MAINTENANCE RESEARCH DAY

8 March 2018

NS Trefpunt - Utrecht

Organised by

UNIVERSITY OF TWENTE.

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Welcome

A lot of research on maintenance is being performed in the Netherlands and in Flanders, ranging from research on wear and failure behaviour to optimization of maintenance intervals or spare parts logistics, and from research on power generation and distribution, to transportation, to manufacturing equipment. We felt that we were missing the overview; your attendance today suggests that you share that feeling.
Today, we tried to get together all the relevant groups involved in maintenance topics.

We have two excellent plenary speakers from the Delft University of Technology and from the Nederlandse Spoorwegen (NS) to open and close the workshop and 15 speakers in parallel sessions from 7 different universities.

Since the primary aim is to know what others are doing, we decided to schedule only two parallel streams of sessions. This should give you, and us, the opportunity to also see presentations that you would not see at your regular conference.
Moreover, this year, we have also planned 3 discussion panels in the afternoon. to discuss with colleagues you already know and to meet new colleagues.

Finally, to enhance our connections between researches and industries, this year the Maintenance Research Day 2018 will host the Alumni Day of the WCM Summer School organised since 2012. We are deeply convinced that this combination can stimulate positive interactions between Academia and Industries.

We hope you could enjoy the day!

Dr. ir. Alberto Martinetti,
University of Twente.

Dr. ir. Dario Di Maio
University of Twente.

Program

Time	Activity
09.30-10.00	**Entry (with coffee and tea)**
10.00-10.20	**Welcome by organization** **Introduction Prof. Dr. Henk Akkermans**
10.20-11.00	**Plenary session by Dr. ir. Wim Verhagen (Tu Delft)**
11.00-11.25	**Coffee and tea**
11.25-12.45	**Parallel Session 1** *1A – Technical Session*: Zhou Su; Ayse Sena Eruguz; James Wakiru Mutuota; Jan-Jaap Moerman/ Seppe van Heusden *1B – Logistics Session:* Sarah Van der Auweraer; Nils Knofius; Sha Zhu; Collin Drent
12.45-13.30	**Lunch**
13.30-14.50	**Parallel Session 2** *2A - Management Session*: Erik Skov Madsen; Sukon Wu; Willem Haanstra *2B – Technical Session*: Michiel uit het Broek; Damian Rommel; Heletjé van Staden; Dimitrios Karampelas
14.50-15.15	**Break with coffee, tea and soda**
15.15-16.00	**Discussion Panels** – Maintenance Management – Dr. ir. Bob Huisman (NS) – Maintenance Technology – Dr. ir. Rob Bosman (UT) – Maintenance and Service Logistics – Prof. Erik Skov Madsen
16.00-16.45	**Plenary session by Cock Liefting (NS)**
16.45-17.00	**Conclusion & farewell by organization**
17.00-18.00	**Drinks**

Plenary session speakers

Dr. ir. Wim Verhagen
Tu Delft
Plenary session

Bio

Dr. ir. W.J.C. Verhagen is assistant professor at the Air Transport and Operations section, Delft University of Technology, faculty of Aerospace Engineering. His research focuses on aircraft maintenance operations, with specific attention to development of knowledge-based maintenance systems, predictive maintenance models and decision support tools to improve the efficiency of aircraft maintenance planning, execution and support.

Abstract

Current and future directions in maintenance research are readily available to any burgeoning researcher in the field: a variety of strategic research agendas promise novel ideas and guidance towards future success. Local, national and international agendas have been defined for a multitude of industries, with a strong overlap in core contents. But when everybody is marching to the same beat, how do you set yourself apart? Should you even try to set yourself apart?

