage or invest appropriately. This allows users of the model to apportion risk based on their operation, for example by renormalizing an estimate based on national passenger train kilometres travelled using the number of passenger train kilometres for their operation.

2. Response of SRM to rapid change

During the COVID-19 pandemic, from late March 2020 onwards, the operation of the GB railway network was significantly affected by a sudden

reduction in the number of trains operating and the number of passengers using them. As GB emerged from the pandemic the opposite happened, albeit not as sudden and more of a gradual increase. What became apparent during this period was that the risk models and monitoring tools based upon them were not resilient and responsive to such rapid changes in the underlying normalization. This breakdown of some of the modelling assumptions led to the outputs of the model needing to be carefully interrogated, interpreted and explained to users. To achieve this a number of issues needed to be resolved and specific actions were taken to address them.

3. Development of more responsive models

One such step is the development of more responsive normalizers that can track what is happening in real time. Currently the risk from a signal passed at danger (SPAD) and train collision are normalized using train kilometres. This has some significant drawbacks (Harrison et al, 2022), and in recent years a data-driven system (Red

Aspect Approaches Towards Signal, RAATS) has been developed to provide a better understanding of the probability of SPAD at different levels (including national, regional, and operator levels).

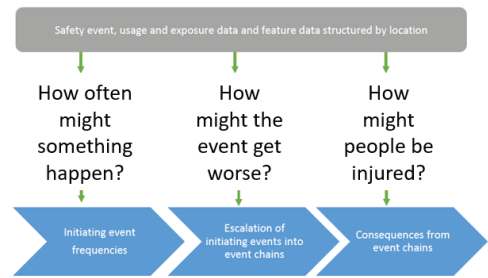


Fig. 1. Overview of the risk modelling process used in the Safety Risk Model

RSSB has also recently updated and redeveloped the SRM. Figure 1 provides an overview of the modelling process and the steps undertaken to estimate the risk on the Great British rail network.

In this latest development of the SRM, RSSB investigated the feasibility of normalizing SPAD and collision risk using the more responsive train approaches to a signal, rather than train kms. The advantage being that such a metric tracks what is happening in real time more closely and enables more representative normalization of the risk estimates to be made.

4. Conclusions

Understanding how risk models perform in a rapidly changing environment is key to making them more resilient. The COVID-19 pandemic presented a unique set of circumstances that tested the assumptions underlying some of RSSB’s key risk modelling tools and techniques. This has led to new approaches being explored that can be used to better normalize and understand rapid changes as they occur and the effect they have on risk estimates, and more generally how to make the risk models more responsive and resilient to rapid changes.

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External Probability Safety Assessment Framework

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Considering the climate change, a new analysis is needed for external events related to natural disasters on nuclear power plants. In the case of extreme natural disasters such as tsunamis and earthquakes, the consequences of accidents will be very serious. After screening and analysing the natural disasters affecting the nuclear power plant, the nuclear power plant structure and components affected by the selected natural disasters are derived through the nuclear power plant walkdown. After the failure mode and effect analysis of the derived component is performed, the initial event analysis is performed by referring to the internal event PSA(Probabilistic Safety Assessment Framework). It is necessary to analyse the accident scenario according to each initiating event. In addition, hazard and fragility analysis is performed on the screening component.

Keywords: Probabilistic Safety Assessment Framework, Extreme External Event, Risk Assessment, Natural Hazard

1. Introduction

It is expected that there will be changes in the safety assessment for natural disasters in nuclear power due to the impact of climate change. In particular, the Korea Climate Change Assessment Report predicts that temperature, precipitation, typhoons, seawater temperature, and sea level will increase. The average temperature is increasing by about 1.8°C from 1912 to 2017, and the average precipitation is increasing by 11.6mm per decade from 1912 to 2017. Sea temperature is rising by 0.024°C per year from 1984 to 2013, and sea level rose by 2.9mm per year from 1989 to 2017.

As the frequency of natural disasters and accidents are expected to increase due to climate change, studies on the safety analysis of nuclear power plants have recently been conducted abroad. Safety evaluation of extreme natural disasters in nuclear power plants and development of safety improvement technology using the results are required, and a systematic and quantitative evaluation method for analysis of natural disasters is required. Accordingly, we present a methodology to analyse possible extreme natural disaster scenarios, evaluate the

safety of nuclear power plants, and derive safety improvement measures.

2. External Probability Safety Assessment

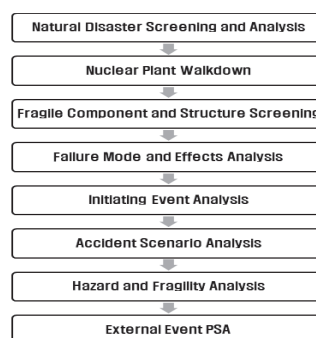


Fig. 1. External Probability Safety Assessment

Fig.1 is a framework for evaluating the probabilistic safety of power plants against natural disasters. An evaluation was conducted on the site for Shin-Gori Units 1 and 2 in Korea, and an analysis was conducted on natural disasters related to high wind.

2.1. Natural Disaster Screening and Analysis

In the case of extreme natural disasters, the frequency of occurrence is low, but analysis is necessary because the impact on power plants will be very large, and the frequency of occurrence of natural disasters is predicted to increase according to climate change. In this study, an analysis of high winds was conducted.

2.2. Nuclear Plant Walkdown

In this step, Structures, Systems and Components (SSC) affected by high winds are derived using site visits and drawings. The survey includes up to 1km from the power plant area, and most of the buildings outside the nuclear power plant are targeted.

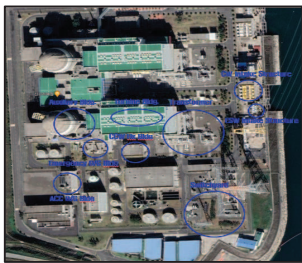


Fig. 2. Shin-Gori Site information

2.3. Fragile SSC Screening

In this study, SSC selection is carried out through walkdown and case analysis of external events. A total of 22 external events caused by high winds in Korea were analyzed, and the systems likely to be damaged by high winds include the component cooling water system, circulation water system, and off-site power system.

2.4. Failure Mode and Effects Analysis

The failure mode of the SSC, which is vulnerable to high winds, must be evaluated, and the failure mode and effect analysis of the derived devices is performed by referring to the internal event data.

2.5. Initiating Event Analysis

The initial event analysis is performed by referring to the external event case analysis and the internal event data. Accidents affected by high winds include Loss of Offsite Power (LOOP), Station Black Out (SBO), and Loss of Component Cooling Water (LOCCW).

2.6. Accident Scenario Analysis

Accident scenarios were derived by considering SSC vulnerable to high winds. It was analyzed by assuming that the component would be damaged if the structure was damaged. Fig. 3 is the high wind accident scenario used in this study.

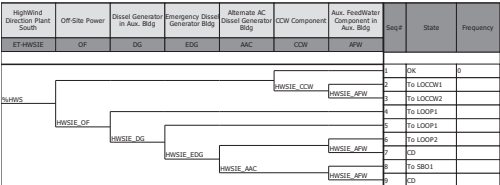


Fig. 3. High Wind Accident Scenario

2.7. Hazard and Fragility Analysis

The hazard of strong wind was derived using the data of the Korea Meteorological Administration, and the fragility of strong wind was assumed by referring to the fragility of earthquake.

2.8. External Event PSA

The Core Damage Frequency (CDF) was derived using the accident scenario of high winds, the degree of disaster, and the degree of vulnerability. For existing equipment failure rates, internal event PSA was referenced. Results such as the table below were derived.

Table 1. High Wind CDF

	LOCCW	LOOP	SBO	Total
CDF	8.99E-11	9.75E-09	2.79E-08	3.78E-08

3. Result

In this study, the high wind risk evaluation for the Korean nuclear power plant site was conducted according to the external event framework as shown in Figure 1. As shown in Figure 2, in the case of SSC affected by high wind, most of the buildings outside were affected. Such as Auxiliary building, Off-Site Power, Diesel Generator building, CCW Heatexcahnger structure, CW Intake structure. In the case of high wind CDF, it was derived as 3.78E-8/yr. Depending on climate change, analysis of other external events is also needed.

Acknowledgements

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Feasibility Study on Integration of Operator Modelling in DICE™

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Keywords: Nuclear Power Plant, MCET, DICE™, Operator Model, Exploring Scenario.

EXTENDED ABSTRACT

Due to its unique characteristics, an NPP(nuclear power plant) requires a higher level of reliability than other engineering systems. In order to achieve a higher level of safety and systematic evaluation of NPPs, deterministic safety analysis and probabilistic safety assessment are performed respectively. As the scope of risk expands temporally (i.e., long-term) and spatially (e.g., multi-units), the need for an analysis that reflects more contextual behavior showing non-linear tendencies is steadily being raised. In addition, there is a potential weak point in that it is difficult to discover scenarios particularly for a new type of reactor.

To address this issue, Kyung Hee University has developed a modular platform for dynamic event analysis called DICE(Dynamic Integrated Consequence Evaluation) that makes probabilistic and deterministic methods into a calculation framework. DICE has been steadily developed with case studies:

In the past, research was conducted to evaluate the coverage of the simplified EOP(Emergence Operator Procedure) of NPPs, and recently, research are being carried out to calculate branch probability using MCET(Monte-Carlo Event Tree) method with MELCOR.

DICE also has two simulation methods with different branch generations previously, those called single-branch mode and multi-branch mode, and now called DDET(Discrete Dynamic Event Tree) method and MCET method, depending on the analysis purpose or the method

of how to assign probability distributions. It is shown a schematic of the calculation process in Fig. 1. The explanation of DDET is referred to the literature. We describe briefly MCET methods below down:

- Possible to build boundary scenarios for MCET method analysis boundary

The MCET method has the following characteristics.

- Reflect on random failure/recovery of system and operator actions at random times
- In other words, scenario development reflects time-dependent changes in the power plant state according to the random system failure or operator actions and the creation of various scenarios through many simulations
- Scenario variability analysis according to random state/time change of equipment and operator action

→ It is possible to explore unknown or new scenarios. (Update the EOP and PSA)

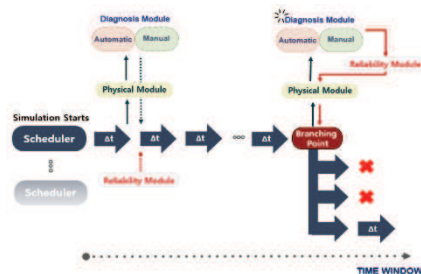


Fig. 1. DICE calculation process(MCET method)

In particular, the MCET method focuses on exploring unknown scenarios and can be applied to a new type of reactor as an initial part of PSA. To explore unknown scenarios using MCET, variability in time should be reflected, and this requires the operator model to provide the operator action time. In this paper, we present the results of applying a dynamic operator model based on HRA(Human Reliability Analysis) that provides various operator action times based on SPAR-H.

The operator model provides operator action time along with the HEP(Human Error Probability) resulting from SPAR-H. To do this, the operator action time for diagnosis is calculated, and then the operator action time for execution is also calculated. Additionally, if the diagnosis is performed quickly, it is also taking into account that the range of time for execution becomes wider. In Figure 2, the results of 7,000 calculations using the operator model based on specific operator tasks and data are shown. When the operator model conducts simulations with DICE, the temporal variability provided by the operator model can lead to different results even for the same accident sequence.

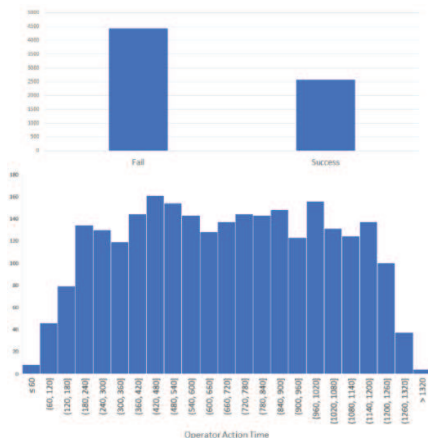


Fig. 2. Result of Operator Model(Upon: Success/Failure, Down: Operator Action Time Frequency)

In various HRA methods, the purpose is to calculate a HEP(Human Error Probability), but this approach is confronted with the difficulty of exploring unknown scenarios. However, by providing temporal variability similar to this operator model, there is a possibility of

exploring unknown scenario possibilities. In order to effectively apply DICE using the MCET, the operator model that can provide temporal variability is necessary. Furthermore, this operator model can be applied to the SPAR-H and other HRA methods. we are planning to develop the operator model editor that enables the simulation of various operator models and methods with DICE.

Using this operator model concept and MCET together for accident simulations makes it possible to see various variabilities in accident scenarios. By applying this approach, it is possible to explore

A systematic approach to improve reliability of storm surge barrier closures

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Coastal defenses must be upgraded to combat increasing flood risk due to climate change and other factors. Storm surge barriers, large movable hydraulic structures that close temporarily during storm surges to prevent coastal floods, play a vital role in protecting estuaries. Due to the complexity of their risk analyses, important improvements are sometimes overseen. Our objective is to develop a systematic approach which is more likely to find these important improvements. We tested the method to three historic cases where important improvements were initially overlooked. We anticipate that our method can be applied to other safety systems with a large number of failure modes as well.

Keywords: Climate change adaptation, risk reduction measures, coastal flood, safety system.

1. Why adapt storm surge barriers?

Increasing coastal flood risk is caused by climate change, growing populations, and the value of assets in coastal zones (Hallegatte et al., 2013). In the regions they protect, a failure to close the barrier is often the most likely cause for such a catastrophic flood (Mooyaart et al., 2023). To adapt to the rising coastal flood risk, reducing the probability of a failed barrier closure is a promising strategy (Fig. 1). However, the failure to close consists of over a thousand potential failure modes with similar (low) probability. As a result, dominant failure factors and important improvements are sometimes overseen. We propose a systematic approach which is more likely to incorporate these important improvements. To develop this approach we 1) explore dominant failure factors and 2) propose a comprehensive list of principle improvements.

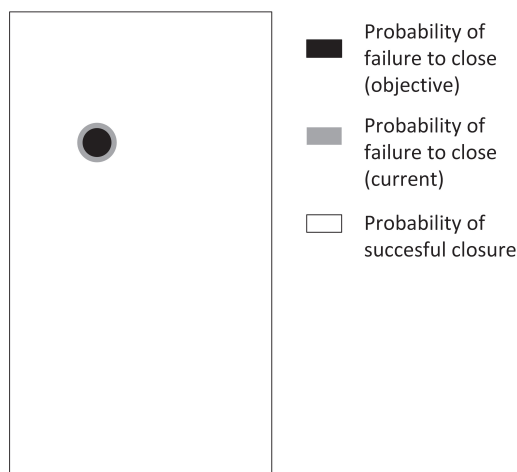


Fig. 1. Venn diagram with a current probability of non-closure of 1/100 on demand and a probability of non-closure objective of 1/200 on demand

2. Dominant failure factors

In the Netherlands, the probability of a failed closure is assessed using large fault trees. Well-known methods such as sorting minimal cut-sets and importance measures often result in long lists of failure modes with a similar probability. Several scientists (e.g. Cheok et al., 1998; Borgonovo and Apostolakis, 2001) recognize the importance of grouping to find dominant failure factors. However, no literature was found how to best group failure modes. Therefore, we group failure modes in four ways: 1) type-based (i.e., hardware/software/human), 2) formula-based (e.g. test interval, failure frequency), 3) phase-based (design/construction/maintenance) and 4) object-based (using an object tree).

3. Comprehensive List of Principle Improvements

Even when dominant failure factors are identified, important improvements can be missed. For instance, failure model improvements can be overlooked while focussing on tangible improvements. We propose to use an comprehensive list of principle improvements. We discuss and extend upon the twelve principle defences against common cause failures as proposed by Paula et al. (1990). Examples of principle improvements are adding redundancy or improve staff training.

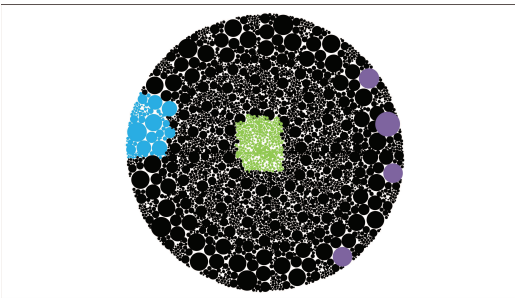


Fig. 2. Zoom in of Venn Diagram of fig. 1 showing that the probability of a failed closure consists of many failure modes. Several groups of failure modes are indicated with blue, green and purple colors to emphasize the importance of grouping failure modes. The blue group could, for instance, correspond to failure modes which all are influenced by a specific yearly test

4. Case studies

The approach is applied to three cases of Dutch storm surge barriers. In two cases, the improvements were initially overlooked, but later found and implemented. In the last case, no improvements were required as the risk was found to be acceptable. Some improvements were, however, suggested based on sorting minimal cut-sets. We compare this initial list, with the possible improvements we found with our approach. We discuss whether important improvements were missed.

5. Implications

We expect that our approach can assist in identifying effective solutions to reduce the probability of a failed storm surge barrier closure, thereby adapting these structures to climate change and increasing flood risk. The method may also be useful for other industries using Quantitative Risk Assessment (QRA) and dealing with a large number of failure modes.

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Estimating Tropical Cyclone induced Power Outages in Future Climate Scenarios

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This study investigates the impact of tropical cyclones on power outages at the census tract level, considering climate change's impact on the hazard's intensity and frequency. For this analysis, we use seven climate models to generate the synthetic tropical cyclones corresponding to historical data and future scenarios as well as a power outage model to predict the fraction of outages at each census tract. Our main objective is to evaluate if future climate scenarios will increase the frequency or produce longer-lasting outages for the Gulf and East Coast of the US.

Keywords: Power outage predictions, outage model, climate models, data analysis, climate change projections.

1. Introduction

The energy system is one of the most critical services, enabling communities to meet their most basic needs. Nevertheless, the occurrence of natural disasters, such as tropical cyclones, floods, and tsunamis, frequently disrupts this system, leading to power outages. Simultaneously, climate change projections indicate that these hazards will become more frequent and severe (Knutson et al. 2010), thereby prolonging the duration of outages. As the duration of an outage increases, it results in greater economic and societal losses while simultaneously disrupting dependent critical infrastructures such as water and communications systems.

Although many hazards can inflict significant damage on energy systems, tropical cyclones are particularly dangerous as they can severely damage critical components of the system, (e.g., substations and distribution lines). Climate change projections indicate that future tropical cyclones are likely to exhibit slower movements and prolonged lifespans. This prolonged exposure

to stronger winds increases the likelihood of extensive damage to the energy system's infrastructure.

One of the main approaches for estimating power outages are statistical analysis models. Statistical outage forecasting models use weather forecasting information as well as information on the infrastructure exposed to the hazard to predict the number of outages at an aggregated spatial level, such as the census tracts or county level.

2. Methods and Results

This research uses a power outage model to examine how tropical cyclones could affect power outages at the census tract level using seven climate models. For each model, 4000 synthetic tropical cyclones were generated for the Atlantic and Gulf Coasts regions, 2000 corresponding to historical conditions and 2000 based on the SSP5-8.5 socioeconomic pathway projection, which assumes high levels of greenhouse emission and a 4.5-degree Celsius temperature increase by 2100.

The power outage model builds from McRoberts et al. (2018). This two-step model predicts power outage by first using a binary random forest classification model to determine whether an outage will occur at the census tract level. If the binary model indicates an outage, the second step of the model predicts the number of outages at each location using a random forest regression model. We reduced the set of predictor variables utilizing only publicly available and accessible information, including hurricane-related characteristics, socio-demographic and environmental variables. We conducted statistical analysis to ensure the fraction of outages generated with the reduced dataset did not significantly differ from the original results. For this analysis, we used an alpha level of 0.1.

Our final set of variables includes the maximum 3-sec wind gust, the duration of sustained winds exceeding 20 m/s, the census tract population density, and three land cover variables: forest, grassland, and wetlands. To estimate the maximum 3-sec wind gust and the duration of sustained winds exceeding 20 meters per second, we utilized a parametric wind field model that has been validated in previous studies (Nateghi et al. 2014; Guikema et al. 2014). Population density data were obtained from the 2020 US decennial census, while land cover data was sourced from the National Land Cover Database.

Our analysis focused on 24 states along the Gulf and East Coasts of the United States. Fig.1 displays the average annual fraction of outage difference between the historical data and the SSP5-8.5 projection for the CNRM-CM6-1 climate model. The graph colors indicate whether the projection presented a greater (red) or lower (blue) fraction of outages compared to the historical data. Results indicates that for the CNRM-CM6-1 climate model, there is an increase on the average annual fraction of outages for all the Gulf and East Coast states.

In the final analysis, which will be presented at the conference, we compare the average annual fraction of outages difference between the historical data and the SSP5-8.5 projection, for all seven climate models as well as an ensemble at the census tract level.

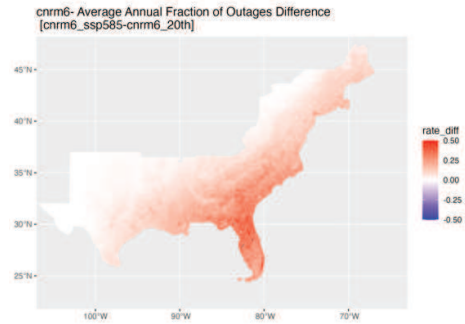


Fig. 1. Average annual fraction of outages difference between the historical data and the SSP5-8.5 projection, for the CNRM-CM6-1 climate model.

3. Conclusion

This study provides a basis for understanding if future climate scenarios will increase the frequency of outages for the Gulf and East Coast of the US. The findings can be used to inform the development of strategies to mitigate the climate change risks and ensure the resilience of the energy system. Furthermore, it provides a basis for additional economic and societal impact analysis of future climate projections.

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Operational Response to Extreme Weather Events

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Any operational response to extreme weather should consider both the immediate risk that it mitigates, and any secondary risk that the operational response will introduce. A whole system risk model has been produced that is designed as a decision support tool for the railway industry to improve the current operational responses to extreme weather events. This initial iteration of the model considers how speed restrictions may be applied to mitigate the immediate risk from soil cutting failures during extreme convective rainfall. However, the scope of considering whole system risk can be extended to other extreme weather scenarios and operational responses.

Keywords: extreme weather, rainfall, earthworks, operational risk.

1. Introduction

During periods of extreme weather, a whole system approach to risk needs to be taken to ensure that any operational controls (speed restrictions or service suspension) limit the overall risk and not just the immediate risk posed from extreme weather. A whole system approach also considers the hazards that operational controls may introduce (crowding, signals passed at danger and fatigue) and the associated risks that accompany these hazards. With this balance of risk, a more informed decision can be made as to what the operational response should be during an extreme weather event.

2. Model Development

A statistical model has been developed based on analysis into the frequency of extreme convective rainfall events and their impact on soil cuttings on the Great Britain (GB) mainline railway. Gilchrist et al. (2022). The model takes the output of this analysis to consider the likelihood of failure of any soil cutting given the characteristics of the cutting in a range of extreme convective rainfall events. Ganthu (2022). The train service over the section of line is fed into the model and this is used to determine the probability and consequences of a train striking an obstruction caused by a cutting failure. Statistical analysis is then used to derive the risk from any operational controls that are imposed. The two risk values are

accounted for in the model to determine the impact on the overall risk by the operational controls in that given scenario.

The immediate risk is calculated in two parts: the likelihood and associated speed of a train derailling, and the determination of the average consequences of such a derailment. An event tree is used to determine the first part of this, using a number of variables including the probability of a cutting failure and the train running speed. The consequences have been adapted from the event trees used in the Safety Risk Model, also developed at the Railway Safety & Standards Board (RSSB). The consequences are expressed in Fatalities & Weighted Injuries (FWI).

The model determines the delay minutes by considering the increased sectional running times from running at a reduced speed along with considering whether drivers need to be stopped and cautioned by signallers. Reactionary delays can also be calculated by the model, which depends on the location of the response.

Earlier work by RSSB looking at the Global System for Mobile Communication for Railways (GSM-R) failures established a strong correlation between train performance and certain types of hazards such as slip, trips & falls and passenger assaults. Gilchrist and Griffin (2016). The model uses the methodology of this work to convert the

delay minutes into FWI, so that it can be compared with the immediate risk.

The model splits the outputs by operational route section. Within each section the model considers the immediate and secondary risk for each train type that runs across each section. This is determined by the characteristics of both the train type and the track that the trains are running on. Such characteristics include train speed, line speed, number of trains per day and the type of train (passenger, empty coaching stock or freight). As operational route sections can be short, the model can suggest a single operational response across multiple consecutive sections. This would consider the immediate and secondary risk across all the sections to suggest the most appropriate, and drivable, operational response.

3. Applying the model

The output of the model can be used to assist in any decision making for imposing operational controls on sections of the GB mainline railway. It can suggest the optimal operational response for a section of the network given the amount of convective rainfall that has been experienced over that section. This can range from no reduction in speed to a full suspension of services. The outputs of the model show the tradeoff between the reduction of the immediate derailment risk and the possible increase of other risks that may be introduced by the given operational response. The numerical values for both the immediate and secondary risk vary depending on the operational characteristics of the route and the severe weather being experienced.

Alongside the optimal operational response, the model outputs also show the overall risk balance for a range of other operational responses. This enables the user to understand how the risk balance changes as the operational response changes. As a decision support tool, the model outputs would need to be considered along with other operational factors. For instance, the final response would need to be drivable, without increasing the workload for railway staff. The risk posed from other hazards on the railway outside the modelling scope would also need to be factored into any final plan.

3.1. Model Trial

To determine how the model could be used as part of a wider whole system response, RSSB worked with Network Rail in March 2023 to apply the model across multiple route sections as part of a desktop exercise. The outputs of the model were not used on the network at this time, but the trial demonstrated how the model could be used as a decision support tool. A framework to incorporate the model as part of a larger decision making process has been drafted based on this exercise. RSSB continues to work with Network Rail to embed the model and any future iterations of it into the process for imposing speed restrictions during extreme weather.

4. Further development

The model currently focusses on convective rainfall and its impact on soil cuttings but the whole system approach could be applied to a far wider range of possible events that the railway faces. Future development of this model could consider frontal rainfall and how the operational response may need to be different in this scenario. Failures from embankments could also be incorporated into the model which would give a more holistic view of the risk posed by all earthworks on the railway. Development of a user interface for the model with fully automated inputs could enable the model to be used more widely and have a greater impact on the way operational controls are imposed across the whole GB mainline railway.

Even though the short term focus remains on using the model to provide operational decision support, the system risk-based view at operational route section level could be used in future to prioritise investment decisions. For example, instead of focussing remedial work on the asset in the worst condition, this approach could switch to focussing on the asset that poses the largest contribution to whole system risk.

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Application of Adaptive Time-Stepping in the Resilience Analysis of Interdependent Infrastructure Systems Using an Iterative Optimization-based Simulation Framework

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Civil Infrastructure Systems (CISs) play a crucial role in the socioeconomic development of communities. CISs are also known as critical infrastructure systems because of providing essential commodities and services. Due to complexity and interdependency, a disruption in the function of CISs may result in cascading failures and malfunction in the performance of other infrastructure systems, such as water and communication. Hence, the resilience of the CISs against natural hazards has taken stakeholders' attention. Improving the resilience of infrastructure systems can reduce the damages to the CISs and economic losses of urban communities. This research introduces an Iterative Optimization-based Simulation (IOS) framework to quantify the resilience of interdependent infrastructure systems to natural disasters. This IOS framework comprises five modules, namely, risk assessment, database, simulation, optimization, and controller.

The role of the risk assessment module is to simulate the hazard and assess its impacts on the functionality of infrastructure networks' components. After evaluating the components' vulnerability, the data regarding the post-disaster status of infrastructure networks is transferred to the database module. Next, this data is called by the simulation module to trace the evolution in the performance of infrastructure networks. The data generated by the simulation module is populated in the database. Then, the simulated data is applied to the optimization model to find the optimal flow of services within the networks. According to the optimal solution stored in the database, the simulation module changes the supply and demand patterns and the same time, models the recovery process and updates the functionality level of the components in the interdependent CISs. In the end, this module simulates the operation of the infrastructure networks to trace the performance evolution for the next step of the recovery. In the meantime, the controller module computes the resilience metric defined for this research. The procedure is iterated between the simulation, database, optimization, and controller modules until the stopping criterion is met.

Most research studies considering an optimization-based framework have applied Equal Time-Stepping (ETS) to the resilience assessment period (e.g., one day). This approach is applicable to small and deterministic case studies. The computational burden for the probabilistic resilience assessment of large-scale interdependent infrastructure networks is a serious challenge, especially in the case of using Equal Time-Stepping (ETS). Since the optimization module of the proposed IOS framework incorporates a Mixed-Integer Linear Programming (MILP) problem to find the optimal service distribution within the infrastructure networks, to reduce the

computational cost, this research proposes deploying an Adaptive Time-Stepping (ATS) approach. The ATS approach changes the size of steps during the resilience assessment period of interdependent CISs.

The interdependent infrastructure networks (power, natural gas, and water) located in Shelby County (TN), USA, are the case study of this research study. The seismic resilience of Shelby County's infrastructure networks was evaluated against the earthquake with a magnitude of 8.2 and an epicenter located at 35.3 N and 90.3 W by using Adaptive Time-Stepping (ATS) and Equal Time-Stepping (ETS) approaches. In the ATS approach, the length of the time steps varies between T , $2T$, and $3T$ (T is equal to one day). Due to the complexity of the problem, the performance evolution of interdependent CISs is not predictable. Hence, the automatic determination of step size is not applicable to the IOS framework for resilience assessment. The interval for each time step size varies by case study since each case study has a particular behavior during the post-disaster recovery. For the case study of this research, the time step size is T for the interval starting from the first day and ending on the 45th day. The IOS framework is implemented with a $2T$ time step between the 46th and 75th days. After the 75th day, the time step size for the IOS framework is $3T$.

The results show that applying ATS to the resilience assessment period reduced the computation time by 35.7 percent (from 133.7 seconds to 86 seconds) compared to the ETS approach in the case of using Gaussian distributed restoration functions. However, using the ATS approach resulted in a 1.6 % error in the computed resilience metric. Therefore, time efficiency improvement using ATS outweighs the computational error, especially for the probabilistic resilience assessment of interdependent CISs. Since the failed components with higher importance are often restored earlier, there are rapid changes in the interdependent CISs' performance evolution in the initial days after the hazard occurrence. As a conclusion, it is recommended that the resilience assessment of the interdependent CISs is carried out using ATS such that in the shortest time step for the initial days (e.g., the first 30-60 days) to closely follow the changes in the CISs' performance evolution. Then the time step size can gradually be lengthened so that the total error of the discretization remains low while increasing the computation speed.

Keywords: Resilience, Adaptive Time-Stepping, Iterative Optimization-based Simulation framework, Interdependent Infrastructure Networks.

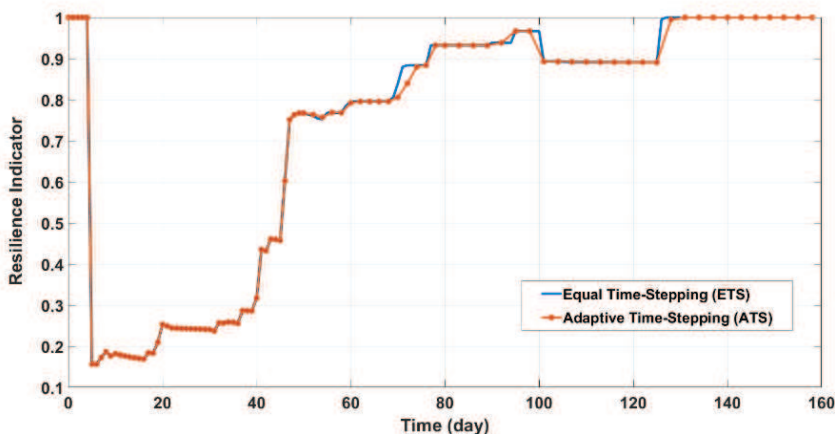


Fig. 1. The evolution of the resilience indicator for the case study computed by using ATS and ETS.

A Bayesian Population Variability-based Methodology for Reliability Assessment in the Oil and Gas Industry

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Scarcity of historical failure data is very common in many situations, especially in the Oil and Gas (O&G) industry. In this context, the Bayesian analysis is paramount to obtain reliable estimates for the system of interest. To perform this analysis, we propose using the Bayesian population variability analysis in a two-step approach. Such an approach allows the assessment of the variability of reliability measures among a similar population of systems. The first step is based on the prior estimation, and it involves gathering available data from similar systems (generic data) and constructing the prior distributions, that represents the population variability. This prior information consists of data of systems that exhibit similar, yet different reliability behavior. In the second step, one can proceed to posterior estimation, where the prior distribution is updated with the available evidence from the system of interest. To obtain the posterior estimates, Markov Chain Monte Carlo-based methods are required. In this work, we illustrate this approach assuming systems with non-constant failure rates, and the model was validated using synthetic data and the results indicate the usefulness of this approach in the O&G industries to better address the reliability measures of its systems.

Keywords: Bayesian analysis; Particle swarm optimization; Markov Chain Monte Carlo; Oil & Gas Industry.

1. Introduction

High quality reliability estimates commonly requires a considerable amount of data, what can be scarce, expensive, or even unfeasible to collect. To face this situation, we proposed a Bayesian approach to use generic data that considers non-constant failure rates that can be modelled by a power function of time, such as a Weibull distribution. Thus, an appropriate Weibull counting process is required to perform the estimation of the Weibull parameters of the prior distributions, via Empirical Bayes (Figure 1), using the Maximum Likelihood Estimation (MLE) (Shultis et al., 1981). The Bayesian approach is implemented to estimate the posterior distribution, by updating prior beliefs using system-specific failure data (censored or not) as a Weibull likelihood. In this case, the posterior distribution cannot be obtained analytically, and Markov Chain

Monte Carlo (MCMC) (Bolstad, 2010) was applied for a numerical solution.

2. Methodology applied

We focus on generic data given as paired entries (k_{ij}, t_{ij}) of the number of failures over an observation time for equipment j of subpopulation i . The estimation of the prior distribution is obtained via Empirical Bayes in terms of the hyperparameters $(h = a_\alpha, b_\alpha, a_\beta, b_\beta)$ and Particle Swarm Optimization (PSO) (Bratton & Kennedy, 2007) and MLE are applied to find the set that maximizes the likelihood function of the prior information Eq.(1). Figure 1 presents the methodology that incorporates non-homogeneous generic data as basis for the posterior distribution estimation with specific data.

$$\sum_{i=1}^{NP} \log P(E_i | a_\alpha, b_\alpha, a_\beta, b_\beta) \quad (1)$$

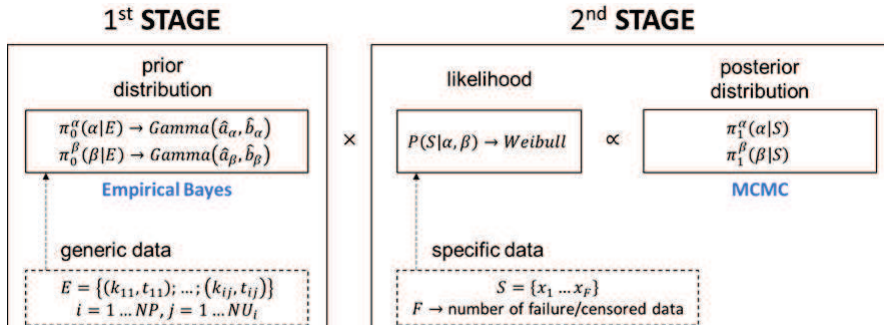


Figure 1. Two-Stages Bayesian approach to non-constant failure rate.

For each case, we ran PSO several times to better assess the variability inherent to the method. NRMSE (Normalized Root Mean Squared Error) is the metric we use to evaluate the results of the prior distribution estimation, since the PSO's results can be feasible (i.e., an optimum solution satisfying the restrictions), although they may not properly represent the input data.

The non-parametric posterior distribution is obtained via MCMC and fit tests are performed to identify the parametric probability distribution that best represents the sampled data. The maximum likelihood hyperparameters are estimated and the quality of fit of each of the resulting distributions is assessed using a Kolmogorov-Smirnov test (Corder & Foreman, 2014).

3. Results

The proposed methodology was run 30 times using synthetic data comprised of 5 equipment and 5 subpopulations for the prior estimation $\{a_\alpha, b_\alpha, a_\beta, b_\beta = 8, 0.0022, 13, 8.5\}$ and a simulation of failure times considering a Weibull (with $\alpha=3566.61$ and $\beta=1.34$) for the posterior. Fig. 2 brings the results of this test. The posterior distributions seem to deviate from the prior in the sense that it is more skewed toward data.

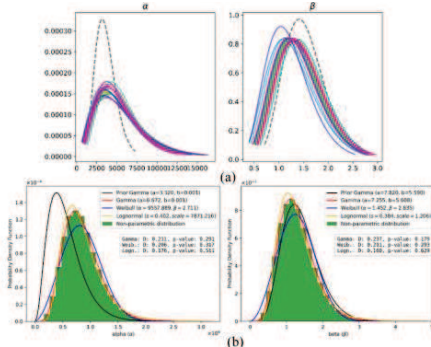


Figure 2. Prior (a) and posterior (b) estimation results.

Aside from the non- parametric distribution results, we also fit these results to three distributions: Gamma, Weibull, and Lognormal. Generally, the Gamma distribution provides a good fit in terms of the p-value based on the Kolmogorov-Smirnov test (always above 0.05).

4. Conclusion

The proposed methodology provides a solution to enable reliability estimation when we face the following problems: scarce specific data, generic data in the form of (k,t) and non-constant failure rates. As future work, we intend to investigate the variability in the prior estimation by using different heuristic methods for the MLE.

Acknowledgement

The authors thank Petrobras S.A., CNPq, FACEPE, and PRH 38.1, managed by ANP and FINEP, for the financial support through research grants. This study was financed in part by CAPES – Finance Code 001.

