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ABSTRACT
BOOK**

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An overview of optimisation models for offshore windfarm maintenance - Prof. Rommert Dekker (Erasmus School of Economics, Netherlands)

In this talk we give an overview of optimisation approaches for reducing maintenance costs of offshore windfarms comprising of many identical windmills. Many coastal countries are building very large offshore windfarms and the success of the energy transition depends on the profitability of these windfarms where maintenance cost play a dominant role.

We will first consider the maintenance of one windmill, in terms of components and failure modes as well as the choice for time-based and/or condition-based maintenance. Next we will consider the logistic challenges around the maintenance of these offshore windfarms and how these have been addressed by operations research methods.

On Missions' Quality of Performance for Systems with Partially or Completely Observable Degradation - Maxim Finkelstein

At some instances, it is better to terminate operation of a system than to wait for its failure or completion. However, here we are mostly interested in missions that are cost-effective during the whole mission time and, therefore, do not require termination. We consider two failure models for systems executing missions of the fixed duration. In the first model, degradation is partially observed via the number of shocks experienced by a system. Shocks act directly on the failure rate, forming the shot-noise process. In the second model, degradation is completely observed and is modeled by the Poisson process. Thus, the number of shocks or the number of failed components are the degradation parameters in our models, respectively. The detailed numerical examples illustrate our findings. Specifically, the bounds for the number of events (shocks or component's failures) observed at each instant of time that guarantee cost-effectiveness of a mission are obtained.

Prognosis for a deterioration system with deteriorated sensor systems

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We consider the monitoring of a gradually deteriorating system. For predictive maintenance planning, based on the observed health indicator of the system, the Remaining Useful Lifetime (RUL) of the system is estimated. However, the observations are given by sensors and can be also impacted by measurement errors. Moreover, the sensor systems, composed of several sensors, can be deteriorated if one or more sensors are failed or faulty. Since the efficiency of the prognosis results depends substantially on the precision of the available observations, taking into consideration the deterioration of sensor systems is an important issue. To be able to study all tiny deviations from the nominal behavior of a system and to model all possible deterioration states, the monitored system and the sensor system deterioration are both modelled by a Lévy process such as Wiener or gamma process. The observations of the health indicator are considered to be an addition of the two deterioration phenomenon and a possible noise. First, through filtering methods, the system health indicator is estimated and then an estimation of its short-term and long-term remaining useful lifetimes is given. Two filtering methods are used: Particle filtering and Gibbs sampling - Markov chain Monte Carlo (MCMC) filtering method. Each of these methods is used in the literature by there is no comparison of these methods in the framework of deterioration models considering Lévy processes for both system and sensor system deteriorations. The main purpose of this paper is to analyze the impact of the filtering method on the prognosis and to carry out a sensitivity analysis of different parameters and models on the prognosis efficiency.

Each observation at time t is considered to be a function of the deterioration level of the system, the health indicator of the sensor system, and a possible noise at that time. The deterioration processes and the noise are supposed to be all stochastically independent. The filtering method will give an estimation of the deterioration level of the system associated with a given uncertainty presented by a distribution. The precision of the estimation requires the definition of specific metrics. Based on the metrics under consideration, the estimation via different filtering methods can be compared. Afterward, the comparison will focus on the prognosis results and their associated uncertainty.

Keywords: Prognosis, Deterioration modeling, Sensor systems, Gamma process, Wiener process, Particle filtering, Gibbs sampling.

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A Novel Pattern-driven Stochastic Degradation Process for Battery Forecasting - Zihan Zhang

In recent decades, there has been significant growth in the development of rechargeable battery-powered devices, such as electric vehicles, leading to a huge demand for batteries with high reliability and quality. End of life (EoL) is a critical indicator of battery health; it can be estimated by either adaptive stochastic processes or advanced machine learning techniques. However, these approaches either follow the degradation path having a specific form or lack stochastic interpretation due to its black-box nature. To address these challenges, an GRU-driven stochastic degradation process is proposed that can formulate battery degradation, in which degradation fluctuation is controlled by a recursive Gaussian distribution with its mean learnt from an GRU-driven degradation pattern. Due to the non-Markovian state transitions, a sampling-based expectation maximization algorithm is developed to estimate model parameters based on historical observations. To validate the superiority of the proposed methods, a case study of battery data was implemented. The results show a better performance with respect to EoL accuracy than that achieved with traditional methods.

Incorporating defect specific condition indicators in a life cycle cost analysis of metal bridges

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Civil infrastructure such as bridges are critical to the operation of transportation networks. Infrastructure managers are responsible for ensuring that these assets adhere to stringent safety protocols to prevent structural failure and ensure reliable and functional operation. Infrastructure managers commonly employ Whole Life Cycle Cost (WLCC) modelling to ensure an optimal use of the available resources and to present different maintenance strategies to stakeholders.

WLCC modelling is composed of deterioration modelling to predict future asset condition and decision modelling, which simulates different maintenance strategies. The stochastic modelling of bridge deterioration is well established in literature, with models commonly calibrated using condition records from visual examinations. Such records typically use condition scales that represent deterioration as a single process. However, bridge deterioration is composed of many distinct degradation mechanisms all of which result in the reduction of the structural integrity of the bridge.

A Petri net model using novel Dynamic Conditional Transitions is presented to model the defect specific condition indicators, which incorporate the interactions between defects. The model calibration encapsulated several local, material and structural bridge properties that influence deterioration rates. Moreover, the additional indicators facilitate enhanced WLCC analysis including the evaluation of the effects of early defect-specific maintenance interventions.

The performance of the mixed Weibull model as a contribution tool to optimized maintenance policies of multi-component systems

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Abstract

Applying an effective maintenance policy generally requires the use of decision support models. The mixed Weibull model, characterized by its mixing parameter (W_i), has the property of assigning to each subsystem its real contribution to the degradation of the overall system by allowing a better view on the behavior of the system by highlighting hidden phenomena generated by predominant subsystems.

The mixed Weibull model makes it possible to better understand the overall behavior of the system by integrating a partition coefficient W_i into the simple model. The latter makes the modeling more relevant by evaluating the weight of each subsystem on the recurrence of the failure.

The mixing parameters (W_i) are evaluated by the maximum likelihood approach (MLE) based on real data from the TRAUB TNA 500 system. This modeling aims to optimize the maintenance policy and the overall efficiency of the system installation.

The key words: maintenance policy, mixed Weibull model, mixing parameter (w), Maximum likelihood.

Discussions on the reuse of items based on the delay time modelling

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ABSTRACT

The delay time concept has been used in a wide variety of applications for modelling important aspects regarded to the maintenance of systems. In some situations, the time in the defective state may interfere with the performance of the component or system, by reducing its efficiency, or may interfere with the cost of repairing components, for their subsequent reuse. As a consequence, on both occasions, the longer the time in the defective state, the worse the influence promoted by this period. Despite these facts, a small number of contributions deal with the influence of the time in the defective state and its respective cost. In addition, a limited number of works links delay modelling with the reuse of items. We thus present insights into the delay time model for second-hand items proposed by Santos et al. (2020). In general terms, the mentioned model may be applied to any component that wears along the time and may be replaced by a new or refurbished one. In the present work, the main contribution is the new discussions on the reuse of items in the context of single-component systems, from which new directions for further studies are established.

Keywords: Delay time, Single-component system, Reuse of items; Second-hand items.

Imperfect condition-based maintenance for deteriorating systems with different maintenance efficiencies

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This paper focuses on continuously deteriorating systems subjected to condition-based maintenance with imperfect repairs. In case of preventive action, a maintenance decision-maker can decide to plan a costly perfect replacement or cheaper imperfect maintenance which may lead to an additional perfect action if necessary. The effect of imperfect maintenance is random and reduces the system degradation level with a proportion that is described as a random variable. The distribution of this random variable can take different shapes to describe a possible loss of efficiency in imperfect actions. This work considers the Inverse Gaussian process for system degradation modeling and beta distribution for imperfect maintenance. A maintenance decision rule with three decision variables is proposed. Its aim is jointly to find an optimal dynamic inspection planning and an optimal balance between perfect and imperfect maintenance from an economical point of view. A long-term cost rate is assessed and minimized. Numerical results are given to describe the behavior of the maintenance policy for different configurations when the efficiency of imperfect maintenance is decreasing.

Assessing Trustworthiness of System Operability Checking

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Maintenance based on equipment instrumental inspection is widely used in technical systems with different physical properties. For commercial and military aircraft, such inspections are performed after a predetermined time. Therefore, in the research literature, the mathematical maintenance models based on equipment operability checks are highly valued. However, as the related published articles show, almost all relevant studies assume that the probabilities of correct and incorrect decisions are constant and do not depend on the parameters of the degradation model. This study proposes a mathematical model for assessing the trustworthiness indicators of the operability checking for a deteriorating system. The set of mutually exclusive events at the time of operability checking are analyzed. Correct and incorrect decisions correspond to events such as true-positive, false-positive, true-negative, and false-negative. General expressions for computing the probabilities of possible decisions when checking the system operability at discrete times are proposed. The paper introduces the effectiveness indicators of corrective maintenance in the form of average operating costs, total error probability, and a posteriori probability of failure-free operation. We illustrate the developed approach by calculating the probabilities of correct and incorrect decisions for a specific stochastic deterioration process.