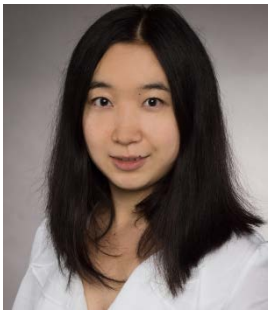
In my plenary talk, I will briefly survey the main research agendas influencing aircraft maintenance research today. I will subsequently highlight how these agendas have been co-opted and operationalized into a single, consistent vision on aircraft maintenance research. On the basis of this vision, my group has been highly successful in recent years in acquiring EU funding. Two particular EU projects will be discussed, as examples of how an integrated set of research activities can be used to bring novelty, value and actual impact into play.

Cock Liefting
Nederlandse Spoorwegen
Plenary session

Bio

Since 1979 employee of Dutch Railway at NS Techniek.
Many years of experience in production-, project- and asset management. Last three years responsible for the preparation of maintenance and introduction of a new commuter train fleet of 118 Sprinter Next Generation trains into the NS maintenance organization.
Before this project responsible for the preparation of maintenance and as assetmanager of the FYRA trains in the Netherlands. My biggest challenge and motivation is to make things happen, implementing lessons learned from previous projects and to have influence at the right time with the right people to realize big challenges.
I have developed myself by making maximum use of by broad practice experiences supported by evening studies in mechanical engineering and higher technical business administration.

Parallel session speakers
1A – Technical Session



Zhou Su
Delft University of Technology
Session 1A – Technical Session

Integrated condition-based track maintenance planning and crew scheduling of railway networks

Abstract

We develop a multi-level decision making approach for optimal condition-based maintenance planning of a railway network divided into a large number of sections with independent stochastic deterioration dynamics. At higher level, a chance-constrained Model Predictive Control (MPC) controller determines the long-term section-wise maintenance plan, minimizing condition deterioration and maintenance costs for a finite planning horizon, while ensuring that the deterioration level of each section stays below the maintenance threshold with a given probabilistic guarantee in the presence of parameter uncertainty.

The resulting large MPC optimization problem containing both continuous and discrete decision variables is solved using Dantzig-Wolfe decomposition to improve the scalability of the proposed approach. At a lower level, the optimal short-term scheduling of the maintenance interventions suggested by the high-level controller and the optimal routing of the corresponding maintenance crew is formulated as a capacitated arc routing problem, which is solved exactly by transforming it into a node routing problem.

The proposed approach is illustrated by a numerical case study on the optimal treatment of squats of a regional Dutch railway network.

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Ayse Sena Eruguz
Eindhoven University of Technology
Session 1A – Technical Session

Integrated Condition-Based Maintenance and Spare Parts Optimization for Partially Observable Multi-Component Systems

Abstract

The rapid development of sensor technologies facilitates the implementation of condition-based maintenance. Condition-based maintenance requires a measurable condition indicator (e.g., temperature, vibration etc.) and the existence of warning limits. Using sensor technologies, service providers can remotely monitor the systems installed at their customers. It is not always affordable and/or feasible to install sensors dedicated for each component of a multi-component system. When a sensor is on (sub-) system level, it provides partial information about the condition of the system. In other words, sensor information does not indicate the condition of the components, but it is possible to observe a defect or a failure in the system. The decision maker needs to infer the exact state of the system from the current condition signal and the past data, in order to decide (1) when to intervene, i.e., visit the customer for inspection and maintenance; and (2) which spare parts to take along with on a customer visit. We model this problem as a partially observable Markov decision process.

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James Wakiru Mutuota
KU Leuven
Session 1A – Technical Session