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PetroBayes' Modules for Reliability Assessment for Oil and Gas Industry

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PetroBayes is user-friendly software that performs Bayesian reliability estimation. The software comprises three main modules that can provide the reliability measures. The first, the Bayesian module, enables the user to assess the variability distribution of non-homogenous failure data. In this module, one can obtain a prior distribution for the reliability measure of interest based on generic data; the posterior distribution is a result of the update procedure with specific information of the system of interest. The Statistical module can fit data into distributions (e.g., the duration of maintenance actions) and perform statistical tests (e.g., goodness of fit). The Availability module can be fed with data from the previous models to build a continuous time homogenous semi Markov process (CTHSM) and estimate the system's availability. The failure rate can be derived from the Bayesian module, while the repair rate, from the Statistical module in a straightforward workflow. Note that these rates need not to be constant (i.e., exponentially distributed), thus allowing a more robust assessment. All the results can be displayed to the user, be given in written reports and images. The software can be hosted on a remote server, minimizing the usage of the user's own computation resources. We illustrated the use of the Availability module considering generic databases.

Keywords: Bayesian analysis; Weibull distribution; Availability assessment; Web-based app; Oil & Gas industry.

1. Introduction

Continuous time homogenous semi-Markovian processes (CTSM) are important tools in the context of reliability engineering, since it allows modeling the future behavior of systems only as a function of the current and next state that the system will occupy, as well as the time of permanence in that state. Thus, it was feature required in our under development software, the *PetroBayes*, that performs Bayesian reliability estimations.

The novel module for availability assessment was developed to be able to assess the behavior of a given system over time, obtaining the availability of the system, i.e., the probability, over a given mission horizon, in which the system remains in the state (or set of states) that it can perform within a desirable level. Therefore, to improve the flexibility of the model, the transition rates will not necessarily follow exponential distributions, but rather they can follow any distribution, providing a broader

range of applications. We also included repair rates as events to recover the system from failures or degradation. This approach complements the work detailed by Santana et al. (2022) as illustrated in Fig.1.

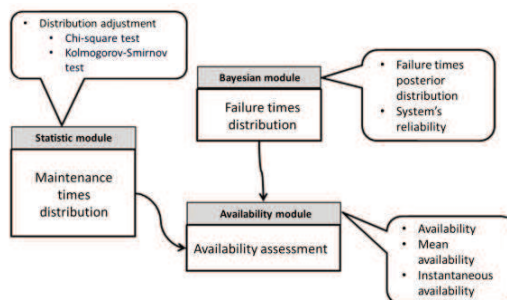


Figure 1. Integration between Petrobayes' modules.

2. Methodology

We build a CTHSM described by transition rates between states (Moura & Drogue, 2010). The model structure can be chosen from three available options (Table 1). The decision

regarding which model to choose relies on the data available, which dictates the complexity required to parameterize it, the level of. The state probabilities are obtained through Monte Carlo simulation.

Table 1. Summary of the models implemented in the module for availability assessment

Model	State description
2-states	Operational (0) and Failed (1)
3-states	Operational (0), Degraded (1) and Failed (2)
4-states	Operational (0), Degraded without downtime (1), Degraded with downtime(2)and Failed (3)

3. Results

To illustrate, we considered the 3-state case. The failure rate is obtained from the Bayesian module (Santana et al., 2022), and the repair rates by fitting the repair time in probability distributions. The transition from $0 \rightarrow 1$ is described by $Exp(\lambda_1 = 0,000389/h)$; $1 \rightarrow 0$ by $LogN(\mu_{10} = 1,49, \sigma_{10} = 1,00)$, $0 \rightarrow 2$ by $Weibull(\alpha_{02} = 500h, \beta_{02} = 2,35)$; and $2 \rightarrow 0$ by $LogN(\mu_{20} = 0, \sigma_{20} = 0,91)$ Fig. 2 depicts the 3-state CTHSMP.

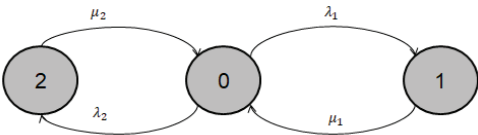


Figure 2. Semi Markovian system with 3 states.

The results were obtained considering a time horizon $T = 2.000h$, and $M = 100.000$ Monte Carlo replications. The main reliability metrics are given in Table 2 while the availability and unavailability are presented in Fig. 3.

Table 2. Reliability metrics obtained in the availability module

Metric	Values
Mean operational time (h)	1994.23
Mean failed time (h)	5.77
Mean unavailability	0.0029
Mean availability	0.9971

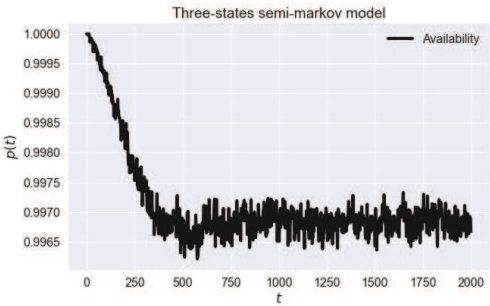


Figure 3. 3-state system’s availability.

4.Conclusion

The novel module seeks to combine treatability and relevance in the results, ranging from simpler models to more complex models, better capturing the conditions to which the system may be subject. With this, the flexibility of the model allows it to adapt to the circumstances and needs of the user. Additionally, a visual analysis is provided to support the decision making.

Acknowledgement

The authors thank Petrobras S.A., CNPq, FACEPE, and PRH 38.1, managed by ANP and FINEP, for the financial support through research grants. This study was financed in part by CAPES – Finance Code 001.

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Design and validation of a digital twin to the intelligent well completion

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The intelligent completion (IC) has been implemented in new oil wells, especially in the pre-salt exploration areas. One of the most relevant components is the Interval Control Valve (ICV), responsible to execute the switching between production zones. The use of ICVs is critical to the O&G completion and drawbacks in their operation can lead to productive losses. Given the hard and costly maintenance, it is fundamental to have means for diagnosis and prognosis of this component. Digital twin (DT) has been increasingly researched for emulating physical assets in a computational environment, in order to understand their behavior in several operation conditions and carry out failure analyses. The present work develops a DT for a hydraulic ICV system, considering simulations of ICV normal and anomalous operation, comparing with open-source databases. The DT includes modeling of hydraulics and thermal exchanges phenomena, as well as different control sequences applied to the valve systems.

Keywords: Keyword1, keyword2, keywords3, keywords4, keyword5, keywords6.

1. Introduction

In the recent years, the creation of virtual models that represents a physical object is being used for research purposes. The tool known as Digital Twin concept has been firstly presented on 2002 (Rathore et al., 2021), and can be used for reliability estimations.

The study of well completion in the Oil and Gas (O&G) field can be enhanced by the application of a Digital Twin of the physical model. There is a trend to electronically monitor and control actuators and sensors distributed along a well to switch between production lines to better produce oil. This makes possible to acquire experimental data in order to validate a DT model.

In some Pre-Salt basin, interval control valves (ICV) are used to produce oil, and a well usually has some of them installed taking turns to equally produce oil. These ICVs are hydraulically operated by one pressure pump from the platform once every few weeks. It is possible via DT to make a virtual model that can provide reliability results for the model.

2. Digital Twin

The first step of the concept of a DT is to build a numerical or virtual model of the physical ICVs hydraulic actuators along with the oil lines and pumps. The second would be to validate it with real or experimental data in order to adjust the parameters so the DT model represents a real ICV actuation system.

The assembly of a model was already proposed by Moura et al. (2022) which shows the ICV analysis within a second ICV stucked and also for a pump failure. It was built on the software Matlab® with Simulink® and also Simscape® toolbox, which has models for the many components of the ICV actuation line. The ICV itself has no modeling among the toolboxes modules, but it can be represented by a Double-Acting Hydraulic Cylinder.

3. Parameter Estimations

The parameter estimation can be done manually by varying some specific parameters and running the code until the desired results match an experimental data or via Parameter Estimation application built in Simulink®.

The procedure to use the App is basically to

change whichever parameter one wants to estimate into a variable and open the Parameter Estimation App on simulink. One must have either a physical experimental data or a generated data to estimate which parameters values would make the DT model closer to it. The software also has a learning curve built while estimating the parameters. Fig. 1 shows the procedure: on top, after running the first initial guess for all the variables, and at the bottom a couple of iterations after with a better estimation.

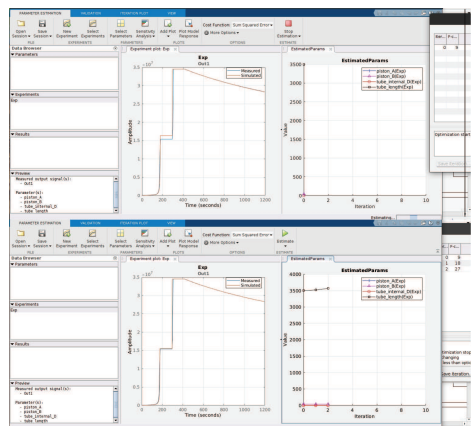


Fig. 1. Parameter Estimation.

The target of the present parameter estimation was the increase in pressure until 2500 psi at around 3 minutes and then a drop to 2000 psi while the piston starts to move, and after the end of the actuation at around 7 minutes the pressure should increase to 5000 psi which is the pump working pressure. The best results are presented in Fig.2 showed below, with a peak at 2370 psi and returning to 2220 psi during actuation.

The times for the piston movement were not as accurate as needed, 2 minutes instead of 4, but it is representing reasonably the experimental data within the time limits that were required by the company that provided the data. As the velocity of the actuator movement increases, it reaches the region where the cylinder friction starts actuate. Resulting in a pressure increase of almost 10% of the actuation desired value and then drops due to the velocity being higher than the value specified

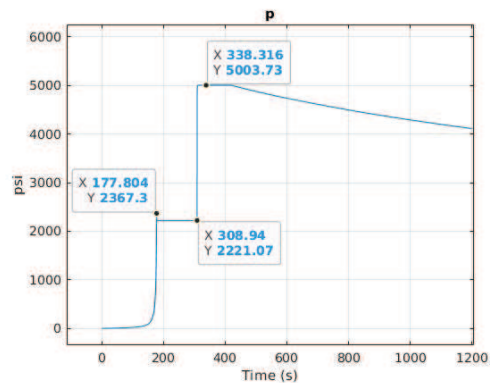


Fig. 2. Hydraulic actuator pressure.

in the friction block parameters.

4. Conclusions

Parameter estimation can be used to find closer values of many variables that otherwise would be time consuming. In the present work 10 variables were analyzed and the results were close to the experimental conditions. It is possible now to use the validated model for reliability studies.

Acknowledgement

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Development of a software tool to implement reliability assessment of developing technologies

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The reliability assessment of under development O&G equipment is a critical matter to the industry and has been increasingly pursued by the stakeholders. In this context, it is essential to aggregate information from different taxonomical levels and from different development phases, which consists in a challenge to the traditional reliability tools. The use of a multilevel reliability model, in conjunction with the Bayesian approach, is one of the possible pathways to estimate reliability of developing technology. However, given the large amount of data and the hermetic knowledge needed to apply Bayesian methods, it is fundamental to have a reliability computational tool to implement the reliability estimation. In this work, a reliability software developed to deal with multilevel Bayesian reliability models specifically developed for the O&G industry is presented. The software tool allows the user to input equipment information and characteristics, and provide the reliability estimation all over the development process, giving the decision-makers the means to use the reliability as a key decision variable in the developing technology pathway.

Keywords: reliability analysis, O&G industry, software applications, developing technologies.

1. Reliability Estimation Methodology

Recently, a methodology for reliability estimation of developing equipment has been established, which considers the details of the development process (Azevedo et al., 2022; Maior et al., 2022). This considers the evolution of technologies according to the TRL scale, ranging from TRL 1 to TRL 9. In each phase of the process, different data sources and qualification testing are available. The methodology aggregates all these information data in a single reliability estimate in each TRL, as shown in Fig. 1. It begins in requirements planning and scope definition analysis. Next, the technology begins in TRLs 1-3, where the expert elicitation is used to estimate basic events probabilities. The following TRLs use multilevel reliability model and Bayesian methods to update the reliability estimation.

2. Software Tool

The reliability estimation steps of the MRM methodology were implemented as a software tool, aiming to enable users to access its

functionality and perform robust analyses without worrying about the theoretical knowledge required to understand the MRM in its entirety.

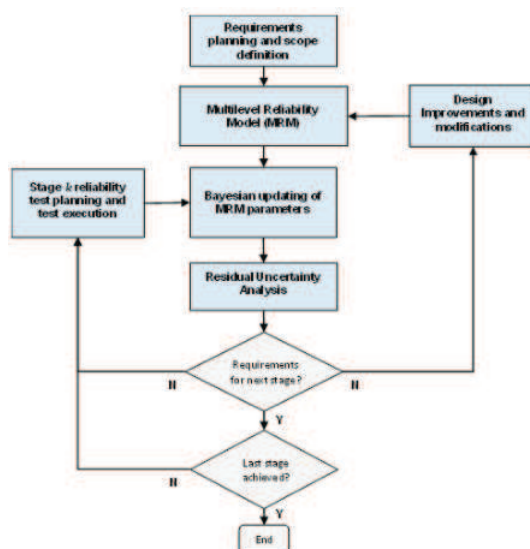


Fig. 1. Multilevel Reliability Model overview.

Fig. 2 shows a summary of the software tool, where the main implemented components can be seen, as well as their relationship in the methodology process. These elements will be further explained in the following sections.

These modules largely cover the portion of the MRM methodology represented by the three central blocks in Fig. 1: “Multilevel Reliability Model (MRM)”, “Bayesian Update of MRM Parameters”, and “Residual Uncertainty Analysis”.

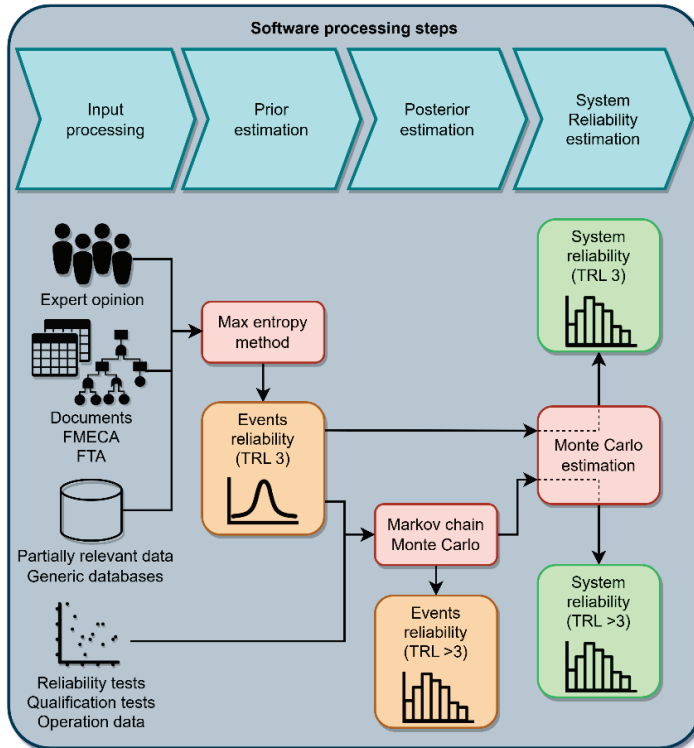


Fig. 1. Multilevel Reliability Model overview.

2.1. Processing steps

In order to perform the steps that compose the MRM methodology, several processing modules were implemented. The current software modules are listed below:

- i) A maximum entropy method implementation is used to estimate the prior distributions for each undesired event.
- ii) Markov Chain Monte Carlo (MCMC) is used to perform a Bayesian update for each event.
- iii) A Monte Carlo method is used to sample the nonparametric posterior distributions of all undesired events, forming an estimate for the system reliability.

2.2 Inputs and Outputs

In order to estimate the prior distributions, several data sources are used, such as partially relevant data (from similar technologies and/or previous design iterations), document sources (e.g., risk assessment documents, PRA, FMECA, etc) as well as expert opinion. Failure tree analysis (FTA) can be used to identify the basic failure events. Each basic event is analyzed independently, so that there is at least one prior distribution for each basic event.

For the Bayesian update procedure, the prior distributions are used along testing data, which will be used to build likelihood functions for the events.

Finally, for estimating system reliability, the resulting nonparametric posterior distributions for each basic event are used. A Monte Carlo approach allows estimating system behavior, based on the FTA relationship.

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Methodology for extracting reliability from the qualification tests ISO 23936-2

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In the O&G production chain, the presence of non-metallic materials is widely spread in several applications, often as a critical component. In this context, the equipment manufacturers are claimed to standard-proof their products and systems relative to material requirements. This process is mandatorily ruled by the qualification standard ISO-23936, which establishes the baseline procedures for testing non-metallic materials for use in O&G production. The standard determines pressure, temperature, loads, and number of specimens required for the qualification process of the material, and as a result, presents a procedure for the lifetime estimation under operating conditions. However, the ISO-23936 does not present guidelines to extract a reliability measure from the samples tested in many different conditions. In this work, a methodology to use the data coming from the tests of ISO-23936 with the aim of obtaining reliability estimation is presented and an O&G industry case study is performed. Additionally, the discussion about ISO 23936 lifetime traditional approach and reliability methods is carried out, emphasizing the difference between them.

Keywords: O&G industry, reliability estimation, qualification tests, elastomers properties, ISO standards.

1. Introduction to ISO 23936

Non-metallic materials are used in the petroleum and natural gas industries for pipelines, liners, seals, gaskets, and washers, among others. ISO 23936 describes the requirements and procedures for the qualification and selection of non-metallic material used in those equipments (ISO 23936-1, 2022). The standard proposes a series of component requirements to be considered and evaluated when qualifying and selecting the material, for which it provides test procedures and/or normative references (ISO 23936-1, 2022; ISO 23936-2, 2011). Specifically, a test and analysis procedure for qualifying the material against the ageing resistance reliability requirement is mainly presented in the documents.

2. The ISO 23936 aging (reliability) qualification test

In the ISO 23936 aging test, material specimens are exposed to test fluids and soaked at three different elevated temperatures above the operating one, to thermally accelerate chemical reaction (if this occurs), along different time intervals. Then, physical/mechanical properties are measured for each unit. Let $x_{t,k}$ be the value

of some mechanical property (e.g.: tensile strength) for the item submitted to temperature k , during t time units. An aging curve over time is got for each of the three temperature levels by fitting a parametric function to the subset of $x_{t,k}$ related to the specific temperature level.

Thus, three different service times are defined (one for each temperature level) by finding the point in the aging curve for which the material property will reach an acceptance boundary previously defined (e.g.: a change of 50% in the original tensile strength). By applying the plotting method (Modarres et al, 2017), the Arrhenius equation is obtained enabling the estimate of service time at the operating temperature. Limits of acceptability are defined as failure criteria, and the material is considered to have “failed” when this limit is attained. Then, this method is supposed to forecast material service life, providing a tool for selecting competing materials for a component design.

3. The limitations of the ISO 23936 aging test

There are two main limitations to the method presented in section 2:

- 1) **There is no proven relationship between the acceptance criteria and the component failure:** For example, will the 50% change in tensile strength cause the component to fail? It is not possible to relate service times with service life nor to claim that materials with longer service time up to reach the acceptance boundary will fail later.
- 2) **There is no reliability quantification:** Even though it is possible to relate the acceptance criterion to failure occurrence, it does not mean the material will have exactly that service life when used in the same application. There is uncertainty not captured in the section 2 method. It is more useful to assess reliability performance (i.e., the probability of operating without failure during the mission time) than to estimate an imprecise and improbable service lifetime.

This work does not propose a change in the aging test procedure defined in ISO 23936, but rather a different way of analyzing the data, to overcome the presented limitations.

4. The method for extracting reliability analysis from ISO 23936 aging test

The method proposed in this work advocates running exposure tests with test fluids at 3 different elevated temperatures, during different time intervals, exactly as described in ISO 23936. From this point the following steps must be performed:

1. Define the actual acceptance criteria for relevant properties through a simulation model.
2. Find the service life in each of the three temperature levels such as in ISO 23936 but for acceptance criteria defined in step 1.
3. Build a likelihood function for the 3 service lifetimes found in step 2 from Eq. (1), where t_k is the service life at temperature k , and $\{a, b, \beta\}$ are the AW model parameters (Modarres et al, 2017)
4. Estimate the Arrhenius-Weibull parameters (a^* , b^* , β^*) via maximum likelihood estimators (MLE) or Bayesian methodology, and quantify the reliability for the mission time (T) and operating temperature (k_0) from the AW reliability function (see Eq. (2))

$$L = \prod_k \frac{\beta t_k^{\beta-1}}{(b e^{\frac{a}{k}})^{\beta}} e^{-\left(\frac{t_k}{b e^{\frac{a}{k}}}\right)^{\beta}} \quad (1)$$

$$R(T, k_0 | a^*, b^*, \beta^*) = e^{-\left(\frac{T}{b^* e^{\frac{a^*}{k_0}}}\right)^{\beta^*}} \quad (2)$$

If step 1 is unfeasible, try to label each specimen as pass/fail by assembling them in the component and verifying if the component fails to perform some function with the aged material (or by measuring their properties and verifying if the component fails to perform some function via simulation model), and built the likelihood function by using the CDF AW function for the failure data and the reliability AW function for the non-failure data. If none is possible, use the ISO 23936 acceptance criteria in step 1, and perform the next ones.

5. Conclusions

This work proposed a method to better define failure criteria and to assess the uncertainty about the service lifetime estimated according to ISO 23936 aging test. The approach doesn't modify the setup and physical requirements of the test but only proposes a different way to define acceptance criteria and the use of the probabilistic physics of failure model (PPoF) AW to treat the data statistically. Then it comprises a simple tool to qualify non-metallic materials for use in Oil & Gas production based on quantitative reliability analysis.

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Proposal of a test protocol for reliability assessment of the new all-electric intelligent completion interface

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One of the large breakthroughs in the O&G industry is the complete electrification of the completion. In this regard, a whole new group of equipment has been developed for implementing electric completion. One of the most critical is the subsea interface (SI), with the role of providing the subsea valves with the necessary power and the communication layer to the topside instrumentation and control. In order to evaluate the reliability of the SI, a complete test protocol must be designed, encompassing mechanical, thermal, electronic and electrical testing, since the equipment involves different mechanical support parts, power electronics and communication devices. In this work, the elaboration of a test protocol for the SI is executed according to the most recommended guidelines, academic research and reliability considerations.

Keywords: accelerated test protocol, O&G industry, intelligent completion, test guidelines.

1. Reliability assessment in the O&G industry

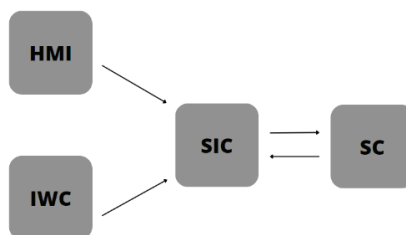
Given the complexity and long useful life of O&G equipment, the reliability evaluation needs to utilise alternatives to traditional methods. Indeed, the main source for reliability estimation relies on data from the equipment, describing its useful lifetime and failure conditions. The data can be obtained from experimental tests specifically designed to obtain reliability estimates, in which the tested device is led until failure, or from field data of equipment in real field applications. In the O&G industry this is not possible to accomplish due to the cost and long time-to-failure of the components, designed to endure 20-30 years of operation. In this context, accelerated life tests must be employed (Modarres et al., 2015). Besides this methodology, the qualification tests of industry standards can also be used to estimate reliability, although with less impact (API, 2018).

2. Subsea interface for intelligent completion

2.1. System

The intelligent completion valves are operated from a top-side computer, the intelligent well computer (IWC). This is a dedicated system with embedded intelligence. It delivers commands for the subsea interface top-side computer (SIC), which processes and forward commands for the

Fig. 1. SI schematic diagram



subsea computer (SC). This is the last interface, which sends the commands for the downhole valves. The SIC can also receive

inputs from an operator, by means of a human-machine interface (HMI), as shown in Fig. 1. As an important part of the SI, there is a health monitoring system, with plenty of sensors collecting temperature and vibration data.

2.2 Construction of FMECA

The first step to establish the test protocol is the construction of a Failure Modes, Effects and Criticality Analysis (FMECA) (Peyghami et al., 2019). A multidisciplinary team was gathered to rank the most important failure modes of the SI. These were identified as no power supply, no communication, degraded communication, incorrect command, loss of sealing of SI compartment. Each failure mode is associated with a risk priority number (RPN). The reliability analysis established that every failure mode with $RPN > 20$ must be tested.

2.3. Stressors

Following the methodology to establish a test protocol, each failure mode is associated with a failure mechanism and stressor. The latter corresponds to the physical variable responsible for causing the failure. In the identified failure modes, these were: vibration, shock, temperature, electromagnetic field and input overvoltages. These act on the SI main components: compartment, electronic devices (power converters and sources), modems and CPUs, and the health monitoring sensors.

3. Designed tests

The tests have been designed following the methodology of accelerated life tests and a test matrix was elaborated, containing all the recommended levels for the stressors (Novaes Menezes et al., 2021).

3.1. Vibration and shock

For sweep vibration test, follow API17F for vibration screening. For random vibration, an accelerated vibration life test must be established, following the power law to estimate test time. We use $m=5$ as acceleration test coefficient, which is a common value for electronic components. This results in 9.75 *grms* of vibration, consisting in 48h of test time, corresponding to 15-years of accelerated life.

3.2. Temperature

The steady temperature test should follow Arrhenius Law to estimate test time. Use 0.7 eV as baseline value (Toshiba Electronic Devices & Storage Corporation, 2018). This results in 85°C and a test time of 5000h. The degradation should be evaluated before end-of-test, which consists in 15-years of accelerated life. For cycle tests, use Coffin-Manson law, with $k=3.4$ (typical value in literature).

3.3. Input overvoltage and electromagnetic interference

In this case, the recommended test follows the API17F power variation in item 9.2.3.2.4. For surge, use the wave shape in IEC EMI-related standards (IEC 60533 and IEC 61000). It is worth noting that the electrical stressors can not be accelerated since they are not related with degradation over time.

4. Conclusion

Executing a systematic procedure from FMECA definition towards accelerated test design based on prevailing literature can improve O&G reliability evaluations.

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Reliability criteria estimation of O&G Industry Equipment in the concept selection process

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The design and development of new products are complex processes. After defining potential alternatives, frequently called “concepts”, that fulfil most criteria, they must be compared, ranked, and/or selected. The concept selection becomes even more challenging at an early stage of development, when a limited amount of data is available, making it difficult to quantify some criteria, such as reliability. However, there is little to non-existent reliability data at the concept selection stage. Also, many studies do not detail the reliability criterion when estimating it. We can obtain a prior reliability distribution for each concept, by using data from generic sources, such as expert opinion. This study proposes a method to estimate reliability criterion in the concept selection process. The criterion is quantitative, considers the reliability with an associated probability distribution, accounts for the reliability uncertainty, and based on probabilistic reliability models, specified using experts’ opinions. We apply the Weighted Rating Method (WRM) for multicriteria decision-making regarding the concept selection. Three different concepts of oil well equipment is compared. Besides the reliability criteria, costs, flexibility, integration, and time are also evaluated. The results can help the parties involved in the process to base decisions on more robust reliability criteria, enabling the selection of more credible equipment to contribute to the industry’s end activities’ efficiency.

Keywords: Concept Selection, Oil and Gas Industry, Oil Well Equipment, Reliability Criteria, Bayesian prior distribution, Weighted Rating Method.

1. Introduction

Selecting concepts that meet organizations’ criteria is a crucial step in new technology development. However, this is a complex task as the performance and relevance of each concept against the criteria must be carefully considered. Additionally, the relevance of each criterion can vary across projects.

Reliability-based approaches are increasingly used to assess new product specifications (Jia and Guo 2022). However, reliability is not deeply explored as a criterion. Despite limited reliability data available during concept selection, alternative sources like expert opinions and databases of similar equipment can be utilized to establish a prior distribution of each concept’s reliability. Therefore, the uncertainty incurred should be considered in the analyses. (Maior et al. 2022).

Thus, this study introduces a methodology that quantitatively incorporates reliability into the selection process, accounting for concept uncertainty. We present a case study comparing

three oil well equipment concepts, evaluating reliability, costs, flexibility, and development.

3. Methodology Overview

Here we apply the Weighted Rating Method for multicriteria decision-making to concept selection. As it is a simple methodology to understand, experts are able to critically analyze the results, identify inconsistencies, and reassess concepts if needed. Additionally, a simpler method facilitates the systematization and formalization of the concept selection process. To define the reliability criterion, we perform an elicitation step where expert j provides the probability of failure estimate of concept c , x_{cj} . A simple way to aggregate the experts data is by linearly pooling the experts’ opinions as $x_c = \sum_{j=1}^N p_j \times x_{cj}$, where x_c is an estimate of the probability of failure of concept c , p_j is the weight of expert j , and N is the number of experts involved. Biases can occur when experts assign weights to criteria due to limited knowledge or overconfidence. To address this, we conducted a

virtual elicitation without expert interaction, allowing each expert to provide individual opinions. An analyst then assigned weights based on their knowledge levels.

We assume that x_c is the mode (b) of the triangular distribution that describes the real values of the reliability of concept c , $R_c(t)$, and that the optimistic (a) and pessimistic (d) reliability values are respectively 1 and 0 (maximum uncertainty was associated with expert opinion due to the very early stage of development). Then, we calculate the expected value of the distribution using $E[R_c(t)] = \frac{a+4 \times b+d}{6}$. After computing $E[R_c(t)]$ for all concepts, we determine the baseline $\bar{E}[R(t)]$ and the reliability criterion score (S_{R_c}) values of each concept.

$\bar{E}[R(t)]$ corresponds to 50% of the scale, concepts with expected reliability values up to 25% higher have S_{R_c} equal to 4. Concepts with an expected reliability value between 25 and 50% greater than the reference value have $S_{R_c} = 5$. Concepts with an expected reliability value up to 25% lower have $S_{R_c} = 2$, while concepts with an expected reliability value between 25 and 50% lower than the reference value have $S_{R_c} = 1$. To illustrate the applicability of the proposed methodology, we present an example applied in a Brazilian oil company.

4. Case Study

The problem consists of concept selection for developing a new subsea interface for intelligent electrical well completion. More specifically, three concepts were evaluated: concept (1) consists of a system integrated with the subsea control module (SCM) of the wet Christmas tree, concept (2) has no redundancy in SCM and has a Central Process Unit (CPU) and Electric Power Unit (EPU) pair for each well in the control and supervision system (SCS), and concept (3) has two redundant CPUs and two high voltage supplies in SCM and shares one set of CPU and EPU for each well in SCS.

Five criteria were evaluated: cost (the price of developing the equipment), time (required to develop the technology), flexibility (capacity to adapt to different equipment), integration (capacity, to guarantee interoperability), and reliability (ability to perform satisfactorily during a specific mission time). Firstly, the experts evaluated the relevance of the criteria (w),

provided the values for each criterion (S), adopting the same scale from 1 to 5 (see Table 1) and provided x_{cj} . After eliciting the estimated failure probability in 15 years of each concept we computed their respective expected reliability. Then, the mean value $\bar{E}[R(15)] = 85.88\%$ was adopted as baseline, and the reliability criterion values of each concept were set using the scale described previously.

Table 1. Criteria scores for each concept.

Criteria	Relevance	Concepts		
		1	2	3
		$w \times S$	$w \times S$	$w \times S$
Cost	$w_c = 3$	3	9	15
Time	$w_t = 4$	12	16	20
Flexibility	$w_f = 3$	6	9	12
Integration	$w_i = 5$	10	15	25
Reliability	$w_r = 4$	8	8	12
Total	-	35	65	88

Finally, the scores of each criterion were computed for each concept by multiplying the criteria, the results are summarized in Table 1, and indicates that concept (3) is the more suitable to the organization.

5. Conclusion

This study’s results can support the individuals involved in the decision-making process to base the concept selection, despite the data limitation, on more robust reliability criteria that consider a quantitative estimation aligned with other critical criteria, as cost and flexibility. In this sense, the selected equipment can be more credible and aligned with the organization main objectives. This research focuses on equipment development in the O&G industry, but its applicability can extend to other contexts and equipment types.

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User-centered Evaluation Framework for Telerobot Interface and Interaction factors – a case study on medical device manufacturing

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The use of telerobots for surgery, military missions or rescue activities are increasingly commonplace, and so are guidelines to achieve an ergonomic design and optimal system-operator performance. However, in medical device manufacturing, in particular for fine-manipulation and highly precise operations, the existing human-machine interface and interaction (HMII) design standards to date are insufficient to ensure a cost-effective ergonomic teleoperation solution, that complies with the learnability, usability, dependability and efficiency required for this case-study. We analyze the most relevant human-system interface and interaction requirements for telerobotic systems applied to medical device manufacturing, and expand on the current standards with knowledge from recent research results in this field. We further our contribution by proposing a use-case-based telerobotic system architecture and experimental setup for human-centered evaluation of the telerobotic system HMII design.

Keywords: Telerobotics, Human-in-the-loop, Medical Device Manufacturing, Standards, EEG, Eye-tracking

1. Introduction

In the medical device manufacturing industry, precise assembly tasks and manipulation of complex materials and objects are common challenges, including precise cutting on miniature pieces made of deformable material. Adaptable automation solutions are urgently needed to maintain competitiveness in today's high-cost society. A human-in-the-loop teleoperation system provides a solution for these automation needs, combining the benefits of the robotic system (motion scaling for highly precise movements, speed, accuracy, repeatability) with the expertise of the operators, reducing automation costs, lowering safety requirements (compared to the use of cobots or manual operations), and reducing the costs of maintaining a clean room, a common requirement for the manufacturing of medical devices. Teleoperation is still a difficult task for non-expert users Rea

and Seo (2022), and more focus should be put in user-centered interface and interaction solutions to solve the outstanding challenge of operator performance. User-centered problems revolve around either awareness and understanding of the remote environment (remote perception), or the control of the robot Chen et al. (2007) Rea and Seo (2022). These problems should be primarily considered when designing a teleoperated system and the interactions between the operator and the robot.

2. Human-in-the-loop telerobotic system for medical device manufacturing

In our telerobotic system we implement a novel combination of mixed-reality-based interface and haptic shared-control interaction that has not been yet applied to human-in-the-loop medical manufacturing applications, aiming to increase remote situational awareness, reduce operator workload and reduce training time.

The system is designed and developed taking into consideration the manufacturing tasks that have to be carried out. It consists of a remote station with a KUKA KR4-Agilus 6-DoF robotic arm with different end-effector tools options, such as a hot-wire and a gripper, force-torque sensors, and three 2D cameras (two fixed on the workspace and one attached to the end-effector). The operator controls the robot with a Phantom Omni controller with six DoF, that provides haptic feedback to the operator representative of the forces received by the robotic arm in the remote environment.

A mixed-reality interface is developed to provide a higher sense of immersion and virtual functionalities, such as an interactive camera and a 3D workspace-robot representation. Haptic feedback is used as a complementary information channel for the operator to sense the environment and the interaction of the robot with other elements. Additionally, the control schema was simplified so the user can control directly the end-effector of the robot, and shared-control options were developed to assist with complex precise operations (using haptic virtual fixtures).

3. HMII design guidelines considerations

Human-robot interaction via teleoperation has commonalities with human-computer interaction field (HCI), however existing GUI-based usability design and evaluation methods lack the integration of the new interaction technology currently being used to improve teleoperation systems, and the consideration of the new challenges it creates. A document is created compiling and integrating heuristic design guidelines from multiple fields, including the human-computer interaction, virtual reality, robotics and haptic interaction field, for the user-centered design and compliance evaluation of the developed teleoperation system. The developing document contains several guidelines retrieved from current standards and recent research results, and provides practical evaluation questions and methods.

4. User-centered evaluation

Since cost-effective solutions for low-volume manufacturing scenarios are required, the design efforts are focused on achieving an ergonomic and intuitive system for skilled manual operators. The evaluation of the developed system is done from the point of view of the user, focusing on the user experience, and assuming the technical and functional properties of the system are appropriate for the requirements of the intended use. The following evaluation data will be collected to assess the system for compliance with the key guidelines identified:

- Task performance data, such as task completion time KPI's related to the specific tasks carried out.
- Operator state data: objective metrics estimated from physiological sensor data, including a consumer-grade mobile EEG-cap and eye-tracker mounted on a monitor, and subjective metrics gathered from user questionnaires.
- Human-system interaction data, to assess interaction efficiency and effectiveness.

5. Conclusion

Our work aims to provide other researchers and practitioners with a better understanding of the potential of human-in-the-loop robotic solutions, with insights into the applicable standards, recommendations drawn from recent research and a user-centered evaluation framework that can be used to assess compliance and improve human-robot interactions.

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Software reliability analysis in the O&G industry: a review with applications

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With the increasing digitalization of the O&G industry, the presence of software applications has been growing consistently. Software reliability presents special characteristics when compared to other O&G equipment, including the process of reliability growth at each software release and the use of special reliability models. This work has the aim of reviewing the concepts and methods regarding software reliability, applied for a completion interface software responsible to manage the communication between subsea and topside equipment.

Keywords: software reliability, O&G industry, SRGM models, software guidelines.

1. Software Reliability and the O&G industry

Digital systems have been increasingly utilized for O&G exploration, replacing the instrumentation and control analog or hydraulic-based. This trend is particularly relevant for the new intelligent completion systems employed in the most recent wells (Lamb, 2018). This imposes new challenges concerning reliability of the well, regarding both the hardware and software of the systems. Hardware components, including converters, circuit boards, and communication interfaces represent a reliability issue. Nonetheless, the methods for evaluate their reliability are similar to the ones employed in other physical components of completion, such as the use of accelerated life tests (Menezes et al., 2022). On the other hand, software failures have different causes and are not related to degradation over time, but rather to unstated requirements, misplaced logical paths and lack of contingency. Software failures can lead to unpredictable and severe consequences, especially in the case where the firmware is dedicated to safety functions in the O&G industry (Pasman, 2015).

2. Software Reliability Guidelines

2.1. Definition

The reliability of a software system can be defined as the the probability of performance without failing of the computer program in a specified environment for a given time (Yaghoobi, 2020). The process of evaluating this metric is called Software Reliability Engineering (SRE), which encompasses both the statistical evaluation of software failures and the best practices to avoid logical and programming errors

2.2 SRE Procedures

The most recognized method to evaluate SRE is presented in the IEEE Recommended Practice on Software Reliability (IEEE 1633-2016). It contains the main steps for reliability planning, testing during development, support release decision and software reliability in user-operation. The basis of SRE procedures are defined in 5 phases, as follows.