A condition-based maintenance for a two-unit system subject to dependent soft and hard failures: A reinforcement learning approach

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Maintenance planning plays an essential role in improving the reliability of a system and its effectiveness. Condition-based maintenance (CBM) suggests preventive actions to avoid failures, considering the state of a system. In this paper, an opportunistic CBM policy is developed for a series system composed of two units whose conditions are monitored regularly. The reliability functions are obtained using the proportional hazards model (PHM) to estimate the system's remaining useful life. When the deterioration of a unit exceeds a predefined threshold, a soft failure occurred, which can be detected through inspection. Hard failures are rectified by a corrective action immediately, including minimal repair, general repair, and replacement. The objective is to find an optimal policy that minimizes the total expected cost of the system. The problem is formulated in the semi-Markov decision process (SMDP) framework, and a reinforcement learning algorithm is proposed to find the optimal control policy and the long-run expected average cost per unit time. This study extends previous models, suggesting a new opportunistic CBM policy using the PHM in which actions with different levels can be performed on a two-unit series system.

Condition-based maintenance with imperfect preventive maintenance actions and inspections for multi-component system with various dependencies

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Abstract

Condition-Based maintenance (CBM) is promising policy that aims to improve system's availability and performance while keeping low maintenance costs. Inspections are required to reveal the system's state; however, measurement errors occur due to imperfect inspections thus leading toward incorrect decisions. When the system requires maintenance, necessary actions are carried out. These actions may restore the system to as good as new or restore it to an imperfect state in-between its current state and as good as new state. Most of the existing literature on CBM policies have considered imperfect inspections apart from imperfect maintenance actions for single-component systems, whereas in practice, systems are more complex. In this paper, we develop a discrete-event simulation-based model for a multi-component system considering both imperfect inspections and imperfect maintenance actions. Stochastic and economic dependencies among the components are also included. The model is applied on a case study and various scenarios are studied to obtain the best maintenance policy which minimizes the system's long-run annual cost. The results show that the imperfect maintenance has a major impact on cost compared to imperfect inspections. For imperfect inspections and maintenance, sensitivity analysis reveals that corrective maintenance cost is the primary factor that increases the annual cost.

Keywords:

Condition-Based Maintenance, Imperfect Maintenance, Continuous degradation process, Imperfect Maintenance action, Stochastic dependency, Economic dependency, Discrete-event Simulation.

Reliability and Cost Modelling of Diesel Particulate Filter Regeneration

Considering Driver Behaviour Prediction Uncertainties

Abstract

Diesel particulate filter (DPF) is an essential device in modern diesel automobiles for controlling exhaust gases passing to the environment and a mandatory requirement to meet emission legislation. During the vehicle operation, soot particles are accumulated in the filter, and when they reach a critical level, regeneration has to be triggered to maintain the filter efficiency and protect the engine. Traditional approaches for DPF regeneration modelling ignore driver behaviours' impacts on the regeneration process. In this paper, a condition-based regeneration model is presented considering driver contextual intelligence by the RusBoosted Tree Ensemble (RBTE) machine learning algorithm. The DPF reliability and operation are modelled as a multi-state repairable system with the accumulated soot mass in the filter as a system health indicator. Since the driver behaviours prediction always produces outcomes with uncertainties, a probabilistic cost function that includes both direct costs associated with fuel consumption during the regeneration process and indirect costs due to regeneration impacts on the engine's oil quality and operation is proposed. A case study and analysis for an industrial dataset with statistics of multiple vehicle journeys is provided to highlight the advantages of the proposed model compared to traditional approaches of DPF regeneration modelling.

Key words: reliability modeling, probabilistic cost, driving behaviour prediction, uncertainty, diesel particulate filter regeneration.

On Conditional Survival Signatures

Daniel Krpelík

Survival signatures are used to summarize system's structure function into a conditional probability table. System reliability can then be calculated via the law of total probability. Constructing these tables generally requires us to iterate over the path or cut sets of the system's structure function which still makes the computation NP-hard. Nevertheless, subsequent repeated assessments – like reconstruction of the system's survival function or comparing adversarial designs – are of only polynomial complexity in system size.

In this contribution, we aim to show how to extend survival signatures for computing reliability assessments conditional on the system state. This enables us to apply similar compressed system specifications for online predictions of remaining system's lifetime and use it for making decisions about preventive maintenance and other interventions.

Reliability Centered Maintenance (RCM) In Refrigerators Compressors of a Soft Drink Industry-A Case Study- Diego da Silva Tavares Ribeiro, Viviane Vasconcellos Ferreira Grubisic and Andrea Cristina Santos

Maintenance activity is a fundamental resource for companies that seek to stand out competitively. In order to extract the best efficiency and productivity ratio for this activity, Reliability Centered Maintenance (MCC) is a strategic methodology to structure the maintenance process in companies. The present article seeks to implement a MCC plan for the item market refrigerators of a soft drink industry. The application was carried out through a case study in which it was possible to map the refrigerator failure data and select the most critical subsystem whose function should be studied. In this sense, the case study, applied the MCC to the compressor of the refrigerators. To this end, a literature review on maintenance and MCC was carried out. Then, the case study was outlined, in which the proposed MCC model was presented, which was designed in a structured way following well-defined steps from system selection and information collection, application of Failure Mode and Effects Analysis (FMEA) until the definition of the periodicity of the defined maintenance activities. The results obtained with the case study allowed the company to update the current maintenance plans for MCC application model.

Keywords: Reliability Centered Maintenance (RCM), Refrigerators, Failure Mode and Effect Analysis (FMEA).

A time-dependent Proportional Hazard model for cutting tools Remaining Useful Life estimate under varying cutting parameters

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The replacement of cutting tools is a recurring subject in the manufacturing industry, as their improper management induces considerable costs. Among the common approaches to the replacement of the cutting inserts, the survival analysis of failure data is often proposed, taking covariates such as cutting parameters, which are often considered constant over time. However, this approach has not allowed yet to use condition monitoring data as a covariate. In this study, we propose the use of the extended Proportional Hazards (PH) model to the case of cutting tools maintenance. With help of this model, the Remaining Useful Life (RUL) of cutting inserts may be estimated when varying cutting parameters are used, considering past and planned future operations. The extended PH model also allows using condition monitoring data as covariates. This model is first illustrated on data generated by a stochastic model producing the evolution of the tool degradation over time. Then, it is applied to an original experimental data set, with 29 cutting inserts worn at constant and varying cutting parameters in C45 steel. The tool life prediction of this work is similar in quality with results of traditional PH models, while it can additionally accept time-varying data.

Multi-level Opportunistic Maintenance Policy for Multi-Component System with Multiple Dependences

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Maintenance policy for system with multiple dependences is an attractive research topic for decades. Indeed, the dependences between components include stochastic, economic and structural dependence. Economic dependence implies that joint maintenance of several components can save setup cost. The structural dependence implies that maintenance of the components requires disassembly of other components. This study proposes a multi-level opportunistic maintenance (M-OM) policy for multi-components system to take account not only the economic but also the structural dependence between components. The M-OM policy consists of two levels of opportunistic maintenance threshold (OMt), that are economic dependence and structural dependence opportunistic maintenance thresholds, denoted as eOMt and sOMt, respectively. When corrective/preventive maintenance occurs, the eOMt is used to select the components for opportunistic maintenance taking into account the economic dependence between components. The maintenance of the above components may require disassembly of other components. The sOMt is then used to decide whether or not the disassembled component should be opportunistically maintained with other components since opportunistic maintenance of the disassembled component can save not only setup cost but also downtime cost. The proposed maintenance policy is then applied to a conveyor system to show its feasibility and value added in maintenance optimization framework.

Key words: *Multi-component system; multiple dependences; opportunistic maintenance; maintenance optimization.*

A periodic inspection policy for heterogeneous complex systems

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It is well-known that systems are more and more complex (consisting of many components) and heterogeneous. For heterogeneous systems, components can be subject to different mechanisms of failure. It means that some components may fail suddenly without advance warning while other components are subject to a continuous degradation process.

In this paper, the maintenance cost is analyzed for a heterogeneous system. This system consists of m monitored components and n non-monitored components. Monitored components are subject to a degradation process, which follows a homogeneous gamma process. A monitored component fails when its degradation level exceeds a failure threshold. Non-monitored components are subject to sudden failures and they can only be maintained correctively upon failure. When a component (monitored or non-monitored) fails, a signal is sent to the maintenance team. Maintenance team takes τ ($\tau > 0$) units of time to arrive on site and starts the repair. The state of the system is checked each T units of time. These inspections reveal the degradation level of each monitored component and/or the failure of the non-monitored components.

An opportunistic maintenance strategy is implemented for this complex system, that is, a repair (or an inspection) can be used as opportunity for the maintenance of the rest of the components. By opportunity time, in this paper, we mean the time of a repair or an inspection. The implementation of an opportunistic maintenance program along with condition-based maintenance can reduce the maintenance costs. In an opportunity time, if the degradation level of a monitored component exceeds a preventive threshold but it is less than its failure threshold, this component is maintained preventively. In an opportunity time, if the degradation level of a monitored component exceeds its failure threshold, it is maintained correctively. In the case of a non-monitored component, if it is failed in an opportunity time, it is maintained correctively.