Simulating the influence of maintenance actions on equipment reliability

Abstract

Significant capital investments, in the form of facilities and equipment require to attain high productivity to remain economic and competitive through their useful life. There is evidence that maintenance plays a crucial role in preserving and restoring the equipment's condition to physically perform as required. However, maintenance not only lengthens the equipment life, but also reduces the negative impact caused by component failure in an equipment. This impact, which affects the time to next failure (TNF) of a component, depends on the inherent characteristics and severity of respective maintenance action carried out on the component. Corrective and preventive maintenance actions carried out such as replacement, repair, recondition, reuse and overhaul have different impact levels on the equipment's TNF, thus their optimization would potentially enhance the plant productivity through increased availability. This study models the impact of the maintenance action on components time to next failure and further analyses their effect on the equipment availability and maintenance time. The proposed study is demonstrated through the use case of a thermal power plant, where the turbocharger which is one of the critical subsystem is modelled. From a moderate base turbocharger availability (with high reliance on replacement action), enhancement of reuse, reconditioning and repair actions indicate an improvement in equipment availability. These findings have significant implications for the understanding of how various maintenance actions influence equipment reliability offering insights towards future subsystem optimization research.

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Jan-Jaap Moerman / Seppe van Heudsen
University of Twente.
Session 1A – Technical Session

Design for adaptability in train interior: A case study

Abstract

Passenger railway organizations need to provide reliable and high-quality train services to its passengers. To improve the service quality in train operations during both peak, and off-peak hours, trains need to be able to adapt between these two functional states to meet the changing needs of railway passengers. The main objective of this research is to design a train interior which is able to adapt to peak and off-peak hours during train operations.

Adaptable design:

The objective of adaptable design is to extend the utility of products and their designs Parallel adaptability of a product means that the same product can be set up in various ways to perform different functions. This typically results in the development of versatile products which are capable of performing several functions and corresponds with the challenge of designing a train interior that is able to adapt to peak and off-peak hours.

The starting point of the design process in this research is to design new, more adaptable, concepts for seats or places in the train.

Case study:

The VIRMm trains are a series of electric multiple unit double-deck trains operated by the Dutch Railways, the principal railway operator in the Netherlands. These trains have reached half of its operational life and require refurbishment and modernization. Besides maintenance work on the electrical, mechanical and hydraulic technology, the modernization of the VIRMm requires work on the train body, both on the inside and on the outside of the train. This provides the opportunity to design and measure train interior that is able to adapt to peak and off-peak hours.

Co-authors: Alberto Martinetti, University of Twente.

Parallel session speakers
1B – Logistics Session

Sarah Van der Auweraer
KU Leuven
Session 1B – Logistics Session

Forecasting spare part demand using service maintenance information

Abstract

We focus on the inventory management of spare parts that are used for service maintenance. These parts are commonly characterized by a large variety and an intermittent demand pattern. We develop a method to forecast the demand of these spare parts by linking it to the service maintenance policy (either preventively or upon failure). As the demand of these parts originates from the maintenance activities that require their use, it is related with the number of machines in the field that make use of this part (known as the installed base), in combination with the part's failure behaviour and its maintenance policy. By tracking the installed base (through machine sales and discards) and estimating the part failure behaviour, we provide a forecast of the future spare parts demand during the upcoming lead time.

Our work is validated by a numerical experiment. We show that our policy has the potential to provide cost savings compared to the traditional forecasting techniques for intermittent spare part demand

Co-authors:
Robert Boute, KU Leuven and Vlerick Business School

Nils Knofius
University of Twente.
Session 1B – Logistics Session

Transitioning to additive manufacturing for spare part supply

Abstract

Additive Manufacturing (AM) is a computer-controlled production process, in which a complete item is build up layer by layer from raw materials. In practice, 3D printing is an established synonym for AM. Various institutions attribute AM a bright future. In general, AM technologies are becoming faster, cheaper, safer, more reliable, and environmentally friendly. This clearly demonstrates the value to get acquainted with the technology and its opportunities. The low-volume, high-variety spare parts business is often identified as one of the prime beneficiaries of AM technology. This perception stems from the belief to substantially increase the responsiveness of spare part supply chains with AM technology. For instance, consider the option to print spare parts on demand. In the future, this concept may reduce safety stocks and obsolescence risks. Also, we may think about the option to print spare parts with multi-purpose AM equipment close to the customer site. This approach does not only present a viable alternative to expensive emergency shipments and decentral stocking but may also represent a response to more demanding service level requirements. A transition to AM technology after the regular production phase, however, comes with several challenges. Typically companies possess the capability to source spare parts with conventional manufacturing (CM) while the AM process has not been prepared yet. Another aspect is the uncertainty associated with switching to a less matured production process. For instance, a decrease in AM production costs is likely in the near future, while the order of magnitude and the timing remains difficult to predict. Taking these aspects into account, we discuss if and when an additional investment in AM technology is justified. A case study, conducted at an OEM of radar systems, will contextualize our results and will exemplify the potential of AM technology in the spare part business.