2.2.1. Characterize the software system

Determines which system components are appropriate for SRE, how the software will be used operationally, how the software impacts the overall system.

2.2.2. Define failures and criticality

Determines the specific types of failures that impact reliability for the particular system. It may require the development of an S-FMEA, as decided by the reliability team.

2.2.3. Perform a reliability risk assessment

Identifies risks such as safety, security, product maturity, size, and reliability growth that can affect both the reliability and the required SRE tasks.

2.2.4. Assess the data collection system

Identifies any refinements needed to data collection system to support SRE. It includes the definition of using CPU or clock time and the systematic method to log software failures.

2.2.5. Develop a Software Reliability Program Plan

Identifies which SRE activities will be implemented and when. This step defines the testing program and sequence, which must be based on the analyzed failure modes and the software operational profile (OP). Also, the SRE mathematical model needs to be defined in this phase.

2.3 SRE Models

Given the intrinsic software reliability characteristics, the evaluation models are based on reliability growth. It means that at each software failure correction/update, a new failure curve should occur, changing reliability parameters, as shown in Fig. 1

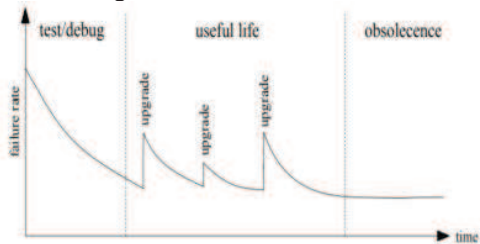


Fig. 1.Example of SR evolution, showing the useful life characterized by the upgrades (Cusick, 2018).

. Researchers have developed different Software Reliability Growth Models (SRGMs) to deal with this phenomenon. These are split in parametric and

non-parametric models. The parametric models are mainly the Non-homogeneous Poisson Process (NHPP), the stochastic differential equations, and the Bayesian update. Non-parametric models include deep neural networks based on automatic software collection data (Wang & Zhang, 2018).

3. Application in O&G industry

The SRE was applied to an interface system with IC-valves. Software failure modes were identified based on discussions and system FMEA. Following the IEEE-1633, it was established an OP and anomalous conditions to be tested in a software stress test. The result is a sequence of software tasks and their occurrence to be tested. Results are input to an NHPP model to provide software reliability.

Actor (System)	Operation	Occur. Rate	Occur. Prob.
Subsea CPU	Get command from top-side CPU	10 Hz	HIGH
Subsea CPU	Get Health Monitoring Data	1 Hz	LOW
Subsea CPU	Switch IC redundancy	on demand	LOW
Subsea CPU	Turn	on demand	LOW

Fig.2:Example of part of OP for O&G subsea software

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Categorization of aircraft missions for exploitation by a digital twin

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The use of new recurrent neural models with layers of attentions has proven to be very effective in monitoring the internal state of an aircraft's engines. Our research work has shown the effectiveness of these methods for predicting corrosion or just measuring a deterioration in performance. However, until now, only the data broadcast by the engine has been readily available, but it seems logical that the description of the mission and the way the pilot handles the aircraft seem equally important. We have therefore developed a mathematical method to describe each mission, in this way it becomes possible to import new data helping to monitor engine wear. In the meantime, these new measurements also give us a new methodology to explore the use of our systems. For example, we are now able to categorize flights and it will become possible to adapt our design and our maintenance offer to the real needs of airlines.

Keywords: Aircraft Engines, PHM, Neural Network.

1. Introduction about PHM

Prognosis & Health Monitoring (PHM) of aircraft engines consists in identifying characteristics to assess its condition. These algorithms are generally separated into two parts: an on-board component to build indicators from the measurements collected during each flight and another, on ground computers, which processes these measurements with other contextual elements to estimate trends or drifts in engine behaviour (Fig. 1). These drifts will be analysed by experts or artificial intelligence algorithms to anticipate risks of degradation.

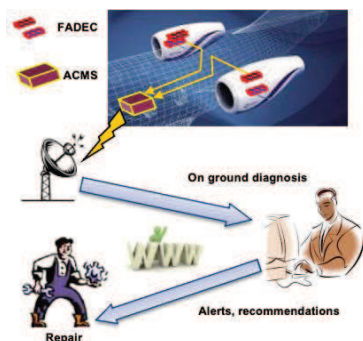


Fig. 1. PHM process.

Initially, PHM directly used summary data produced during each flight in the form of snapshots. This first static analysis made it

possible to identify damage present on the engine or a performance drift. By adding contextual data, such as meteorological and pollution data, the damage estimators could be seriously improved (Flandrois et al. 2009).

2. Recurrent neural methods

Finally, very recently, we have started to use recurrent temporal models that evaluate a latent state updated after each flight. The addition of this temporal component, which considers the history of the engine's successive missions, has improved the quality of our predictions (Fig. 2).

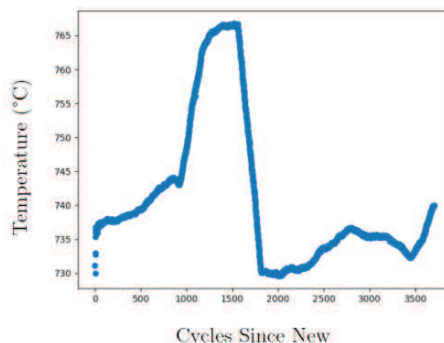


Fig. 2. Observing the wear of an aircraft engine by increasing exhaust temperature and the effectiveness of subsequent repair work. Each point represent the mean value of 10000 simulated flight using the neural network.

The data set corresponds to the entire flight history of 40 aircraft equipped with the new LEAP engine. For each engine of these aircraft, we had information from visual inspections by boroscopy as well as from maintenance operations. The dynamic models seem more efficient than the previous static models even if potential counters which capitalized, for example, the time spent beyond certain load levels, are computed on board the aircraft (Langhendries and Lacaille 2022).

3. Missions categorization

One crucial element was still missing from these models, a description of the missions themselves. Indeed, each flight is different, and we have therefore implemented a detailed method of categorizing flights with a metric allowing them to be compared two by two. This method first performs a decomposition of the rotational speed of the fan, which in our case of turbojets is a relevant indicator of thrust. Once the flight has been segmented from this control signal, each flight segment is categorized. The complete flight can thus be described as a sequence of labels (Cottrell et al. 2019). To build a metric between the flights, we took care to use a topographic categorization procedure using self-organizing maps (SOM) to classify the segments. This type of categorization automatically gives a distance measure between segments, which makes it possible the use of an edit distance as a similarity measure between flights.

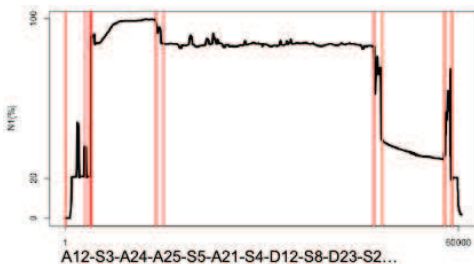


Fig. 3. Automatic division of the flight into transient and stabilized segments. Each segment is then categorized by an unsupervised classification algorithm. The flight is thus transformed into a sequence of labels, as shown below the graph, which represents core rotations speed versus time.

This metric consists of measuring the minimum cost of transforming one flight into another by exchanging, adding, or removing labels. Hence,

we categorize the missions and enter the flight class as a new contextual data of the recurrent model.

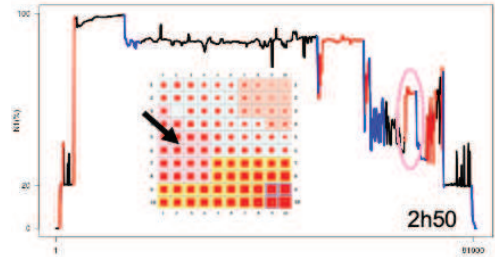


Fig. 4. This chart shows a specific type of flight identified by a category (each box on the self-organizing map) among all flights in a given airline fleet. Here a specific behaviour can be observed by an increase in thrust before landing.

4. Conclusion

An advantage of this method is that it applies to a very large database of past flights automatically and is fast enough. When some missions are original, for example in the case of helicopter or military aircraft tracking, it is not possible to have instant flight summaries easily. Our method makes it possible to identify the categories of the most frequent flight segments and thus to reconstruct such snapshots from temporal data. This allows us to better control the evolution of the state of these engines, much more difficult to follow than for airliners.

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Generating Controlled Physics-Informed Time-to-failure Trajectories for Prognostics in Unseen Operational Conditions

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The performance of deep learning (DL)-based methods for predicting remaining useful life (RUL) may be limited in practice due to the scarcity of representative time-to-failure (TTF) data. To overcome this challenge, generating physically plausible synthetic data is a promising approach. In this study, a novel hybrid framework is proposed that combines a controlled physics-informed data generation approach with a DL-based prediction model for prognostics. The framework introduces a new controlled physics-informed generative adversarial network (CPI-GAN) that generates diverse and physically interpretable synthetic degradation trajectories. The generator includes five basic physics constraints that serve as controllable settings. The regularization term, which is a physics-informed loss function with a penalty, ensures that the synthetic data's changing health state trend complies with the underlying physical laws. The synthetic data is then fed to the DL-based prediction model to estimate RUL. The framework's effectiveness is evaluated using the New Commercial Modular Aero-Propulsion System Simulation (N-CMAPSS), a turbofan engine prognostics dataset with limited TTF trajectories. The experimental results demonstrate that the proposed framework can generate synthetic TTF trajectories that are consistent with underlying degradation trends and significantly improve RUL prediction accuracy.

Keywords: Prognostics, Time-to-failure trajectory generation, Deep learning, Physics-informed generative adversarial networks.

1. Introduction

One of the corner stones of Prognostics & Health Management (PHM) is the prediction of the remaining useful life (RUL) of industrial assets, which enables decision-makers to plan maintenance actions in advance and prevent failures [1]. However, the performance of deep learning (DL)-based approaches for RUL prediction in practice is limited due to the lack of representative TTF data. Inspired by the Time series Generative Adversarial Networks (TimeGAN) [2], this study focuses on the challenging problem of RUL prediction when the available TTF trajectories are not sufficiently representative, specifically when the observed operating conditions (OC) in the training dataset do not match those in the testing dataset. To overcome this issue, the proposed approach introduces a physics-informed generative framework for prognostics that enables controlling the TTF trajectory generation while ensuring that the generated trajectories are realistic, fully

interpretable, and consistent with the underlying degradation processes. This framework is referred to as a controlled physics-informed generative adversarial network (CPI-GAN).

2. Methodology

This section presents the proposed approach for generating synthetic data and using a DL-based prognostics model, as shown in Figure 1. The framework comprises three main steps: data pre-processing, synthetic trajectory generation, and prognostics. In the first step, the data is pre-processed through downsampling, normalization by flight class, and statistical analysis (obtaining the physical characteristics of the degradation trajectories under various flight classes as basic physics constraints for synthetic trajectory generation). Since real health parameters are only available during training, a surrogate model (deep neural network with three layers) is developed to replace the

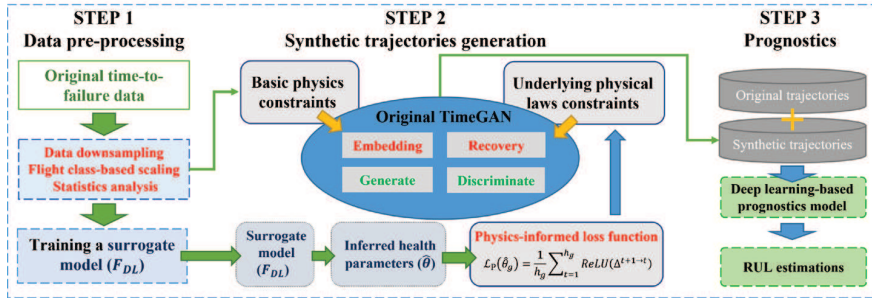


Fig. 1. The framework of the proposed controlled physics-informed data generation for RUL prediction.

traditional physics-based system performance model to obtain the inferred health parameters. In the second step, the basic physics constraints are used to initialize the generator. Then, the generated sequence is fed into the surrogate model to infer the unobservable health parameters. These parameters are used to enforce penalty targets of the physics-informed loss function during generation, ensuring adherence to the engine's underlying degradation characteristics. In the final step, the synthetic degradation trajectories and original degradation trajectories are combined into a training dataset, which is then used as input to the prognostics model to output RUL estimations.

3. Results and Conclusions

The proposed framework was evaluated on the new Commercial Modular Aero-Propulsion System Simulation (N-CMAPSS) dataset. As depicted in Table 1, the hybrid outperforms the purely data-driven approach with the same 1D-CNN architecture by 17.67% in terms of RMSE and 52.08% in the NASA *score* reduction, demonstrating a clear improvement. This performance improvement is primarily attributed to the four synthetic units that belong to unseen OCs. Moreover, the proposed framework handles RUL overestimation more efficiently, as evident by the substantial decrease in the score metric, which penalizes overestimation rather than underestimation, compared to the symmetric RMSE metric.

Table 1. Overview of the results of the hybrid framework and the baseline approach, respectively. The Mean and standard deviation of the prediction results are obtained over five runs.

DS-02			
Metric	Baseline	Hybrid	rel. Delta
RMSE	4.64±0.14	3.82±0.11	-17.67%
<i>score</i>	0.48±0.05	0.23±0.04	-52.08%

4. Conclusions

The proposed approach in this study presents a novel solution to overcome the challenges of limited representativeness and missing time-to-failure trajectories by utilizing a controlled data generation technique based on physical information to generate synthetic data for unseen scenarios. Our proposed approach leverages prior knowledge and underlying physical laws to generate time-to-failure data that complies with basic physics constraints and the system's degradation trend under different operating conditions. The generated synthetic data, combined with real data, are used to train a DL-based model to predict the RUL. Extensive evaluations demonstrate that the synthetic data adheres to the physical constraints and the degradation trend of the system, and the inclusion of synthetic data leads to improved RUL prediction accuracy.

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A Study on Gradient-based Meta-learning for Robust Deep Digital Twins

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Deep-learning-based digital twins (DDT) are a promising tool for data-driven system health management because they can be trained directly on operational data. A major challenge for efficient training however is that industrial datasets remain unlabeled. This is remedied by simulators that can generate specific run-to-failure trajectories of assets as training data, but extensive simulations are limited by their computational cost. Therefore, it remains difficult to train DDTs that generalize over a wide range of operational conditions. In this research, we propose a novel meta-learning framework that is able to efficiently generalize an arbitrary DDT using the output of a differentiable simulator. While previous generalization approaches are based on randomly-sampled data augmentations, we exploit the differentiability of the full pipeline to actively optimize the training data sampling by means of condition parameter's gradients. We use these gradients as an accurate tool to control the sampling distribution of the simulator, improving the representativeness, robustness, and training speed of the DDT. Moreover, this meta-learning approach leads to a higher quality of generalization and makes the DDT more robust to perturbations in the conditional parameters.

Keywords: Meta-learning, Deep Digital Twin, Differentiable Simulator, Digital Twin Generalization

1. Introduction & Motivation

DDTs are deep neural networks that encode the behavior of complex physical assets and have the ability to continuously adapt to operational changes. A major challenge in training DDTs is that their performance depends on the training data quality and representativeness Booyse et al. (2020). Manual estimation of the training distribution is non-trivial for prognostics and health management (PHM) because DDTs are required to work reliably under all operating conditions and must be robust to data distribution shifts. A recent trend in other applications has shown that DDTs can be successfully trained in purely simulated environments, which enables algorithmic tuning of the training sample distribution. There are two potential issues that should be noted. First, existing algorithmic tuning makes no use of the differentiability of the simulator Wang et al. (2022), and second, although an increasing number of differentiable simulators appear in the literature, they have little focus on improving DDT robustness.

2. Meta-learning Framework

In this research, we propose an approach that enables to increase the generalization and robustness

of the DDT w.r.t operating condition parameters $\phi \in \Phi$ of a simulator. To achieve this, we first train the weights θ of a DDT with a user-defined task loss \mathcal{L} on synthetic data $x \in \mathcal{X}$ from a differentiable data source, the differentiable simulator S . Second, we guide the training process of the learner to *challenging* (to learn) data samples $x^c \in \mathcal{X}$, identified by the loss and associated with ϕ^c , by gradient ascent and train the DDT on it. Finally, we alternate between the two steps until completion. We categorize this approach as meta-learning because on a meta-level, we shift the training distribution in Φ -space to increase the generalization efficiency of the training process while on the task level, we optimize the DDT to find optimal θ^* .

2.0.1. Algorithm

Given a differentiable simulator S , with initially sampled operation conditions Φ^T , and initially generated training data $\mathcal{X}^T = \{x_k \mid x_k = S(\phi_k^T)\}_{k=0}^P$, we find a sequence of loss-increasing condition parameters $[\phi_0^c, \dots, \phi_i^c]$ starting from $\phi_0^c = \phi_k$ for i gradient ascent steps performed as:

$$\phi_{n+1}^c \leftarrow \phi_n^c + \beta \frac{\partial \mathcal{L}_n}{\partial \phi_n^c} \quad (1)$$

We generate new *challenging* examples using the simulator $x^c = S(\phi_i^c)$. Finally, we optimize the DDT parameters θ using Adam optimizer.

3. Results

We consider the nonlinear damped pendulum as a standard benchmark case study for dynamical systems. The dynamical behavior of this model is governed by the ODE:

$$\ddot{\psi} + b\dot{\psi} + \frac{g}{L} \sin \psi = 0 \quad (2)$$

We implemented a video-generating S trained on the Runge-Kutta (RK4) integration of eq. 2. The DDT task is to estimate the frames of the video with pendulum velocity below a certain threshold (dead points). The \mathcal{L} is the MSE between the estimated and actual dead points. In this scenario, ϕ represents the pendulum length L and b the damping factor. We compare our method to conventional training without ascent learning (baseline). Our approach with four gradient ascent steps (eq. 1) is demonstrated to be superior to the conventional method, as presented in Figures 3, 2, and 3. Since the data source is synthetic, both approaches have access to unlimited samples, hence both generalize. However, Fig. 3 shows that in our framework, the associated minimum mean loss is achieved more efficiently with 68% of the samples of the conventional method. Fig. 2 demonstrates a higher level of flatness of the loss surface, which corresponds to an overall increase in robustness and generalization of the DDT across various operating conditions Φ .

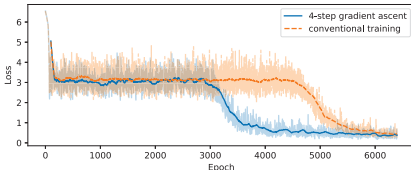


Fig. 1. Loss of conventional training compared to our method. We reach baseline generalization 32% faster.

4. Conclusion

Due to the high computational cost of simulators, the number of computations is often limited. Achieving a better generalization with the same computational budget is therefore desirable. In

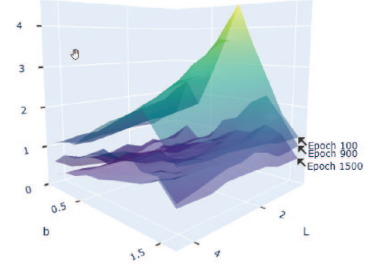


Fig. 2. Loss surface over the Φ space across epochs. The flatness of the loss landscape, including boundary regions, shows generalization and robustness across Φ -space.

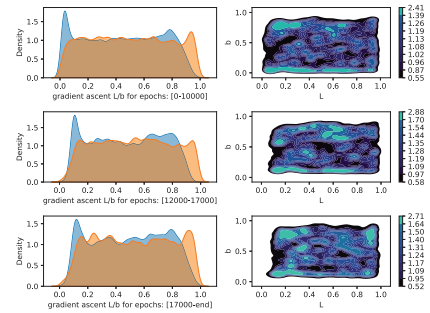


Fig. 3. Adaptive sampling densities in Φ at the beginning, middle, and end of training. L in orange and b in blue (of eq 2).

such cases, our framework is an attractive choice for data-driven safety and reliability applications as it improves robustness and sampling efficiency while increasing DDT task performance and retaining fully trainable components. The achieved flatness of the loss landscape implies robustness with respect to condition parameter perturbations, making the DDT more resilient. By exploiting the increasing availability of end-to-end differentiable industrial simulators, our meta-learning framework is applicable to a growing set of applications for DDTs.

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Learning dynamics of spring-mass models with physics-informed graph neural networks

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We propose a physics-informed message-passing graph neural network (GNN) for learning the dynamics of spring-mass systems. The proposed method embeds the underlying physics directly into the message-passing scheme of the GNN. We compare the new scheme with conventional message passing and demonstrate the generalization capability of the method. Additionally, we infer the learned parameters of the edges and show that these parameters serve as explainable metrics for the learned physics. The numerical results indicate that the proposed method accurately learns the physics of the spring-mass systems.

Keywords: Graph networks, Physics simulations, coupled-spring mass systems.

1. Introduction

Previous research has shown that GNNs can efficiently predict pairwise interactive dynamics between discrete masses when represented as graphs Battaglia and et. al. [2018] Pfaff and et al. [2021]. This is due to the inductive bias of GNNs, which models pairwise interactions as messages passed between the edges of the graph. Recently, a new type of GNNs called E(n) - Equivariant Graph Neural Networks - have been proposed Satorras and et al. [2021]. The goal of these networks is to enhance the inductive bias by preserving the rotation and translation symmetries in Euclidean space. These networks operate on Euclidean graphs where nodes and edges are assigned positions and relative distance vectors, respectively, in addition to their corresponding features. Building upon the aforementioned research, our study presents a novel message-passing scheme that integrates physical inductive biases to simulate the dynamics of spring-mass systems. Similar to the prior work, our method operates on graphs defined in Euclidean space.

2. Physics-informed GNN

We propose a GNN framework for spring-mass systems, where learned edge messages operate on embeddings of connected nodes.

2.1. Physics-informed message passing

Our message passing is based on the following ingredients. **(1)** Edge message m_{ij} is constructed as $m_{ij} = \phi_e(\|\vec{x}_{ij}\|^2)$, where ϕ_e is a learned function and $\vec{x}_{ij} = \vec{x}_i - \vec{x}_j$ is the edge vector. Our formulation results in $m_{ij} = m_{ji}$. We consider m_{ij} to be a hidden representation of the magnitude of the spring force. **(2)** At each node incoming edge vectors are weighted and summed to estimate a latent internal force on nodes, where weights are determined by ϕ_w with m_{ij} as inputs i.e. $\vec{f}_i^l = \sum_{in} \vec{x}_{ij} \phi_w(m_{ij})$. This formulation ensures that the force from node i to j is equal and opposite to that from j to i . Then, two functions $\phi_{n \rightarrow s}$ and $\phi_{n \rightarrow v}$ transform the node embeddings to a scalar α and a vector \vec{f}_{ext}^l , respectively. Next, the latent node acceleration is calculated as $\ddot{x}^l = \alpha \vec{f}_i^l + \vec{f}_{ext}^l$.

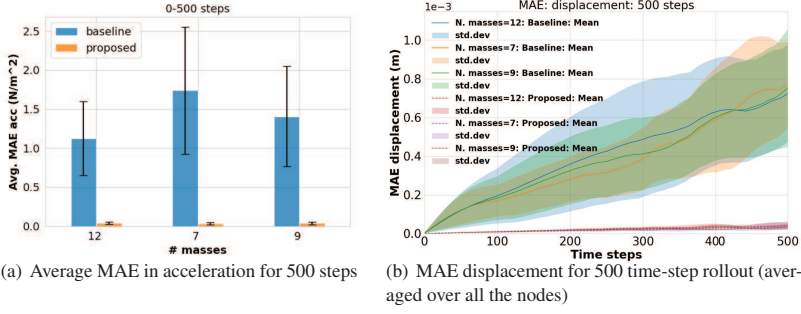


Fig. 1.: Comparison with baseline GNN

(3) The updated edge vector \vec{x}_{ij}^{upd} is calculated by adding the parallel and orthogonal projections of \vec{x}_i^t onto \vec{x}_{ij} . Next, the edge message is updated as $m_{ij}^{upd} = \phi_{upd}(\|\vec{x}_{ij}^{upd}\|, m_{ij})$. (4) Finally all the latent node accelerations are aggregated after n message passing steps to predict the acceleration on the node.

2.2. Inference of edge parameters

Edge parameters are inferred by calculating the eigenvalues of the Jacobian matrix of node acceleration \ddot{x}_i with respect to the edge vector \vec{x}_{ij} . For a spring with stiffness K_{ij} and rest length ℓ_{0ij} , the eigenvalues are given by:

$$eig_1 = \frac{K_{ij}(\|\vec{x}_{ij}\| - \ell_{0ij})}{\|\vec{x}_{ij}\|} \quad \text{and} \quad eig_2 = K_{ij}.$$

3. Results

To evaluate our method, we predict the trajectory roll-out of various configurations of 1kg masses connected by springs with 50N/m stiffness and 4m rest length. The GNN model proposed in Pfaff and et al. [2021] is used as baseline. Our model is trained on simulated 1000 time-step noisy trajectories of configurations with 4, 5, 6 and 8 masses. The performance of trained model was evaluated on the configurations of 7, 9 and 12 masses. Notably, the latter two configurations represent extrapolation scenarios beyond the training data. Our model achieves excellent performance in predicting the dynamics of the spring-mass systems, as well as inferring the underlying physics. The proposed method generates stable roll-outs, as shown in Figure 1 and Table 1. Table 2 shows

the inferred K and ℓ_0 parameters for each edge in a configuration of 9 masses at the 100th and 250th steps.

Table 1.: Avg MAE acceleration 0-500

mean \pm std.	baseline	proposed
m:12 ℓ_0:4 K:50	1.286 \pm 0.207	0.125 \pm 0.096
m:3 ℓ_0:4 K:50	1.193 \pm 0.637	0.057 \pm 0.037
m:7 ℓ_0:4 K:50	1.445 \pm 0.272	0.146 \pm 0.124
m:9 ℓ_0:4 K:50	1.590 \pm 0.222	0.137 \pm 0.111

Table 2.: Inferred spring stiffness and rest length for 9-mass configuration

Edge	Mean \pm Std.dev.			
	step = 100		step = 250	
	K	ℓ_0	K	ℓ_0
0 \rightarrow 1	48.64 \pm 0.74	4 \pm 0	50.32 \pm 0.60	4.4 \pm 0.01
2 \rightarrow 1	48.52 \pm 0.62	4 \pm 0.01	49.90 \pm 0.54	4.2 \pm 0
1 \rightarrow 2	50.14 \pm 2.35	4 \pm 0	49.81 \pm 0.40	4.1 \pm 0
3 \rightarrow 2	48.46 \pm 0.69	4 \pm 0	48.76 \pm 0.98	4 \pm 0.01
2 \rightarrow 3	50.22 \pm 2.41	4 \pm 0	48.71 \pm 0.96	4 \pm 0.01
4 \rightarrow 3	50.16 \pm 2.31	4 \pm 0	49.72 \pm 0.33	4.1 \pm 0.01
3 \rightarrow 4	48.4 \pm 0.64	4 \pm 0.01	49.84 \pm 0.42	4.2 \pm 0
5 \rightarrow 4	48.41 \pm 0.67	4 \pm 0.01	49.84 \pm 0.44	4.2 \pm 0
4 \rightarrow 5	50.13 \pm 2.35	4 \pm 0	49.7 \pm 0.41	4.1 \pm 0
6 \rightarrow 5	48.46 \pm 0.69	4 \pm 0	48.69 \pm 0.96	4 \pm 0.01
5 \rightarrow 6	50.17 \pm 2.32	4 \pm 0	48.78 \pm 0.98	4 \pm 0.01
7 \rightarrow 6	50.21 \pm 2.40	4 \pm 0	49.82 \pm 0.34	4.1 \pm 0.01
6 \rightarrow 7	48.52 \pm 0.60	4 \pm 0.01	49.9 \pm 0.53	4.2 \pm 0
8 \rightarrow 7	48.57 \pm 0.71	4 \pm 0.01	50.26 \pm 0.50	4.4 \pm 0.01

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Learning linearized degradation of health indicators using deep Koopman operator approach

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In this study, we showcase the successful application of the Deep Koopman operator approach to model the dynamics of industrial systems at multiple time scales. Specifically, we demonstrate its effectiveness in modeling the rapidly changing operating conditions as well as the slowly evolving degradation of the systems. Furthermore, we propose a novel approach inspired by Koopman theory to model the degradation of controlled dynamical systems. The proposed algorithm allows to predict the degradation trend with a limited number of full run-to-failure trajectories.

Keywords: Deep Koopman operator, remaining useful lifetime, predictive maintenance.

1. Introduction

Recent studies show that incorporating prior physical knowledge and utilizing inductive bias can lead to a significant improvement in the performance of deep learning algorithms Hao et al. (2022). It has been demonstrated by the Deep Koopman operator approach (DKO) Lusch et al. (2017) that it is capable of modelling dynamical systems. The objective of this study is to demonstrate the effectiveness of utilizing DKO for accurately predicting the remaining useful life (RUL) of industrial systems. Furthermore, we propose a novel architecture that allows to separate the degradation of the system state representation and imposed control.

2. Methodology

The Koopman theory offers a means to discover intrinsic coordinate systems where nonlinear dynamics can be expressed in a linear form. Acquiring linear representations of highly nonlinear systems is particularly useful for controlling and predicting their dynamic behaviour. Recently, Lusch et al. (2017) proposed a data-driven approach to learn the Koopman operator. Our proposed approach involves utilizing the Deep Koopman (DK)

approach to model the dynamics of degrading industrial systems, which inherently exhibit the combination of two distinct time dynamics.

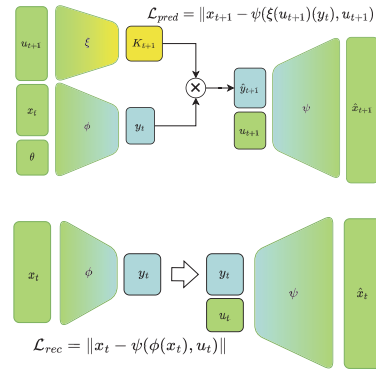


Fig. 1. The Koopman Inspired Degradation Model.

Accurately modeling the dynamics of a system in many industrial applications often requires the incorporation of control variables. Despite the distinct time scale of degradation in comparison to the operating dynamics, prior Koopman-based architectures did not possess the capability to capture the degradation of hidden health indicators of the system through construction. This paper introduces the Koopman Inspired Degradation Model

(KIDM) algorithm. The architecture of KIDM, illustrated in Fig. 1., involves the utilization of the control vector in two distinct ways. Firstly, it is used to enforce the degradation of the latent representation of the system state. Secondly, it is utilized to decode the latent state back to initial state space.

3. Results

We test the DKO on two case studies - a CNC milling machine Li (2021) and Li-ion battery simulation Teubert et al. (2022), both of which incorporate both degradation and dynamics of operating conditions. The first dataset Li (2021) contains high-frequency time series data of real CNC milling machines. The dataset consists of three run-to-failure trajectories of machines with different initial conditions. The second dataset involves Li-ion battery degradation trajectories simulated using the simulator proposed in Teubert et al. (2022) under a constant current load. Our objective is to predict the remaining useful life (RUL) based on the learned state representations.

The CNC milling machine data was preprocessed using the Learnable Denoising Sparse Wavelet Network (DeSpaWN) Michau et al. (2022) with 7 levels of decomposition. The DKO reaches achieves a mean squared error (MSE) of 0.016 on the RUL prediction task. The feed-forward network (FNN) achieves 0.07 MSE on the same task with DeSpaWN features. Additionally, we applied DKO to model the dynamics of a Li-ion battery under a constant current load, resulting in an MSE of 0.15 for RUL prediction. The principal component analysis (PCA) of the latent representations indicates a correlation coefficient of 0.97 and 0.37 with the two distinct unobserved battery health indicators (qmax and R) that were not presented to the algorithm during training.

To evaluate the performance of the proposed KIDM algorithm, we simulated a Li-ion battery under varying current loads. The current load was used as a control variable. The KIDM achieved an MSE of 0.02 on the voltage prediction task. Principal component analysis shows 0.79 and 0.33 correlation coefficients of 2 principal components and 2 distinct unobserved battery health indicators.

The KIDM haven't fully disentangled health indicators. Despite this the latent representation of observables has shown to be informative enough to predict the trend of degradation of health indicators. To compensate the remaining non-linearity in the latent representation we applied a simple random forest (RF) algorithm to predict the RUL based on the latent representation, which was trained on 5 run-to-failure trajectories. We compared these predictions with FNN trained on a feature set of the KIDM encoder. The RF algorithm trained on the prepared latent representation outperforms the FNN, which failed to determine the degradation trend due to lack of training data.

Model	MAE	MAPE	MSE
FNN	0.40	2.56	0.23
KIDM+RF 2	0.27	1.21	0.09

4. Conclusion

The successful application of DKO in modelling real-life dynamical systems and its informative latent space for predicting the RUL inspired us to propose the KIDM, KIDM extends the DKO by modelling the degradation of controlled dynamical systems. Our studies show that KIDM inherited the benefits of the DKO latent space and successfully models system degradation, making it a promising approach for predicting RUL.

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SAFETY AND RISK ASSESSMENT OF OFFSHORE WIND TURBINES: THE HUMAN FACTOR PERSPECTIVE

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ABSTRACT

The limited research on the adverse implications of offshore wind turbine operations on the health and safety of workers. Workers are exposed to harsh weather conditions, including falling ice from the blades, electromagnetic radiation, and electrocution from high-voltage wires. The study aims to identify reported associations between offshore wind turbine operations and potential health risks for workers, conduct a risk assessment, and provide mitigation measures to address identified risks. The use of Digital Twin technology will be employed to create and test the future risks of the new energy system.

Keywords: Offshore Wind Turbine, Risk Assessment, Hazards Identification, Digital Twin, Digital Twin Technology

1.0 INTRODUCTION

The safety risk assessment of offshore wind turbines from a human factor perspective involves evaluating potential risks and hazards associated with offshore wind turbine operations, including harsh weather conditions, ice formation, electromagnetic radiation, electrocution, and personnel transportation to and from the turbines. It is important to consider the impact of these factors on the safety and performance of offshore workers and to implement appropriate mitigation measures to minimize the likelihood of accidents and injuries. The use of Digital Twin technology can be employed to create and test the future risks of the new energy system, and effective training programs and safety culture development are also crucial to ensuring safe offshore wind turbine operations from a human factor perspective.

2.0 MATERIALS AND METHODS

This research requires an appropriate methodological framework in order to follow a user-focused procedure. To respond to the research questions, it is important to collect, analyse, and evaluate data. This chapter examines various user-centric frameworks and approaches that can be utilised to produce a UX design for the operation and maintenance of Digital Twin Technology. The figure 1 below summarises how human factor elements will be integrated into digital twin technology :

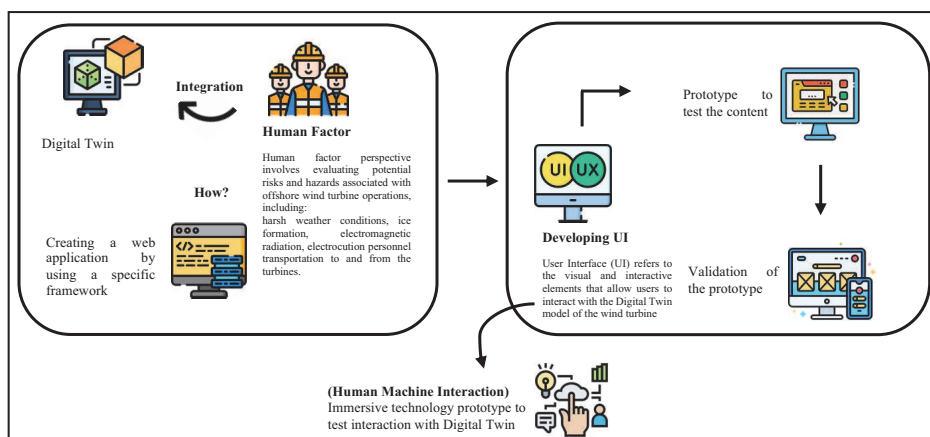


Figure 1: Summarization of integration between human factor and digital twin technology

Perdomo et al. propose a user-centered system design methodological paradigm for developing web applications [1]. The process is divided into several stages, starting with planning, where the purpose, audience, goals, and

requirements of the site are determined. User profiles are generated based on the information collected, which serves as the basis for information structure during the design phase. Prototypes are evaluated early in the development phase using heuristic evaluation and user testing to assess key elements of the interface. The authors discuss various properties of an application, such as structure, navigation, layout, search, accessibility, assistance, control, and feedback. The goal is to identify faults and rectify them to achieve effectiveness, efficiency, and user satisfaction in achieving specific goals in certain contexts.

Information architecture (IA) is the structure behind an application with the purpose of meeting the information needs of users. It involves structuring, classifying, and labeling content, organizing it in a way that fits users' informational needs. [2]. For a digital twin (figure 2) in operation and maintenance, IA can be categorized into many profiles, with the basic profile containing the least amount of information and the asset manager profile containing the most. The article presents six options available on the main menu for the basic profile, including decomposition, monitor, search, notes, task list, and explore. A prototype is developed to test the IA's content, which helps determine whether it contains logical ordering and unambiguous labeling of requirements. By converting the IA into a physical prototype, it becomes easier to comprehend and test.

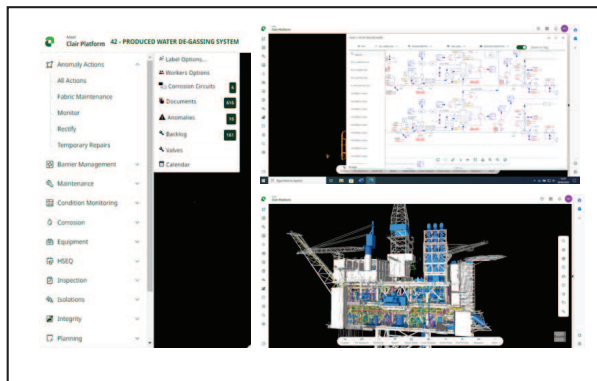


Figure 2: Digital Twin Technology

SUMMARY AND CONCLUSION

Incorporating human factors into digital twin technology can bring several benefits. Firstly, it can improve usability as digital twin technology can be complex and difficult to use, especially for non-experts. By incorporating human factors such as user centered design and user testing, designers can create digital twin interfaces that are more intuitive and easier to use, leading to increased user adoption and productivity. Secondly, it can enhance safety in high-risk environments, such as industrial processes and infrastructure, by incorporating human factors such as ergonomic design and situational awareness. This can reduce the risk of human error and improve the ability of operators to respond to emergencies. Thirdly, it can improve decision-making by creating interfaces that help users make better-informed decisions based on the data available through data visualization and decision support tools. Lastly, it can increase efficiency and productivity by creating interfaces that incorporate human factors such as task analysis and workflow optimization, which can help automate and optimize industrial processes. Overall, incorporating human factors into digital twin technology can make it more accessible, safer, and more effective for users across a wide range of industries and applications.