Each maintenance task (preventive or corrective) and each inspection imply a certain fixed cost. A cost per unit time is also incurred when a component is down. Each monitored component in operation provides a reward. Based on [2], a reward function is proposed depending on the degradation level of each component. The reward function for the i -th component is given by

$$g_i(x) = \theta + g \exp(-\gamma_i x), \quad x \geq 0, \quad (1)$$

where $\theta > 0$, $g > 0$ and $\gamma_i > 0$ for $i = 1, 2, \dots, m$. An infinite time horizon is assumed for the life cycle of this system. The expected cost rate is minimized through the optimization of

the preventive thresholds of the monitored components and the time between inspections. To obtain this expected cost rate, a semi-regenerative approach will be used. The use of this approach to evaluate the expected cost rate improves the computation time compared to the use of renewal techniques [3]. Special emphasis will be put on the case in which all the monitored components are identical.

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Maintenance at pre-planned schedule times considering opportunistic replacement

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ABSTRACT

In this paper, we examine the impact of opportunities on systems that are maintained periodically. In a fleet of systems, such as a wind farm, a failure in one can serve as an opportunity for others, allowing maintenance actions to be carried out at a lower cost. Consequently, this work proposes a maintenance policy with two phases. In the first phase there are inspections, and in the second phase, only corrective maintenance is carried out. Our main idea is to introduce flexibility to phase two, whereby opportunistic replacements may be carried out. Besides the fact that any action can only be taken at predefined fixed times, we also consider defaulting. The proposed model is based on the delay time concept, where a single component system has three states: good, defective and failed. The system operates in both the good and the defective state. The defective state is only observable by inspection. The purpose of this study is to provide some insights for the decision-maker related to best practice when a system is accessible only at pre-planned, fixed times, where a default can occur, and installation problems can affect the reliability of the system and change significantly its expected life.

Keywords: defaults, offshore platform, opportunistic replacement, Periodic Inspection.

Modelling the interaction of a disruptive external event and human error in the quality of inspection for a technical system

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ABSTRACT

To implement an effective maintenance program, it is paramount to understand the properties of the quality of the activities set out in the established policy and that are being carried out. In this paper, the influence of external events combined with human error on maintenance quality is considered, in a novel way, within the context of a hybrid inspection and preventive replacement policy, assuming a single component system. The impact on a maintenance policy is modelled by supposing that external events can disrupt appropriate conditions for an inspection, making maintenance staff subject to errors that can lead to inducing defects during this intervention. Economic and reliability implications are determined. A mathematical analytical model is introduced, and some results are obtained. The study aims to provide a better look at how operational day-to-day practices can impact the overall quality of the maintenance policy proposed.

Keywords: Maintenance, Inspection, Quality, Human Error, External Event.

Modeling Alternative Inspection Protocols for Latent Failures

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Abstract. Fault Tree analysis has a history in modeling risks in many industrial instances. A focus is given to the use of Conditional Gates and Dormant Events to explore the inspection protocols for several points on a single system. Inspections on dormant components vary in complexity and cost, such that identifying an appropriate inspection protocol requires sensitivity to these costs. The free open source R package FaultTree is used to demonstrate an example problem to illustrate this kind of modeling.

Multivariate parameter analysis of cutting processes

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Abstract. Tools for steel cutting ensure highest precision and product quality. Within this research work, a multivariate process parameter analysis is performed in order to rate and optimise lifetime regarding durability of tools and to increase the efficiency of the process itself. In Addition to the tool data such as geometrical data, process variables such as cutting speed and feed rate are analysed in combination with different materials and dimensions. The output variable is used to determine whether the parameter combination of a cutting operation is the proper one. In order to evaluate the process, Machine Learning algorithms (Ensemble Learning) are used.

The Importance of Data Quality in Energy Pipelines Condition Assessment

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Abstract

Energy pipelines reliability assessment has been a complex issue from theoretical and practical point of view but it attracts researchers' interests. Differential equations have been established in order to explain the energy transportation process through a pipeline, but their solution faces some difficulties through analytical approach, even with numerical methods. Collecting data and carrying out statistical analysis is one of the effective methods in practice. Data quality is one of the significant factors to be considered in evaluation of the condition of pipelines. High-quality data is therefore required for energy pipeline condition assessment. Currently, there is a lack of systematic review and study of quality criteria of pipeline condition measurement data. In this paper, we first provide a review of energy pipeline condition monitoring techniques, data collection and data quality issues. The challenges in energy pipeline condition assessment using the available measurement data will be discussed. The future research potential for pipeline condition assessment using the available condition monitoring data based on the current industry practice level will be indicated.

Keywords: Condition Monitoring Data, Data Quality, Degradation Modelling, Energy Pipeline Condition Assessment, In-line Inspection, Pipeline Integrity Management

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A comparison of the performance of the geometric process and its variants

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The geometric process (GP) is a stochastic process that is introduced to model the failure process of a repairable system and has been used in optimisation of maintenance policies. It has also been extended into several variants, which are proposed to overcome its various drawbacks. These restrictive assumptions or implications, include: (1) it cannot describe the failure process with non-monotonous inter-arrival times of a system and (2) it results in the fixed shape parameter during different gap times if the probability distribution of the time to first failure is the Weibull distribution, and (3) it assumes that the times between failures are independent. These limitations possibly influence the application of the GP in the real world. In this article, we review the variants of the GP, which include the extended Poisson process, the α -series process, the doubly GP and the threshold GP, and compare their performance based on 25 datasets in terms of the Akaike information criterion. We then locate the 'turning points' of the doubly GP and the threshold GP, respectively, and develop preventive maintenance policies. Considering the estimation errors of the parameters in the GP, we derive the confidence intervals of the maintenance policies for the doubly GP and the threshold GP, respectively. Numerical examples are used to illustrate the methods developed in this paper.

Affinity analysis using apriori algorithm to identify failure dependence in multi-component systems

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Abstract.

Maintenance decisions in multi-component systems are of great interest to maintenance managers. The equipment during its operation, produces and stores a large amount of data, especially discrete event data such as alarm, failed situation, change of operation modes, stop of the systems, and so forth, and produced via processings supported by PLCs, supervision system, SCADA. Considering this data to assist in maintenance management and decisions is an area with a growing interest in maintenance management. In this paper, we study the stochastic dependency in a multi-component system through data from CLP database. We use appriory algorithm and affinity function to identify failure dependence in multi-component systems. The results of failure dependence can be used as input for planning group maintenance, purchase spare parts, or planning opportunistic maintenance.

Cyber Physical Systems Analysis: what can be the contributions from the “MIMAR community” ? - Prof. Anne Barros (CentraleSupélec, France)

The chair “Risk and Resilience of Complex Systems” at CentraleSupélec (Paris), starts in 2020 a research activity dedicated to the modelling and the resilience analysis of cyber physical systems. The partners involved in the project are EDF (French national power supplier), Orange (French Telecom operator), SNCF (French national railways operator) and Paris Airports. The objective is to define use cases encompassing three networks, one for the physical transportation system, one for its power supplying and one for its telecom services providing. The following questions will be addressed: which kind of decisions can be optimized in relation with safety and business continuity, what are the relevant performance indicators for such decisions and what are the suitable modelling techniques?

A review of similar problem statements with related modelling techniques will be provided, including among others, physical models, stochastic hybrid models and networks of networks. Contributions of the proposed approaches will be discussed within their validity domain and the needs for new contributions from the “MIMAR community” will be highlighted.

Physics-informed stochastic Petri nets for the deterioration modeling and maintenance assessment of torrent protection structures

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Mountain territories are remarkably exposed to natural phenomena such as torrential floods, arising due to climate and geophysical environmental changes. Protection structures, such as check dams on torrents, are thus constructed in mountains in order to protect people, properties, and infrastructures exposed to these natural hazards. Such protection structures (in our case, check dams) deteriorate with time due to the harsh phenomena they are subjected to since their construction and their deterioration has negative consequences on the induced level of risk and therefore on the vulnerable asset located downstream. If not regularly maintained, the level of protection offered by these structures will be reduced. Because of limited budgetary resources available for their maintenance, it is essential thus to assess the time-dependent efficacy of check dams and to prioritize maintenance strategies.

In this work, we develop a methodology for maintenance decision-aiding for checks dams. One of the encountered difficulties is that few deterioration data are available on these structures, as they are not easily accessible and not instrumented nor automatically monitored. The proposed methodology integrates physics-based and dependability models for modelling the deterioration state evolution of protection structures and improving the maintenance decision-making process. The modeling approach proposed is based on

1. Defining a new degradation indicator that synthesizes both functional and structural deterioration mechanisms of the dam taking into consideration the dynamic interactions between failure modes;
2. A physics-based modeling that captures the time-dependent evolution of the defined degradation indicator using multi-scale physical and analytical hydraulic models to determine the external stability analysis of the structure. This physics-based maintenance modelling relies on deterministic equations for the involved hydraulic and mechanical phenomena and randomness can be introduced through random events (e.g. rainfalls, rockfalls, ...) that primarily drives the protection structure deterioration. This model is then used to simulate deterioration histories, which allows identifying the probabilistic laws of the transition times between the defined deterioration states of the protection structure depending on its behavior over time;
3. Providing a stochastic model for the temporal evolution of the deterioration, implemented using stochastic Petri nets comprising the different deterioration states identified for the structure and integrating the state transition laws built at the previous step. This stochastic Petri nets model can be used to assess the efficiency of preventive maintenance policies to be applied to the dam and to compare them depending on their cost and their efficiency on increasing the availability time of the dams in non-critical states.

The proposed approach is applied and illustrated on a check dam located within a series of check dams in the Manival torrent in Saint-Ismier, France.