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Sha Zhu
Erasmus University Rotterdam
Session 1B – Logistics Session

Life time extension and an application to PC upgrading

Abstract

In the field of maintenance, many literature consider the physical deterioration of capital asset, e.g. using Weibull distribution to model the deterioration process. However, in some cases physical deterioration is not the key reason of maintenance. For example, PC customer wants to replace CPU not because of its breakdown but the launch of new version of CPU with higher performance. Comparing with physical deterioration we call it commercial deterioration.

We consider asset life time extension based on commercial deterioration which means increase the economic life of asset. The trade-off is between replacing the asset completely and conducting a partial upgrade. We build a Markov decision model to obtain upgrading policy which has a positive impact on life time extension.

We apply our model to PC case including the upgrading of CPU, GPU and HDD. We fit the curve of commercial deterioration of CPU, GPU and HDD with hand collected dataset. Based on the commercial deterioration, we obtain the performance level above which LTE policy refers to upgrade the component instead of replacing a PC.

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Collin Drent
Eindhoven University of Technology
Session 1B – Logistics Session

Dynamic Dispatching and Repositioning Policies in Service Logistics Networks

Abstract

Motivated by the increasing demand for faster service when advanced capital goods fail, we address the problem of dispatching and pro-actively repositioning service engineers in a service logistics network such that extremely short solution times to service requests can be realized in a cost-efficient way. By formulating this problem as a Markov decision process, we are able to investigate the structure of the optimal policy, thereby focusing on specific characteristics of this optimal policy. Using these insights, we then propose scalable static and dynamic heuristics for both the dispatching and repositioning sub-problem for networks of industrial size, based on the minimum weighted bipartite matching problem and the maximum expected covering location problem, respectively. The dynamic dispatching heuristic takes into account real-time information about both the state of equipment and the fleet of service engineers, while the dynamic repositioning heuristic maximizes the expected weighted coverage of future service requests. In a test bed with a small network, we show that our most advanced heuristic performs excellent with an average optimality gap of 4.6% under specific circumstances, but strictly outperforms all other heuristics across all instances. To show the practical value of our proposed heuristics, we conducted extensive numerical experiments on a large test bed with networks of industrial size where significant savings of up to 61.9% compared to a benchmark static policy are attained..

Co-authors:
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Minou Olde Keizer, CQM BV

Parallel session speakers
2A – Management Session

Erik Skov Madsen
Southern University of Denmark
Session 2A – Management Session

Modularization of Maintenance in the Offshore Wind Power Sector

Abstract

The wind power sector is booing in the northern part of Europe and wind turbine generators have for many years been erected at on shore sites. However, because wind turbine generators become larger and larger it has become more difficult to erect these turbines at onshore sites - neighbours have complained by "not in my backyard" and because of stronger and more stable wind conditions, offshore locations for wind farms have moved further of the coast. Wind farms are now planned to be erected very far from the coast and in the middle of the North Sea. One issue is the development of reliable turbines, erection and commission of these turbines at harsh and challenging sea location. Another and even more challenging issue, which constitute up to 1/3 of the total life time cost, is the operation and maintenance for the expected 25 years of lifetime of the offshore wind turbine generators at very harsh weather conditions.