ACKNOWLEDGEMENT

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Computing Upper Probabilities of Failure Using Optimization Algorithms Together with Reweighting and Importance Sampling

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The presentation addresses efficient computation of the upper probability of failure of engineering structures, when the uncertainty is modelled by a family of probability densities. We develop an algorithm significantly reducing the sample sizes required in the optimization algorithm by adopting a recursive importance sampling scheme.

Keywords: Upper probability, global optimization, importance sampling, reweighting, imprecise probability.

1. Parametrized and Upper Probabilities

Let $\{X_t\}_{t \in \mathcal{T}}$ be a family of multivariate random variables $X_t : \Omega \rightarrow D \subseteq \mathbb{R}^{d_1}$ with corresponding density functions $f_t : D \rightarrow \mathbb{R}$ which are parametrized by $t = (\tau_1, \dots, \tau_{d_2}) \in \mathcal{T}$. Further let $h : D \rightarrow \{0, 1\}$ be an indicator function on D where $h(x) = 1$ means failure and 0 no failure. Then the probability of failure depending on t is $p(t) = P(h(X_t) = 1) = \int_D h(x) f_t(x) dx$ and the upper probability of failure \bar{p} is obtained by solving the global optimization problem $\bar{p} = \max_{t \in \mathcal{T}} p(t)$. To explain the situation we start with a numerical example.

2. Numerical Example

We consider the re-calculation of the reliability of a part of an airplane. The corresponding FE-model has $4.7 \cdot 10^6$ degrees of freedom and needs 48 different input parameters. Only the two most decisive input parameters $x = (x_1, x_2)$ are taken into account which are the Young's moduli of two metal components. The output of the FE-computations is the value of the above indicator function h in some complementary components.

The uncertainty about the values x_1 and x_2 is modelled by a family of two-dimensional random variables $\{X_t\}_{t \in \mathcal{T}}$ with $X_t \sim \mathcal{N}(\mu(t), \Sigma(t))$ parametrized by $t = (\varphi, \rho)$. The means $\mu(t)$ may vary on a disc of radius $r = 2$ GPa and midpoint

(m, m) with $m = 70$ GPa. Since for upper probabilities the boundary of the disc is relevant we consider only the circle

$$\mu(t) = \mu(\varphi, \rho) = 2 \cdot \begin{bmatrix} \cos(\varphi) \\ \sin(\varphi) \end{bmatrix} + \begin{bmatrix} m \\ m \end{bmatrix}, \varphi \in [0, 2\pi].$$

The coefficient of correlation varies in an interval, $t_2 = \rho \in [0, 0.8]$, and the coefficient of variation $\nu = 6.5\%$ is assumed to be deterministic. This leads to a parametrization of the covariance matrix

$$\Sigma(t) = \Sigma(\varphi, \rho) = \begin{bmatrix} \sigma_1(\varphi)^2 & \sigma_1(\varphi)\sigma_2(\varphi)\rho \\ \sigma_1(\varphi)\sigma_2(\varphi)\rho & \sigma_2(\varphi)^2 \end{bmatrix}$$

with $\sigma_i(\varphi) = \nu \mu_i(\varphi)$.

3. Estimating $p(t)$ and Their Derivatives

An optimization algorithm for obtaining upper probabilities needs a sequence of parameter values t_1, \dots, t_m and their probabilities (function values) $p(t_1), \dots, p(t_m)$. To estimate these probabilities $p(t_i)$ by Monte Carlo simulations it is crucial that for all t_k the simulations are based on the same single set $\omega = \{\omega_1, \dots, \omega_N\}$ of N random numbers, see Troffaes et al. (2018). These random numbers are then transformed to sets $R_{\omega, t_k} = \{r_1, \dots, r_N\}$ of sample points distributed according to densities f_{t_k} as for the estimates needed. For parametrized Gaussian distributions it means starting from random numbers $\omega_i \sim \mathcal{N}(0, I)$ and transforming to sample points

$r_i(t) \sim \mathcal{N}(\mu(t), \Sigma(t))$ by $r_i(t) = \mu(t) + C(t)\omega_k$ with Cholesky factor $C(t)$ of $\Sigma(t)$.

Estimating $p(t_k) \approx \frac{1}{|R_{\omega, t_k}|} \sum_{r \in R_{\omega, t_k}} h(r)$ by Monte Carlo simulation independently for all $k = 1, \dots, m$ would lead to mN evaluations of function h . For reducing this high computational effort it is important for an estimate of $p(t_n)$ in step n of optimization to re-use $h(r)$ and sample points r in sets R_{ω, t_k} from previous steps $k < n$. We use reweighting or importance sampling as in Fetz (2017) and Owen (2018), but here on each set of a partition $D = D_1^n \cap \dots \cap D_n^n$:

$$p(t_n) = \sum_{k=1}^n \int_{D_k^n} h(x) \frac{f_{t_n}(x)}{f_{t_k}(x)} f_{t_k}(x) dx \\ \approx \sum_{k=1}^n \frac{1}{|R_{\omega, t_k}^n|} \sum_{r \in R_{\omega, t_k}^n} h(r) \frac{f_{t_n}(r)}{f_{t_k}(r)} =: p_{\mathcal{R}_{\omega}^n}(t_n)$$

where $R_{\omega, t_k}^n = R_{\omega, t_k} \cap D_k^n$ is the set R_{ω, t_k} of sample points restricted to the set D_k^n of the current partition and \mathcal{R}_{ω}^n the set $\{R_{\omega, t_1}^n, \dots, R_{\omega, t_n}^n\}$ of all samples considered in step n . The expensive $h(r)$ is evaluated for $r \in R_{\omega, t_n}^n$ only, all other $h(r)$ are already known from the steps before. The ratios between the original density f_{t_n} and the densities f_{t_k} used instead are the importance sampling ratios which should not be too large (Owen (2018)), because large ratios mean fewer sample points in a considered area leading to less reliable estimates. Taking this into account we define

$$D_k^n = \{x \in D : f_{t_k}(x) \geq \max_{j \leq n, j \neq k} f_{t_j}(x)\}.$$

We do not have to know D_k^n in detail. It is sufficient to know the sets R_{ω, t_k}^n of sample points r keeping only these r where $f_{t_k}(r) > f_{t_j}(r)$, $j = 1, \dots, n, j \neq k$. We generate such sets recursively for $n > 1$ setting $R_{\omega, t_1}^1 = R_{\omega, t_1}$ and

$$R_{\omega, t_n}^n = \{r \in R_{\omega, t_n} : f_{t_n}(r) > \max_{k < n} c_k^{n-1} f_{t_k}(r)\}$$

for the newest and updating all previous ($k < n$):

$$R_{\omega, t_k}^n = \{r \in R_{\omega, t_k}^{n-1} : c_k^{n-1} f_{t_k}(r) > f_{t_n}(r)\}.$$

In addition we may use factors c_k^{n-1} to be more tolerant allowing lower densities to get fewer new sample points. These factors are also recursively defined as $c_k^n = c_n c_k^{n-1}$ where the cumulative multiplications ensure that $R_{\omega, t_k}^n \subseteq \dots \subseteq R_{\omega, t_k}^{k-1}$.

Further we may go one step back in the recursion if $|R_{\omega, t_n}^n|$ is less than some percentage q of N .

For the computation of the i^{th} partial derivative at t_n needed in the optimization algorithm we use $(p_{\mathcal{R}_{\omega}^n}(t_n + h^{(i)}) - p_{\mathcal{R}_{\omega}^n}(t_n)) / h_i^{(i)}, h_j^{(i)} = 10^{-8} \delta_{ij}$.

4. Optimizing and Results

For our optimization problem we choose $q = 10\%$, a sequence $c_n = (c_{n-1} - 1)/2 + 1$ with $c_1 = 1.5$ preventing too large tolerances, and $N = 50\,000$. The MATLAB global optimization algorithm needs 2777 parameter values t_k requiring 218 160 evaluations of h compared to 2777 N without this new method which re-uses the $h(r)$ from former samples together with good importance sampling ratios on the sets D_k^n of the partition increasing the accuracy of the estimates. In Fig. 1 we show the contour lines of estimates for p (classical and with $p_{\mathcal{R}_{\omega}^n}$). All parameters t_k used in optimization are visualized as dots where the colour/size indicates the sample sizes used (gray: no new samples, red: new samples needed, the greater the dot the more sample points). We obtain the upper probability $\bar{p} = 0.021$ at $t = (2.438, 0)$.

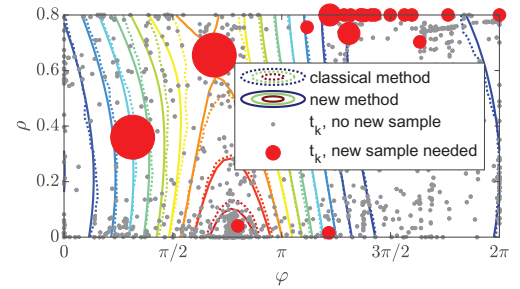


Fig. 1. Contour lines of estimates of p and points t_k .

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Consideration of polymorphic uncertainty in model-free data-driven identification of stress-strain relations

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The method of data-driven identification, introduced by Leygue et al. (2018), enables the determination of large stress-strain data sets based on displacement fields and applied boundary conditions without postulating a specific constitutive model. The algorithm has shown to be applicable to synthetic and real data taking linear as well as non-linear material behavior into account (Dalémat et al. (2019)). The consideration of uncertain material properties by data-driven approaches, e.g. shown in Zschocke et al. (2022), leads to the requirement of data sets representing uncertain material behavior. In this contribution, different sources of uncertainty occurring within the identification of stress-strain relations are addressed and an efficient method for the identification of data sets representing uncertain material behavior based on the concept of data-driven identification is proposed. In order to demonstrate the introduced methods, numerical examples are carried out.

Keywords: Data-Driven Identification, Polymorphic Uncertainty, Data-Driven Computational Mechanics, Data Science.

1. Introduction

Data-driven methods are of increasing importance in computational mechanics. Commonly distinguished are model-based methods, aiming to approximate the constitutive material description e.g. by neural networks, and different model-free methods. The approach of material model-free data-driven computational mechanics, introduced by Kirchdoerfer and Ortiz (2016), enables to bypass any material modeling step by directly incorporating material data into the analysis. A basic prerequisite for both types of data-driven methods is a large amount of data representing the material behavior, in solid mechanics consisting of stresses and strains. Obtaining these databases numerically by multiscale approaches is computationally expensive and requires the characterization of lower scale models. In case of an experimental characterization, constitutive descriptions are generally required to compute the stress states corresponding to displacement fields.

In order to obtain realistic simulation results, uncertainty needs to be considered. Generalized polymorphic uncertainty models are utilized in order to take variability, imprecision, inaccuracy and incompleteness of material data into account by combining aleatoric and epistemic uncertainty models (Graf et al. (2014)). The objective of this contribution is the observation of possible uncertainty sources as well as the introduction of an efficient framework for uncertainty consideration in data-driven identification of stress-strain relations representing elastic material behavior.

2. Methodology

The method of data-driven identification (DDI), introduced by Leygue et al. (2018), enables the identification of stress-strain relations based on given boundary conditions and a displacement field of a test specimen, which can be obtained by digital image correlation. Based on the theoretical concept of data-driven computational mechanics, the objective of DDI is to identify material states

$(\hat{\epsilon}_i, \hat{\sigma}_i)$ with $i = 1, \dots, n$, which are representative samples of the associated mechanical states $(\epsilon_e^X, \sigma_e^X)$ of the integration points $e = 1, \dots, m$. Thereby, the stress field of the considered specimen is obtained as a by-product. Required input are snapshots indicated by $X = 0, \dots, N_X$ with applied forces f^X , boundary conditions, a displacement field u^X as well as geometry and connectivity of the structure obtained by a finite element discretization. Associating suitable material and mechanical states is expressed as

$$\min \sum_X \sum_e w_e^X \|(\epsilon_e^X - \hat{\epsilon}_i, \sigma_e^X - \hat{\sigma}_i)\|_{\mathbb{C}}^2 \quad (1)$$

according to a given energetic norm with the artificial stiffness \mathbb{C} and integration point weights w_e as well as constrained by equilibrium and compatibility. Based on this, an equation system is derived by applying LAGRANGE multipliers η . The algorithm consists of the following steps:

- compute mechanical strains ϵ_e^X ,
- calculate mechanical stresses σ_e^X and η^X ,
- set material stresses $\hat{\sigma}_i$ as cluster centers,
- update mappings $i_e^X : (e, X) \mapsto i$,

executed iteratively until the mappings remain equal. If a random initialization of material states in the first iteration step is used, variation in the results needs to be considered. A detailed description as well as remarks concerning the individual steps are given in Leygue et al. (2018).

In this contribution, uncertain forces f^{Xu} , resulting e.g. from measurement tolerances as well as errors arising within the conversion to applied nodal forces due to load differences, corresponding to deterministic displacement fields are considered as input. Accordingly, the desired resulting states are $(\hat{\epsilon}_i, \hat{\sigma}_i^u)$ and $(\epsilon_e^X, \sigma_e^{Xu})$. Following a conventional Monte Carlo approach by repeating the analysis with samples of the uncertain input vector is not possible in this case, because different applied forces lead to different mappings and, therefore, uncertain mechanical and material strains as well. Instead, the mappings are computed based on a representative measurements of the uncertain forces analogously to the deterministic case. Based on these mappings, steps (b) and

(c) are executed, whereby an uncertainty analysis is applied to compute $\hat{\sigma}_i^u$ and σ_e^{Xu} .

3. Results and Conclusion

The introduced method is demonstrated by means of a truss example with synthetically generated input data for $N_X = 250$ snapshots and $n = 75$ desired stress-strain states. The resulting material and mechanical states with interval valued stress states are displayed in Figure 1. The obtained results are reasonable and no over- or underestimation of the desired uncertainty is visible.

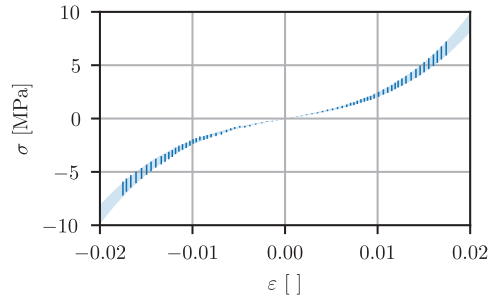


Fig. 1. Material states obtained by the introduced approach and uncertain reference constitutive description.

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A nested Petri Net – Fault Tree approach for system dependency modelling

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The Dynamic and Dependent Tree Theory (D^2T^2) provides a safety analysis framework able to model complex features of engineering systems, such as dynamic behaviour, complex maintenance strategies or components dependencies which cannot be represented in traditional Fault Tree methods. This is achieved through the tailored integration of flexible modelling techniques, such as Petri Nets and Markov Models, within the Fault Tree framework: differently from similar approaches (e.g., Dynamic Fault Trees), the D^2T^2 methodology does not impose any restriction on the location or type of dependencies. However, when these involve multiple components, such as in the case of redundant trains, the resulting Petri Nets or Markov Models can become rapidly large and convoluted, putting strain on the analyst. This work proposes a generalization of the D^2T^2 methodology based on the nesting of Petri Nets and Fault Trees models: the use of the first is extended to represent dynamic or complex relationship involving entire sets of components (e.g., trains or subsystems represented by section of the main Fault Tree) rather than merely individual ones, dramatically reducing the complexity of the user-defined models. A simple case study is proposed to demonstrate the approach, and the results obtained investigated throughout together with the potential for automatic generation of the dependency models.

Keywords: Fault Trees, Safety Analysis, Component Dependency, Degradation, Markov Models, Petri Nets

1. Introduction

Risk analysis methodologies commonly applied to real-world engineering systems, such as Fault and Event Trees, lack the capability to model realistically the dependencies existing between system components. This limits the accuracy of the prediction of system behaviour due to the need for simplifying but often unrealistic assumptions. The Dynamic and Dependent Tree Theory (D^2T^2) [Andrews and Tolo (2023)] was designed to overcome such limitations and offer a more realistic modelling of system behaviour through the integration of traditional Fault and Event Tree with more flexible techniques such as Petri Nets and Markov Models. These are applied to the modelling of dependencies or complex behaviour (e.g., non-standard maintenance models, dynamic features) of individual components, and the information obtained reintroduced in the initial Fault Tree model in order to proceed with its computation [Tolo and Andrews (2022)]. However,

in real-world applications, dependencies often involve entire subsets of components rather than individual ones: this may imply the construction of large Petri Nets or Markov Models representing individual components dependencies and may result challenging for the analysts. This study offers a generalization of the D^2T^2 methodology aimed at simplifying the dependency modelling of subsystems or trains by-passing the representation of their individual components. The suggested approach relies on the identification of the components trains governed by the dependency relationship, and the extraction of the relative sub-trees in the Fault Tree. These sections are then analysed regardless their implicit dependency. The results obtained are then combined into the construction of a Petri Net entailing the independent failure mechanisms of the components in the subsets as well as their dependent relationship.

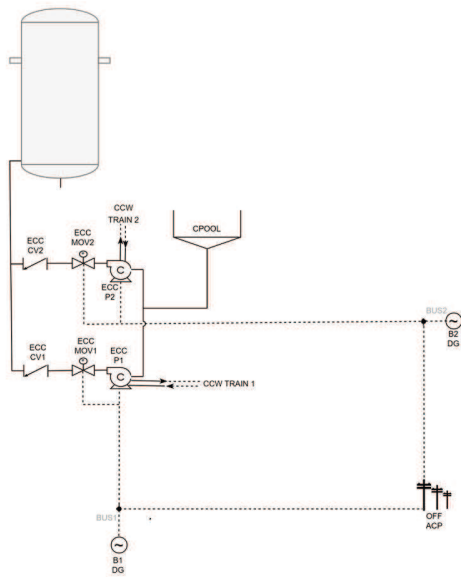


Fig. 1. Overview of the system

2. Case Study

The proposed approach is applied to the Emergency Core Cooling (ECC) system of a Boiling Water Reactor (BWR), consisting of two redundant trains, as shown in Fig.1. Each train includes a circulation pump, a motor operated valve and a non return valve. The two trains, labelled 1 and 2, are fully redundant: train 2 is requested only if train 1 has failed, while it is automatically back in standby when train 1 is repaired (i.e., train 1 has priority). In addition to this activation mechanism, the dependent relationship between the two trains is further complicated by the mutually exclusive servicing (i.e., the two trains cannot be simultaneously in maintenance), and by their dependency to external subsystems, such as power trains 1 and 2, condensation pool (CPOOL in Fig.1) and the Component Cooling Water (CCW) system trains 1 and 2.

3. Application

The proposed approach consists of seven phases, summarised as followed:

- (1) **Identification** of relevant sub-trees interested by complex relationships (i.e., sections asso-

ciated with ECC trains 1 and 2);

- (2) **Extraction** of common, explicit source of dependencies (e.g., servicing, power sources, condensation pool etc.) from the sub-trees identified in phase 1;
- (3) **Analysis** of the modified sub-trees over a selected time interval and extraction of the resulting failure and repair probabilities;
- (4) **Implementation** of the dependency Petri Net modelling the relationship existing between the identified sub-trees. The results obtained from step 4 are adopted, together with the initial input, to capture the independent failure and repair behaviour of the trains/subsystems under study, while the dependencies are explicitly represented by the network;
- (5) **Simulation** of the Petri Net dependency model and collection of the converged results, expressed as joint probability of the dependent model sub-sections;
- (6) **Re-integration** of the Petri Net output (i.e., joint probabilities) in the initial Fault Tree framework;
- (7) **Resolution** of the initial Fault Tree through BDD conversion (including dependencies) according to the D^2T^2 algorithm.

The approach is applied to the system in Fig.1 for demonstration purposes, and the results discussed throughout together with the potential and limitations of the proposed methodology.

Acknowledgement

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A Digital Twin Model for Drone Based Distributed Healthcare Network

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In the recent years we noticed that a distributed healthcare network can improve the efficiency of the healthcare system significantly. Drone logistic network for delivering medical goods is one such example of distributed healthcare network. A trial of such network was performed near Rome by Leonardo and Telespazio Li et al. (2020), where the medical objects were delivered in 25 minutes by drone while the road journey along the coast took about 45-60 minutes. The effect of drone transportation on biological samples has also been analyzed by F. V. Daalen and Geerlings (2017). They investigate the benefits of a drone logistic system and it has been observed that there are no negative effects on the objects for a turnaround time of less than 4 hours. Back in 2020, Matternet (2020) announced a collaboration with lab facilities in Berlin to transport patients' samples from hospitals by drone. Matternet have also undertaken similar project in Switzerland with Swiss Post, to transport laboratory samples between two hospitals. Moreover, Amukele et al. (2016) conducted tests where microbiological specimens including blood cultures were transported by drone and compared with stationary specimens to assess whether the specimens are affected by drone transport. For the microbes used in the trial no significant impact was found on the specimens flown for 30 minutes. Flight tests for medical delivery have also been successfully conducted in Spain by Quintanilla García et al. (2021).

Moving towards this direction, the UK government is presently investing in the realization of an autonomous drone logistic network that allows the delivering of medical equipment and assistance to remote areas. The CAELUS project, financed by the UK Industrial Strategy Future Flight Challenge Fund, has the aim of exploring the usage of drone delivery systems for the dispatching of medical items. This paper presents part of the analyses done during the second phase of the project. The main objective is the realization of a digital blueprint - a combination of a digital twin models of the complex network and a set of optimization tools - of the drone logistic network with a twofold applicability.

The first application of the digital blueprint corresponds to the design process of the whole drone logistic network such to be optimal for the given key performance indicators as defined by the stakeholders. This task takes place in advance of the physical network construction and it is entirely performed in the virtual environment simulation. The design problem translates to a multi-objective generative network optimization as shown by Gao et al. (2019) where the network is iteratively defined, simulated and improved. The indicators considered in this work are: capital costs of investment and operational cost of the delivery, delivery time and resilience under internal and external unexpected events. In particular, the resilience is considered as the ability of the whole network system to absorb negative and unpredictable events and recover after the failure.

For this generative network optimization, a biologically-inspired methodology has been developed which extend the work proposed by Masi (2013). It is inspired by the behavior of the by Physarum organism and it has shown to perform well in many engineering problems including network topology (T. Nakagaki (2000)) and Steiner tree problems (Tero et al.

(2000)).

The methodology includes two integrated steps: the generation of a sub-optimal delivery network that is progressively optimized and the simulation over the generated network of the drone delivery system. The former is a network optimization problem while the latter, with the task of selecting the correct drones and finding the optimal routing and scheduling, can be classified as a vehicle routing problem.

The second tasks performed by the digital blueprint is the network operational problem: the on-line simulation of the digital twin during the actual operational life of the drone logistic network and optimization of its scheduling and planning. Once the physical network system is operative, sensor data can be collected from the physical systems and used to refine the digital twin models. The digital blueprint is used in this phase to simulate many possible scenarios affected by uncertainty in the medium-short period of time, and determine the optimal actions to take.

Keywords: Digital Twin, Drone Logistic Network, Vehicle Routing Problem, Network Optimization Problem.

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Comparative Study on Optimization Methods in Finite Element Model Updating

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Finite element model updating has been widely studied in the civil engineering field owing to its applicability to damage detection, system identification, and digital twin construction. Its general scheme is to find the best-fit model with sensor data by updating various model parameters, such as elastic modulus, mass density, and rotational stiffness. It is definitely an optimization problem where lots of algorithms can be introduced. Not only first-order optimization methods but also second-order methods can be utilized. In many studies, zero-order optimization methods have been introduced to find global optimum even though those are computationally expensive. In this study, the optimization methods are compared in terms of accuracy and computational cost in a finite element model updating problem with a numerical example of Euler-Bernoulli beams.

Keywords: Finite Element Model Updating, Modal Analysis, System Identification, Euler-Bernoulli Beams, Nelder-Mead Simplex Method, Optimization, Digital Twin.

1. Introduction

Finite element model updating is a technique that has gained significant attention in civil engineering due to its applicability in damage detection, system identification, and digital twin construction. The general approach involves updating various parameters of the finite element model to obtain the best-fit model that matches the sensor data. The parameters that can be updated include elastic modulus, mass density, and rotational stiffness. This process can be viewed as an optimization problem, where the objective is to minimize the difference between the predicted and actual sensor data. Researchers may sometimes select an optimization method without conducting an extensive preliminary study. However, as digital twins that can be computationally expensive models have

frequently introduced to many types of structures nowadays, the optimization performance would become an important issue.

2. Optimization Methods

In this study, we aim to investigate the computational cost and performance of various optimization methods in finite element model updating. We evaluate the performance of different optimization methods using a numerical example of a beam structure. The optimization methods considered in this study are first-order optimization methods, such as a gradient descent and a momentum method, second-order optimization methods, such as a Newton's method, and zero-order optimization methods, including a particle swarm optimization and a Nelder-Mead simplex method (Nelder et al. 1965).

3. Comparative Study

In this study, a simply-supported beam model (Kim et al. 2016) is constructed using MATLAB to investigate the performance of optimization methods in finite element model updating. The model consists of twenty meshes with rectangular cross-sections; where, an elastic modulus of 200 GPa, and a mass density of 7850 kg/m³. The boundary conditions of the system are manipulated by two rotational springs attached at the supports of the beam, and those rotational stiffnesses are the target variables.

Table 1 shows the performance of different optimization methods based on their accuracy and computational cost, where the epoch denotes the number of updating during optimization process, the FEA means finite element analysis, and the error is root-mean-squared errors between optimized and true values. Our investigation reveals that the first-order methods require a large number of finite element analyses to find the optimal solution, and their performance is highly sensitive to the choice of the learning rate. Therefore, a carefully designed hyperparameter is required for optimal results. On the other hand, the second-order method converges to the optimal solution in fewer epochs, but the number of FEA per epoch is higher in order to estimate Hessian matrices. In addition, we found those first- and second-order methods can be improved by introducing the line search method. In contrast, the zero-order methods demonstrated excellent performance in terms of computational cost, and are consistent with the recent trend in finite element model updating which favors zero-order optimization methods.

Table 1. Performance of optimization methods

Order	Method	Epoch	Number of FEA	Error (%)
0	Nelder-Mead simplex	36	69	1.00
0	Particle Swarm	44	900	1.00
1	Gradient	10,00	30,000	1.06

	Descent	0		
1	Gradient	10,00	1,436,1	1.01
	Descent with line search	0	00	
1	Momentum	6,081	18,246	0.97
1	Momentum	979	2,940	0.97
	with line search			
2	Newton	123	1,612	0.97
2	Newton	13	182	0.98
	with line search			

4. Conclusions

In this study, we evaluated performances of various optimization methods for finite element model updating using a simply-supported beam model designed in MATLAB. Our findings suggest the zero-order methods and second-order with line search demonstrated superior performance in terms of accuracy and computational cost. These results may strengthen the validity of a recent trend of introducing zero-order optimization methods for finite element model updating. The authors think not only the traditional zero-order methods but recently developed zero-order optimization methods, such as La-MCTS (Wang et al. 2020), or a deep meta-learning-based optimization named ‘learn to optimize (Li and Malik 2016)’ could be further investigated for their potential applicability in finite element model updating.

Acknowledgement

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DIGITAL TWIN TECHNOLOGY FOR RISK MANAGEMENT OF THE SAFETY-CRITICAL SYSTEMS IN THE ENERGY TRANSITION

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ABSTRACT

Digital twin technology enables engineers to identify and address potential faults and hazards in a product's design prior to completion. This approach encompasses risk management solutions such as automation and monitoring systems that contribute to the protection of people and property. By simulating real assets in virtual environments, digital twins supply valuable data that facilitates risk analysis and identification of potential accident scenarios. Incorporating human factors in digital twins fosters the development of safety-critical systems, particularly within the context of the energy transition. The industry is expected to establish regulations for data storage, driven by the growing prevalence of digital twin technology.

Keyword: Digital Twin, Digital Twin Technology, Risk Analysis, Risk Assessment, Safety-Critical System, Energy Transition

1.0 INTRODUCTION

Digital Twin technology is used to manage risks associated with safety-critical systems during the energy transition. It creates virtual replicas of physical assets, allowing operators to predict and identify potential risks and issues before they occur. Digital Twins can monitor and manage safety-critical systems such as power grids, offshore wind farms, and nuclear power plants. By simulating different operating scenarios, operators can identify the most efficient and safe way to operate the system, improving its efficiency and reducing the likelihood of safety incidents. Overall, Digital Twins are a powerful tool for managing risks and ensuring the safety and reliability of the energy system during the transition to a sustainable energy future.

2.0 MATERIALS AND METHODS

For safety-critical systems in the energy transition, a suitable methodological framework is required, depending on the specific application and the system being monitored [1]. This section discusses materials (Figure 1) that may be required to achieve a design that can form a good user interface and experience include:

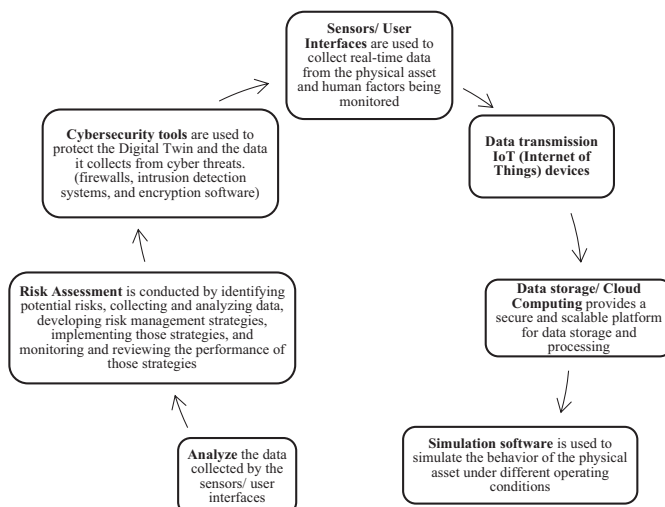


Figure 1: Digital twin technology for risk management

The methodology for using digital twin technology for risk management involves several steps, including identifying the safety-critical system, by using an existing Digital Twin Technology (Figures 2-5), identifying risks, developing mitigation strategies, testing and validation, and implementation [2]. By following this methodology, stakeholders in the energy transition process can effectively manage and mitigate risks associated with safety-critical systems, improving the safety and reliability of the energy system.

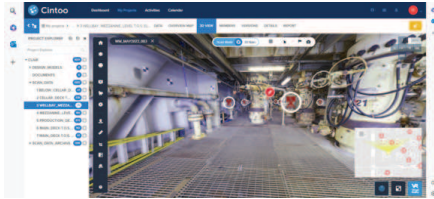


Figure 2: Laser scanning for digital twinning using Cintoo cloud



Figure 3: One click away of Smart P&ID in digital twin

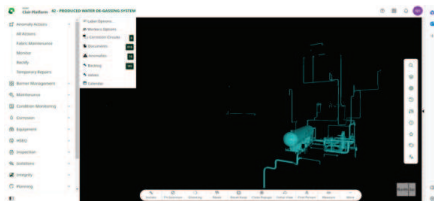


Figure 4: Digital twin of selected systems at the offshore operation

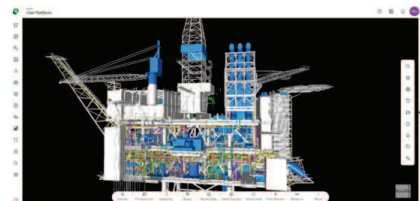


Figure 5: Digital twin streamlined offshore operations

SUMMARY AND CONCLUSION

Whilst the use of digital twin technology for risk management is still relatively new in the energy sector, its potential benefits are clear. As the energy transition continues to gather pace, the use of digital twin technology is likely to become increasingly important for managing the risks associated with safety-critical systems. By embracing this technology and developing robust risk management strategies, we can help ensure a successful transition to a more sustainable energy future.

ACKNOWLEDGEMENT

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The Extension of Commonly used Measures of Importance for Dynamic and Dependent Tree Theory (D²T²)

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Traditional Fault Tree Analysis (FTA), known as Kinetic Tree Theory (KTT), was derived by Vesely et al (1970) to model and analyse engineering systems. The tree structure provides a clear visual representation of the causes of system failure. FTA has two stages, qualitative and quantitative analysis. Part of the quantification process is to calculate measures of importance. FTA is limited by the necessary assumptions of constant component failure and repair rates and independence of component failure and repair rates. The D²T² methodology overcomes these assumptions, but a new methodology to calculate measures of importance when such assumptions are not met is required. This paper proposes extensions to 5 common used measures of importance.

Keywords: Importance Measures, Fault Tree Analysis, Quantitative Analysis, Dependencies.

1. Introduction

The performance of a system is dependent upon that of its components and Minimal Cut Sets. Some components or minimal cut sets will play a more significant role in causing or contributing to system failure than others. The contribution that a component or a minimal cut set makes to system failure is its importance. Birnbaum first introduced the concept of importance in 1969. He developed what we now term Birnbaum's Measure of component importance which is denoted by $G_i(q)$, and defined as the probability that component i is critical to systems failure, i.e., the system is in a working state such that the failure of component i causes it to fail. An expression for this measure is given in Eq. (1):

$$G_i(q) = Q_{sys}(1_i, q) - Q_{sys}(0_i, q) \quad (1)$$

where, Q_{sys} is the system unavailability function and $Q_{sys}(1_i, q)$ is the probability that the system fails with component i failed and $Q_{sys}(0_i, q)$ is the probability that the system fails with component i working.

An alternative expression for this measure is given in Eq. (2):

$$G_i(q) = \frac{\partial Q_{sys}(t)}{\partial q_i(t)} \quad (2)$$

Since this time, numerous measures of importance have been developed to assess the role that a component failure plays in the deterioration of the system state. Each measure gives subtly different information. Measures of importance assign a value between 0 and 1 to each component, with 1 signifying the highest level of contribution.

Engineers can use importance analysis to rank the contribution each component or minimal cut set makes to system failure. In this way, weaknesses within the system can be identified and resources can be used most efficiently to improve system reliability. This paper will focus on five key measures, Birnbaum's Measure of importance defined in Eq. (1) and Eq. (2). The Criticality Measure of Importance, defined as the probability that component i is critical to the system and has failed, weighted by the system unavailability at time t . An expression for this measure for systems involving only independent basic events is given in Eq. (3).

$$I_{Ci} = \frac{G_i(q) \cdot q_i(t)}{Q_{sys}(t)} \quad (3)$$

The Risk Achievement Worth (RAW) which calculates the relative increase in the system unavailability when it is known that component i has failed. It can be calculated using Eq. (4).

$$I_i^{RAW} = \frac{Q_{sys}(1_i, t) - Q_{sys}(t)}{Q_{sys}(t)} \quad (4)$$

The Risk Reduction Worth (RRW) calculates the relative reduction in the system unavailability when it is known that component i is working. It is calculated using Eq. (5).

$$I_i^{RRW} = \frac{Q_{sys}(t) - Q_{sys}(0_i, t)}{Q_{sys}(t)} \quad (5)$$

The Fussell-Vesely measure of component importance is concerned with the contribution component failures make to system failure. It is calculated using Eq. (6).

$$I_{FV_i} = \frac{P(\bigcup_{k=1}^{n_c} C_K)}{Q_{sys}(t)} \quad (6)$$

All of these measures can be efficiently calculated during FTA. However, for systems which experience dependencies between the component failures the D²T² methodology can be employed which will require a new approach to calculating the importance measures.

2. Dynamic and Dependent Tree Theory

In Andrews Et al (2023), published the D²T² methodology designed specifically to address limitations in the traditional method of fault tree analysis which restricted its ability to represent the performance of modern engineering systems. These limitations include the need for component failure and repair rates to be assumed constant, components failures to be independent and very limited processes employed to represent the asset management strategy. The methodology retains the tree structure and integrates Binary Decision Diagram (BDD), Markov and Stochastic Petri Net (SPN) methodologies to perform the analysis.

The D²T² methodology is a multi-layer methodology which culminates in a final BDD for the top gate of the Fault Tree. A variety of sub-models can feed into this BDD, and each can have a variety of inputs too. Fig 1 illustrates the possible inputs for each element of a system.

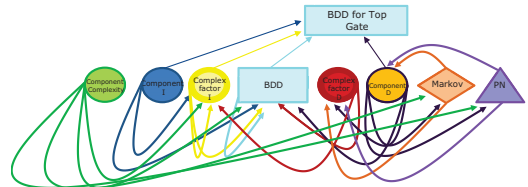


Fig 1: Illustration of possible inputs for a system analysed using the D²T² methodology.

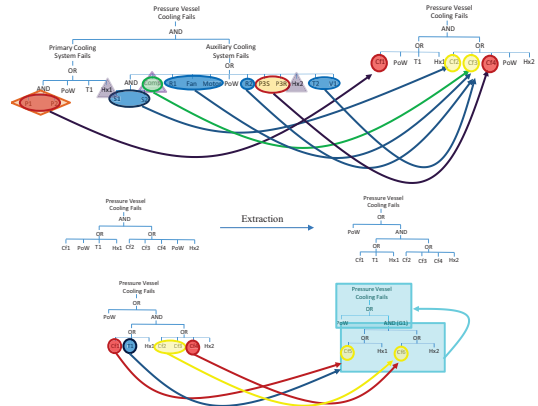


Fig. 2. D²T² modularisation structure for the pressure vessel cooling system.

Fig. 2 illustrates the modularisation structure for the Pressure Vessel Cooling System case study introduced in Andrews et al (2023). This paper presents the algorithm to integrate the importance calculations into the D²T² methodology.