References

N. Chahrour, M. Nasr, J.M. Tacnet, C. Béranger, Deterioration modeling and maintenance assessment using physics-informed stochastic Petri nets: Application to torrent protection structures, *Reliability Engineering and System Safety*, 210 (2021), 107524

Evolutionary algorithms for identifying urban resilient designs of cellular power distribution networks

- The power system most relevant: due to dependency on continuous power supply of most of all critical infrastructures
- Energy transition towards a renewable energy system, allows the utilization of decentralized energy sources (PV, wind turbines, storages...) instead of centralized power plants.
- Emerging risks: new vulnerabilities of the power system, statistical failure probabilities, combined with a change of boundary conditions (climate change that not only stresses the versatile hardware infrastructure but also cause drastic increases in loads ...), dark doldrums, and Cyber risks: FDI...
- In times of power scarcity or brownouts affecting a distribution grid caused by whatever, smart energy management systems can protect the whole distribution system from a large-scale power blackout if there are certain energy cells that are able to switch into island mode or are able to shift energy surpluses to other cells, or protect the dissemination of worms.
- The impact of a total large-scale blackout on the whole urban system affecting a system of other critical infrastructures not necessarily be equipped with emergency power units suffer.

The energy transition targets at a smart power grid that consists of decentralized energy sources and thus bears an increased vulnerability potential. Furthermore, in a world with changing boundary conditions (climate change, energy consumption etc.) the envisioned future grid is accompanied by the emergence of hardly assessable risks, due to an enhanced statistical failure probability of components, unpredictability of peak loads, uncertainty w.r.t. energy availability (dark doldrums), cyber risks etc.

In the context of energy systems, one important aspect of resilience is the ability to perform as good as possible, although being in a degraded state, which could mean to have at least partial energy supply instead of large-scale blackouts. Symptoms of stress could be the unavailability of energy (power scarcity, brownouts). Smart energy distributions systems may avoid large-scale power blackouts if there exist energy cells that are able to switch into island mode or are able to shift energy surpluses to other cells.

However, designing a reliable, feasible, and *urban resilient* cellular distribution system does not mean to define just some cellular structures. Besides known graph-based indicators for efficiency and resilience of networks, we utilize a further indicator that takes criticalities and peak loads of CIs into account and based on them we describe an evolutionary algorithm for identifying urban resilient and efficient SG topologies and present first results.

Performance Analysis of Maintenance Practices Based on World Class Manufacturing in Brazil: Professional Maintenance Pillar - Ingrid Carneiro da Silva, Viviane Vasconcellos Ferreira Grubisic and Sanderson César Macedo Barbalho

The increase of the global competitiveness between companies of different sectors, has forced companies to reduce costs and create continuous improvement in their processes. One of the most renowned management models is called World Class Manufacturing (WCM), which seeks excellence in the entire production system and elimination of losses based on concepts such as “zero defects”, “zero breaks”, “zero waste”, and “zero stock”. One of the strategic areas of companies is Maintenance, and for this, WCM has the Professional Maintenance pillar, which aims to optimize the equipment reliability and efficiency through failure analysis techniques. Within this context, this study aims to analyze the performance of maintenance programs based on the principles of WCM Professional Maintenance pillar. This article can be classified as a survey, qualitative, exploratory and applied. For that, a questionnaire was developed and applied in 11 companies of different segments in Brazil. As a result, the most used aspect in companies was the existence of a record of failures and maintenance activities performed on the equipment, while the lowest one was the use of the 5W1H tool.

Keywords: World Class Manufacturing; Professional Maintenance; Performance.

A simulation-based LCC model for railway track

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Because of the complexities of the railway track system compositions and their degradation mechanisms, the existing models built for the relevant LCC estimation are either too simplified or focused on a part of the system. In this paper, a simulation-based model is proposed which is to incorporate all of the major track components such as rail, ballast and sleepers with the ability to be extended to embrace more. The cost-break down methodology is adopted to estimate the cost on a component-by-component and activity-by-activity basis. The interaction of the different components can be considered during the simulation process. Some activities whose implementation is purely experience-based can be loosely added as extra cost elements by disregarding its connection with other activities. Though attempting to embrace all, the simulation-based model is still considered easier to implement and potentially faster to run compared to the more complex and probably more powerful models including the Petri-Net models: only the basic knowledge of the Monte Carlo simulation is required with the back up of the domain knowledge about the management practice with the railway track assets. Not only a tool for the planning of maintenance actions the model may also be used to evaluate different track form options. By replacing the simulation-based models with parametric models or limiting the focus to one or several track components, the model can be simplified conveniently.

Two Critical Levels Policy for The Joint Optimization of Condition-Based Maintenance and Economic Production Quantity - Mohamed Elfadel Elfadel

Production-related decisions have traditionally been distinguished from maintenance decisions in the manufacturing sector. This led to coordination lack and cost inefficiencies. Due to the advancements in sensory technology, the integration of production and maintenance decisions is feasible nowadays. In this paper, we propose a new integrated model of preventive maintenance (PM) and production lot size optimization to minimize the system's overall cost. Our interest is on the condition-based maintenance for continuously degrading components modeled with random coefficient regression model. At the end of each lot, a decision based on the system's degradation is taken from the following: (i) production lot is kept the same, (ii) production lot is reduced, or (iii) PM is scheduled. Whenever the system fails it incurs a downtime cost, and a corrective maintenance is executed. Two critical levels are proposed. Level V is the level after which the lot production time is reduced. Level C is the level after which preventive maintenance takes place. A simulation-based approach is adopted to obtain the optimal values of the decision variables. Our model is applied to a real case study from the literature. In comparison with the current results, our results reveal a 15% cost reduction.

Modeling Environment Dependency in Partially Observable Markov Decision Processes for Maintenance Optimization - Ragnar Eggertsson, Rob Basten and Geert-Jan van Houtum

Partially Observable Markov Decision Processes (POMDPs) are studied in the maintenance literature because they can incorporate information uncertainty. This uncertainty may, for instance, arise from imperfect information from a sensor placed on the equipment to be maintained. Examples of such system-sensor pairs are an engine with a temperature sensor or an HVAC system with a temperature sensor. The latter pair motivated our research into environment-dependent POMDPs. Failures of an HVAC system are obvious in the summer when it should keep the temperature low. In the fall, winter and spring, failures also occur, but these failures are not as obvious from the temperature read-outs. This setting can well be modelled as a POMDP since the temperature read-out does not give complete information on the system's current state. We model the following three actions: an imperfect inspection, i.e., giving incomplete information, a perfect inspection, and maintenance. We add a Markovian environment to this model, giving rise to a model in which environment-dependent partial observations, degradation, and costs are included. For this model, we show that an environment-dependent 4-region policy is optimal. We further perform numerical experiments that lead to interesting insights.

Optimal Maintenance Planning Under Population Heterogeneity with Data Retrieved from Multiple Systems - Ipek Dursun, Alp Akcay and Geert-Jan van Houtum

In this study, we focus on a finite-horizon maintenance planning problem for multiple systems. Each system has one critical component with the same time-to-failure distribution, and there is uncertainty in the time-to-failure distribution, referred to as model uncertainty. Specifically, we assume that there are different populations of the component (i.e., weak and strong type) with different time-to-failure distributions, components are always provided from the same population, but the decision maker does not know the component type with certainty. A discrete-time partially observable Markov decision process (POMDP) is formulated to optimize the preventive replacement decisions of each system. There is an initial belief associated with the type of components and this belief is updated in a Bayesian way as new data are obtained from all of the systems. The resulting policy minimizes the total cost over a finite lifespan based on the available information and meanwhile learns the true population type.

Reliability and Maintainability Optimization for Aircraft's Repairable Components based on Cost Modeling Approach

Adel A Ghobbar

Shenila Sewgobind

Abstract

The airline industry is continuously challenging how to safely increase the service lifetime of the aircraft with limited maintenance budgets. Operators are looking for the most qualified maintenance providers of aircraft components, offering the finest customer service.

Component owner and maintenance provider, Fokker Services, is offering an Abacus agreement (Aircraft Component Leasing) to increase the efficiency and productivity of the customer service. To increase the customer service the current focus on No Fault Found (NFF) units must change into the focus on Early Failure (EF) units. Since the effect of EF units has a significant impact on the customer satisfaction. Subsequently it is desired to increase the reliability of EF units at minimal cost, which leads to the goal of this thesis:

Identify and improve the reliability of early failure (EF) units with respect to No Fault Found (NFF) units, in particularly the root cause analysis with integrated cost analysis of EF units with the use of a failure mode analysis tool and a new cost model, leading to a set of EF maintenance improvements.

The data used for the investigation of the EF units will be obtained from the Pentagon system, an Enterprise Resource Planning (ERP) system used by Fokker Services. The Pentagon system monitors components, which needs to be repaired from Fokker aircraft owners, Abacus exchange pool and commercial customers. The data will be selected on several criteria's: time span, failure rate and cost driver.

When the selected data has been acquired, the failure mode and root cause analysis of EF units is initiated. A new approach of failure analysis will be used, which will be adapted from the multiple analysis methods found in the literature study, such as: FMEA (Failure Mode and Effects Analysis), SFMEA (Service Mode and Effects Analysis) and MEMCDM (Multi Expert-Multiple Criteria Decision Making).

The new failure analysis approach tool will be implemented, resulting in the proposed failure solution of EF. This will lead to specific EF maintenance improvements, which can be set-up to decrease the EF units and hereby increasing the reliability.

The obtained solution must have a minimum impact on the cost structure. To satisfy this requirement a new cost model will be established. This new model will give a clear overview of the cost effectiveness of the proposed failure solution. Resulting in a more reliable and cost-effective EF solution.