Acknowledgement

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Machine Learning in Construction Industry: Opportunities and Challenges for Decision-Making and Safety Management

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As the construction industry continues to embrace digitalization, machine learning is emerging as a powerful tool to improve efficiency and enhance decision-making throughout the project lifecycle. This study presents an exploration of the potential of machine learning in the construction industry, focusing on reducing accident risks through decision support. Through a combination of workshops and analysis of machine learning applications in other sectors, this study provides insights into the opportunities and challenges associated with machine learning in construction. Results suggest that machine learning tools can enhance information-gathering, visualization of trends, prediction of outcomes, and evaluation of effectiveness. However, challenges such as increased complexity, criticality, and lack of trust in machine learning must be addressed. The study recommends developing a theoretic safety model for machine learning tools, focusing on finding the correct parameters and addressing challenges associated with machine learning. Overall, the study concludes that adopting machine learning can benefit construction, but it is essential to consider these challenges carefully.

Keywords: Machine Learning, Accident Risk, Decision Support, Construction Industry, Visionary ML tools, Safety Management, Decision-making

1. Introduction

Significant changes are ongoing in various industries due to new technological developments. Among these is machine learning, which may contribute to many new opportunities. Traditional work parts can be simplified and improved using machine learning (ML) tools, and the work methodology can be renewed. It involves streamlining information-gathering and decision-making processes in general. New tools and technological developments lead to new opportunities. When using these ML tools, it will be essential to be prepared and to know how it affects the industry. A further focus area is to understand what such tools entail. In this way, preventive preparations can be carried out to ensure

safety. An understanding of the decision-making process and how it is affected by ML is central to adapting to changes and practices in the decision-making process.

This extended abstract presents the results of an explorative study on how ML tools can support decisions to reduce accident risk in the construction industry, which needs innovative solutions to reduce accident frequency.

2. Method

Interviews were conducted in various industries with different applications of new technological tools. This was done to gain a broad understanding of both opportunities and challenges associated

with them and to serve as inspiration for application to safety management in the construction industry. A workshop with participants from a client, a designer, and a construction company was conducted to discuss the results of the interviews.

3. Results

The study of the application of ML tools in other industries shows that such tools could be implemented for information gathering, visualizing trends, predicting possible outcomes, and evaluating effectiveness.

3.1 Challenges and Opportunities

Machine learning (ML) has the potential to streamline decision-making processes in the construction industry by automating information gathering, consequence assessment, and result analysis. It can also offer previously untapped data, leading to a more extensive decision-making basis and real-time feedback for better planning and communication. However, using ML may result in "information overload," where decision-makers struggle to distinguish important from less important information, potentially leading to neglected practical details. This may lead to valuable details being ignored or overlooked by decision-makers. Additionally, ML's inherent complexity may increase the system's overall complexity, and its use in critical areas may cause unwanted incidents and accidents, leading to a lack of trust among users. Despite these challenges, ML offers improved learning, competency, and experience transfer opportunities. Therefore, it is crucial to understand and address the challenges associated with using ML tools while taking advantage of their opportunities to improve the construction industry. High levels of complexity and criticality in implementing ML tools can lead to a lack of trust among users.

3.2 Visionary ML-Based Solutions for Improved Safety Management in Construction Industry

A workshop was arranged based on the mapped application of ML tools in other industries. Among other things, the workshop identified three visionary ML-based solutions that could innovate safety management in the construction industry:

- (i) A dashboard with a construction company's project portfolio based on available project performance data provides a continuous leading indicator of the degree of control of hazards.
- (ii) A system that gives designers and engineers feedback on suggested risk-reducing measures through safety in design solutions.
- (iii) A system that automatically measured the degree of compliance with Construction Client Regulations.

These visions are currently followed up in the research project 'Sustainable value creation by digital predictions of safety performance in the construction industry' (DiSCo).

4. Conclusions

The study indicates many opportunities to take advantage of, including increased efficiency, more significant decision basis, reduced use of resources, and decreased accident risk. Further in the study, it has been revealed that it can be beneficial to base a safety model for a new ML tool in the construction industry. During the development of tools, one should focus on finding the correct parameters that ML tools will be based on and trained with, as tools depend on having good data to make good predictions. On the other hand, challenges appear, such as increased complexity, criticality, and lack of trust in machine learning. Thus, an important focus is reducing the challenges associated with using machine learning tools while also taking advantage of the opportunities. Overall, the study suggests that while many opportunities can be gained from using machine learning in the construction industry, it is essential to consider and address the challenges carefully.

Acknowledgment

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Using NLP for Automated Contract Review and Risk Assessment

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Introduction:

Construction projects are notoriously risky due to the involvement of multiple parties having different objectives, limited project time and budget, high organizational and technological complexity, and vulnerability due to dynamic macroenvironmental conditions. Contracts are legal documents that define the responsibilities of the parties and allocate risks. To create an adequate risk management plan, contractors must conduct tedious contract review processes to identify the risks retained by them.

Problem Statement:

Although legal professionals try to assess risks in documents in detail, the possibility of errors due to unrecognized or misinterpreted risk elements remains as in-depth review of contracts is usually not possible during the short bidding period. Therefore, there is a growing need for intelligent systems that automatically analyze contracts to ensure that clauses in contracts are accurately defined and categorized with minimal human intervention. Automated analysis of contracts can be a solution for early detection of contract risks.

Methodology:

This research project involves the development of an automated text analysis model based on natural language processing (NLP) and supervised machine learning (ML) to improve the contract review process in the bidding stage. To demonstrate the applicability of the model, the FIDIC standard form of contract was selected, and all sentences were labeled with the sentence type and risk ownership in order to create a training dataset. Sentence type consists of Risk, Right, Obligation, Heading and Definition labels. The risk ownership consists of Contractor, Employer and Shared labels. In addition, the test dataset was created using a real contract of a construction project. The selected real contract has been prepared based on FIDIC Silver Book for an airport project. Preprocessing methods such as lemmatization and stop word removal were employed. After the preprocessing steps, the number of sentences in the training dataset created from the FIDIC Red, Silver, and Yellow Book decreased from 5346 sentences to 2268 sentences when repeated sentences were removed. On the other hand, the number of sentences in the test data set created from the real contract decreased from 1305 sentences to 1217 sentences when only unique sentences were kept. The labels in the training and test datasets were validated with the help of expert meetings with six participants who were working in departments of contract. One of them has a Ph.D. degree, and three of them have an M.Sc. degree. Half of them have more than 10 years of work experience. Randomly selected 10% of sentences in each dataset were relabeled by experts for both sentence type and risk ownership. Expert labels were compared with the labels given by researchers and the deviation between the two sets was calculated as 3%. Datasets used to train and evaluate 12 ML models.

12 machine learning models were built based on Bag of Words, Term Frequency-Inverse Document Frequency, pre-trained Spacy and Glove word embeddings and Bidirectional Encoder Representations from Transformers (BERT) word embedding techniques and logistic regression, support vector machine, decision tree, recurrent neural network and BERT algorithms. The classification models were evaluated based on four parameters: True Positive (TP), False Positive (FP), True Negative (TN), and False Negative (FN). The confusion matrix for binary classification and multi-class classification were created, respectively. The performance of a machine learning model is usually measured by six metrics: Accuracy, Precision, Recall, F1 score, Specificity, and Area Under the Curve, which are calculated using TP, FN, FP, and TN values. The most appropriate performance metric for the study is accuracy. However, the accuracy measures may not perform as expected if the dataset has a non-uniform distribution across different classes. Therefore, accuracy and f1 score, which is the harmonic mean of precision and recall and calculated as $2 \times TP / (2 \times TP + FP + FN)$, were used as evaluation metrics in this study.

Results:

The BERT model achieved 87% accuracy for sentence type classification, which has 5 labels as heading, definition, risk, right and obligation, and 80% accuracy for risk ownership classification, which has 3 labels as contractor, employer and shared. The best tree models were ensembled with the competitive voting method. After implementing the competitive voting method, accuracy increased to 89% for sentence type classification and 83% for risk ownership classification. Table 1 presents the individual performance results of each ML and competitive voting results for sentence type and risk ownership classification.

Table 1. Classification Performance of Individual Models and Competitive Voting

ML Model No	Text Vectorization	ML Algorithm	Sentence Type		Risk Ownership	
			f1-score	Accuracy	f1-score	Accuracy
1	BAG OF WORDS	Logistic Regression	0.77	0.79	0.67	0.71
2	BAG OF WORDS	Support Vector Machine	0.75	0.77	0.64	0.69
3	BAG OF WORDS	Decision Tree	0.72	0.68	0.67	0.72
4	TFIDF	Logistic Regression	0.78	0.77	0.66	0.72
5	TFIDF	Support Vector Machine	0.83	0.81	0.69	0.77
6	TFIDF	Decision Tree	0.70	0.66	0.45	0.70
7	Spacy	Logistic Regression	0.70	0.71	0.59	0.66
8	Spacy	Support Vector Machine	0.75	0.72	0.61	0.70
9	Spacy	Decision Tree	0.61	0.52	0.49	0.61
10	Keras Embedding	RNN	0.80	0.79	0.65	0.72
11	Glove Embedding	RNN	0.80	0.78	0.67	0.73
12	Word Embedding	BERT	0.83	0.85	0.73	0.80
13	Competitive voting (combination of Model 5, 11 and 12)		0.86	0.89	0.76	0.83

Discussion of Findings and Conclusions:

This study explores the potential of using NLP and ML for automated contract review in the construction industry. Manual contract analysis is currently time-consuming, costly and error-prone. The study uses FIDIC books to create datasets for ML models and compares their classification performance. With the proposed method, sentences in terms and conditions can be classified as type and ownership to identify parties' risks, rights and obligations. The results obtained, with an accuracy of 0.89 and an f1 score of 0.86, are promising, especially considering the relatively small training dataset. The study highlights the importance of using pre-trained models based on large datasets to improve classification performance, which is particularly useful when there is a limited amount of input in a domain. This approach can provide a way to combine domain-free information from large datasets with domain-specific information to solve problems. The automated construction contract review model, while may not be ideal as a stand-alone method at the bidding stage, can provide valuable information to reduce time and errors due to overlooking. The proposed approach can reduce staff workload and increase the quality of work in risk assessment at the bid stage, which can be helpful for contractors when deciding on risk premiums. Overall, this study provides a new and promising approach for contractors to review construction contracts using automated methods, which can improve efficiency and reduce errors.

Future work and limitations:

Although the results are promising about utilization of ML and NLP for automated contract review, there are limitations and further research is needed in this area. The dataset used in this study is limited to FIDIC books and the classification model was only tested on construction contracts based on FIDIC. To build a more general classification model, the dataset needs to be extended to include different types of standard contracts. While 12 ML models have been trained based on 5 algorithms and 6 vectorisation methods, further research needs to evaluate other alternatives for both the algorithm and vectorisation sides. In addition, the integration of a rule-based approach and the consideration of ambiguity in the natural language are also important factors which may increase the classification performance. Finally, the usefulness of the classification model depends on the appropriateness of the labels in the training dataset and needs to be verified according to the company's risk perception.

Keywords: Construction Contract Review, Machine Learning, NLP, Text Classification, Deep Learning

Impact of thermo-mechanical effects to the measurement behavior of a molded SO16 System-in-Package current sensor investigated by a physics-based design for reliability (DfR) approach

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In this work a physics-based design for reliability approach (DfR) is presented investigating the thermo-mechanical behavior of a AMR current measurement sensor device in a SOIC16 package. Due to the exposition to different thermal loads during production and operation the intrinsic strain values at the internal sensor cells are changing. This is suspected for a significant impact to the stress/strains at the AMR sensor cells and possibly affecting the measurement accuracy. For investigating the impact from different influences and uncertainties several simulation-based design-of-experiment (DoE) studies were performed. Beside the incorporation of effects from the material behavior, also process related parameters and tolerances were included in the virtual model. The modelling of stiffening effects caused by mold compound ageing at the outer layers during operation was also included. The generated design for reliability “environment” represents a comprehensive approach to combine production process and operation to examine possible thermo-mechanical effects during an early development stage.

Keywords: Design for Reliability, Sensitivity study, Uncertainty quantification, Design-of-Experiments, Current sensor, System-in-Package, Thermo-mechanical effects

1. Introduction and motivation

Due to the progressing electrification for future mobility applications accurate and reliable information from current sensors are essential during operation to control the complete electrical system. Harsh environmental conditions as well as specific mission profiles have to be considered during the development phase. Thermo-mechanical effects caused by temperature loads during production and operation as well as influences from design or production related tolerances could lead to unfavorable situations. Unfortunately, different aspects or quantitative influences are often uncertain at an early design stage. With the incorporation of parametric sensitivity studies and modern Computer-Aided-Engineering (CAE) methods it is possible to face

these issues and achieve a deeper understanding of the later physical device behavior.

The investigated electronic device presented in this work was developed as molded SO16 System-in-Package (SiP). Based on a magneto-resistive measurement principle the AMR sensor was designed for industrial and automotive applications. Due to different process schemes during production, the strain at the internal AMR sensor surfaces are changing (see Fig. 1). Furthermore, depending on the specific mission profile the electronic device is exposed to different thermal loads during its operation. This can result in a manifestation of a sensor calibration inaccuracy affecting the overall measurement performance.

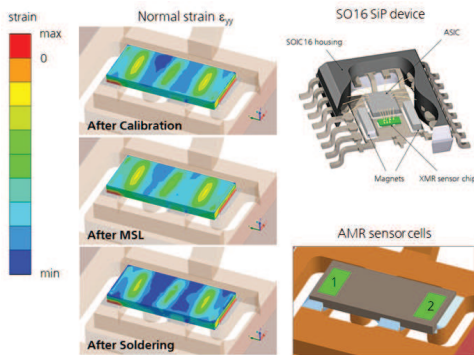


Fig. 1 Strain distribution at the AMR sensor surface during production (left) and influenced sensor areas (bottom right)

2. Physics and simulation based DfR approach

To understand the device behavior and helping to improve the later product reliability for the purposed operation environment, various aspects were incorporated in a FE simulation model. Influences from materials (Young's modulus, CTE, post mold cure shrinkage etc.) and processes (dwell temperatures and times) are important for the initial device state [1]. The production process scheme itself has also an impact on the strain changes after the calibration step (Fig. 2).

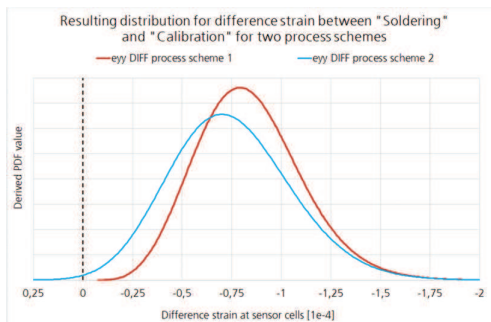


Fig. 2 Distribution of strain changes at the sensor cells after calibration for two different process schemes

Furthermore, a certain mold compound aging was recognized during reliability tests. This reflects in a growing oxidized layer at the outer surface of the molded package with changed material properties. According to literature [2], a layer based FE model approach was implemented and effects to the resulting strain values of the sensor were investigated during production and operation (see Fig. 3).

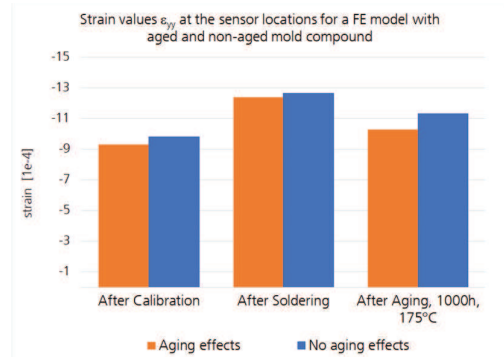


Fig. 3 Comparison of strain values caused by the incorporation of aging effects in the FE model

3. Conclusions

The presented DfR approach was developed to investigate the possible impact of specific thermo-mechanical effects to the behavior of an AMR current measurement device. It represents an appropriate method to combine influences from production process and operation (mission profile). Due to the incorporation of fluctuations and conduction of sensitivity studies it helps to understand certain reliability issues of the later product and supports major design decisions during the development early stages.

Acknowledgement

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NLP Advances in Risk Analysis Context: Application of Quantum Computing

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The models used for facilitating Risk Analysis have undergone notable changes in recent times. This can be attributed to the significant progress made in computing capabilities, as well as the breakthroughs achieved in the field of artificial intelligence. These developments have allowed for the effective extraction of information from complex and unstructured datasets. A particularly useful tool in this regard is Natural Language Processing (NLP), which facilitates the extraction, organization, and classification of information from textual sources. This enables the identification of patterns and trends in an automated fashion. The emergence of Quantum Computing (QC) over the last fifty years has made it one of the most significant fields in computational science. Although fully scalable QC remains elusive, the availability of intermediate noisy scalable QC devices has enabled the realization of near-term computation on quantum devices using quantum algorithms. QC can (i) solve classically intractable problems and (ii) problems that, while tractable, are classically infeasible. Given the significant computational resources required by state-of-the-art NLP models to extract meaning from text, exploring methods to address such problems using QC would be valuable. The primary aim of this study is to develop a model based on Quantum Natural Language Processing (QNLP) to classify whether human error caused aviation accidents, based on the accident narrative. The research utilizes a database of accident investigation reports conducted by the National Transportation Safety Board (NTSB) spanning from 1982 to 2022.

Keywords: Quantum Natural Language Processing; Quantum Computing; Aviation Accidents; Accident Investigation Reports.

1. Introduction

RA is critical for guiding investments to prevent and mitigate risk events, particularly in the aviation industry where accidents often result in loss of life. The aviation industry collects vast amounts of data from various sources, such as written accident reports. The internal investigation and reporting of accidents are aimed at preventing similar incidents from occurring in the future. However, due to the sheer volume of reports produced, a complete human review is impractical [1].

There has been an increase in the number of NLP approaches to RA, mainly due to breakthroughs in the field of artificial intelligence and advances in data processing and recording [2]. However, as far as the authors are concerned, no QNLP approaches have been proposed in the context of RA. Thus, the main objective of this research is to develop a QNLP-based model that can extract knowledge from textual data in aviation accident reports that can be useful to improve safety culture.

2. Natural Language Processing

In general, algorithms need to convert raw text inputs into numerical representations (word embeddings) through a process known as language modeling, which forms the basis for knowledge distillation [3]. Thus, several modelling approaches have been designed, such as Deep Learning-based models. However, training such models has a high computational cost.

In recent years, quantum computing has become increasingly popular due to its potential to significantly enhance computational power. This technology harnesses the properties of quantum mechanics, including superposition and entanglement, to manipulate and represent data. By allowing for the simultaneous evaluation of multiple hypotheses, quantum computers offer a significant advantage over classical computers.

Quantum embeddings, which capture the semantic structure of text data, are created by utilizing the principles of quantum mechanics. Initially, text data is transformed into a vector space using classical techniques. Subsequently, a

quantum circuit applies a series of unitary operations to the vector representation to map it to a quantum state [4].

In this paper, we developed a QNLP model that can effectively classify aviation accidents as either caused by human error or not using binary classification. The experimental methodology and results are presented in the following section.

3. Experiment

The proposed model was applied using a public database comprising accident investigation reports conducted by the National Transportation Safety Board (NTSB) between 1982 and 2022 [5].

First, the accident descriptions were preprocessed by applying two operations: (i) stop word filtering and (ii) lowercasing. All descriptions, written in English, were processed using Python string methods and functions from the NLTK library. Aviation accidents caused by human error were randomly selected by searching for the expression 'pilot's failure' in the accident descriptions. In other words, accidents with the 'pilot's failure' expression were categorized as caused by human error, while all others were considered due to non-human error.

Three datasets were constructed, comprising (i) 32 training and 9 test samples, (ii) 80 training and 21 test samples, and (iii) 160 training and 41 test samples, and used to train and evaluate the performance of the QNLP classifiers. The Lambeq pipeline [6] was adopted to convert sentences to quantum circuits, and develop a QNLP model for determining whether an aviation accident was caused by human error based on the accident narrative. The models were trained using the 'binary cross-entropy' loss function, with a 'sigmoid' activation function applied in the final layer. 'Adam' was chosen as the optimizer, and a learning rate of 10^{-3} and batch size of 4 were employed in training the classifiers.

The QNLP models demonstrated accuracy rates on test data of 55.56% (i), 57.14% (ii), and 65.85% (iii). Notably, the training duration for (i) was less than one minute, while the training for (iii) took about five minutes. Additionally, we ensured that the accident narratives were as realistic as possible without oversimplification, further strengthening the validity of the model. These promising results demonstrate the potential of QNLP in identifying human error as the cause of aviation accidents.

4. Conclusion

Quantum embeddings have demonstrated potential in a range of natural language processing tasks, including sentiment analysis, text classification, and machine translation. Although achieving fully scalable quantum computing remains elusive, the world's major technology companies, including Google, IBM, Microsoft, and Amazon, invest billions of dollars in quantum computing research and development and provide limited access to quantum computers for public use. Consequently, developments in quantum computing hold significant promise for enhancing the efficiency of NLP-based models.

Acknowledgement

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Using Natural Language Processing to Generate Risk Assessment Checklists From Workplace Descriptions

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Workplace risk assessments are mandatory in Germany. Despite this, up to 50% of workplaces are estimated to never have been assessed. We propose to empower occupational safety practitioners by employing artificial intelligence techniques. From previous work we gathered that most of the available risk assessment data is more or less digitalized and more or less structured text. Therefore, we focus the algorithm family of natural language processing to boost the capabilities of analysing large amounts of documents. More specifically, we show the feasibility of retraining an algorithm for handling accident data and hazard identification and risk assessment checklists as well as the transferability to a German text corpus. A dataset of roughly 2500 job descriptions in German forms the basis for this German text corpus. We further explore how the interaction with such a system should be designed to accommodate for the specifics of interacting with artificial intelligence as well as maintaining the users' competencies.

Keywords: Risk Assessment, Natural Language Processing, Occupational Safety, Workplace, Artificial Intelligence, Hazard Identification.

1. Introduction

In Germany, risk assessments are estimated to be missing for up to every second workplace (Arbeitsschutzkonferenz 2014), while they are even mandatory by law. In light of the growing introduction of innovative technologies (Barth, Eickholt et al. 2017) and the overall lack of adequately trained personnel (IFA 2021), this problem will likely only get worse. As checklists for hazard identification and risk assessment are the most common tools for occupational safety practitioners, we set our focus on improving their use. Although the checklists present a useful assessment tool, their availability and applicability leave much to be desired. On the one hand, often only generic and static checklists for broad categories of workplaces are available. On the other hand, since the available checklists are developed to cover as much as possible, some of their items might not be applicable at all. Therefore, for complex workplaces (fitting more than one workplace category), several static

checklists have to be merged and adjusted, while for unique workplaces (with no immediate category fit), a checklist would need to be compiled from all the potentially applicable legislations, guidelines, and regulations. As such, due to the large volume of material and the lack of a systematic approach, assuring completeness and consistency of the final checklist requires a large effort. We propose to use Natural Language Processing (NLP, see e.g. Chowdhary (2020)) to generate tailored checklists from textual workplace descriptions.

2. Considerations on Algorithm and Interaction Design

The algorithm is based on the work of Martinc, Škrlić et al. (2022) and Westhoven and Jadid (2023) and compares all the available checklists and the workplace description to identify matches, dependencies and contradictions between the clauses to yield a list of necessary

workplace checklist items together with an additional list of potentially fitting items. Checklists were obtained from an accident insurance. They include all typical hazards and are enriched with meta-data, such as corresponding law texts. Workplace descriptions are hard to come by, which is why we fell back to using related data. We found that internal job descriptions used for assessing the paygrade for different jobs contain rather detailed data about the work processes. We were able to obtain around 2500 such descriptions to fuel our retraining to our application domain. As the final decision to include each item is left to the user, the algorithm also collects feedback to improve the quality of future proposals. Westhoven and Herrmann (In Press) explored the design of Human-AI interaction in this setting already, so this work can expand on it in regard to the implementation of the Human-Machine-Interface. As with the setting of Westhoven and Herrmann (2023), also for this work a hybrid intelligence should be the goal of the interaction.

3. Future Research

In this work, we show how to generate a custom-tailored checklist, which incorporates all the definitely and potentially suitable items while excluding the unnecessary ones, with the use of NLP techniques.

With this drafted setup, new research questions arise, such as the fitness of the used retraining data, and the evaluation of both the algorithm's performance and the user satisfaction during and after use.

We plan to follow up these new questions by assessing means to evaluate the retraining data, and to evaluate how good the AI interaction design can actually cover the requirements set out for such a system.

At the same time, we constantly

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An asset management framework for wind turbine blades considering reliability of monitoring system

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In this study, a wind turbine (WT) blade asset management (AM) Petri net (PN) model is presented, which incorporates risk-based maintenance and structural health monitoring (SHM). Firstly, PN modules cover the entirety of the blade AM process, describing degradation, condition monitoring, and maintenance processes. The PN model is used to predict the future blade condition for a given AM strategy and provide information to support AM decision-making for blades during WT operation. Secondly, the monitoring system reliability is considered by calculating expected sensor network information gain/loss using a Bayesian inverse approach. The effect of the monitoring system's accuracy on maintenance cost can be obtained.

Keywords: Asset management, Wind turbine blades, Petri nets, Bayesian inference, Value of Information, Reliability of monitoring system.

1. Introduction

It's crucial to develop reliable asset management models for wind turbines to minimize maintenance costs and improve reliability amidst the rapid growth of wind energy. PNs are directed bipartite graphical and mathematical modelling tools. Due to their flexibility and applicability to dynamic process simulation, Petri net models are used to build an asset management model for wind turbine blades, providing decision makers with a realistic representation of degradation processes and complicated maintenance actions Murata (1989). In the framework proposed in this paper, the monitoring system has some variability of monitoring accuracy. As a result, the influence of the reliability of the monitoring system on the adopted asset management strategy can be analysed. Sec. 2 gives the proposed model. The simulation results are presented in Sec. 3.

2. Proposed model

2.1. PNs concepts

PNs consist of four simple elements: places, transitions, arcs, and tokens. The Petri net is described by circular nodes, called places, and square nodes, called transitions, with a number of arcs connecting places and transitions. The state of a Petri net is described by the distribution of black dots, called tokens, in the places. The movement of tokens between places is based on the firing rule. Firing removes or adds a certain amount of tokens between places.

2.2. PNs modules

The AM framework consists of degradation, inspection, condition monitoring and maintenance modules. WT components can be monitored in various ways, but we are limited to ultrasonic monitoring technologies here. Descriptions of the

different modules are shown below:

- Blade degradation: stochastic distributions are used to simulate the degradation process of different types of damage. Distribution parameters are obtained from inspected failure history data using maximum likelihood estimation.
- Condition monitoring (CM): CM can provide a continuous indication of blade condition. Ultrasonic monitoring can be used to detect damage on the inner surface of blades. Sensors installed in these monitoring systems may degrade over time, affecting monitoring accuracy; this module includes this degradation process.
- Maintenance and cost: engineers grade the damage by size and then decide on a repair strategy. Five damage ratings and corresponding repair actions are considered. Rating 1 is "no need for immediate action". Rating 2 is "repair if nearby damage is to be repaired (Type I)". Rating 3 is "repair within 6 months (II)". Rating 4 is "repair within 3 months with monitoring (III)". Rating 5 is "stop turbine and repair/replace (IV)". The repair cost ratio of Type II, Type III and Type IV is 1:2.95:206.32 Mishnaevsky Jr and Thomsen (2020). Type I is not considered for current research.

2.3. Considering of SHM system reliability

The most intuitive manifestation of the reliability of the monitoring system is monitoring accuracy. However, the monitoring accuracy of a complex monitoring system is difficult to directly measure. In this study, firstly, Kullback-Liebler divergence with Bayesian inverse Thomas and Joy (2006) is used to calculate the information loss due to sensor failure. Secondly, the relationship between information loss and monitoring accuracy is established. Thirdly, the monitoring accuracy is linked to the number of tokens to reflect the reliability of the monitoring system in the PN's module.

3. Results

Monte Carlo simulation is used to analyse the PN's, with the changing PN marking used to analyse the changing system state, which could

be used to investigate the system lifecycle by analysing the system condition or cost for example. The convergence criterion is set according to whether the number of different repair actions reach a stable value. The monitoring accuracy decreases over time. An example set of results is shown in Fig. 1, which shows the cost of different repair actions for varying rates of degradation of the monitoring system. Level 1 indicates a perfect monitoring system. The monitoring system's failure rate increases from Level 2 to Level 4. Although the repair cost of Type II falls as the failure rate increases, the repair costs of Types III and IV, as well as the total cost, increase significantly. This shows that monitoring system degradation will bring additional cost, which can be quantified using the proposed PN model. This result emphasises the importance of the CM system reliability on system performance and lifecycle cost.

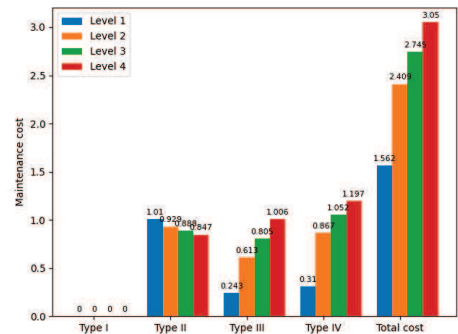


Fig. 1. The observed change in maintenance cost for decreasing levels of CM system reliability

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Using Predictive Analytics Approaches to Investigate Climatic Reliability and Humidity Robustness issues of PCBA under Different Conditions

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Nowadays, climatic reliability and humidity robustness of electronic devices has become significant issue for both consumer and industrial electronics due to various reasons. One reason for this increased problem is the widespread use of electronics in many locations. The climatic reliability of electronics is attributed to the interaction of external climatic conditions and printed circuit board assembly (PCBA) characteristics as the main part of each electronic device, which compromise the performance of electronics due to the electrochemical failure process. In order to improve the reliability of electronics, requires a detailed understanding of the synergetic and interaction effects of various controllable factors, such as humidity, temperature, pitch distance, voltage, contamination types, and contamination levels. Moreover, it is crucial for reliability assessment to understand the relative importance of factors and their levels to take remedial action at an earlier stage based on selecting the best PCBA material, soldering process, and optimizing the design in desired tasks for particular applications and climatic conditions. This study presents the most suitable approach and prediction model based on the input datasets by using a combination of statistical analysis, probabilistic approaches, and machine learning algorithms to predict leakage current (LC), time to failure (TTF), failure state, and highly risky conditions, that could provide a better perspective of PCBA reliability and helps to reduce electronic waste due to failure.

Keywords: climatic reliability, PCBA characteristics, humidity robustness, predictive analytics, failure prediction models.

1. Introduction

The climatic reliability of electronic devices is determined by the complex interplay between external climatic conditions (extrinsic factors) and the characteristics of the printed circuit board assembly (PCBA), which constitute the intrinsic factors of electronic devices. These factors have the potential to compromise the performance of electronic devices due to the occurrence of electrochemical failure processes (Bahrebar 2022). Electronic components and systems (ECSs) used in various applications are subjected to diverse climatic conditions and must therefore be highly reliable and robust to operate under extreme circumstances. Climatic conditions can induce reliability issues in ECSs, resulting in intermittent or permanent failures. Many of these failures arise due to transient water film formation on the surfaces of PCBs or other assembly components exposed to varying climatic conditions (Ambat and Conseil-Gudla 2016). This triggers an electrochemical process between

the biased points on the PCBA surface, resulting in a drop in surface insulation resistance and, eventually, an electric short circuit due to electrochemical migration (ECM) (Bahrebar and Ambat 2021), (Bahrebar and Ambat 2022). However, other corrosion failure modes are also possible depending on the materials and environmental conditions (Bahrebar et al. 2018), (Rastayesh et al. 2020). Therefore, it is crucial to focus on enhancing climatic reliability and developing preventive strategies to mitigate PCBA failure using predictive knowledge. Based on prediction methods, several preventive measures are possible, including extrinsic strategies such as using conformal coating as a barrier protection, or special enclosures to minimize the effect of climatic conditions (Conseil-Gudla 2017), and intrinsic strategies such as changing PCBA characteristics using different materials, designs, and soldering processes during production (Guene 2017).

2. Overall Discussion

In this investigation, we aimed to predict leakage currents (LCs) and time to failures (TTFs) due to ECM failure on PCB surfaces, as well as categorical failure states of different conditions. To achieve this, we employed a variety of predictive analytics approaches, including statistical, probabilistic, and machine learning models, using different datasets of laboratory test results (Bahrebar, Homayoun, and Ambat 2022). Overall, this investigation provides valuable insights into predicting ECM failures on PCB surfaces and can be used as a basis for improving the reliability and reducing the risk of failure in electronic systems (Bahrebar 2022). In terms of failure prediction, various methods were considered, including multivariate regression analysis, ANOVA, probability distribution analysis, common machine learning algorithms, and some combination of these methods. Furthermore, the correlation between PCB failures was presented, which is useful for predicting TTF before ECM happens. The general current behavior in three parts (stable part, transient part, as well as unstable part) was modeled as a sigmoid curve, and a logistic function was used to predict future changes.

3. Overall Conclusion

Our investigation revealed that humidity significantly influences both failure status prediction due to ECM and LC values. Humidity plays a significant role in climatic conditions by inducing the formation of a water layer on the surface of PCBs. This phenomenon is closely associated with contamination type effects, as the hygroscopic nature of the activators present in the flux ionic residue contributes to the overall influence. The combined impact of these two factors accounts for more than 70% of the observed effect on the failure status. Moreover, machine learning algorithms offer several advantages over other methods for predicting failure status and LC values. In particular, machine learning algorithms provide more profound insights with remarkable accuracy, and they can handle big data with good speed. These algorithms can map nonlinear relationships and perform well with messy data that may contain outliers and missing values. Additionally, machine learning algorithms can visualize multiple and complex interactions, especially tree-based algorithms.

Among the most common machine learning algorithms for both classification and regression analysis in our study, the RF (random forest) algorithm showed the most well-organized performance on the training dataset. We evaluated the RF algorithm using appropriate metrics on the validating dataset and found that it performed well in predicting PCB failures as the most suitable classifier and regressor model. Accordingly, we recommend the RF algorithm for predicting PCB failures. Fig. 1 presented the evaluation of classification accuracy using (a) the confusion matrix and (b) regression accuracy through the Kernel density estimate (KDE) plot of the RF.

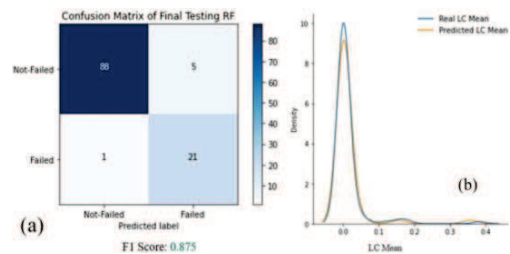


Fig. 1. Confusion matrices (a), and KDE plot (b) of RF algorithm on the test dataset.

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Complexity of tourist safety in the Arctic: stakeholder's knowledge co-production

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Keywords: natural hazards, occupational safety, risk management, knowledge co-production, Arctic tourism.

1. Introduction

In light of growing demand on tourism in the Arctic, it is imperative to strengthen the knowledge base, skill set and competencies of the tourism labour force by strengthening tour guide professionalism and safety in the region. Complex logistics, rapidly changing weather, and remoteness, as well as the effects of climate change play significant role in field practices, especially for tour operators in the Arctic. With growing interest in the region, the likelihood of accidents increases, leading to stress on limited local emergency services. Recent findings show that local knowledge, experience and training have been recognized as essential in ensuring safety (Hild et al., 2022) while there is limited data on knowledge exchange between local stakeholders. Knowledge on relationship and interaction between the stakeholders, such as tourism boards, rescue services, academia, tour guiding schools and guiding companies is essential in the coproduction of knowledge; phenomena of ensuring tourist's safety in the Arctic. The objectives of this research are twofold: (1) to explore current state of safety-related knowledge and (2) to map recourses for fostering collaboration between practitioners, theorists, researchers, educators, company owners, government representative and tour guides.

By exploring stakeholder's capacity and standpoints related to issues on safety tourists operations, we seek to explore the possible ways to collaborate in knowledge co-production, with focus on enhancing tour guides education. Hence,

our study sought to address literature gaps by examining:

- 1) What are the safety concerns related to extreme weather events for stakeholders operating in the Arctic environment?
- 2) What is the current state of safety-related knowledge exchange between the rescue services and tourist companies?
- 3) What strategies and resources are needed to establish collaboration between the rescue services, tourist companies, and guiding schools in the Arctic?

The research contributes to the knowledge of tourism management in the safety field, giving insights into a process of potential collaboration in the Arctic, building resilient infrastructure, promoting knowledge sharing and enhancing safety practices, while addressing the importance of cooperation of various stakeholders, including research, and local communities in tourism destination development in the polar regions.

2. Tourists' safety in the Arctic

Extending the tourism seasons, together with increased accessibility to new locations, as a result of climate change pose threat to the commercial operations and tourist safety. The exposure to new hazards, such as extreme weather events or changes within the existing visited sides (such as moving glaciers, new crevasses, unstable sea ice) becomes a challenge for guides and tour operators. With limited regulations and standards on operating land-based tourism activities, such as certification or mandatory training for tour guides, there is inconsistency in approaching

tourist safety as shared responsibility of guides, educators, company owners and policy-makers. While factors, such as harsh climate conditions, remoteness, limited infrastructure, climate change and lack of data and knowledge are considered as fundamental in operational safety (Albrechtsen & Indreiten, 2021), it is imperative to explore how tourism stakeholders approach safety concerns.

Research shows that tour guides have responsibility of ensuring tourist safety. Guides training as an imperative for development of safety competencies (Hild et al., 2022) should be developed in the dialog between theorists, researchers, educators, company owners, government representative and tour guides with emphasis on joints understanding of the safety complexity.

3. Collaboration between Arctic tourism stakeholders

With an aim to address the complexity of tourist safety, more research integration, implementation and participatory processes is needed. In order to respond the research needs Arctic Guide Safety Education Collaboration (AGSE) was established as transdisciplinary project based on knowledge exchange between field of Safety, Tourism and Education, hence represented by researchers, educators and practitioners. The project focus on knowledge co-creation and curriculum development of guide education in the Arctic environment brining attention to increased involvement and integration of research on tourist safety in the Arctic. Working together across educational level creates and opportunity to link and transfer knowledge and experiences between tourism educators in the Arctic, thus preparing the ground to produce materials for teaching development and continue transitional collaboration in the field.

3. Material and methods

In order to address the research questions, workshops with stakeholders are taking place during Arctic Guide Safety Education (AGSE) Collaboration meetings in Iceland, Svalbard and

Greenland between February – September 2023. Representatives from companies, tourist boards, emergency services and academia are invited to participate in 3hours workshop divided into 1h presentation about the network, learning about guiding schools in each location, followed by group discussion. Data collection includes 4 meetings with stakeholders, 3 AGSE seminars and one guide seminar in Svalbard. Data triangulation was used and included following sets of data: participatory workshop, stakeholder's survey, and guide's survey after Svalbard Guide Seminar. With an aim to understand the safety concern faced by the stakeholders, the workshops included discussion on enhancing collaboration on guides education between various stakeholders. The meetings are recorded, transcribed, and organized in thematic themes. We aim to analysed the findings with a theoretical approach of complexity and collaborative research theories.

4. Preliminary findings

Preliminary findings revealed that remoteness, climate change and limited resources are contributing factors in approaching tourist's safety in the Arctic by stakeholders. In addition, findings indicate the need for more integrated research on guides education and knowledge exchange between stakeholders, especially from the top-to bottom approach.

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Optical surface analysis with Support Vector Machines based on two different measurement techniques

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The surface topography as well as the optical perception are important features for evaluating the quality of fine grinded knives. Parameters as the surface roughness, gloss or coloring are used for the quantification of these features. The measuring is implemented by the use of traditional methods, which are manual, time-consuming and cost-intensive. On top of that, the application of these methods for the condition monitoring of the ongoing process is rather limited. Therefore, a new, faster and more cost-effective approach is needed to improve the classical measurement methods. A conceivable approach could be based on image analysis.

Over the past years, different contactless image analysis based approaches have been developed to simplify the traditional roughness measurement methods. Some studies propose picture pre-processing and feature extraction in combination with machine learning algorithms.

The overall goal of the presented research activities is the development of a condition monitoring tool which can be implemented in the ongoing grinding process of the knives. It should be used to ensure the knives quality and to reduce rejects by an immediate detection of deviations of the target values and the possibility to adapt the production process accordingly. For this reason, a data set based on cutlery samples has been generated and analyzed. The extraction of features of the data set is presented for a better understanding of the training process. The features are used to train various machine learning algorithms with and without a combination of logged process parameters to evaluate the surface roughness.

Within this study the image of each grinded surface is analyzed regarding its measured arithmetic average roughness value (Ra) by the use of Support Vector Machine (SVM) and Support Vector Regressor (SVR) algorithms.

Keywords: Machine Learning, SVM & SVR, supervised learning, surface topography, condition monitoring.

1. General Appearance

The optical perception of high precision, fine grinded surfaces is an important quality feature for these products. Its manufacturing process is rather complex and depends on a variety of process parameters (e.g. feed rate, cutting speed) which have a direct impact on the surface topography. Therefore, the durable quality of a product can be improved by an optimized configuration of the process parameters.

To improve the conventional methods of condition monitoring, a new image processing analysis approach is needed to get a faster and more cost-efficient analysis of produced surfaces. For this reason, different optical techniques based on image analysis have been developed over the past years.

In this study, fine grinded surface images have been generated under constant boundary conditions in a test rig built up in a lab. The gathered image material in combination with the classical measured surface topography values is

used as the training data for machine learning analyses.

In real-world applications, data often exists in unbalanced class distributions, which can result in biased trained machine learning models. Since the manufacturer of these surfaces would produce economically prohibitive rejects, the used data also consist of an imbalanced distribution. Since the data basis plays an essential role for the training of machine learning models, the challenge in the application is often to find cost-efficient, fast and at the same time process-adaptable measurement methods that also have sufficient accuracy. Basically, the measured arithmetic average roughness value (Ra) out of two different measurement methods was used as the target variable in this study. The measurement methods used are distinguished between tactile and optical convocal measurement, which ensure different precisions and different scattering. This results in two data sets with unequal imbalanced distributions and different statistical variance.

The present target values are available both as a class and as a continuous value, so that a classification as well as regression analysis with Support Vector Machines can be performed. SVMs are a type of machine learning algorithms which can be particularly applied for any kind of analysis based on extracted features. In order to find suitable parameters for the SVMs, a comprehensive parameter study for the different data sets was performed. Finally, the influence of the different measurement methods with the same input database is analysed and discussed in detail.

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Mitigation of Climate Change. Increased consideration of risk and uncertainty

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To achieve a drastic reduction of emissions and a significant increase in carbon uptake from the atmosphere, the Intergovernmental Panel on Climate Change, IPCC, in 2022, recommended a considerable number of mitigation options whose feasibility and potential are yet to be examined in each context. The IPCC also endorsed an approach to assess the feasibility of mitigation options. We discuss some issues in the IPCC report in 2022 that reflect the need for an increased consideration of risk and uncertainty linked to mitigation options. For example, to account for the uncertainty of a mitigation option, a more detailed specification of mitigation options is required. Concerns are also raised about whether the assumptions involved in specifying mitigation options are systematically assessed. From these issues, it follows that mitigation achievement is potentially compromised.

Keywords: Mitigation, climate risk, risk, uncertainty, feasibility of mitigation, assumptions.

1. Introduction

The need for increased consideration of risk in mitigation is highlighted in the IPCC mitigation report (2022). There is a call for '*Accelerating mitigation (...) [which] will require the integration of broadened assessment frameworks and tools (...)*' and this includes that '*Approaches to risk assessment (...) are complemented by frameworks for probing the challenges in implementing mitigation (...)*' For the IPCC a mitigation option can fail to achieve its intended outcome, or create an adverse outcome elsewhere (IPCC, 2020). This means uncertainty about mitigation outcomes or risk. Next, the IPCC endorsed an approach to assess the 'feasibility' of mitigation options. The approach suggests that the assessment of options can be done by taking into consideration six feasibility dimensions, namely geophysical, environmental-ecological, technological, economic, socio-cultural, and institutional dimensions. The approach has been developed with a special focus on identifying barriers to and enablers of the deployment of mitigation actions and thus assessing their feasibility (IPCC, 2022). Despite these developments, in the following, we identify some issues that show the insufficient importance given

in the approach to the risk and uncertainty that mitigation actions may involve.

2. Feasibility assessment approach issues

Aven (2020) has argued that an unambiguous conceptualization of climate risk is required to improve risk understanding and communication. This author has suggested that the climate risk concept has two main components: i) the consequences of activities, C , and ii) the associated uncertainties, U . For example, the consequences may be related to deviations from the goal of global low-emission. Risk is then defined as both the event of the deviation D from the goal and the associated uncertainties U . Uncertainty is therefore a central concept linked to the concept of risk (Aven, 2020). Uncertainty is lack or incomplete knowledge about a quantity or event (SRA, 2018). Such uncertainty can be measured in terms of probability and fully described by examining the credibility of the background knowledge associated with the probability (Aven, 2020). The lack of conceptualization of risk reflected in the IPCC reports has already been highlighted by Aven (2020). Here, we will not touch upon this further. Rather, we elaborate on other implications when using this climate risk conceptualization.

2.1. Mitigation uncertainty description

A more obvious and accurate specification of mitigation actions has been suggested by Stern et al. (2022). Mitigation feasibility and mitigation potential are distinguished from each other to fully assess a mitigation action. Based on Stern et al. (2022), we shall define mitigation feasibility as the *probability* that an agent will adopt and then implement a mitigation action. In turn, mitigation potential denotes the *probability* of reduction in the '[sources] of an environmental change or the associated damage that would result if a mitigation [action] were completely realized or [its objectives] fully achieved' (Stern et al., 2022). These notions are not explicitly used as such in the IPCC assessment approach. Further, the approach is solely focused on feasibility. However, we add that a mitigation option is not fully specified by assigning a probability. The specification should be informed by the assessment of the credibility of the background knowledge, which includes assumptions associated with the probability, as has been previously suggested by Aven (2020) for the climate risk notion. In total, the uncertainty linked to mitigation actions is currently not fully described in the feasibility assessment approach thus limiting, among other critical tasks, the mitigation options prioritization.

Mitigation actions are mostly unique in relation to the context in which they are going to be set in place. The feasibility and potential of mitigation options can vary across contexts. The context is a significant factor in climate risk mitigation and therefore needs to be explicitly assessed (Stern et al., 2022). To characterise the context, the feasibility assessment approach limits to capture of space, scale, and time factors. Next, the notion of context has never been defined. We, therefore, question whether the IPCC's mitigation options' feasibility assessment approach comprehensively captures the context of a mitigation option.

2.2. The systematic evaluation of assumptions

The mitigation actions specification credibility is also to be examined. Assumptions are critical in the case of the prediction of non-observed events or quantities, such as those involved in mitigation actions. The evaluation of assumptions is not new, but their structured and systematic assessment in the form of a risk assessment has been recently suggested (Aven, 2020). Although the IPCC used

mitigation scenarios to explore different strategies to meet climate goals, the many assumptions involved are not assessed systematically. The assumptions involved include not only modeling assumptions but also input quantity assumptions, choices by modelers, and many other types of assumptions. Yet, Warszawski et al. (2021) illustrated in some aspects how a systematic revision of scenarios, in conjunction with the consideration of the reasonability of the linked assumptions, can be conducted in the setting of the projections of global temperatures. The reasonability of assumptions is determined using experts' judgment. The systematic assessment of assumptions is an ideal link between the feasibility assessment approach endorsed by the IPCC and the scenario exploration as illustrated by Warszawski et al. (2021).

3. Conclusion

In specifying mitigation actions, we suggest further describing uncertainty and exhausting knowledge about the context of the action. We also put forward a systematic evaluation of assumptions. Ultimately, we expect that undertaking these tasks could potentially enhance risk communication and therefore increase the probability of mitigation.

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Building Resilient Governance Frameworks for Human-Robot Collaboration: Towards a More Interdisciplinary Understanding of Risk and Ethics in European Regulation

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This paper explores a wide range of perspectives on the study of AI applications and robotics offered by both technical and social disciplines, and pools them together to best capture their associated risk and safety concerns. After a comprehensive thematic review, the paper concludes that finding the right approach to regulating them requires both an interdisciplinary point of view and the interrogation of the underlying narratives surrounding human-robot interaction. This research contributes to current EU-wide efforts to enact a legislative framework that both supports innovation and protects citizens' rights in the domain of emerging technologies.

Key words: human factors, robotics, artificial intelligence, interdisciplinary research, ethics, risk

1. Introduction

Researchers of the technical and social dimensions of technology face an impossible dilemma: when a novel technology is in its early stages of development, it is often hard to anticipate its repercussions (Collingridge, 1980 as cited in van de Poel, 2020). However, failing to do so in time might result in a lock-in effect, making it hard to tackle any unintended consequences once said technology has become embedded (idem). EU policy circles seeking to regulate Artificial Intelligence (AI) and robotics have tried to reconcile this tension by combining two complementary outlooks: a consequentialist approach – whereby risk gradients determine each product's requisites for compliance, as in the Artificial Intelligence Act (AIA) –, and a virtue-based approach – often crystallized in ethics guidelines, as found in Hagendorff (2022).

2. Methods

To capture how said regulatory trends shape both novel technologies and the society around them, this research draws upon a thematic review of 40 peer-reviewed articles on the topic of AI policy and ethics. These have been selected from a grand total of 2753 relevant entries found in the database Web of Science focusing on either consequentialist or virtue-based assessments of AI-powered devices in human-robot collaboration (HRC) in the workplace. A joint analysis of these publications reveals considerably dissenting understandings of the risks and benefits of HRC, depending on which aspects they highlight – e.g. novelty, expressiveness, exposition time or degree of anthropomorphism – and the values they uphold – e.g. efficiency, reliability, cost minimization or sustainability (Vasilescu & Filzmoser, 2021).

These elements are selected for analysis because they conform the basis of each author's interpretation of the relationship between the social

and technical aspects of HRC, which in turn explains the regulatory and ethical framework they implicitly or explicitly invite (van de Poel, 2020; van Berkel, 2022). Far from anecdotal, such conceptualizations are often 'constitutive and performative', can act as self-fulfilling prophecies, and have the power of 'legitimizing, (...) slowing or speeding up certain innovations (...) by the most powerful actors' (Vicsek, 2021: 6). Thus, finding the most suitable regulatory approach to minimize the irresponsible use of data-driven applications starts with examining these underlying narratives.

3. General Trends

The research finds that most of the reviewed articles align with the value-sensitive design (VSD) endorsed by EU institutions. This approach posits the need to embed a core set of values into new technology, usually a variant of 'Weberian principles at the core of public sector bureaucracies' such as 'transparency, equality, democratic oversight, and safeguarding citizens' well-being' (Willems et al., 2022: 2).

Umbrello argues that this view represents an attempt at shifting the attention towards 'technical means to operationalize' the response to public concerns, without questioning whether the harm could be prevented, or why it happened in the first place (2020: 18). Similarly, Vampley et al. (2018) claim that relying on these values is insufficient (e.g. transparency doesn't guarantee any significant reduction of AI applications' harmful effects), and hardly implementable in practice. Instead, several authors suggest concentrating on enhancing human agency and autonomy by asking 'what social visions technologies serve' (Vicsek, 2021: 13) and seeking to embed further constraints to ensure AI design doesn't only consider 'the optimal end result, but also acceptable ways to achieve this goal' (van Berkel et al., 2022: 2). Similarly, they urge regulators to be aware of many AI applications' track

record of taking undesirable shortcuts such as 'changing users' preferences so that they are more predictable' (Whittlestone et al., 2021: 1012).

4. Ways Forward

Multiple articles issue a shared recommendation that is of relevance here: there is insufficient exchange between stakeholder groups in the field (from civil society and interest group representatives to multilevel institutions, the private sector and standard-setting organizations), and even between professionals of the same sector (Whittlestone et al., 2021; Brynjolfsson, 2022). While calls for interdisciplinary approaches to policymaking, research and technology design are widespread, detailed guidelines on how to carry this out in practice or ambitious experiments on the matter remain scarce. Van Berkel et al. (2022) argue that it is precisely this disconnect between those concerned with the 'technical' and the 'social' side of technology that is responsible for many of the biases, inefficiencies and responsibility gaps associated with human-robot collaboration, thus justifying the need for urgent action on this front.

Equally as widespread in the sources reviewed are fears that robots will soon curtail the agency of workers, consumers and even by-standers. The perspective of large-scale deployment of robots in the workplace is commonly associated with negative psychological effects on workers (Vasilescu & Filzmoser, 2021) and fears of downward pressure on working conditions, a rise in inequality, and unemployment (idem).

In response, Brynjolfsson (2022) proposes moving from *automation* to *augmentation* to avoid concentrating knowledge and power predominantly in the side of technology, and designing robots (or, more appropriately, *cobots*) with the aim of making them more complementary to humans, prioritizing each sides' capabilities and fair task allocation instead of cost-cutting and efficiency (idem). This necessitates that trade unions are involved in both the design and decision-making processes in the sector (Vicsek, 2021), so that each worker retains their agency to determine how they interact with their technological counterparts (idem).

4. Conclusion

The implications of this research are multifold. First, it becomes apparent that each actor's portrayal of the relationship between the social and technical aspects of HRC serves to contextualize their regulatory proposal. Second, we find that while the prevailing view in both the European private and public sectors support some version of VSD, critics point out that this approach proves insufficient at addressing the harms that come with the use of AI applications and robotics. Thirdly, it is concluded that while most authors believe interdisciplinary research,

policymaking and design to be the most viable pathways to address the shortcomings of widespread AI and robotics deployment, most activity in the field is far from incorporating such perspective in practice. Further research is needed to anticipate the implications that these legal and ethical governance trends will have on the future of most economic sectors, as they all progressively come to rely on AI applications and robotics to carry out more of their critical operations.

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Does Redundant Systems Make a Remote Control MASS Safer

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ABSTRACT

Recently, Maritime Autonomous Surface Ships (MASS) have attracted numerous attention, which is expected to improve the efficiency, safety, and environmental friendly of maritime transportation. Remote control ship that is one type of MASS is promising before the ship can be fully autonomous, where the human and autonomy system (machine) are both active in the control loop. For a remote-control MASS, the human operators in Remote Control Centre (RCC) received sensing information from the ship side and sent the control commands such as propeller commands and rudder angle back to the autonomy system on board. The introduction of two control agents, i.e., remote control operators (RCOs) and autonomy systems (AS), increases the redundant degrees of the system, which is expected to overcome the uncertainty and reliability issues of the MASS. However, for one thing, two control agents increase the potential human-machine conflict; for the other thing, the communication delay between the ship and shore intensifies the conflict. Specifically, since RCOs are not on-board ships and the information flow from/to them suffers from the delay, in this case, whether the redundant design will still be valid is lacking answers. To answer the question and investigate the performance of remote control MASS (RC-MASS) with redundant systems in such a communication environment, this paper introduced a simulated environment and tested the performance of RC-MASS with/without AS, which is expected to conclude some tips for the design of remote control ships.

For the RC-MASS without an autonomy system (AS) onboard (see Fig. 1a), the MASS would directly execute the received commands from remote control operators (RCOs). Thus, the behavior of the ship might be out of the expectation of human operations when the ship-shore communication has problems, such as packet loss, delay, etc. In some extreme cases, the office on watch (OOW) on board should take over control. For the RC-MASS with AS onboard (see Fig. 1b), the MASS would judge the safety of the commands. If the command is still valid and safe, e.g., the tracking errors are tolerable, the MASS would directly execute the received command; while if the command is invalid, the autonomy system onboard would take over control. Additionally, when the AS found the encounter scenarios are too complicated to handle, the OOW onboard would be invited to handle the issue.

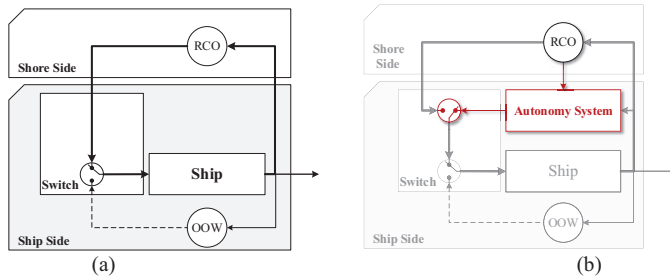


Figure 1 Structure of RC-MASS with/without AS

To compare RC-MASS with/without AS, a simulation environment from the ROS platform is used, a catamaran boat with the size of 2.5m*1.6m*1.8m is engaged (See Fig. 2a), and two groups are set:

- Standard Group (SG): the RC MASS without AS onboard is set as SG, which is controlled by RCOs in RCC. In this paper, a Light-Of-Sight PID (LOS-PID) controller is introduced to simulate the controls from RCOs, which would send control commands to ship based on the delayed sensing information from the ship.
- Control Group (CG): the RC-MASS with AS is set as CG, which are control by RCOs in RCC and AS onboard. The AS onboard could judge the tracking errors of the MASS. If the error is acceptable (i.e., xxx meter), the ship would execute the delayed commands from the RCC; otherwise, a LOS-PID controller [3] onboard using instantaneous information will take over control of the ship.

Table 1. The parameter of the path-following algorithm.

parameter	value
P	3
I	0.8
D	9
Look-ahead distance	10m
The radius of the way-point circle	4m

Ships in two groups are assigned to track given waypoints under various communication conditions.

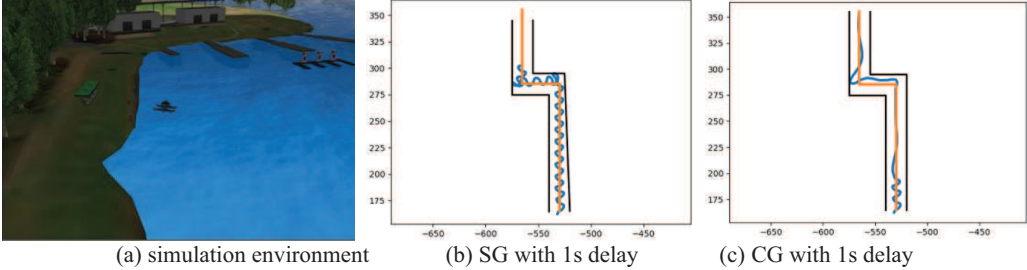


Figure 2 Demonstration of Remote Control MASS Simulation

A simulation result of RC-MASS tracking a “Z” path with a 1-second communication delay is shown in Fig.2b-c. The result shows that (1) the redundant system would improve the performance of the RC-MASS. Specifically, if the communication delay is less than 0.3 seconds, the tracking errors are quite small, however, when the delay is longer than 0.8 seconds, the RC-MASS without AS is unable to follow the path. (2) the redundant system does not always improve the performance of the RC-MASS. When the communication delay is small, the performance of the MASS in SG might perform better than that in CG, specifically, the RC-MASS without AS might have fewer tracking errors.

In conclusion, a redundant system would be necessary for RC-MASS when the quality of ship-shore communication is still uncertain; however, the redundant system might not always perform well, especially when the communication delays are low; the design of arbitrator onboard might play a crucial role, which needs further research.

KEYWORDS: Waterborne transport safety; Autonomous ships; Remote control; Redundant system

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Complex-Valued-Autoencoder for Structural Health Monitoring with Frequency Modulated Continuous Wave Radar

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Frequency Modulated Continuous Wave (FMCW) radar is a low power, compact mechanism which can be used for non-destructive health monitoring and inspection of surface and subsurface materials. It enables the detection of defects that are internal to the analyzed structural element and not visible from the surface. The key benefits of this technology are that it offers a non-contact monitoring tool at reduced costs, risk and duration of inspection. Although a recent study proposed the use of FMCW radar sensing for composite material characterization, it has not yet been applied to the context of health monitoring. In this work, we propose to study the feasibility of FMCW radar to detect anomalies in monolithic surfaces. We propose to consider the analytic representation of the difference between the emitted signal and the incident wave to limit the interferences between the echo delay and gain difference between both signals. From a methodological perspective, we propose a complex-valued-AutoEncoder (AE) with a new activation function. We compare the proposed methodology to other state of the art methods.

Keywords: FMCW Radar, Non-Destructive Evaluation, Complex-valued Autoencoder, Anomaly Detection, Analytical Representation.

1. Industrial context

Inspection during the manufacturing process is essential to ensure that composite materials are fabricated consistently. As a result, there is a need for sensing technologies that can detect anomalies in this high-quality material. Although there are various methods of inspection currently available or being developed for structural health monitoring in composites, embedding sensors during the curing process can potentially affect the curing process. Current research trends suggest a preference for non-contact sensing, such as Frequency Modulated Continuous Wave (FMCW) radar Tang et al. (2021). The aim of this study is to enhance the quality assurance of the manufacturing process

by utilizing FMCW radar as a non-destructive tool. Thus, we propose a new anomaly detection methodology based on complex-valued residual AE applied to the analytic FMCW signal.

2. Method

We consider the experiment conducted in Tang et al. (2021). The raw data obtained from the microwave sensor consists of 1501 feature points acquired in 0.3 seconds in the time domain. This occurs across a frequency sweep from 24-25.5 GHz. The signal output from the FMCW sensor is the Intermediate Frequency (IF), which is the difference between the emitted signal and the target interaction with the incident wave. We propose the analytical representation of the IF. The goal

is to decompose the effect of the delay and gain between the emitted and incident wave into their phase and amplitude components, respectively, within the analytic representation. The analytic representation is computed as $\mathbf{x}^H = \mathbf{x} + i\mathcal{I}[\mathbf{x}]$, where $\mathcal{I}[\bullet]$ is the Hilbert transform.

To perform anomaly detection based on the IF signals, we use an AE that is trained to reconstruct the healthy input only Chao et al. (2021). In the application phase, a decision on a newly measured sample is made based on the norm of its residual, which is the difference between the input and the output of the AE. An anomalous sample contains specific features that make it different from the healthy distribution, so it will not be reconstructed correctly by the AE and will have a high residual norm. The proposed AE contains an encoding network with two dense layers with 64 nodes, plus one of 32 nodes, while the decoder consists of two dense layers with 64 nodes. ReLU activation functions ($R(x) = \max(0, x)$) are used after each layer, except the last one.

Regarding the analytic representation of complex values, denoted by \mathbf{x}^H , a complex-valued AE is used. Considering the polar representation of a complex number $z = |z|e^{i\phi_z}$, where ϕ_z is the phase value, the two most common extensions of the ReLU layer for complex number are Bassey et al. (2021) $CR_1(z) = R(|z|\cos(\phi_z)) + iR(|z|\sin(\phi_z))$ and $CR_2(z) = R(|z| - b)e^{i\phi_z}$, where b is a learnable parameter. In this work, we propose a new activation function called Exponential Amplitude Decay (EAD) and denoted by:

$$EAD(z) = (1 - e^{-b|z|^2})e^{i\phi_z} \quad (1)$$

In addition to being differentiable, the activation function utilizes the assumed Rayleigh distribution of amplitude values in order to restrict the range of amplitude values to the unit circle.

3. Results

The 530 healthy samples are divided into three sets: training, validation and test, with a ratio of $[0.6, 0.2, 0.2]$. Only the test data set contains the 362 abnormal samples. For more details on the experiment conducted please refer to Tang et al.

(2021). In order to establish the threshold that distinguishes between healthy and abnormal samples, based on the residual magnitude, we select the uppermost value, such that 95% of the samples in the validation dataset are considered healthy.

In Table. 1, complex-valued AE with CR_1 , CR_2 and the proposed EAD activation function, as well as the real-valued AE using the IF signal, are compared. Additionally, we consider other unsupervised anomaly detection methods like K-Nearest Neighbors using (KNN), isolation Forest (iForest), DeepSVDD, Local Outlier Factor (LOF). The scores used for comparison are the average F1 score, accuracy and Area Under the Curves (AUC) over a 5-fold cross validation experiment, where our proposed approach outperformed the other methods.

Table 1. Anomaly detection performances of different methods. (Acc.= Accuracy score).

Method	F1	Acc.	AUC
cAE EAD	0.94	0.91	0.978
cAE CR_1	0.93	0.90	0.973
cAE CR_2	0.88	0.88	0.96
AE	0.91	0.89	0.970
KNN	0.90	0.85	0.972
LOF	0.90	0.86	0.970
iForest	0.70	0.64	0.90
SVDD	0.76	0.82	0.90
DeepSVDD	0.72	0.66	0.81

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Expert-in-the-Loop Framework for MBSE-assisted Automatic Process FMEA Generation

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This paper introduces an expert-in-the-loop framework for MBSE-assisted automatic FMEA generation to enhance the productivity and integrity of the manufacturing process design assurance. The MBSE-assisted FMEA tool is implemented in the Matlab System Composer environment, and supports the implementation of the framework as an iterative process including three activities: MBSE process model development; detailed process dependencies analysis to enhance the detail of the MBSE model; and MBSE-assisted FMEA generation based on a failure mode taxonomy and ontology with continual learning. The principle guiding the framework and the design of the user interaction with the tool is that the expert should evaluate the validity of the MBSE model and the FMEA generated based on the engineering inputs provided, with corrections applied to the inputs rather than the outcomes. This ensures both traceability of the analysis, and also that all the system design and development documents are updated. The industrial validation of the framework with a complex robotic manufacturing process showed good results in terms of robustness, integrity and productivity.

Keywords: model-based systems engineering (MBSE), process modelling, process analysis, failure mode and effects analysis (FMEA), robustness, design and process assurance..

1. Background

While significant progress has been made with the development and adoption of computer modelling and simulation tools to assist with the systems design, many of the engineering analysis methods, in particular those focussed on robustness and reliability for the design and process assurance, such as Failure Modes and Effects Analysis (FMEA), still remain expert-centred, thus time and resource intensive. While standards like the AIAG (2019) provide up-to-date guidance for the FMEA, many of the widely discussed weaknesses of the FMEA process, including (i) human factors effectiveness (labour intensive, time consuming and error prone process, with outcomes often difficult to update and interpret); (ii) uncertainty of the integrity of the FMEA (completeness and integrity across multiple and often iterative levels of analysis

within a complex system); and (iii) lack of traceability and integration across the whole product lifecycle, remain unaddressed. Recent effort to comprehensively address these issues, largely driven by the development of intelligent robotic and autonomous systems, have centred on the integration of FMEA with Model-Based Systems Engineering (MBSE), to ensure traceability within a Product Lifecycle Management (PLM) digital environment. E.g. Huang et al (2018) have presented MBSE approaches to support FMEA development. In addition, recent efforts to address the resource effectiveness of the methodology have focussed on the automation of the FMEA generation, e.g. Korsunovs et al (2022), Girard et al (2020). This paper builds on this state of the art with the introduction of a comprehensive expert-in-the-loop framework for MBSE-assisted automatic process FMEA generation.

2. Expert-in-the-Loop MBSE-assisted Process FMEA Generation Framework

The proposed framework integrates within a comprehensive modelling implementation three hitherto separate activities: (i) development of an MBSE process model; (ii) analysis and capture of process dependencies within the MBSE model; and (iii) generation of the FMEA analysis. The workflow is implemented within the Matlab System Composer environment, as an MBSE-assisted PFMEA Toolbox. The role of the expert is to provide the engineering inputs required for model generation at and evaluate and validate the outcomes at each step of the activity. Figure 1 illustrates the proposed approach.

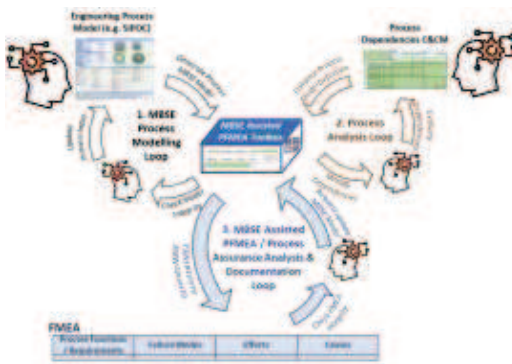


Fig. 1. Framework for Expert-in-the-Loop MBSE-assisted Process FMEA Generation

In the first loop, an MBSE process model is automatically generated (Matlab coding) from an engineering process model (e.g. a detailed process SIPOC analysis) supplied by the process analysts. The generated MBSE model, visualised in System Composer, is evaluated by the process expert; if any changes are required, this will require corrections to the SIPOC input, and the MBSE model will be regenerated. This is an iterative process until the model integrity is accepted. In the next loop an enhanced process MBSE model is developed with information about process dependencies. This is necessary in order to support causal and propagation analysis for product and process failure modes, centred on the critical characteristics. Information about process dependencies is collected from the process experts using a tabular format based on the robust process dynamic control planning methodology described by Ford Motor Company (2011). This is again an

iterative process where the expert visualises the revised MBSE model, with additions or corrections to the inputs applied as necessary. In the third loop, the process FMEA (P-FMEA) is generated based on the enhanced MBSE model, using an intelligent failure modes dictionary (ontology) developed based on the function failure taxonomy (AIAG, 2019), with continual learning from expert-generated input, both on-line and offline (from previous FMEAs). The generated FMEA is evaluated by the experts; any changes should address the modelling inputs (either the MBSE model or the failure modes ontology), rather than edits to the FMEA document. This ensures traceability of the analysis, such that the MBSE process model, process documentation and process FMEA are all aligned.

3. Discussion and Conclusions

The proposed framework has been validated through implementation on real world industrial case study of robotic manufacturing process design for an electric drive unit. The interaction with process experts has provided validation for the proposed framework, highlighting the practical benefits in terms of productivity, robustness and integrity of the outcomes, and traceability and governance of the documents.

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Exploiting Explanations to Detect Misclassifications of Deep Learning Models in Power Grid Visual Inspection

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In the context of automatic visual inspection of infrastructures by drones, Deep Learning (DL) models are used to automatically process images for fault diagnostics. While explainable Artificial Intelligence (AI) algorithms can provide explanations to assess whether the DL models focus on relevant and meaningful parts of the input, the task of examining all the explanations by domain experts can become exceedingly tedious, especially when dealing with a large number of captured images. In this work, we propose a novel framework to identify misclassifications of DL models by automatically processing the related explanations. The proposed framework comprises a supervised DL classifier, an explainable AI method and an anomaly detection algorithm that can distinguish between explanations generated by correctly classified images and those generated by misclassifications.

Keywords: black-box, explainable AI, explanations post-processing, fault diagnostics

1. Introduction

Inspection of infrastructures by drones is emerging as a viable option to monitoring their condition. By processing images collected by drones with Deep Learning (DL) models, the accuracy of detecting defects and degrading conditions in infrastructure components can be significantly improved. This, in turn, leads to increased efficiency in implementing targeted maintenance interventions. DL models are indeed capable of delivering good performance; however, they can be biased and may achieve accurate results by relying on non-causal shortcuts (Geirhos et al. 2020).

Different types of explainability techniques have been proposed to identify the elements of the input that contribute the most to the output of the DL model (Samek et al. 2021). With the help of these explanations, domain experts can identify instances where the DL model is making inferences based on irrelevant parts of the input, thereby indicating that the output should not be relied upon. However, the manual procedure of evaluating the explanations is inefficient and

time-consuming, requiring each explanation to be analyzed by domain experts. In (Lapuschkin et al. 2019) the unsupervised spectral relevance analysis (SpRAY) method is proposed to semi-automatically post-process explanations. It has been shown to effectively identify clusters of similar explanations, thereby reducing the expert effort by focusing on the cluster prototypes alone. In this work, we propose a novel framework to automatically process explanations of a supervised DL model in order to identify its misclassifications and shortcuts.

2. Method

In this research, we automatically process the explanations to identify the unusual ones by applying a semi-supervised anomaly detection algorithm. In the proposed framework, after applying a supervised DL model, the images in the validation dataset are labelled as correctly or incorrectly classified by the DL model. Due to the high accuracy of DL models, the number of images labelled as incorrect is typically small, resulting in an imbalanced problem. In the subsequent step, explanations of images of the

validation dataset are obtained by applying CartoonX (Kolek et al. 2022a), an algorithm that generates relevance maps based on Rate Distortion Explanations (Kolek et al. 2022b). CartoonX extracts the most important features of the input in the wavelet domain and highlights them in the original image.

To process explanations, we apply the deep Semi-Supervised Anomaly Detection (*Deep SAD*) (Ruff et al. 2019) algorithm to generate a compact representation of explanations corresponding to correctly classified images, while also discerning explanations of incorrectly classified images. It is worth noting that in the proposed framework, a Deep SAD model is developed for each class of the classification problem. Finally, domain experts are requested to manually reclassify only those images whose explanations, as per the Deep SAD method, are dissimilar to typical explanations of correctly classified images.

3. Results

We evaluate the performance of the developed framework using a MobileNetV3 (Howard et al. 2019) DL model, whose task is to diagnose faults in insulators' shells based on images captured by drones. Table 1 presents the results obtained by applying *Deep SAD* to the images in the test dataset assigned to the class of broken insulators shells by the DL model. The performance metric considered is the classification accuracy, which represents the number of correctly classified images divided by the total number of images assigned by the DL model to the broken shell class. By reclassifying images with explanations dissimilar to those observed when the broken insulator shells are correctly classified, the classification accuracy increases from 89% to 95%. Domain experts are specifically asked to review only 20% of the test images, among which 36% are found to be incorrectly classified by the DL model. Additionally, among the remaining 64% of the images identified by *Deep SAD* as having explanations not similar to those of broken insulator shells, some shortcuts are discovered.

Table 1. Results of the application of Deep SAD to explanations.

Initial accuracy of DL model	89.20%
Final accuracy of DL model after revision	94.87%
Accuracy improvement of DL model	5.67%
Images fraction that is revised by experts	19.52%

Figure 1 illustrates an example image along with the corresponding CartoonX explanation. The explanation highlights the pixels that the DL model focused on obscuring the parts of the image that were not considered for classification. In this example, a shortcut is evident: the DL model correctly classifies the image as a broken insulator shell, but it mistakenly focuses on the background instead of the actual damage on the insulator shell. The consistent results obtained demonstrate that the proposed explanations-based framework effectively assists domain experts in identifying misclassifications and shortcuts of the DL model.

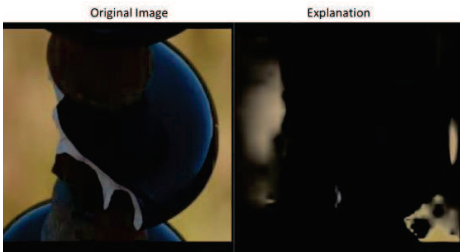


Figure 1: Example of a correct classification obtained by using a shortcut.

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Influence of transformation capacity expansion of a substation on the distribution network resilience: a study of a substation in the metropolitan region of Recife-Brazil.

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In face of the climate changes caused by global warming, the energy transition became a relevant aspect in the energetic planning to be less dependent on fossil fuels. The Brazilian energy mix is already predominantly renewable, and until the end of the decade more investments in renewable energies expansion are expected. So, the electrical system must be structured to operate safely, efficiently, and reliably, to ensure the continuity of the electrical and energy supply. For this, the expansion and implementation of substations is essential since they contain the equipment responsible for the continuity of the power flow and voltage transformation that will be distributed. Thus, addressing these requirements in the system's planning, the concept of resilience is highly appropriate to tackle them. Specifically dealing with substations, which are responsible for the transformation, protection, control, and manoeuvre of electrical energy supply until the final consumer, is a way of mitigating problems related to the supply discontinuity, making necessary to carry out studies in order to investigate the resilience of the substation and the power transmission network to which it is inserted. In this context, a metric to assess the reliability in this context is proposed and is applied in a real substation considering disruption scenarios.

Keywords: Resilience; Energy transition; Reliability; Substations.





1. Introduction

The steep expansion of the Electric Power System (EPS) as well as the advance of non-dispatchable renewables, have imposed on the Brazilian Electric System (BES) several challenges associated with energy security, overload in transmission lines (TL) and extreme weather events, which although rare in Brazil, have devastating effects on the public services sector, whose recovery can take months. Still, EPS must also have enough flexibility to adapt to severe disturbances without losing its full version. This behavior matches with the resilience concept, although in the power grid context there is no consensus over a definition (Ghiasi et al., 2021). Therefore, it is essential to study the need to implement new substations (SE) and expand existing SEs, we have to assess its resilience in order to understand the situation. To implement a resilience metric has the potential of gathering more professionals in the discussion.