Keywords: Supportability, No Fault Found, FMEA, Early Failure, Availability, Operational Reliability, Predictive Model.

Insights into a two-scale policy for protection systems subject to shocks when meeting demands

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ABSTRACT

Protection systems usually remain inactive and are only required to function in the face of specific demands, such as emergency events. The system activations to contain demands may act as shocks upon itself, accelerating its deterioration. However, protection systems may also be subject to deterioration due to wear and tear over time. Considering this, we propose a two-scale inspection-maintenance policy for protection systems, which considers both the age of the system and the number of shocks as parameters for decision-making on preventive maintenance. We introduce a model for estimating the performance of the inspection-maintenance policy in terms of costs and rate of unmet demands. The model was applied in order to optimize the inspection-maintenance policy for protection systems in different contexts, which differ with respect to the mechanisms that are prevalent in the deterioration and failure of the system. We present some insights from these applications: we provide some guidelines that can support the definition of appropriate maintenance policies for protection systems in accordance with their deterioration and failure process. We then present some suggestions for approaches that could be considered to facilitate the policy modelling and optimization process in particular cases.

Keywords: Protection Systems, Inspection, Maintenance, Shocks.

Risk modelling incorporating complex maintenance strategies

Silvia Tolo, Andrew Jackson, John Andrews

Realistic modelling is the key to the adequate understanding of engineering systems' behaviour and hence plays a crucial role in their design and operation. This is all the more relevant when considering asset management and maintenance optimization: only the availability of accurate models and reliable analysis tools can ensure the identification of optimal strategies and operation. However, the modelling approaches most common in engineering practice, i.e. Fault and Event Trees, lack the capability of fully capturing the behaviour of components and systems, such as for component degradation and underlying dependencies.

This research aims at providing a solution for overcoming the limitations of current tools, ensuring the accurate modelling of complex maintenance strategies and their integration in the overall system analysis. The proposed methodology relies on the in-depth integration of Petri Nets and Markov Models solutions with Fault Tree analysis through the use of Binary Decision Diagrams. Such solution results into a more effective balance between computational feasibility, modelling flexibility and analysis accuracy, without undermining the familiarity of the FT modelling language and the robustness of the analysis.

In order to test the validity and effectiveness of the proposed approach, a simple case-study and its numerical analysis are investigated.

Title: A comparative analysis for gas pipeline risk analysis based on international standards and a multicriteria model

Authors: Heitor Fagner Lopes de Lima; Francisco Filipe Cunha Lima Viana; Marcelo Hazin Alencar; Rodrigo José Pires Ferreira - REASON (Risk Assessment and Modelling in Environment, Assets, Safety, Operations and Nature) Research Group - Federal University of Pernambuco - Brazil

Abstract:

Due to a new natural gas regulation framework, it is expected that a significant volume of investments in this sector will come to Brazil within the next few years. This means that the country must expand the current pipeline network for transporting natural gas, thus increasing the relevance of ensuring that the risk management of natural gas is structured. Control and monitoring are appropriate steps to eliminate or mitigate risk and its consequences for society, the environment, and organizations. Additionally, some accidents can produce catastrophic losses. Therefore, Risk models aim to assess gas pipelines and undesirable events, thereby supporting decision-making in choosing or prioritizing mitigation actions. A multicriteria risk evaluation model is presented in this research, which considers consequences in three dimensions (human, environmental and financial). The main contributions of this research involve a comparative analysis of risk analysis tools for pipelines that transport natural gas. This includes using a multicriteria model and the ASME B31-8 standard and its complements. An analysis of the advantages and disadvantages of a case study in a pipeline natural gas system located in northeast Brazil is presented.

Keywords: Risk analysis; Multicriteria decision model, Gas Transmission and Distribution Piping Systems

SAFETY-AWARE EVALUATION OF SEMANTIC SEGMENTATION MODELS USED FOR PERCEPTION IN AUTONOMOUS DRIVING

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The computer vision task “semantic segmentation” forms a crucial building block in the interaction of several redundant systems. As metric to evaluate the performance and reliability of this perceptual function, one commonly considers the number of false negatives (FNs), i.e. counting instances that have been overlooked by the perception model. From a practitioner’s point of view, however, faulty detections need to be considered in a more differentiated way. For example in autonomous driving, detection errors of vulnerable road users (VRUs, e.g. pedestrians) far away from the probable travel path of the ego vehicle are not as safety-relevant as detection errors of VRUs on the path ahead. Moreover, standard evaluation approaches do not consistently specify how well the VRU instance must be covered by the perception model in order to consider the VRU to be found. In this work we therefore introduce a sophisticated evaluation framework that assesses semantic segmentation models for autonomous driving not only based on their classification and localization abilities but also on distance information of VRUs within a safety-relevant region of interest ahead of the ego vehicle. This allows distinguishing irrelevant FNs from potentially relevant FNs and thus provides more safety-aware metrics.

Keywords— semantic segmentation, autonomous driving, vulnerable road users, perception, evaluation framework, safety-aware metrics, false negative reduction

Prioritization of maintenance planning for natural gas pipelines using multicriteria portfolio assessment

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Abstract. Planning maintenance policies is a common task for many organizations in order to line up production efficiency, cost reduction, and quality standards. Notwithstanding, designing a maintenance planning faces operational and resource limitations so that preventing multiple losses encourages managers to implement the best mix of strategic actions. Especially on industrial systems as natural gas pipelines, damages from failure modes embraces multiples perspectives related to risk safety. Then, organizations must implement the best mix of policies that avoid catastrophic consequences and obeying their constraints. So, it is a combinatorial problem that aims to sort a subset of items out of a set under constraints. Based on this backdrop, this paper proposes a multicriteria decision model for portfolio selection of maintenance policies under financial constraints. Apart from a numerical application, social, financial, and environmental risks are taken into account for investigating the best mix of preventive actions to compound a strategic portfolio. Hence, this model provides a broad range of information that supports managers to implement preventive actions, turning the assets capable to enhance the integrity of individuals and would be better productive.

Insights into a flexible maintenance policy for safety-critical systems

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ABSTRACT

Failure of safety-critical systems can lead to adverse consequences in terms of human, social and economic losses. This has been cited as one of the main justifications for adopting maintenance policies that can prevent failures and their catastrophic consequences. In this paper, we present some insights that can conveniently guide the definition of a maintenance policy to be applied to systems whose failure triggers drastic events. We introduce a delay-time based model for a flexible two-phase inspection-maintenance policy applied to a single component system. The proposed policy is a generalization of several policies explored in the previous literature; consequently, the model presented can be used to compare different policies. We discuss about the importance of developing a hybrid policy with more than one phase and with the interval between inspections adjustable according to a decision variable that is related to the degradation level of the system. We then provide an interesting comparative analysis that highlights the importance of considering these aspects when dealing with safety-critical systems.

Keywords: hybrid inspection policies, safety-critical systems, two-phase maintenance policy, delay time.

Using data mining techniques to identify sequential patterns in order to support maintenance management

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ABSTRACT

With the evolution of technology, industries are increasingly using devices that allow the uninterrupted collection of data, such as sensors. Maintenance management has the opportunity to use this data to guide actions more efficiently. The more efficient the use of resources, the greater the cost saving and the availability of the production line. However, the challenge faced is how to extract knowledge from the available data to support decisions in maintenance planning and control. This study aims to apply data mining extraction techniques to a database of a manufacturing system to discover sequential patterns and rules that will serve as a basis in the development of effective maintenance policies. The KDD (Knowledge Discovery in Databases) is a process of knowledge extraction that will be used throughout this paper. As a step of this process, the data mining will be done using GSP (Generalized Sequential Pattern) algorithm. As a result of the study, we show how the definition of maintenance policies can be supported by the combination of these techniques with a database of events related to maintenance.

Keywords: maintenance, database, data mining, sequential patterns.

Assessment of pavement degradation through statistical analysis model: A case study of Department of Transportation (DOT) of Iowa, USA

Transportation network, especially highways, is considered the national and international assets and by proper maintenance system, public and private organisations can prioritise the budgeting of repair and reconstruction. The problem is to have a reliable and practical model creating a solid understanding of the pavement degradation condition by cheap measurable parameters for municipalities. This study focuses on the road pavements condition, particularly the statistical evaluation of the processes of degradation involved in various road sections. Quantitative statistical analysis of a sample taken from the Iowa Department of Transportation (DOT) in the united states provides a better understanding of the needs in the maintenance processes on pavements. It can identify the critical factors of pavement maintenance. Through a case study, it has been proven that organisations can make a solid base statistical decision-making model even by the very basic and cheap parameters. The model has two different approaches with and without pavement type used by creating several dummy variables to include each pavement as independent variables.

Some recent developments on failure processes with masked failure data

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Abstract: The starting point for the optimisation of a maintenance policy for a physical system is usually in possession of the failure process for this system. Such a failure process is normally a stochastic process that models time between failures and that should be estimated based on failure data collected either from the lab or from the field. Field data are often noisy. For example, for a multi-component series system, times between failures are recorded but which components causes the system to fail may be missing. Namely, only masked failure data are available. In this case, we need to estimate a failure process from the aggregate, masked failure data.

This paper reviews three recently developed methods on modelling the failure process with masked failure data.