2. Methodology

This article presents the contingencies foreseen in (ONS, 2022), focusing on SE Bongi, responsible for serving the metropolitan region of Recife, which will undergo expansion (EPE, 2020). The modeling in permanent regime of the power flow problem, being this a pillar that bases the decisions regarding the expansion of the network and the improvements that must be carried out for certain time intervals. The ANAREDE program was used, due to its speed in the simulation of power flow in extensive systems, such as the Brazilian one. To assess SE Bongi resilience in face of violations of operational criteria, that is, disruptive events, the section Frontier Transformers from (ONS,2022a) was used as a reference, which relates the loads with the operational capacities of long and short duration, in the conditions of contingency and normal operation. The relationship between loading and operating conditions are in Table 1.

Table 1. Classification found in (ONS,2022b)

μ	Network states
	Loading exceeding long-term (LT) operating capacity under normal operating conditions
	Loading exceeding short-term (ST) operating capacity under contingency conditions
	Loading higher than LT operating capacity, but lower than the short-duration operating capacity, in a contingency condition .
	Loading below LT operating capacity under contingency conditions

From these network states and considering LT and ST operational capacities for each one and the remaining capacity of the line in front of contingencies are used to create Table 2, which allows to generate a quantitative assessment of the resilience of an electric grid with performance both in integral network and in contingency. For the metric proposal, a situation when the integral network violates ST and LT limits is included only from the theoretical point of view, since the planning of the BES never allows an integral network to violate the normal and emergency capabilities of the system.

Table 2. Quantification of resilience

Remaining flow (%)	Resilience performance
[0]	Integral network and potential load shedding
[0,10)	Deficient
[10,20)	Poor
[20,40)	Regular
[40,50)	Good
[50,100)	Optimal

3. Results

The cases selected for the power flow analysis were the Contingencies in the LT 230 kV Bongi – Joairam – involving two lines of double circuit and the transformer 04T2 230/69 kV of 100 MVA. The results obtained can be seen in Tables 3 and 4.

Table 3. Double Loss in TL 230kV Bongi-Joairam











Network state		Remaining capacity	Resilience
Performance		43%	good
under contingency		13%	poor
		-75%	null
Integral network		-2%	null
Integral network violating ST-LT		-10%	null

Table 4. Transformer Loss 04T2–230/69kV 100MVA

Network state		Remaining capacity		Resilience
		LT	ST	
Performance under contingency		8%	14%	deficient
		-21%	-14%	null
		-95%	-84%	null
Integral network		-5%	1%	null
Integral network violating ST-LT		-25%	-18%	null

4. Conclusion

We suggest a metric to quantify resilience, using as reference BES's own documents regarding its planning and expansion. The results obtained show a metric consistent with the applications made in ANAREDE, involving power flow. We plan to extend the use of the metric, considering the influence of renewable generations, especially wind and photovoltaic, which are expanding in Brazil, especially in the Northeast region, where SE Bongi is located.

Acknowledgement

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Reliability analysis of European power system assets

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Large interconnected systems can be severely destabilized due to failures of interconnector lines and large generating units. Therefore, identifying the failure behavior of critical assets can be invaluable for modeling and research purposes. In this work, we analyze outages of European generation and transmission system assets, obtained from the ENTSO-E transparency platform. We analyze the data using Markov chain and analytical methods. Our results show that the reliability of generating units is primarily impacted by the technology type and country of origin. Nuclear and fossil units have the lowest availability, resulting from their high unavailability due to planned and forced outages, respectively. Furthermore, we observe that units with high frequency of planned transitions, tend to have a low frequency of forced transitions, and vice versa. This emphasizes the positive impact of preventive maintenance measures in ensuring the safe and reliable operation of generating units. Regarding transmission system assets, we find that AC interconnectors are substantially more reliable than DC interconnectors. Additionally, we observe that internal lines, transformers, and substations are more available compared to interconnector lines. The results obtained from this work can provide important insights for the operation of European assets, helping system operators and researchers identify key vulnerabilities.

Keywords: European power system; transmission assets, generating units; availability; transition rates.

1. Introduction and Methodology

Operating a safe and reliable power system is imperative for the unobstructed supply of consumers. Being more interconnected than ever, modern power systems are susceptible to failures of interconnector lines and large generating units. Although work has been done in the field of power system component reliability, most of the literature focuses on North American generating

units (NERC 2023). Therefore, identifying the failure behavior of critical European assets can be invaluable for modeling and research purposes. In this work, we analyze outages of generation and transmission system assets, obtained from the ENTSO-E transparency platform (ENTSO-E 2022; Hirth, Mühlenpfordt, and Bulkeley 2018). We utilize cleaning and clustering techniques to process the data, resulting in a dataset of 7'675

transmission asset events, and a second dataset of 39'529 generating unit events. Each event contains information about the asset, the country of origin, date, time, and the type of the failure (planned or forced). The assets in question include generating units, interconnectors, internal lines, substations, and transformers. We use this data to calculate the transition rates and steady-state probabilities of the assets using Markov chain analyses. The Markov model for transmission assets is comprised of three states: operational, planned outage and forced outage. Generating units can also be in a derated state, in which they operate with reduced capacity. Therefore, for this analysis, we use a model with five states: operational, planned derated, forced derated, planned outage, and forced outage. The steady-state probabilities obtained with this method help us perform component availability analyses based on the methods defined in the IEEE Std 762™-2006 standard (IEEE 2006).

Results and Discussions

Our results show that the technology and country of origin of the generating units play an important role in their availability. Fossil and nuclear units have the lowest availability of all technology types, with 78.3% and 75.8%, respectively. In the case of fossil units, this is a result of their high unavailability due to forced outages, while nuclear units have the highest unavailability due to planned outages. We observe the best performance indicators for solar and wind units, although it should be noted that their sample size in our analyses is significantly smaller. Analyzing the frequency of forced outages, hard coal units in Spain have the worst performance with 0.16 transitions per hour. On the other hand, we observe the highest frequency of planned outages in hydro reservoir units in France, with 0.12 transitions per hour. Our results show that units with high planned transition rates tend to have low forced transition rates, and vice versa. This observation is valid for most countries, emphasizing the positive effects of preventive maintenance measures.

Analyzing transmission system assets, we identify interconnectors as the worst performing asset with an availability of 96.2%. The interconnection with the highest frequency of planned transitions is between Sweden and Germany, with an average of 0.005 transitions per hour. Regarding forced transition rates, the Finland-Russia interconnection is the worst performing with $7.7 \cdot 10^{-4}$ transitions per hour. According to our results, DC interconnectors more frequently experience outages compared to AC interconnectors. We observe the highest availability of 99.5% in substation components, followed by transformers with 99.1%. Internal lines also have a high availability with 98.7%. For this type of components, we observe the highest frequency of forced transitions in Lithuania and Spain.

The results presented in this work provide key operational indicators for assets in the European transmission system. These indicators can be beneficial to operators, researchers, and regulatory bodies to identify vulnerabilities and ensure the safe operation of the European power system. In our future publications, we will further explore this topic and present the steady state probabilities for the observed assets.

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Facility-Level Downtime Estimation Using Only Publicly Available Data

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This paper develops a model for estimating the likelihood of building-level loss of infrastructure services due to natural hazards based on only publicly-available information. The three steps to the method are: (1) generate synthetic infrastructure systems, (2) generate engineering performance models for these systems, and (3) simulate hazard impacts on these synthetic systems. The approach provides a strong basis for building-level downtime estimation for infrastructure systems.

Keywords: natural hazards, risk analysis, infrastructure, downtime.

1. Introduction

One of the key challenges in natural hazard risk and resilience estimation is estimating the downtime of key infrastructure services at the level of individual facilities such as a residential home, a hospital, or a commercial facility. Here downtime consists both of estimating the probability of a given service (e.g., electric power, drinking water, or cellular communications) being lost as a result of a hazard event together with the conditional distribution of how long that service is out at that location given that it was initially lost.

Downtime estimation is critical for a number of different uses. The first is determining which sub-populations in a community face the greatest risk of not having access to essential services after a disruptive event. This is essential to support assessment of inequities in hazard resilience within a community (Logan and Guikema, 2020). A second key use of downtime estimation is to help community members, businesses, government agencies, and other organizations better plan risk mitigation measures. This requires the ability to assess the impacts of specific interventions (e.g., installation of a backup generator at a particular

water pumping station). Third, downtime estimation is essential for better pricing of downtime insurance by insurers and better ability to consider downtime insurance as a risk transfer option by commercial entities and others in the community. All of these uses require detailed, facility-level estimation of the likelihood of losing each of the critical infrastructure services and the duration of the outage if an outage occurs.

2. Challenge and Approach

A key challenge in infrastructure downtime estimation is that detailed data about infrastructure system layout and performance models is generally not available outside of the utility operating the system, yet the downtime estimation is needed by many other entities without access to this data. This paper presents an approach for infrastructure downtime estimation that is based on only publicly available data yet yields validated estimates at the facility level. The general steps in this approach are: (1) create a synthetic representation of the infrastructure system layout, (2) create a system-appropriate engineering performance model or

approximation of the performance model, (3) simulate hazard loading on the system from hazard events, (4) simulate loss of service at the facility level, and (5) simulate the restoration process at the facility level if outage duration is needed. This approach is demonstrated for power distribution systems, drinking water systems, and cellular communication systems. The advantage of this approach is that it allows detailed, accurate estimation of downtime at a facility level without requiring security-sensitive infrastructure data that is generally not available.

3. Example Results

Figure 1, from Zhai et al. (2021), gives an overview of the synthetic system generation approach applied to generate a power distribution system. This approach first clusters the service points (buildings) and assigns them to substations. It then creates network topologies, including both lines and poles. It then uses a validated machine learning model to determine if each line segment is an overhead line or a buried line.

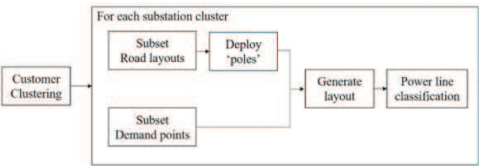


Figure 1. Example of the synthetic system generation approach (Zhai et al., 2021).

This synthetic system is then coupled with an appropriate hazards model and asset-level fragility functions to form the basis of a Monte Carlo simulation of the impacts of a hazard on the system. The end result is an estimate of the number of the probability of each building losing power. An example of this output is given in Figure 2. This figure is an estimate of the probability of experiencing a power outage at the

building level for Hurricane Harvey impacting Corpus Cristi, Texas, United States.

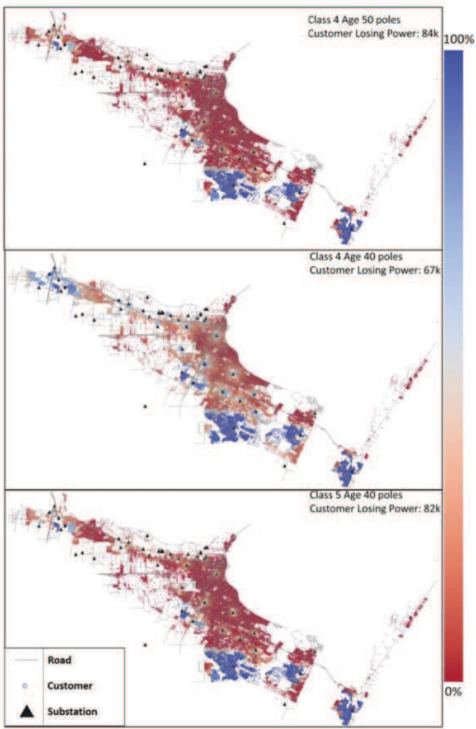


Figure 2. Example of output from the coupled synthetic system – hazard impact simulation model. Zhai et al. (2021).

4. Conclusions

This approach provides a basis for estimating building-level risk of loss of infrastructure service based on only publicly-available information. The approach has been extended for both potable water systems and cellular communication systems.

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Stress-test Based Transition Model for Lifetime Drift Estimation and RUL Prediction of Discrete Parameters in Semiconductor Devices

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In recent years, self-driving technologies in cars have become more and more mature. This affects the whole automotive industry. Autonomous cars are expected to have more up-time and more total usage time compared to the current generation of non-autonomous vehicles.

In semiconductor industry for automotive applications, functionality over lifetime is a quality target. With the increasing usage time in self-driving cars, new challenges arise in the prediction of remaining useful life (RUL) in the context of prognostics and health management (PHM). Predictions of remaining useful life are both important for on-line monitoring and product testing before shipping. For this, statistical models for lifetime based on accelerated stress tests are needed.

We propose a semi-parametric transition model for the calculation of the lifetime drift of discrete electrical parameters based on accelerated stress tests. We further discuss methods for extrapolation of projected drift to calculate interval estimators for the remaining useful life.

Keywords: Lifetime Drift Model, Quantile Regression Methods, Remaining Useful Life Prediction, Semiconductor Industry, Transition Model

1. Introduction

Accelerated stress tests are used in the semiconductor industry to simulate the lifetime of devices in a shorter-than-real time frame.

Electrical parameters of devices are first measured, then they are put to harsher-than-usual stress conditions, i.e., heat, cold, or humidity. Then, the parameters are measured again at certain, predefined times, called readout times, and the devices are put back to the stress test and so on.

The electrical parameters of the devices change as the devices age. This drift of parameters is called lifetime drift and is taken as an indication of the level of degradation within the device. A statistical model for the lifetime drift is needed to guarantee customer quality and calculate the RUL.

2. Methodology

A model for continuous lifetime drift has already been proposed previous work of the authors, Lewitschnig (2022), based on Hofer (2017). We

now introduce models for discrete parameters in the case of both discretized and truly discrete data. The model for discretized data is based on an adaption of existing methods and the model for truly discrete data uses non-parametric estimations of transition probabilities to obtain a Markov model for the lifetime drift.

3. Outlook

We further discuss extensions of the models to extrapolate future behaviour and compare them with different regression-based methods for the calculation of the RUL. We discuss both quantile and expectile regression methods and also propose a regression method based on calculated model quantiles to obtain interval estimations for the remaining useful lifetime.

Acknowledgement

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All ArchitectECA2030 related communication reflects only the author's view and ECSEL JU and the Commission are not responsible for any use that may be made of the information it contains.

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A Bass Diffusion-Inspired Methodology to Predict Device Activity

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Understanding device activity over the lifetime of consumer electronic products is critical in two ways. First, it determines the extent to which a product maximises utilization during its usage phase, which is a critical pillar of circular products. Second, it allows for better estimations of usage phase carbon footprint, which is essential in Life cycle Assessment (LCA) of consumer electronics. This manuscript proposes a methodology for cold start forecasting of device activity data via a Bass diffusion inspired model to predict Monthly Active Devices (MAD) over the lifetime of a product.

Keywords: Bass diffusion, device activity, circularity, product reliability, optimization, consumer product

1. Introduction

A better understanding of the useful life of consumer electronics has two major benefits. Firstly, optimizing the utilization of a product during its usage phase is a pivotal pillar of a circular product system design, [1] where a key requirement of improving the utilization is extending the life span of products. Secondly, inaccurate estimations of device lifetime can significantly hinder the accuracy of Life Cycle Assessment (LCA) and environmental impacts in consumer electronics [2]. The useful life span of a product is governed by customer engagement, which can be captured via device activity. We can use a device activity metric, such as Monthly Active Devices (MAD) over time, in order to measure the useful life of a device [3]. During the product development cycle when a new generation of a product is launched, an estimation of the useful lifetime of a device is essential for informing the design decisions for the development of the next generation of the device. This manuscript proposes a methodology for cold start forecasting of MAD when only early lifetime device engagement is available.

2. MAD and Device Useful Lifetime

Device useful life can be defines as:

$$L_{avg} = \frac{1}{12} \frac{\sum MAD_i}{Total Sales} \quad (1)$$

Where L_{avg} is the average lifetime in years, MAD_i is the number of devices active in a given month over the lifetime of the product.

We have observed that the cumulative MAD profile of most consumer electronics over time follows an S-curve (Figure 1).

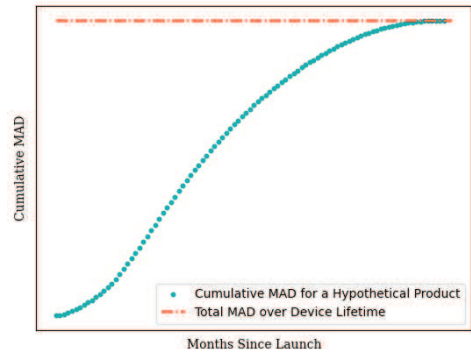


Figure 1 – Cumulative MAD for a hypothetical product

We can use the Bass Diffusion Model, [4] which was developed for technology adoption forecasting, to model the trend of cumulative MAD over time. The Bass model is an S-curve and can be formulated as follows:

$$F(t) = \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}} \quad (2)$$

In the original Bass model, $F(t)$ represents the cumulative adoption over time. p is the coefficient of innovation, which represents external influence or advertising effects and q is the coefficient of imitation and represents the internal adoption effects like word of mouth. Since, $F(t)$ is bounded between 0 and 1, we adjust equation (2) with a scaling factor:

$$f(t) = L \frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}} \quad (3)$$

Where $f(t)$ would be the cumulative MAD over time and L would be the total MAD over the lifetime of the device. And p and q are parameters that define the shape of the function.

3. Prediction

The challenge of predicting any S-curve is that early data may not be enough to find a unique solution to the curve-fitting problem needed to construct the whole MAD portfolio across the lifetime of the device. In order to alleviate this problem, we add a penalty function to the objective function to apply the knowledge we have from previous generations to inform the optimization. Using the insights from historic MAD data, we formulate the following optimization problem:

$$\min: [y - (f(t) + E)]^2 \quad (4)$$

Where y is the observed MAD value and $f(t)$ corresponds to the Bass cumulative function and the added penalty term (E) ensures that the values of p^* and q^* stay within the accepted boundaries that make sense relative to the prior knowledge from the previous generations of the same product. We use the Powell's "dog-leg" [5] algorithm to solve the optimization problem formulated in Equation 4. Solving the optimization problem produces the results illustrated in Figure 2. In our case study, this method predicted the total cumulative MAD of a product within 10% of the actual data.

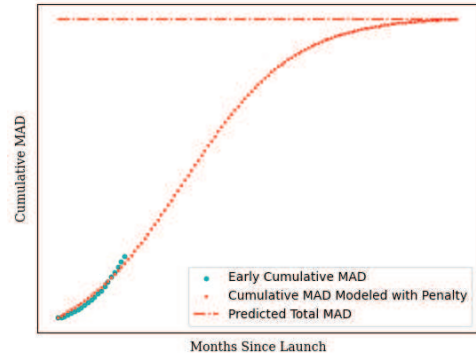


Figure 2 – Prediction of total cumulative MAD using a penalty function

4. Conclusions

Early prediction of device activity over its lifetime is essential in informing the product development cycle to improve the circularity potential of future generations of the product. This study proposes a methodology for cold start forecasting of monthly active devices using the Bass model and a penalized nonlinear optimization approach.

Acknowledgement

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A GENERALISED LINEAR MODEL FOR THE RISK ASSESSMENT OF CIVIL AIRCRAFT BOMB SABOTAGE ATTACK

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The risk of a civil aircraft being exploded by terror or criminal groups stays one of the largest concerns in aviation security nowadays. Significant efforts have been made by the industry to mitigate this risk by the introduction of advanced methods of passengers, baggage and cargo screening. Nevertheless, several successful and failed attacks on civil aircraft were registered in recent years. In this paper we argue that it is possible to predict the risk of a bomb attack based on historical data. We show that security and geo-political data can inform a Generalized Linear Model that estimates a likelihood of bombing incident on a civil aircraft in a given country.

Keywords: aviation bombing, security, risk, machine learning, generalized linear model.

1. Introduction

With over 90 cases of civil aircraft bomb sabotage and more than 2400 casualties of these attacks registered since 1949, aircraft bombing is one of the key risks faced by the aviation industry (Jenkins, 1998)(Network, 2022).

Aviation industry has gradually introduced mitigating actions in an attempt to prevent bomb threat nevertheless terror groups continue attempts to attack civil aircraft. The most recent examples of aircraft bomb sabotage incidents include explosion of Somalian Daalo Airlines aircraft in 2016 and Russian MetroJet Airlines aircraft in Egypt in 2015 (Network, 2022). Also, several attempts of aircraft explosion were thwarted, the most known of which were the explosion attempts of two cargo aircrafts bound to US airports in 2010 (cnn.com, 2010) and the foiling of the plot to explode a passenger aircraft enroute from Australia to UAE in 2017 (bbc.com, 2019).

It is understood that aircraft security risk is influenced by the security situation of the country and of the country economic status or geopolitical factors (Bukhman, Brito, & Sung, 2022). In this paper we propose a method to quantify the risk of aircraft bombing based on these factors.

2. Methodology

In our previous research we have identified that *type of conflict* in a given country (*Conflict_Type*), intensity of a conflict (*Conflict_Intensity*), *GDP per capita* in thousands of US dollars (*GDP_PC_1000*) influence aviation security, hence we use these factors as independent variables (Bukhman, Brito, & Sung, 2022). As bomb sabotage is linked with terror or criminal activities, we introduce the variable *target of the threat* (*Target_Of_Threat*) to define what was the most contributing factor for the attack – threat at the country of origin, destination or other threat. One more independent variable that was identified as significant is *nature* of the flight – a type of the flight (scheduled, non-

scheduled, cargo, military etc.) in accordance with ICAO classification of flights (*Nature_Of_Flight*).

In our previous research we have demonstrated that generalized linear model can be used to estimate the likelihood of an event of aircraft downing by surface to air missiles, in this study we propose to use this methodology to estimate the probability of bombing incident.

3. Dataset

We use Aviation Safety Network dataset (Network, 2022) to capture bomb sabotage incidents and their descriptions given in the global terror database (Terrorism, 2022). In addition we use the World Bank datasets for GDP per capita per country per year (Bank, 2020) and aircraft departures per country per year necessary to calculate the probability of an incident (Bank, 2019). Merging all datasets and removing records with missing data (e.g., GDP data was collected by the World Bank only from 1960) results in 59 datapoints.

4. Modelling result

We run the Generalized Linear Model with dependent variable *P_Attack* and independent variables provided in section2. The dataset is divided to training and test dataset for out of sample validation in 80/20 proportion.

Table 1. Parameter estimates – generalized linear model

Parameter	Hypothesis Test		
	Wald Chi-Square	df	Sig.
(Intercept)	136.207	1	.000
[intensity_level=1]	2.231	1	.135
[intensity_level=2]	1.126	1	.289
[intensity_level=3]	.	.	.
[type_of_conflict=2]	.480	1	.489
[type_of_conflict=3]	.249	1	.618
[type_of_conflict=4]	5.559	1	.018
[type_of_conflict=5]	.	.	.
[Nature_Of_Flt=1]	3.082	1	.079
[Nature_Of_Flt=6]	.	.	.
[Target of threat=1]	5.099	1	.024
[Target of threat=2]	5.401	1	.020
[Target of threat=3]	.	.	.
GDP_PC_1000 (Scale)	29.745	1	.000

The results of modelling demonstrate that variables *Target_Of_Threat*, *GDP_PC_1000* and *Nature_Of_Flight* are significant for predicting he probability of bombing. The *Type_Of_Conflict* is significant only in case of internationalized internal conflict and conflict intensity has low significance in case of bombing incidents.

To assess whether there is any significant difference between the predicted and observed values, let us assume we test the null hypothesis that there is no significant difference between observed and predicted values of *P_Attack* using Chi Square test. We identify that p-value is close to 1, confirming that the null hypothesis – that there is no significant difference between observed and predicted values of probability of attack.

5. Conclusions

The proposed methodology demonstrated a good model fit, hence it can be employed to improve existing risk assessment approaches as independent method or in combination with other existing risk assessment methods.

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Application of Data-Driven Bayesian Belief Network for the Analysis of Factors Contributing to Risk of Civil Aircraft Shooting Down Over Conflict Zones

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Aviation security incidents such as shooting down civilian aircraft over the conflict zones stay one of the most significant challenges of civil aviation industry. While industrial regulations do not provide standardized objective risk assessment methodology, a significant array of publicly accessible data is available for an analysis with the help of machine learning algorithms. This study demonstrates a possibility to utilize data-driven Bayesian Belief Networks in order to develop probabilistic model and identify factors influencing on aviation security event.

Keywords: Bayesian Belief Networks, data-driven, probabilistic model, risk, security, aviation.

1. Introduction

International regulations require air carriers to implement a process of risk assessment (ICAO, 2018), however the tool recommended by the regulations to facilitate this process – risk matrices – have several disadvantages. Risk matrices are susceptible to ambiguity and uncertainty (Anthony Cox Jr, 2008; Duijm, 2015).

Large arrays of publicly available data can contribute to the process of risk assessment of civil aircraft overflying conflict zones. Our previous research identified a number of economic and geo-political factors that influence aviation security and can be used to calculate the probability of civil aircraft shooting incidents. Amongst these variables are the GDP per capita, the type of war conflict and its intensity (Bukhman, Brito, & Sung, 2022). In this study the authors adopted a Generalized Linear Model to predict the probability. However, regression models do not support prognostic or diagnostic inference. This type of inference is supported by causal probability models, such as Bayesian belief networks (Qazi & Khan, 2021).

In this paper we propose a data driven Bayesian belief network to predict civil aircraft shooting probability. We use a dataset of nearly 1600 data points containing recent incidents affecting civil aviation flights in the Middle East, the Gulf and North Africa in 2009-2020 (Solutions, 2022). This dataset was supplemented by the data related to geo-political and economic factors.

2. Proposed Methodology

A Bayesian Belief Network is a graphical probabilistic model composed of vertices and edges. Vertices, also called nodes, are random variables and edges capture the causal link between variables. The algorithm to solve a BBN inference was developed by J. Pearl (Pearl, 1985).

3. Risk Assessment Model

To build the model we will use structural learning capabilities of BBN and EM (Estimation-Maximization) algorithm (Hugin, 2022). The datasets used for the model consist of:

1. A dataset of security related incidents and weapons used in conflicts (Solutions, 2022).

2. A dataset of conflict type (1 – extra-systemic, 2 – interstate, 3 – internal, 4 – internationalized internal conflict, 5 – absence of a conflict) and intensity (1 – minor conflict, 2 – war, 3 – no conflict) (Harbom, 2010) .
3. The data of income categories of countries that replaces GDP per capita for this model as Bayesian Belief model requires categorical data (1 – Low-, 2 – Lower-middle-, 3 – Upper-middle-, 4 - High-income economies) (Bank, 2022).
4. A dataset consisting of the types of weapon (1 – anti-aircraft artillery; 2 – anti-tank guided missile; 3 – anti-tank weapon; 4 – conventional surface-to-air missile; 5 – improvised explosive device; 6 – Rocket / Mortar / Artillery; 7 – rocket-propelled grenade; 8 – small arms; 9 – surface-to-surface missile).
5. A dataset consisting of the type of incident/event (1 – missile launch, 2 – Air & Air Defence Activity, 3 – UAV Event, 4 – Weapon test, 5 – Projectile event).

4. Simulation results

For the simulation we run the Bayesian Belief model using Hugin software, the result is provided on Fig 1. This example demonstrates probability distribution given minor (*intensity_level* = 1) internationalized internal conflict, meaning a conflict between the government and internal opposition, with intervention from other states (Harbom, 2010) (*type_of_conflict* = 4) in a country with low-income level (*income_cat_q* = 1) and using rocket/mortar/artillery (*weapon_type* = 6) that can cause projectile event with probability of 93.71%.

The accuracy of the model calculated with built in tools of Hugin software is 69%, according to the research literature this is a good fit (Marcot, 2020)

5. Conclusions

Identification of factors causing aviation security event is extremely important in current geopolitical circumstances. It can support decision making process of planning civilian flights to or over conflict zones. Data-driven approach utilizing Bayesian Belief Networks can bring benefit to current risk assessment and decision-making process in the industry.

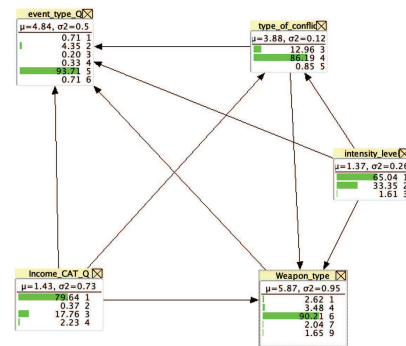


Fig. 1. A Bayesian Belief model representing probability distribution of factors influencing on aviation security event

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The Need for a Durability Index Framework for Electrical and Electronic Equipment to Support a Circular Economy

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Enabling a circular economy aims to reduce the amount of global waste generated from electrical and electronic equipment, mitigate the associated risk to the ecosystem and human health, and address concerns over limited material resources. Durability is a critical concern because keeping products in use for a longer time should reduce resource consumption and waste. Assessing the durability of products and sharing these assessments with the public form a strategy that not only encourages and enables consumers to purchase more durable products but also gives manufacturers an incentive to compete and improve the durability of their products. Although there are some recent initiatives for indexing product durability, there is not yet a standard method for measuring and indexing durability. This extended abstract discusses how indexing product durability can support the shift to a circular economy and overviews the most relevant efforts regarding measuring and indexing durability and relevant product attributes.

Keywords: durability, circular economy, reliability, repairability, sustainability

E-waste, which contains toxic and hazardous material that can adversely affect human health and the environment, has been identified as a fast-growing waste stream. In 2019, 53.6 million tons of e-waste were generated globally, and it is estimated that it will reach around 74.7 million tons by 2030 (Forti, et al. 2020).

Transitioning to a circular economy is a mitigation strategy to minimize the generated e-waste. A circular economy tries to create a closed-loop product life cycle and keep materials in use as long as possible through recycling, reusing, remanufacturing, and improving durability. Improving product durability supports the circular economy by extending product lifetimes and reducing the number of products that are discarded. This should generate less waste, reduce the production of replacements, and reduce resource consumption.

Defining a practical framework for indexing product durability and sharing the calculated indices with the public may improve the durability of products, which consequently helps a circular economy. The durability improvement happens in two ways. First, a durability index guides consumers to purchase more durable products. Lower demand for less durable products causes manufacturers to stop producing them. Second, it is an incentive for manufacturers to compete by producing more durable products.

There have been some related initiatives for quantifying and indexing durability. For example, in 2020, “EN 45552-General method for the assessment of the durability of energy-related products” was published in response to a European Commission request. France implemented a repairability indexing requirement for five electrical and electronic equipment (EEE) categories, including smartphones, laptops, TVs,

front-loading washing machines, and electric lawnmowers in 2021. In November 2022, four more product categories, including dishwashers, top-loading washing machines, vacuum cleaners, and high-pressure cleaners were added to the list. They plan to introduce a durability index framework by adding more criteria to the current reparability index by 2024.

Although no practical durability indexing method has been introduced so far, we expect that a robust and unbiased durability measure will include a range of relevant product attributes such as reliability, robustness, reparability, upgradability, longevity, and operating time (French Agency for Environment and Energy Management 2021).

Among all the related attributes, reliability and reparability have been widely considered in the previous studies, and these attributes have the most significant impact on product durability (Cordella, et al. 2021, European Committee for Standardization CEN/CENELEC 2020). Although reliability is a well-established knowledge domain, reparability has been more considered in recent years.

Reliability is the probability that a product will perform its intended function adequately for a specified time under specified use conditions. This probability is an index for reliability. Manufacturers assess the reliability of their products using laboratory tests (e.g., accelerated life testing) and field data (e.g., returned devices data). Organizations such as IEEE, IEC, and JEDEC have developed standards and handbooks that provide guidance for measuring product reliability. In addition, many research papers assess the reliability of EEE using more advanced methods such as Bayesian analysis.

Reparability is the ease of returning a product to its functioning state after a failure. The French reparability index, EN 45554, the Joint Research Center repair scoring system, the Assessment Matrix for ease of Repair, ONR 192102, and iFixit are prominent reparability assessment methods, most of which were developed after 2018. These methods commonly calculate a reparability measure by scoring some repair-related parameters (such as the number of steps for disassembling critical parts or the duration of availability of spare parts) and then aggregating these scores into an overall reparability score.

Calculating and combining reliability and reparability measures might yield a durability

measure that promotes a circular economy. A circular economy is also a means to the more sustainable use of the earth's limited resources. Therefore, the question of how improving product durability impacts the circular economy can be answered by integrating the durability measures with a sustainability index. Assessing durability and sustainability together has been considered in some ecolabels (e.g., TCO), not for indexing purposes. However, there are previous studies on indexing product sustainability (Hapuwatte and Jawahir 2021) that can be integrated with the reliability and reparability measures.

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Calibrated Self-Training for Cross-Domain Bearing Fault Diagnosis

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Fault diagnosis of rolling bearings is a crucial task in Prognostics and Health Management, as rolling elements are ubiquitous in industrial assets. Data-driven approaches based on deep neural networks have made significant progress in this area. However, they require collecting large representative labeled data sets. However, in industrial settings, assets are often operated in conditions different from the ones in which labeled data were collected, requiring a transfer between working conditions. In this work, we tackle the classification of bearing fault types and severity levels in the setting of unsupervised domain adaptation (UDA), where labeled data are available in a source domain and only unlabeled data are available in a different but related target domain. We focus on UDA with self-training methods, based on pseudo-labeling of target samples. One major challenge in these methods is to avoid error accumulation due to low-quality pseudo-labels. To address this challenge, we propose incorporating post-hoc calibration, such as the well-known temperature scaling, into the self-training process to increase the quality of selected pseudo-labels. We implement our proposed calibration approach in two self-training algorithms, *Calibrated Pseudo-Labeling* and *Calibrated Adaptive Teacher*, and demonstrate their competitive results on the Paderborn University (PU) benchmark for fault diagnosis of rolling bearings under varying operating conditions.

Keywords: Bearing fault diagnosis, Domain adaptation, Self-training, Pseudo-labels, Confidence, Calibration

1. Introduction

Applications of unsupervised domain adaptation (UDA) methods to bearing fault diagnosis, such as domain-adversarial neural networks (DANN), have been studied on several data sets by Zhao et al. (2021). Self-training methods based on pseudo-labeling of target samples have also been explored in the literature Wu et al. (2020); Zhu et al. (2022); Wang et al. (2022). In particular, *curriculum pseudo-labeling* (CPL), first introduced for semi-supervised learning, is a strategy where pseudo-labels (PLs) are gradually introduced during the learning process in a “easy-to-hard” manner, starting with the most confident target predictions and using prediction confidence (i.e., maximum softmax probability) as a proxy for correctness. Once the model is adapted to the target domain, more samples can be explored. CPL can also dynamically adjust the confidence threshold for each class during training based on its current accuracy using an *adaptive threshold*. This accounts for the varying difficulties of classes

and enables target samples from low-confidence classes to participate early in the training. Another very effective approach is the *Mean Teacher* framework, where a student network receives target PLs from a teacher network, which is updated by exponential moving average (EMA) of the student weights. In the *Adaptive Teacher* (AT) Li et al. (2022), a domain discriminator is added to jointly align features (see Figure 1). However, none of these works has studied model calibration.

2. Calibrated self-training

A model is *well-calibrated* if its confidence scores actually correspond to the accuracy of the predictions. As our aim is to increase the accuracy of the selected PLs and confidence is used as a proxy for accuracy, we seek well-calibrated target outputs. Hence, we propose to calibrate the model outputs before selecting the confident PLs to train on. We evaluate post-hoc calibration via temperature scaling (using only source labels) and calibrated predictions with covariate shift (CPCS) Park et al. (2020) to account for domain shift.

Domain Adaptation with Calibrated Pseudo-Labeling (DA-CPL) combines DANN and CPL with an adaptive threshold. Between each training epoch, re-calibration is performed and the PLs are produced based on the calibrated target predictions. Similarly, we propose **Calibrated Adaptive Teacher (CAT)** to improve the Adaptive Teacher by calibrating the teacher network’s predictions on target samples, as depicted on Figure 1. In both

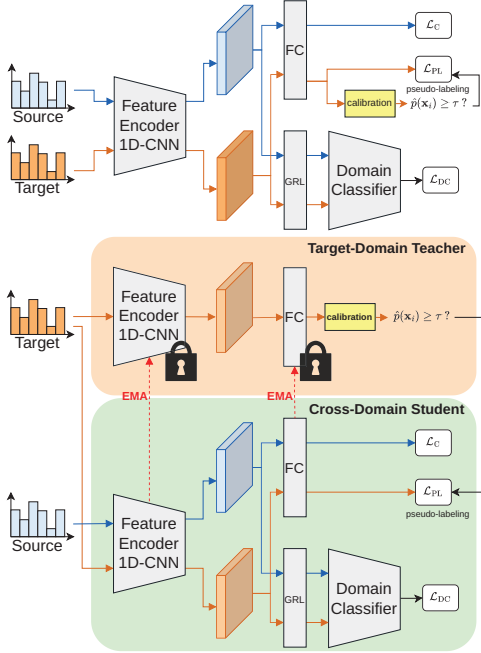


Fig. 1. DA-CPL (top) and CAT (bottom).

methods, the loss function has 3 terms: a supervised source loss \mathcal{L}_C , a target pseudo-labeling loss \mathcal{L}_{PL} and the domain classifier term \mathcal{L}_{DC} .

3. Experimental results

Experiments are carried out on the Paderborn University (PU) data set Lessmeier et al. (2016), which comprises challenging transfer learning tasks between 4 operating conditions. For brevity, results are reported only for the transfer task 0→1 and time-domain inputs. In Table 1, we report the accuracy and expected calibration error (ECE) on the target test set. We use the same experimental setting as Zhao et al. (2021) and introduce calibration at epoch 150. All experiments are repeated

Table 1. Results on the PU data set (task 0→1).