Design and pricing of extended warranty menus based on the multinomial logit choice model

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Abstract. This paper studies the design and pricing of an extended warranty menu, which offers multiple options with differentiated lengths and prices. The power law process is used to model product failures and evaluate warranty costs. The multinomial logit model is adopted to describe customer choice behaviors. From a warrantor's perspective, the design and pricing problem is to determine which candidate options to offer and the associated prices so as to maximize the expected warranty profit. We show that the optimal strategy is to offer all candidate options associated with a *cost-plus-margin* pricing policy, with the same profit margins for all options. If only a limited number of options can be offered, then the options with the highest valuation margins should be selected. In addition, we extend the original model by incorporating free preventive maintenance programs. We find that a free preventive maintenance program should be attached to a warranty option only when it is feasible for that option. Overall, this work will equip practitioners with a quantitative tool to design and price extended warranty menus in practical scenarios.

Imprecise statistical inference for step stress accelerated life testing data

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Abstract

This study presents a new imprecise statistical inference method for step stress accelerated life testing data, where the cumulative exposure model is implemented with failure times following the Weibull distribution with the Arrhenius link function. This function expresses the relationship between the lifetime and the applied stresses in terms of temperature to link the Weibull scale parameters at different stress levels. This method consists of three steps. First, it transforms failure times occurred by different strategies at higher stress levels to the normal stress level. Second, it creates imprecision based on the likelihood ratio test on the accelerating parameter for the null hypothesis that all failure times come from the same distribution. This imprecision allows to transform failure times into interval values at the normal stress level where it is assumed that these transformed failure times are not distinguishable from failure times occurred at the normal stress level. Third, Nonparametric predictive inference is applied with the transformed data to provide robust predictive inference. This method leads to more imprecision if data are used from higher stress levels, and also if the assumed model does not fit the data well. The performance of this method is evaluated by simulation studies.

Keywords: Imprecise Statistical Inference; Step Stress Accelerated Life Testing; Cumulative Exposure Model; Likelihood Ratio Test; Nonparametric Predictive Inference.

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Title:

Integrated Planning of Asset Use and Maintenance for a Fleet of Maritime Assets

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Abstract:

The vast majority of maritime assets is built and periodically inspected/maintained in line with well-thought-out maintenance policies to prevent unexpected failures and related unavailability. When maintenance is executed, a vessel cannot contribute to the maritime operation. In general, the use of assets is planned in order to fulfill specific operational objectives, and this affects when the assets can be maintained. From this aspect, integrating the planning of operations and maintenance can be beneficial. The idea of integrated planning is not a new concept. However, unlike the studies in the literature, we consider a fleet of moving assets located at multiple locations. This brings new opportunities in optimizing within-harbor and between-harbor movements. In this study, usage-based maintenance policy is considered as the underlying maintenance strategy with a given set of operational requirements that need to be met by a fleet of assets. We formulate the problem as a mixed-integer linear program, and provide customized metaheuristics with the objective of minimizing the total discounted cost over a finite planning horizon.

Optimizing maintenance policies for safety brakes used in steel mills

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ABSTRACT

The production and processing of steel in steel mills may expose workers to risks associated with the operation of machinery and accidental exposure to molten steel at high temperatures. Risk control measures include the introduction of safety systems in industrial equipment. Safety systems must remain prepared to be activated to contain emergency events that may happen at random. In order to improve the level of preparedness for a safety brake used in the context of a steel mill, we propose a maintenance policy based on the analysis of the deterioration and failure mechanisms of the system. A model is proposed to estimate the performance of the policy in terms of cost and risk, the latter being measured according to the frequency of hazardous events. The policy has been compared with other policies already explored in the preceding literature and has shown better results. The results show the impact that an appropriate maintenance policy can have on reducing risks without changing the design of the system.

Keywords: steel mill, safety system, maintenance, risk.

A Reinforcement learning based model for the optimization of maintenance in Multi-state multi-component systems under the perspective of product quality degradation.

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Multi-component systems are characterized for a complex relation between components, resultant of structural, economic and/or stochastic dependence. This complex relation coupled with the uncertainties in the operating conditions makes the system degradation and failure mechanism uncertain, which in turns affect the productivity of the system. Besides, depending on the degradation state of the components, the system can switch from an in control state to an out-of-control state affecting different quality features of the products, which are subject to rejection. In this paper, we proposed a model for the maintenance policy optimization of multi-state multi-component systems subject to quality and reliability degradation. The model is based on a deep reinforcement learning algorithm that optimizes the long-term system performance, recommending a set of maintenance actions at each scheduled inspection according to the defective rate of products for different types of defects. The model offers a way of integrating quality control with maintenance decision for multi-state multicomponent systems, fulfilling a gap in the literature, in which models consider either one single component, one single defect, or both. Different from those systems, in multi-state multi-component systems the product quality degradation cannot always be explained by assignable causes, i.e., one-to-one defect and component association.

Multi-Criteria Decision Analysis of subcontractors selection for infrastructure projects: a case study of an electrified railway project

In construction projects worldwide, Main Contractors(MC) have to choose Sub-Contractor(SC) with no previous experience; And brings an extra layer of uncertainty to the projects that may impact costs and time directly or indirectly. Adequately assessing the alternative SCs in each case would contribute to managing the risk associated with their selection, both by minimizing/avoiding threats and maximizing/capturing opportunities. Identifying and weighing the SC and MC characteristics in each project's context will provide a better and clear understanding of the decision-making and SCs selection process. This study used multi-criteria decision analysis (MCDA) through M-MACBETH software to develop a model for selecting SC by applying the MCDA approach in a case study. The case study data collected from the YTL company construction manager (CM) is located in Johor, Malaysia, who has given the decision problem, decision-making criteria, audit data and SCs information. The research method uses MCDA in M-MACBETH to create a model for choosing a subcontractor of a cabling project of a double electrified railway in Malaysia and performing sensitivity and robustness analysis on the proposed model to reach a reliable and practical outcome.

New Maintenance Orientation in The Frame of Industry of The Future: Challenges and Opportunities Brought by Data Analysis - Prof. Benoît Iung (Université de Lorraine, France)

Next generation of industry such as those promoted by “Industry of the Future”, “Industry 4.0.” paradigm, holds the promise of increased flexibility/adaptability in production (e.g. manufacturing) to cope with the challenges of producing individualised products as expected by customers with a short lead-time to market and at the cost of mass production. These challenges can only be met by further developing the digitalisation of production systems (towards Cyber Physical Production System - CPPS) in which data science, smart manufacturing objects (SMO) and services are predominant. This vision should increase global competitiveness by promoting innovative business models mainly driven by servitization (anything-as-a-service) and stakeholders’ collaboration in the way to keep industrial employment in Europe. More precisely, CPPS is a new way to organise the system (heterarchical vs holistic approach) to enable fast integration feedback and control loops throughout distributed manufacturing infrastructures all along its life cycle. So, the resulting organisation is assimilated to a complex manufacturing ecosystem based on interaction of humans, objects (e.g. products, components), customers, society partners ... having to offer a dynamic, real-time optimized and self-organizing value chain from relevant data. These advanced characteristics imply that the system in support of the value chain need to become more adaptable, agile, robust, resilient ... to face fault, unforeseen events while guaranteeing system performance. However, the process of predicting reliability and performance in such context is far from trivial. The main barriers include, at least, the inability to anticipate unknown faults particularly for complex systems, and the inability to sustain system functionality and performance in the presence of system anomalies and severe disturbances. To face these barriers, the conventional challenges on diagnostics, prognostics, maintenance decision-making... should be extending, mainly by using Data Science tools to construct concepts such self-healing, self-assessment, self-maintenance, self-repair ... as promoted by the Prognostics and Health Management (PHM) community. Thus, data processing is a very important tool for (predictive) advanced maintenance leading to consider the technologies and methodologies referred to advanced data analytics (e.g. internet of things, big data, artificial intelligence) as a main pillar to offer predictive capabilities and deploy a new way of organizing and implementing proactive maintenance on an industrial scale.

In that way, the aim of this keynote speech is to survey, with illustrations, the key developments in data analytics-based (predictive) advanced maintenance, and its emerging challenges. In the frame of “industry of the future/industry 4.0”.

Using survival signature in systems failure diagnostics

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Abstract

Diagnosing system failure by determining the components that are most likely to have caused the failure is useful for various aspects of reliability such as maintenance activities. Barlow and Proschan [1] introduced an importance measure which ranks the components based on their probabilities of having caused system failure given the system failed at time t . As this measure is mainly dependent on the structure function, it may be complex to apply it on most real-life systems that are composed of a large number of components [2].

The survival signature, introduced in [2], is a reduced representation of the system structure which is sufficient for computation of the system reliability function. The reduction is based on exchangeability of failure times of components of the same type, so it is particularly useful for large systems with relatively few component types. The survival signature does not allow individual components to be identified, so instead of finding the probability that a specific component caused system failure, we obtain an expression for the probability that system failure was caused by failure of a given component type. Indeed, this provides a new component type based importance probability which can be used in system design and deployment planning.

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A Novel Fault Detection and Diagnosis Methodology for Dynamic Systems

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ABSTRACT

Faults can have significant, negative impacts on the operation and performance of complex dynamic systems such as those in the power, chemical and nuclear industries. Failing to detect and diagnose the cause of faults on time may result in loss of life or other costly incidents such as explosions and emergency shutdowns. This research presents a methodology for developing a computationally-efficient, integrated model for monitoring the operational behaviour and online fault detection and diagnosis of a complex dynamic system. The developed methodology is based on the Generalised Stochastic Petri Net (GSPN) and Bayesian Stochastic Petri Net (BSPN) formalisms.

The GSPN-BSPN methodology operates in two integrated modules. Module I uses GSPN to model the operational and failure behaviour of the analysed system. The GSPN model establishes the causal relationships between component failures and system behaviour, identifying the faulty system state in the event of single or multiple faults. Module II consists of a diagnoser model developed using the BSPN formalism, which traces the paths leading to the faulty state identified by the GSPN model in Module I.

The developed methodology is demonstrated on a water tank system. The performance of the fault detection and failure diagnostic model is evaluated in terms of the fault detection rate and diagnostic accuracy.

IMPERFECT MAINTENANCE AND GAMMA PROCESS

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

- The system degradation indicator is more related to a service quality than a health indicator and the system failure is not considered in this paper;
- A perfect preventive maintenance is performed if the degradation level exceeds a fixed safety threshold L : the operation leads to a "as good as new" system;
- An imperfect preventive maintenance is performed if the degradation level is between L and a preventive threshold M : the imperfect action is modelling to an arithmetic reduction of degradation of order 1. In this later case, the improvement is proportional to the degradation level at the inspection time (with a reduction factor ρ with $0 \leq \rho \leq 1$);
- No action is performed if the degradation level is lower than M ;
- The safety threshold exceeding is not self-announced and this event is detected only during an inspection;
- Maintenance actions do not induce a delay.

Considering the cost of the inspections, of the perfect and imperfect preventive maintenances, we derive the closed form expression of the average long run cost of the maintenance policy in order to optimize the expected total cost between two CM (thanks to the renewal theory). A sensitivity analysis is performed and the robustness of the optimal parameters with respect to uncertainty.

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

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Health Asset using Vibration-based Condition Monitoring in Thermal Power Plants

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Abstract. The use of predictive maintenance techniques such as vibration-based damage identification has been rapidly expanding over the last few years. Vibration-based monitoring provide an excellent and reliable monitoring strategies for maintenance. Furthermore, it represents a tool with great potential in thermal power plants, where the operational context demands high availability and reliability. In this sense, the reliability and availability of the combined-cycle thermal power depend on the correct operation of all its systems and subsystems. Despite this, it often happens that the use of predictive techniques is exclusively dedicated to main systems, without enough attention to auxiliary equipment, which support the entire function of the power plant. This paper presents the implementation of a vibration monitoring scheduling for 144 auxiliary equipment. It is structured in a three-stage methodological proposal: damage detection for condition, possible causes identification and fault diagnosis. The results of the new scheduling make it possible to determine the health status for the assets analyzed and inspection critical path. Therefore, this method is a support to reliability and availability for the operation of thermoelectric power plants.

Keywords: Vibration-based Condition Monitoring; Reliability and Availability; Thermal Power Plants; Combined-cycle.

FUNCTIONAL AVAILABILITY AND RELIABILITY MODELLING IN PLATFORM DESIGN AND MANUFACTURE

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Abstract

Availability, Reliability and Maintainability (ARM) are three attributes that collectively affect the economic life-cycle costs of platforms. Whilst there are different approaches, this paper presents modelling of Intrinsic Availability and Reliability (Ai&R) of Key Platform Functions (KPF) and System Functions (SF) adopted as a modelling approach during the platform design and manufacture (D&M). Ai is a measure of the proportion of time, which required functions are successfully provided, when used in stated conditions. It is a useful indication of the potential availability that the platform offers separate from operational and logistics constraints. When high reliability is achieved and supportability optimised, corrective maintenance is minimised, hence in-service availability realised tends towards the Ai and a limited number of failures are expected that result in support / logistic delays. Ai&R modelling using increasingly mature data, during the D&M phases provides visibility of potential impacts on the Ai&R implicit in the design. Estimating the Ai&R at equipment, SF and KPF levels gives a consistent approach within a complex platform design and allows improved comparative analysis. This paper presents benefits and outcomes of the application of functional ARM for platform modelling and simulation.

Optimal condition-based maintenance for a deteriorating system with unscheduled maintenance opportunities

Abstract

We consider the problem of optimally maintaining a system of which the deterioration follows a Markov process and its deterioration level is regarded as a criterion for performing maintenance. We select one of two actions, keep operation or replace, based on its deterioration level at each time epoch of state transition. Besides the opportunities from state transition, we have some unscheduled opportunities which correspond to random opportunities triggered by failures of other systems in close proximity. We assume that these unscheduled opportunities occur according to a Poisson process. We formulate the optimal decision-making problem of condition-based maintenance with unscheduled maintenance opportunities as a continuous time Markov decision process. Furthermore, we analyze the structural properties of the optimal maintenance policy which minimize the total expected discounted cost over an infinite-horizon. Several assumptions which can simulate some of the real situations are assumed to simplify the calculation and it makes sure the model is feasible. Numerical examples are given and sensitivity analysis is performed to provide reference for parameter setting.

A reinforcement learning-based model for the optimization of a bi-objective condition-based maintenance policy in multi-state multi-component systems

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In systems such as nuclear power plants, offshore facilities and aerospace components, in which there are stressful or remote working conditions, managers are concerned both about the cost efficiency of maintenance policies and the worker's safety, which are usually conflicting objectives. This paper puts forward a reinforcement learning-based framework that enables to find the best trade-off between the cost efficiency of a condition-based maintenance policy and worker safety in a multi-state multi-component system. The framework brings together the approximation power and good scalability propriety of Double-Deep-Reinforcement-Learning algorithms (DDQN) to large state and action spaces founded in multi-state multi-component systems, the capacity of goal programming of solving multi-objectives problems taking into account the preferences of the decision maker over the objectives, and the capacity of artificial neural networks to map linear and non-linear relationships from real data as a free-model approach, that can be used for mapping the relationship between component degradation states and the cost and reliability performance of the system. The paper intends to verify the robustness of the framework regarding the variation of the decision-making elements.

Optimization of Supportability and Reliability for Aircraft's Initial Provisioning Service Operations

Adel A Ghobbar
Sandra Rivas

Abstract:

This article starts from the need of a Logistics Support Service provider to achieve accurate and reliable Spare Parts Recommendations for the Initial Provisioning of a aircraft fleet; the initial provisioning spare part problem is characterized for the lack of historical data for the estimation of the stock requirements. The objective of our project was to develop and implement a process for the computation of accurate Spare Part Recommendation by exploring the relations among RAMS, the spare part problem and the available computational methodologies. This article presents an analysis leading to a computational approach for the required spare parts number based on the available input data and on the spare parts characteristics. The project also performs an analysis of the applicability of the commercial tool OPUS in the aircraft Initial Provisioning stock sizing problem. OPERATIONAL availability of a system depends, to a great extent, in the design of the supportability of the system. Within the aerospace industry and given the resulting costs from having an AOG (Aircraft-On-Ground), the requirements for fleet availability are very high, and thus having an adequate logistics support system is critical. Two of the main determining factors in a logistics supportability system are the available maintenance support and the availability of spare parts. In order to assure the required fleet availability spare parts inventories, need to be available at the required level within the supply chain. Spare parts and the related activities represent a large share of the total Life Cycle Cost of the system, given that the access of spares highly influence the system availability performance. A shortage in spare parts have an effect in the overall system performance as it is translated in a lower availability, which might be insufficient, or an increased operational risk. Therefore, for the correct supportability and availability of a system it is critical to meet the spare parts demand. This demand can be controlled by acquisition of the required number of spares; quantity that has to be forecasted in an optimum way in order to find a balance between the spare's availability and the acquisition investment. The definition of the optimum level of stocks requires an understanding of the technical and economical features of each spare part. Through the development of this method, this research aims on demonstrating the influence that several parameters and data have on the spare part sizing problems, the influence that the spare part characteristics have on the computational methodology and the applicability of a commercial tool such as OPUS10 for the mentioned problem. The details of this research are provided in the article.

Keywords: Optimization, Supportability, Reliability, Maintenance, Integrated Logistics.

Supportability and Availability of Expendable Parts for Aircraft Maintenance: A Multi-Criteria Parts Classification Approach

Adel A Ghobbar
Floris Wolf

The Aircraft Engineering and Maintenance (E&M) delivers is aircraft availability for its customers: Airline and other operators need aircraft to fly as often as possible and as full as possible in order to maximize profit. One of the key performance indicators (KPI) of aircraft maintenance unit is the number of deferred defects due to material shortage. The availability of the required amount of materials and tools is a critical boundary condition in every maintenance process; without either one the ground engineers cannot perform their allotted tasks. The material process was investigated to find which factors influence the performance of the Material Unit with regard to the availability of expendable parts. After studying the bottlenecks found in the material process, it was concluded that the biggest gain in availability could be made by improving inventory control. To offer the best possible inventory control a part classification was made that incorporates five different material characteristics and combines them. Depending on the combined classification an inventory control strategy is advised.

An advisory tool was made to aid material planners in determining the best planning parameter settings for the material ERP system based on the multi-criteria material classification. A simulation based on historical data yielded encouraging results when comparing the amount of stock-outs generated by the advisory tool with actual historical stock-out performance.

The main conclusion of this work is that structural inventory control is necessary to guarantee sustainable material availability. Introducing adequate inventory control procedures and tools will result in improved material availability and less DD's. Furthermore, it will give planners more time to deal with the recovery process and unpredictable material demands. It is recommended that operators introduce a transparent and consistent set of inventory control tools and procedures which will lead to pro-active inventory management. The best option examined in this report was building an advisory tool based on a clear and transparent control strategy. The proposed tool gives inventory control advice based on concrete decision rules and calculations. The experience and knowledge of material planners will always remain vital to the planning process because of the erratic nature of aircraft spare parts demand and the many events that occur in the material process that cannot be anticipated by calculations.