Method	Accuracy (%) \uparrow	ECE (%) \downarrow
Source-only DANN	15.15 \pm 1.03 36.96 \pm 2.45	78.90 \pm 0.96 55.70 \pm 2.27
DA-PL + adaptive thresh.	36.44 \pm 3.20 37.52 \pm 3.32	58.27 \pm 2.78 57.57 \pm 2.88
DA-CPL (Ours) + temp. scaling + CPCS	36.75 \pm 3.89 38.77 \pm 3.01	44.13 \pm 2.72 21.08 \pm 10.2
AT + adaptive thresh.	38.47 \pm 2.83 42.24 \pm 3.07	52.79 \pm 2.78 44.93 \pm 4.07
CAT (Ours) + temp. scaling + CPCS	46.01 \pm 3.01 46.81 \pm 2.75	22.44 \pm 5.37 8.61 \pm 3.56

5 times with different random train/test splits and initializations because we noticed a large variability between runs. We measure the performance at the last training iteration. Our results demonstrate that introducing calibration significantly improves the accuracy and reduces ECE on the target data. Even though temperature scaling does not account for domain shift, it is still effective in our experiments thanks to the well-aligned features. Moreover, CAT outperforms existing methods and achieves state-of-the-art performance on this task.

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Digital Twin Modeling for Enhanced Operational Reliability: A case study on a dredging perception system

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A decision-making system provides system state conditions and general operation instructions to operators based on all available sensing data. This can effectively assist the operators in these decision-making on how to proceed but high reliability of the perception system is, then, crucial.

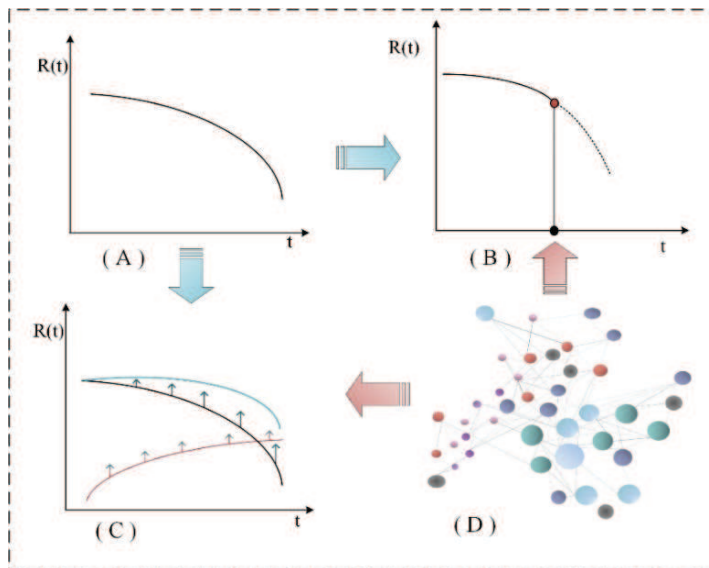


Fig.1 Schematic diagram. Fig.1 (A) depicts the operational reliability of the perception system through a time-varying curve. Fig.1 (B) depicts how, in the event of a sudden failure resulting in operational reliability $R=0$, represented as “0 states”, the system swiftly recovers its reliability by employing a DT model. To improve system reliability, the DT values and measurement values are fused in state (1, 0), as illustrated by

the red and black curves, respectively. The fused values are shown in blue (C). The DT model is constructed using sensor data obtained from the perception system (D).

As shown conceptually in Fig. 1, we consider the service life, as divided in three states according to the principle of operational reliability. In the first state, the sensing equipment is newly installed and calibrated, and all performance indicators are in the optimal state, defined as the reliability state $R = 1$. In the second state, in which the operational reliability state is $R = (1, 0)$, the performance of the sensing instrument gradually declines over time. The third state, labeled as the “0 state”, indicates operational reliability $R = 0$. This occurs when one or more key sensing instruments of the system have sudden failure or reach the specified service life, causing the system to fail to perform assigned tasks (Fig. 1B); this leads to future of the perception system's reliability.

To represent this process, we propose a data-driven approach to establish a digital twin (DT) model of the perception system (Fig. 1D), which can increase in reliability with the service time of the perception system (Fig. 1C). By implementing this model during the “1 state” or “(1,0) state”, we can effectively slow down the decline in operational reliability and prolong the system's working life in the second stage, while also preventing the system from entering the third state (of future) during the service period. To validate the effectiveness of our approach, we present a case study of a dredging perception system.

Keywords: Reliability; Digital twin; Data-Driven Model; Information Fusion; Dredging; Perception System.

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Learnable wavelet transform and domain adversarial learning for enhanced bearing fault diagnosis

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Unsupervised domain adaptation techniques have been widely used to detect the health conditions of rolling bearings. Despite the importance of cross-domain fault diagnosis, it has not received much attention for applications in noisy environments. To address this issue, we propose a novel architecture that combines learnable wavelet packet transform with domain adversarial neural networks (DANN-LWPT). The proposed method involves utilizing the learnable wavelet packet transform (LWPT) and wavelet packet transform (WPT) to decompose and reconstruct signals from the source and target domains. These reconstructed signals are then fed into a domain adversarial neural network (DANN). We introduce a guidance loss that dynamically enforces similarity between the source and target domain signals in the time-frequency domain during the process of decomposition and reconstruction, promoting the learning of domain-invariant and discriminative features. We compare our proposed method with other representative domain adaptation approaches, and the results of the evaluation show its superiority.

Keywords: Rolling bearing, Fault diagnosis, Unsupervised domain adaptation, Learnable wavelet packet transform.

1. Introduction

With the great demand for higher reliability and safety of increasing number of industrial machines, unsupervised domain adaptation (UDA) fault diagnosis techniques have been developed rapidly and applied widely. However, most UDA methods that perform well are designed for low-level noise data in laboratory environments (Zhao et al. 2021). In real-world scenarios, the performance of these methods may significantly deteriorate due to the presence of various types and levels of noise during signal acquisition.

The recently proposed LWPT algorithm can automatically learn meaningful and sparse features of raw signals (Frusque and Fink 2022). Inspired by this, an architecture that combines learnable wavelet packet transform with domain adversarial neural network (DANN-LWPT) is proposed for fault diagnosis of rolling bearings under noisy environment.

2. Method

Fig. 1 illustrates the overall framework of our proposed DANN-LWPT. The first step involves feeding separately the source and target signals into the separate encoders of LWPT and WPT modules for signal decomposition, obtaining learnable wavelet coefficients and traditional wavelet coefficients, respectively. In the second step, the learnable wavelet coefficients and traditional wavelet coefficients are separately reconstructed into time-domain signals by the decoders of LWPT and WPT modules. During the learning process, the features of the learnable wavelet coefficients dynamically approximate the features of the traditional wavelet coefficients during the learning process, under the guidance loss L_G , which is expressed as:

$$L_G = \sum_{j=1}^{2^L} \left| \mathbb{E} \left[\frac{1}{B} \sum_{i=1}^B |c_{i,j}^s| \right] - \mathbb{E} \left[\frac{1}{B} \sum_{i=1}^B |c_{i,j}^t| \right] \right| \quad (1)$$

where L is the number of decomposition layers in LWPT and WPT modules, $E[\cdot]$ represents the expectation of the elements from a vector, B is the batch size, $c_{i,j}^s$ and $c_{i,j}^t$ are the wavelet coefficients of the j -th output node of the i -th source domain sample and target domain sample, respectively.

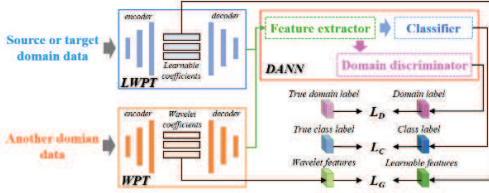


Fig.1 Architecture of the proposed method.

In the last step, the reconstruction signals of the source and target domains are fed into a typical domain adversarial neural network (DANN) (Zhao et al. 2021), which consists of a feature extractor, a domain discriminator, and a classifier. The total loss function of the DANN-LWPT can be defined as:

$$L = L_C + \lambda L_D + \mu L_G \quad (2)$$

where L_C is the classification loss, L_D is the domain discriminator loss, λ and μ are the trade-off parameters.

3. Results

We utilize the vibration data of the drive end bearing of the CWRU dataset with a sampling frequency of 12 kHz, which contains four operating states (0, 1, 2, 3) and ten bearing states (one normal state and three fault types including inner fault, ball fault and outer fault with three different fault sizes).

We segment the original vibration signals into sub-samples using a sliding window of length 1024 without overlapping between adjacent samples. We randomly select 80% of the samples for each bearing state as the training set and the remaining 20% as the test set.

To imitate the case of noisy environments, we added white Gaussian noise to all target domain data to maintain a signal-to-noise ratio of -5. To evaluate the performance of the proposed DANN-LWPT, we compare it with four other methods (Zhao et al. 2021), including correlation alignment (CORAL), multi kernels maximum mean discrepancy (MK-MMD), DANN, and joint maximum mean discrepancy (JMMD). For the

DANN-LWPT, it is worth noting that in order to denoise the noisy target domain data and make them similar to those of the noise-free source domain data, we fed the target domain data into the LWPT module and the source domain data into the WPT module. Table 1 presents the mean and the standard deviation of the classification accuracy for three transfer tasks after calculating with five random seeds. The baseline in the table contains only a feature extractor and a classifier, whose architectures are consistent with those two modules in DANN.

Table 1. Classification results of noisy CWRU dataset.

Task	Q0→1	Q0→2	Q0→3
Baseline	16.6%±4.1%	24.2%±4.3%	18.3%±5.2%
CORAL	11.9%±2.2%	10%±0.0%	15.3%±4.2%
MK-MMD	47.4%±8.3%	45.5%±4.5%	33.4%±5.9%
DANN	65.8%±4.7%	61.8%±5.2%	45.0%±10.7%
JMMD	24.8%±4.5%	27.3%±4.0%	22.5%±3.2%
DANN-LWPT	78.8%±1.6%	82.9%±1.2%	64.4%±0.9%

As shown in Table 1, the proposed DANN-LWPT achieves the highest diagnostic accuracy in all three cross-domain tasks, with an improvement of 13.0% to 72.9% compared to other methods.

4. Conclusion

By utilizing the DANN-LWPT method, UDA for fault diagnosis can be achieved in noisy scenarios. In summary, our findings suggest that 1) promoting domain alignment through enforcing similarity between the representations of source and target data in the time-frequency domain can be effective; and 2) the proposed DANN-LWPT method outperforms other DA methods for fault diagnosis in noisy conditions.

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Preliminary reliability analysis of autonomous underwater vehicle in the polar environment based on failure mode and effects analysis and fault tree analysis

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Autonomous underwater vehicles (AUVs) are often used in extreme environments, making reliability assessment important. To evaluate the preliminary reliability of AUVs operating in polar environments, this study utilized failure mode and effects analysis (FMEA) and fault tree analysis (FTA). FMEA was conducted based on the functional analysis of the AUV, identifying nineteen potential failure modes and thirty failure causes. The results suggest correlations between major failures, accidents, and their causes. Using the FMEA results, a fault tree diagram was constructed by defining the loss of the AUV as the top event (TE) causing the greatest loss. The study categorized basic events (BEs) into two categories: BEs related to equipment reliability, such as equipment aging, equipment failure, and manufacturing defects, and BEs caused by polar environmental factors, such as collision with ice, low-temperature environment, and thermocline. By conducting a literature review, it was obtained failure probabilities of BEs. Using the obtained information, preliminary reliability analysis was conducted. This research can be useful for designing and testing AUVs that can perform reliably in extreme environments.

Keywords: Autonomous Underwater Vehicles (AUVs), Reliability, Risk, Polar Environments, Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA)

1. Introduction

Autonomous underwater vehicles (AUVs) are becoming increasingly important for performing missions in difficult underwater environments. Brito et al. (2010). Due to the high cost of developing or purchasing AUVs, ensuring their reliability is of paramount importance. Thieme and Utne (2017). Unfortunately, the harsh conditions in which AUVs are often used can result in failures or even the loss of the device, which can cause significant losses in terms of time, resources, and data. Loh et al. (2019). To improve the reliability of AUVs, this study aims to analyze the preliminary reliability of AUVs in polar environments using failure mode and effects analysis (FMEA) and fault tree analysis (FTA).

2. Results

First, we conducted a functional analysis of the AUV to define the essential functions required for its operation. And six functions are defined as follows:

- Power supply/distribution function
- AUV movement function
- Acquisition/distribution of necessary information for autonomous navigation
- Navigation and mission control function
- Exploration and measurement function
- AUV normal state maintenance function

2.1. Failure Mode and Effects Analysis (FMEA)

Based on the functional analysis results, we performed Failure Mode and Effects Analysis

(FMEA) to identify potential failure modes such as functional failure, performance degradation, intermittent operation, and unintended operation, and analyzed their effects and potential causes. The severity (S), occurrence (O), and detection (D) of failure mode were evaluated. Then, the Risk Priority Number (RPN) was calculated to prioritize the failure modes. Nineteen potential failure modes and thirty failure causes were suggested. And the following failure modes were identified as high-risk with a high RPN:

- Main thruster motor controller wiring harness short/opens
- Stuck of linear actuator
- Network errors between equipment responsible for internal network communication
- Loss of USBL with ATM signal
- Loss of iUSBL signal and incorrect signal transmission
- Failure of ADCP/DVL to measure velocity and altitude. ,

The results of FMEA were used to make design changes to the AUV and prepare operation and maintenance manuals.

2.2. Fault Tree Analysis (FTA)

Based on the FMEA results, a fault tree diagram was constructed to determine the loss of AUV as the top event (TE) causing the greatest loss. By conducting a literature review, it was obtained failure probabilities of basic events (BEs). Using the obtained information, preliminary reliability analysis was conducted. The analysis of critical systems for mission failure revealed that navigation and communication equipment, battery systems, propulsion systems, and sensors, in that order, have the greatest impact. In addition, BEs were classified into two categories: (1) Equipment failure such as equipment aging, equipment failure, and manufacturing defects, and (2) Failure caused by polar environment such as collision with ice, low-temperature environment, and thermocline.

In particular, we utilized Dynamic FTA to analyze the causal relationships over time and sequence of sensor failures, which are difficult to analyze using traditional FTA.

3. Conclusion

In conclusion, this study aimed to analyze the preliminary reliability of AUVs in polar environments using FMEA and FTA. By FMEA, potential failure modes were identified, and evaluated their severity and occurrence. Then, by conducting FTA, the probability of AUV loss was calculated. The results of this study will be useful for designing and testing AUVs that can perform reliably in extreme environments. While precise failure rates are difficult to obtain for AUVs, the results of this study are expected to contribute to the development of more reliable AUVs in the future.

Acknowledgement

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Estimation of economic losses associated with intentional attacks to process facilities: a vulnerability-based approach

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As security threats increase, the development of quantitative metrics for security assessment has become a concern in the last years. Still, current methodologies mostly focus on the performance of security barriers, without considering the performance of safety barriers and the economic losses associated with intentional attacks. This study evaluated the economic losses of a successful intentional attack accounting for the combined performance of safety and security barriers. The application to a case study highlighted the importance of considering integrated safety-security approaches to guide decision makers in allocating resources correctly.

Keywords: Integrated safety-security assessment, Bayesian Networks, Economic loss estimation.

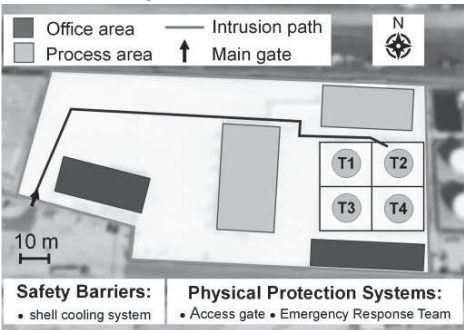
ABSTRACT

Intentional attacks may damage chemical and process facilities leading to severe consequences in terms of casualties and economic losses. Several standards and methodologies for Security Risk Assessment were developed in the last twenty years. Still, the majority of those contributions aim at evaluating the performance of security barriers, i.e., Physical Protection Systems (PPS) without accounting for the contribution of other factors, such as Safety Barriers (SB). Indeed, the performance of SB, e.g., firefighting, interlocks, etc., should also be included in security analyses, as their intervention might prevent/mitigate intentional

attack scenarios (Shuaiqi et al., 2022). Moreover, approaches that focus on estimating the economic losses of a successful intentional attack are still lacking.

This work aimed at evaluating the coupled performance of PPS and SB in reducing the potential economic losses. Vulnerability, i.e., the probability of successfully carrying out the attack, and economic losses were evaluated. A probabilistic approach based on Bayesian Networks (BN) was used to quantify the analysis. The first step of the methodology was the retrieval of performance data associated to PPS (Garcia, 2008; Argenti et al., 2017) and SB (Khakzad et al., 2018). Then, the integrated

performance of SB and PPS were modelled into the BN by using specific sets of nodes. The final step of the methodology was the evaluation of economic losses. In this work a simplified approach based on (Khakzad et al., 2018) was adopted, and losses were associated with the price of the damaged equipment (e.g., storage tanks) and calculated by multiplying the price of each vessel by its damage probability. The methodology was applied to a case study, which is shown in Fig. 1.



T1-T4 are gasoline storage tanks protected by a shell water cooling in case of fire. Fig. 1 also shows the attack path: the intruder trespasses the main gate at night, and targets T2 with 15 kg of explosive. The catastrophic rupture of T2 leads to a pool fire. The consequences have been evaluated with integral models under 2/F stability conditions and eastward wind. The price of the equipment factored the costs of materials, as well as the additional costs of manufacturing, welding, transport, and installation.

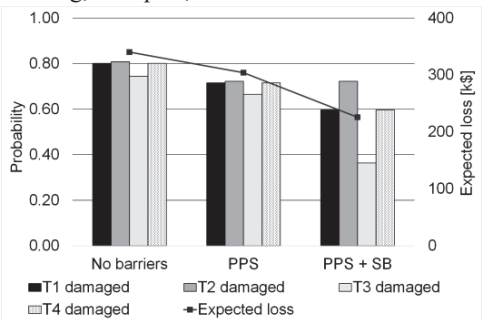


Fig. 2. Results of the application to the case study; PPS = Security barriers; SB = safety barriers

Fig. 2 shows the results of the analysis. Vulnerability of the assets has been evaluated in three cases: i) without any safety/security barrier; ii) only accounting for the contribution of PPS; and iii) synergy of PPS and SB. As shown in Fig. 2, the inclusion of PPS causes a 11% reduction in both probability of damage and economic loss. The inclusion of SB has instead a bigger impact, especially on vessel T3. The intervention of the water deluge system significantly mitigates the received heat radiation, causing a 50% decrease in T3 vulnerability. For T1 and T2 a reduction of 25% in vulnerability can instead be observed. This reflect on the economic loss, which is reduced by 34% compared to the case with no barriers.

In conclusion, this work explored the inclusion of safety-based protection in security studies. The application to the case study showed that the synergic performance of PPS and SB decreases asset vulnerability and expected economic loss. Therefore, the integration of safety and security approaches is necessary to correctly manage the resources of process facilities. Future works include a further characterization of SB performance and the improvement of the expected economic losses by including factors such as plant downtime.

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Stochastic Model Updating and Model Class Selection for Quantification of Different Types of Uncertainties

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Stochastic model updating has been increasingly utilized in various engineering applications to quantify parameter uncertainty from multiple measurement datasets. We have recently developed a stochastic updating framework, in which the parameter distributions are approximated by staircase density functions (SDFs). This framework is applicable without any prior knowledge of the distribution formats; thus, it can be considered as a distribution-free approach. On the other hand, measurement uncertainty should also be considered in model updating since the measurement is typically performed under hard-to-control randomness. However, in model updating, it is difficult to distinguish different types of uncertainties in the measurement datasets, and measurement uncertainty is often embedded in parameter uncertainty. To address this issue, this study employs the Bayesian model class selection framework, in which different types of probabilistic models are used to represent different types of uncertainties and the most appropriate model is determined based on the associated evidence. In this sense, the proposed framework does not require any prior knowledge about the sources of uncertainty in the measurement datasets. Simple numerical examples are used to demonstrate the proposed framework.

Keywords: Uncertainty quantification, stochastic model updating, Bayesian model updating, Bayesian model class selection, staircase density function, distribution-free approach.

1. Introduction

Stochastic model updating has gained increasing attention as a powerful technique to quantify parameter uncertainty by assigning a probabilistic model to the model parameters and calibrating its hyper parameters from multiple measurement datasets. Thus, the updating results depend on the probabilistic model assumption.

We have recently developed a distribution-free approach to stochastic model updating, where the probabilistic model is defined using SDFs (Kitahara et al., 2022). This approach relies only on the bounded set of the probabilistic model, and within this set, a broad range of distributions are arbitrarily approximated using SDFs.

On the other hand, measurement uncertainty should also be considered in model updating since the measurement is typically done under hard-to-

control randomness. In stochastic updating, these two types of uncertainties are often not separated and are both characterized using the parameter distribution. However, this can result in the over-estimation of parameter uncertainty.

In this study, the aforementioned framework is combined with Bayesian model class selection (Beck and Yuen, 2004) to quantify different types of uncertainties. This framework uses different probabilistic model classes to represent different types of uncertainties. The optimal model class is then determined based on the evidence that can be computed as the by-product in the model updating through a Bayesian fashion.

2. Outline of the Proposed Framework

In this framework, the following three probabilistic model classes are considered:

$$\mathcal{M}_1(x, \sigma_\varepsilon^2) = h(x) + \mathcal{N}(0, \sigma_\varepsilon^2) \quad (1)$$

$$\mathcal{M}_2(x|\boldsymbol{\theta}) = h(x|\boldsymbol{\theta}), \text{ with } x \sim \mathcal{SD}(\underline{x}, \bar{x}, \boldsymbol{\theta}) \quad (2)$$

$$\mathcal{M}_3(x|\boldsymbol{\theta}, \sigma_\varepsilon^2) = h(x|\boldsymbol{\theta}) + \mathcal{N}(0, \sigma_\varepsilon^2), \quad (3)$$

with $x \sim \mathcal{SD}(\underline{x}, \bar{x}, \boldsymbol{\theta})$

where h is the simulator with the model parameter x ; $\mathcal{N}(0, \sigma_\varepsilon^2)$ is a random variable that follows the Gaussian distribution with the zero mean and the variance σ_ε^2 ; $\mathcal{SD}(\underline{x}, \bar{x}, \boldsymbol{\theta})$ is the staircase random variable with the lower and upper bounds \underline{x} and \bar{x} and hyper parameters $\boldsymbol{\theta}$. In these model classes, measurement uncertainty is given as the Gaussian variable $\mathcal{N}(0, \sigma_\varepsilon^2)$ while parameter uncertainty is modeled as the staircase variable $\mathcal{SD}(\underline{x}, \bar{x}, \boldsymbol{\theta})$.

The hyper parameters, i.e., $\boldsymbol{\theta}$ and σ_ε^2 , can be calibrated using the well-known Bayes' theorem:

$$P(\boldsymbol{\theta}|\mathcal{M}, \mathbf{Y}_D) = \frac{\mathcal{L}(\mathbf{Y}_D|\boldsymbol{\theta}, \mathcal{M})P(\boldsymbol{\theta}|\mathcal{M})}{P(\mathbf{Y}_D|\mathcal{M})} \quad (4)$$

where $P(\boldsymbol{\theta}|\mathcal{M})$ is the prior distribution of $\boldsymbol{\theta}$ that consists of $\boldsymbol{\theta}$ or/and σ_ε^2 ; $P(\boldsymbol{\theta}|\mathcal{M}, \mathbf{Y}_D)$ denotes the posterior distribution of $\boldsymbol{\theta}$; $\mathcal{L}(\mathbf{Y}_D|\boldsymbol{\theta}, \mathcal{M})$ denotes the likelihood function based on the measurement datasets \mathbf{Y}_D ; $P(\mathbf{Y}_D|\mathcal{M})$ indicates the evidence for the model class \mathcal{M} . The posterior distribution is obtained via the transitional Markov chain Monte Carlo (TMCMC) algorithm. In its procedure, the evidence is obtained as a by-product, which serves as the plausibility measure of the model class given the measurement datasets. Thus, the optimal model class can be determined as the one that provides the largest evidence value.

3. Numerical Example

The framework is demonstrated using examples of a polynomial function $h(x) = 0.1(x + 1)^2 + 0.5$. We consider three synthetic datasets with the same sample size of 1000; (i) datasets with measurement uncertainty, where the true system response $h(0)$ is contaminated by Gaussian noise $\mathcal{N}(0, \sigma_\varepsilon^2)$ with σ_ε chosen as 10 % of the system response; (ii) datasets with parameter uncertainty which are generated by assigning the parameter distribution $x \sim \mathcal{N}(0, 1)$; (iii) datasets with both measurement and parameter uncertainty, in which the multiple system responses are contaminated by the Gaussian noise.

For each datasets, the proposed framework is carried out using the three model classes above;

hence, a total of 9 TMCMC procedures are in use. The evidence values obtained are summarized in Table 1. It can be seen that, for each datasets, the appropriate model class is chosen as the optimal one as it provides the largest evidence value.

Table 1. Evidence for each model class.

Datasets	Model class	Evidence
(i) Measurement uncertainty	\mathcal{M}_1	2.0×10^{-3}
	\mathcal{M}_2	2.3×10^{-5}
	\mathcal{M}_3	2.8×10^{-5}
(ii) Parameter uncertainty	\mathcal{M}_1	5.9×10^{-14}
	\mathcal{M}_2	1.6×10^{-3}
	\mathcal{M}_3	6.4×10^{-4}
(iii) Both uncertainties	\mathcal{M}_1	8.0×10^{-21}
	\mathcal{M}_2	1.2×10^{-5}
	\mathcal{M}_3	5.1×10^{-4}

For datasets (iii), the calibrated distribution of x is obtained for \mathcal{M}_2 and \mathcal{M}_3 as SDF assigning the posterior estimates of $\boldsymbol{\theta}$ and shown in Fig. 1. As can be seen, \mathcal{M}_2 results in the overestimation of parameter uncertainty whereas \mathcal{M}_3 provides an appropriate estimation.

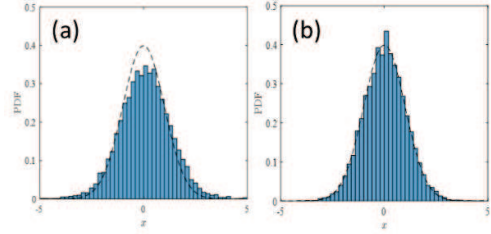


Fig. 1. Calibrated PDF of x for (a): \mathcal{M}_2 and (b): \mathcal{M}_3 .

4. Conclusion

An uncertainty quantification approach combining Bayesian model updating and model class selection is developed. Simple numerical examples indicate that the approach can distinguish different sources of uncertainties and quantify parameter uncertainty as appropriate.

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Quantum Optimization for Redundancy Allocation Problem Considering Various Subsystems

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The Redundancy Allocation Problem (RAP) is a widely studied NP-hard Combinatorial Optimization (CO) issue in reliability engineering. It involves assigning components to parallel or serial subsystems to maximize system reliability within a given budget. RAP has been extensively researched in various fields, such as electrical power systems and computer networks, with different configurations, including multi-objective, bi-objective, and mono-objective setups, as well as series, parallel, and parallel-series equipment arrangements. In recent years, quantum computing has emerged as a promising approach for solving CO problems, including RAP. Quantum processors, such as those developed by D-Wave Systems, have undergone significant research and testing in academic and commercial environments for solving combinatorial problems. This study aims to solve two multi-subsystems RAP instances using a D-Wave quantum annealing computer. The results provide a concept proof of the usability of quantum hardware and hybrid-quantum algorithms for RAP.

Keywords: Redundancy Allocation Problems. Reliability Optimization. Quantum Optimization. Quantum Computing.

1. Introduction

The Reliability Allocation Problem (RAP) involves assigning redundant components to subsystems to maximize system reliability. This problem has multiple applications from both a multi-objective and mono-objective perspective and can be solved using various exact and metaheuristic methods. To effectively handle combinatorial optimization problems such as RAP, several Ising model-based computers, also known as annealing machines, have been developed (Ajagekar et al., 2019). In this study, we aim to solve the RAP problem using a Hybrid Quantum Annealing quantum method, via D-Wave computer. In a previous study (Araújo et al., 2022), we solved the RAP problem with only one system and multiple components. In this study, we consider multiple subsystems and propose an approximative formulation that fits the Quadratic Unconstrained Binary Optimization (QUBO) problem.

2. Problem Formulation

The mono-objective problem aims to maximize system reliability, subject to a cost constraint (C) for purchasing components. The system consists of different component types (ct) organized into subsystems (j), and each subsystem must have components within a minimum ($n_{j,min}$) and a maximum ($n_{j,max}$) limit.

A single subsystem failure in a series-parallel configuration can cause the entire system to fail. The reliability of the entire system is limited by the least reliable subsystem. While minimizing the probability of failure of the least reliable subsystem can increase system reliability. However, it can also compromise the reliability of other subsystems if done excessively. Therefore, it is important to balance the failure probabilities of all subsystems while minimizing the probability of failure of the least reliable subsystem.

The objective function in this approach, Eq. (1), involves the natural logarithm of the product

of subsystems' failure probability ($\prod_{j=1}^s F_j$), and the natural logarithm of the maximum subsystem failure probability ($\text{IF}_{\max} = \ln(F_{\max})$). To prioritize the search for systems with a low probability of failure in critical subsystems, the factor s^2 (i.e., the squared number of subsystems) has been adopted for IF_{\max} . In Eq. (2), the right-hand side is equal to $\ln(F_j)$.

$$\min s^2 \cdot \text{IF}_{\max} + \sum_{j=1}^s \sum_{k=1}^{ct_j} x_{jk} \ln(1 - R_{jk}) \quad (1)$$

$$\text{s. a., } \text{IF}_{\max} \geq \sum_{k=1}^{ct_j} x_{jk} \ln(1 - R_{jk}), \forall j \quad (2)$$

$$\sum_{j=1}^s \sum_{k=1}^{ct_j} c_{jk} x_{jk} \leq C \quad (3)$$

$$n_{j,\min} \leq \sum_{k=1}^{ct_j} x_{jk} \leq n_{j,\max}, \forall j \quad (4)$$

$$x_{jk} \in \{0, 1, \dots, n_{j,\max}\}, \forall j; \forall k \quad (5)$$

We utilized the D-Wave library to convert the problem, modeled as a QUBO, into an Ising Hamiltonian. The decision variables were converted into binary; inequality constraints were transformed into equality constraints by adding slack and excess variables; and these constraints were then incorporated into the objective function as a penalty, resulting in the QUBO formulation. To solve the problem, we employed the Leap Hybrid CQM Sampler from D-Wave's Ocean SDK, which is a hybrid classical-quantum solver that combines a classical optimizer with a quantum sampler. The classical optimizer used by default is the L-BFGS-B algorithm.

4. Results

We tested small instances for analysis and to demonstrate the effectiveness of the hybrid-quantum algorithm. It should be noted that due to qubit limitations, we were unable to test quantum simulators provided by IBM, such as the Statevector and QASM simulator, as we did in the previous study with only one subsystem (Araújo et al., 2022).

The instances used for testing are in Table 1. In instance #1, the hybrid-quantum approach found the optimal solution with an energy value of -8.11. The results showed that subsystem 1 had one unit of component 1, while subsystem 2 had two components (one of type 1 and the other of type 2). The overall system reliability resulted in 0.873. For instance #2, the best solution was at an energy level of -13.86. The reliability analysis showed that at subsystem 1, there was one unit of component 1 and one unit of component 3. At subsystem 2, there was one unit of component 1

and one unit of component 2. At subsystem 3, there were two units of component 1. Overall, the system reliability reached 0.9126.

Table 1. Instances of the multi-subsystem active parallel RAP ($n_{j,\min} = 1$, for $s = 1, \dots, s$).

#	s	$n_{j,\max}$	C	ct_j	R_{1k}	R_{2k}	R_{3k}	c_{1k}	c_{2k}	c_{3k}
1	2	2	8	2	0.9	0.9	-	3	3	-
		2		2	0.7	0.7		2	2	
2	3	3	13	3	0.9	0.9	0.8	3	3	2
		2		2	0.8	0.8		2	2	
		2		2	0.7	0.7		1	1	

It is important to emphasize that all these outcomes were equal to those acquired by the exhaustive method, and they were obtained in less than 20 seconds. Note that, as stated earlier, we tested small instances (detailed in Table 1) that, even though NP-hard in nature, were able to map in reasonable time to feasible solutions through the exhaustive method. In future research, more instances will be tested, and we intend to perform experiments with algorithms that utilize quantum circuits, such as the QAOA and the VQE.

5. Conclusion

The field of combinatorial optimization has been greatly influenced by quantum computing in recent years. This study adds to this trend by presenting a linear problem approximation of a multi-subsystem series-parallel RAP, which is solved using a hybrid-quantum approach. It should be noted that while there are limitations in terms of available qubits, this technique shows promise for future reliability optimization research.

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Towards a Graphical Specification of Operational Rules in RiskSpectrum ModelBuilder

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Model Based Safety Assessment (MBSA) tools encapsulate dependability expertise in the definition of high-level components. Detailed (formal) description of component behavior and interactions can be created by an expert and exposed to users only on the level required for building system models. Knowledge Bases in RiskSpectrum ModelBuilder (KB3) implement this separation by offering an analyst a library of graphical components with their properties and possible connections. Component behavior and interactions are pre-defined using the modeling language Figaro. This includes also operational rules that steer the system under study. We generalize our experience from real-life projects that developed such Knowledge Bases. We investigate how a common graphical formalism such as flow charts can be used, in connection with the Figaro language, to structure the Knowledge Base creation and facilitate quality of the final code. The proposed method takes a graphical specification of operational rules satisfying certain additional conditions on input and guides the Knowledge Base creation process. This is the first step towards automatic generation of the Figaro code from a graphical specification.

Keywords: Model based safety assessment, knowledge bases, Figaro, graphical specification.

1. Knowledge Base Approach

Performing dependability studies, for example reliability/risk assessment of a nuclear station, availability assessment of a production unit is a complex task. If the asset under consideration is large/complex, many persons are involved in such analysis. The model created might also be kept alive and modified as the asset is modified. There is a need for tools that can help to encapsulate knowledge, simplify updates, add unique or tailor-made features in the assessment and facilitate the digitization also in the risk, reliability and availability domain.

There are several frameworks that can to different degree satisfy the above criteria. In this paper we discuss mainly the modelling language Figaro (Bouissou et al., 1991) which is used in RiskSpectrum ModelBuilder (KB3). Some other established MBSA frameworks include AltaRica (Point and Rauzy, 1999), Safety Analysis Modeling Language (SAML) (Güdemann and Ortmeier, 2010), Hierarchically Performed Hazard Origin and Propagation Studies (Hip-HOPS) (Papadopoulos and McDerimid (1999)), and xSAP (Bittner et al. (2016)).

The Knowledge Base approach in RiskSpectrum ModelBuilder (KB3) is based on

the concept that general modelling rules (which component types can be represented, which failure modes and data, how component types are allowed/expected to interact, etc.) are stored in a so-called Knowledge Base. The Knowledge Base is hence a “center for knowledge” and is typically setup by an expert of this type of problem – to simplify and quality assure the modeling across systems. This means that the analyst building the models of the systems can focus on the system itself and the generic modelling routines are managed by the Knowledge Base. Possible application areas for the Knowledge Base approach include production analysis of processing plants, power plants or downstream oil&gas industry. Analyses can evaluate and compare different designs by modifying the plant or its reliability parameters.

The Knowledge Base approach using the modeling language Figaro (Bouissou et al., 1991) offers all flexibility in adapting component type behavior and interactions exactly for the purpose of the dependability study. This includes not only rules for individual types of components, but also encoding relevant rules determining plant behavior based on the global state – operational rules of the plant (Krcal et al., 2022).

2. Graphical Representation of Operational Rules

As an addition to already existing design and debugging tools, this paper proposes a new method for encoding operational rules in the Figaro code of a Knowledge Base. A Knowledge Base creator specifies these rules in a commonly used formalism (e.g., flow charts), following certain restrictions on the conditions and commands. This specification together with the Figaro definitions of the other relevant classes is used by our method to structure the component interaction, information flow and plant decision steps. We also evaluate to what extent can the Figaro code be automatically generated from such high-level descriptions.

We illustrate the conceptual idea by an example. Assume a processing system with three units (1, 2, and 3) sending output product to a storage. Storage is emptied by another process according to its demand D . Storage level L should not fall below a threshold T .

Operational rules of the plan start and stop the processing units according to the priority order where 1 has the highest priority and 3 the lowest. Figure 1 depicts these operational rules in a flow chart. One can derive the following structures in the Figaro code of a Knowledge Base.

Interaction rules of the class representing the operation control unit can be derived directly from the flowchart. If we express conditions and commands in the Figaro language, then each path between two adjacent command represents one rule. Variables $level$ and i become local attributes of the class. They are updated only in the interaction rules of this class and never used outside of this class.

Order of interaction rules execution across the classes (Steps Order) is determined by using attributes from other objects. E.g., L and D have to be calculated before we enter operational rules. Thus, their step order will be lower than that of the operational rules. The processing level of units $P(i)$ also needs to be calculated before we use it.

There has to be a possibility to start and stop processing units. The control unit class needs an interface where processing units will be included. Interaction rules can change the state of the processing units, which update their processing capacity by own interaction rules in a step following interaction rules of the control unit.

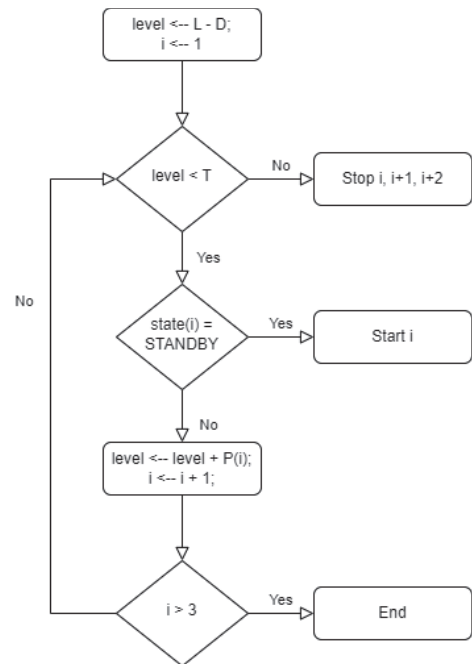


Figure 1. A flowchart for sample operational rules.

2. Conclusions

This work shows the first steps towards a structured or even automatic generation of the Figaro code for Knowledge Bases from a standard graphical representation of operating rules.

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