Keywords: Supportability, Availability, Expendable Parts Classification, Aircraft Maintenance.

Build Real-Time Streaming Analytics with an In-memory, Scale-out SQL Database (VoltDB)

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Abstract: There is increasing interest in building applications against Real time streaming data. In our point of view these applications have three different forms/ patterns which are combined into a single application. These three forms are; real time analytics, real time transactions/ per-event transaction/ real time decisions and the ability to build pipelines that connect incoming streaming data sources to downstream queues/applications or repositories like OLAP systems. Many of these applications start with real time analytics. There are many questions about how to support streaming analytics in a scalable, fault tolerant and reliable way in front of these OLAP systems in order to drive immediate value inside a transparency from real time streams. This paper focuses on this and also on; how VoltDB's scale out SQL relational system can be used to real time analytics against streaming data, description of where these fast data applications fit, in order to state what types of analytics are useful. The word analytics is a very broad term and being able to position the applications into the right part of the eco system will clarify what type of analytics we are discussing, some of the requirements a platform has to have in order to be good at analytics, decisions and creating pipelines for streaming applications, the role of analytics.

Optimizing maintenance budget for an interdependent and heterogeneous multi-asset system

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Abstract. In many industries, decision-makers have to manage several units performing the same function but with different physical characteristics and operating conditions. A maintenance budget determined a priori is shared between the different units and managed throughout an established time horizon. To guarantee a given service level, managers can decide between replacement and repair actions. With the recent advances in monitoring technology and the growth of available data, these decisions that were previously made base on experience or business rules can now be optimized. The focus of our work is to take advantage of condition data to optimize operation and maintenance decisions, and consequently, minimize the total maintenance budget required. However, defining the required budget is a daunting task since each asset condition degradation is uncertain, and with multiple degradation patterns. To tackle this problem, we propose a new stochastic mixed-integer programming model. The model uses a Gamma function to represent each asset condition and incorporate uncertainty. We validate our approach in a case study faced by a distribution system operator that has to define a maintenance budget for the next five years for a portfolio of power transformers operating under different load conditions.

Modelling maintenance of a multi-component system with wear rate-state dependence: the case of a seawater reverse-osmosis desalination train

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Increasing drought worldwide has given prominence to seawater desalination. Desalination plants on the Pacific coast, the Middle East and Asia are impacted by algal blooms. This research is a case study of a Reverse Osmosis (RO) desalination plant in California. Membranes are key components of an RO plant. Membrane degradation due to biofouling is a major operational challenge and an important contributor to operations and maintenance costs. Biofouling shortens membrane life. We have developed a mathematical model of membrane degradation. Broadly, an RO train has membranes (filters) in series and the degradation of a membrane depends on its position in the train and the states of its neighbours. Based on the model, we build a digital twin of an RO train. Indirect condition and direct degradation measurements from four years of operation of the plant are used to calibrate the model and the hence the digital twin. We use the digital twin to study various maintenance policies, which include cleaning, replacement of worn-out membranes, re-positioning of part-worn membranes, the selection of RO trains for intervention, and the timing of interventions. The output of the simulation aims to support decision-making by plant operators. We demonstrate the potential benefits for cost reduction, while meeting operational delivery requirements. The model also contributes to the understanding of how biofouling affects the individual membranes in the vessels of an RO train

Keywords: Maintenance, multi-component system, reverse osmosis, desalination, membrane biofouling.

Petri Net Modelling for Achieving an Optimal Design of a Wind Turbine Condition Monitoring System

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Condition monitoring has demonstrated its effectiveness in improving the economic return of wind turbines. However, a wind turbine consists of hundreds, even thousands, of mechanical, electrical and power electronic components. The failure of any one of them may lead to the shutdown of the turbine. For this reason, a variety of component monitoring systems have been developed dedicated to monitoring these different components. Consequently, a wind turbine usually needs to be monitored simultaneously by several different types of component monitoring systems that benefit wind turbine operation and maintenance to different extents. This not only increases the complexity of the hardware configuration but also increases the costs of the entire condition monitoring system. How to achieve a condition monitoring system that can monitor the most vulnerable components whilst bringing the most economic benefit to the wind turbine operator is an important question. The aim of this paper is to answer such a question with the aid of the Petri net modelling method. The model developed in the paper will investigate the influences of different types of component monitoring systems on the economic return of wind turbines, thereby providing a feasible tool for constructing an optimal wind turbine condition monitoring system.

A railway route model for track geometry maintenance under the impacts of summer heatwaves

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As utilisation of rail transport continues to increase, there is ever growing demand for infrastructure managers to deliver a highly available, low risk rail network. Asset management support tools are used to plan and schedule a variety of maintenance activities, with tamping and stoneblowing being the primary interventions in the treatment of track geometry faults. Elevated summer temperatures are a known disrupting factor on the rail network – due to the risk of a track buckle – and can prevent the delivery of an effective maintenance strategy.

This presentation focuses on a Coloured Petri net (CPN) modelling approach to railway track asset management. This is a flexible method, able to capture the complexities of degradation, inspection, and maintenance over a route of track section assets. Excessively hot weather is introduced as an inhibiting factor for maintenance delivery. The CPN demonstrates a novel search transition function which delivers opportunistic maintenance practice. Simulation results show that frequent inspections and opportunistic maintenance can support high availability performance and resilience to heatwave disruptions.

Train Derailment Risk Model Incorporating Complex Asset Management Strategies

A.Jackson

Rail track and surrounding railway infrastructure condition can make a significant contribution to the risk of train derailment. The interactions between degradation processes, maintenance strategies and railway infrastructure condition are often complex. Traditional fault tree-based approaches to risk modelling are often unable to accurately encapsulate these relationships and their effect on derailment risk.

A new modelling approach is presented which seeks to incorporate the effects of complex asset management strategies into train derailment risk fault trees. This is achieved through the use of Petri net models capable of accurately modelling degradation and maintenance processes. The outputs of these Petri net models can then be propagated through derailment risk fault trees and risk metrics calculated using typical fault tree analysis techniques.

Using simulation and the importance components in reliability systems

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Due to the increasing complexity of modern control systems and the growing demand for quality, cost efficiency, availability, reliability, and safety, the analysis failure systems in complex industrial is gaining more and more importance. Repairable systems such as line productions, pumps, etc., consist of a large number of interacting components that perform the system's required functions.

Simulation studies use computer intensive procedures to assess the performance of a variety of statistical methods in relation to a known truth. Such evaluation cannot be achieved with studies of real data alone.

This paper describes a study to modelling the systems, identify some of the importance component indicator in the systems and simulation the reliability of the coherent and complex equipment.

With the use of simulation and calculation reliability tools, it's possible to improve inspection intervals and optimize cost. An application using different simulations software's is made.

Keywords: Reliability, maintainability, simulation and importance components.

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Assessment of the Influence of Covariates on the Operational Safety of Complex Repairable Systems by a Generalized Proportional Intensity Model (GPIM)

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In this article the future performance of complex repairable systems (CRS) is described using the Generalized Proportional Intensity Model (GPIM). The latter constitutes a realistic model allowing a better modeling of the inter-failure times when the data of the reliability and the maintenance of the system are available. GPIM allows the inclusion of multiplicative scaling factors to assess the effect of preventive (PM) and corrective (CM) maintenance on system behavior. The extended form of GPIM (extended GPIM) also makes it possible to consider other predictive variables (covariates) necessary to bring to light hidden phenomena.

The GPIM was considered for a reliability and maintenance history relating to an oil pump operating at SONATRACH (South Industrial Center, Hassi Messaoud). The parameters of the models as well as their goodness of fit will be evaluated by the maximum likelihood approach using the Matlab programming language.

As GPIM uses NHPP models as a basic function, three forms of intensities (power law, log linear and constant intensity law) are used in this study. The log linear represents the best fit model specifically when simulating both “Time since Last Maintenance Action (TSLM)” and “Failure Severity (FS)” covariates at the same time. This advantage of including this type of information significantly guides the decision on scheduling PM intervals by preventing in particular the effect of the second covariate “Failure severity” which could have critical consequences for the company.

Keywords: Complex repairable systems (CRS), extended GPIM, Covariates, PM, CM, Failure severity (FS), time since last maintenance action (TSLM), maximum likelihood approach.

Diagnosis of Gear and Bearing Combination Defects by Vibration Analysis - Miloudi Zakaria

In modern industry, the importance of condition monitoring and fault diagnosis has steadily increased due to the continuous improvement of safety and quality standards.

Gearbox, as one of the most common components used in modern machinery, is susceptible to failure under severe working conditions and therefore requires the practice of a fault diagnosis.

Early fault diagnosis in advanced mechanical systems, such as gearbox, has always been a major challenge ;Even with the latest emergence of Machine Learning such as deep neural networks. The efficiency of the classic fault diagnostic method depends primarily on the extracting features and subsequently implemented by the classifier.

This Summary introduces a a deep convolutional neural network-based transfer learning approach which not only involves pre-processing free adaptive feature extractions, But it also needs only a limited amount of training data. The proposed transfer learning algorithm consists of two parts ; The first part consists of a piece of a pre-trained deep neural network that automatically extracts the features from the input; The second part is a completely linked stage to classify the features that need to be trained using the data of the gear failure experiment.

The accuracy obtained suggests that the proposed approach would be not only viable and robust, but also has the potential to be readily applicable to other fault diagnostic activities.