This study has been made in one of Europe's leading offshore wind power operators with more than 1,000 wind turbine generators in operation. The study explains how research of operations and maintenance of offshore wind power installation is in its early phase of research.

The study explores how maintenance tasks can be planned, grouped, executed and thereby being improved using modularization. The study reveals how the concepts of Lean can constitute an important first step before concepts of modularization can be used to improve maintenance. The study identifies how modularisation of the maintenance of offshore wind farms can constitute an important concept both to improve planning and execution of maintenance tasks in a complex and ever-changing environment and how the time used on preventive maintenance can be reduced.

Sukon Wu
University of Twente.
Session 2A – Management Session

Impediments for continuously improving maintenance policies: a Dutch railway infrastructure maintenance service provider perspective

Abstract

This paper reports on an exploratory research project that employs a case study research approach to identify the impediments for continuously improving Maintenance Policies (MP) in a maintenance service provider of the main Dutch railway infrastructure, Strukton Rail (SR). It provides a potentially interesting framework for both practitioners and theorists to identify, and categorize impediments for continuously improving MPs. The levels of the asset organization have been identified as the context and stakeholders, asset management, the asset management system, and the asset portfolio.

Using four case studies within SR, found impediments are categorized according to the four levels of the asset organization. The found impediments in the context and stakeholders are the absence of the motivation to improve MPs, and a lack of balance between asset organizational needs and objectives. Asset management requires vertical and horizontal alignment and prioritization of improvement projects, structured evaluation of MPs, and obsolescence management. The asset management system should be designed with the objective of continuously improving MPs, and provide access to information and knowledge. And finally, the asset portfolio should limit variety in physical assets and usage, and data registration requires uniformity in event and maintenance data. The findings are discussed and avenues for future research are presented.

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Willem Haanstra
University of Twente.
Session 2A – Management Session

Life Cycle Costing in Asset Management

Abstract

Life Cycle Costing (LCC) is a powerful instrument in the Asset Management (AM) of physical systems. It is a valuable tool that can be used to support rational decision making and provide transparency and accountability about various operational, tactical and strategic AM decisions and their expected consequences.

However, the application of LCC may not always be straightforward. In order to effectively use LCC in this context, it is important to further the understanding of the main challenges that practitioners face during the application of LCC in AM decision making. The goal of this presentation is to share and discuss some of the pitfalls that practitioners of LCC may face, especially during AM practice.

This presentation summarizes the main descriptions and assumptions from LCC literature into a number of postulates. These postulates about LLC can be regarded as representing commonly accepted "truths" about LCC theory. When these postulates are subsequently compared with empirical findings from several practical case studies, not all postulates seem to apply, indicating inconsistencies between the theory of LCC and the practice of AM.

The results suggest fundamental challenges in the use of LCC in AM, specifically regarding the objectives of using LCC and the scope of what is included in the assessment. The findings from this research will be used to guide further work on developing methods and tools that support AM. Practitioners can use the conclusions to avoid some of the pitfalls of using LCC.

Co-authors:
Jan Braaksma, University of Twente.

Parallel session speakers
2B – Technical Session

Michiel uit het Broek
University of Groningen
Session 2B – Technical Session

Condition-based production and maintenance for systems with redundancy

Abstract

Many multi-unit systems face significant economic dependencies for performing maintenance, e.g., expensive vessels are needed to perform maintenance at offshore wind farms. As a result, it is often cost efficient to cluster maintenance for several units in the system. However, when maintenance for units with different degradation levels is clustered, it follows that maintenance is performed too early for the low deteriorated ones or is performed too late for the highly deteriorated ones. In such situations, an interesting question is whether it can be profitable to adjust the production rates in order to synchronize the deterioration processes for the different units.

The current maintenance literature typically assumes that machines always produce at a fixed production rate and that we cannot influence the deterioration rate. However, there are many real-life situations where we can adjust production rates for machines. The deterioration rate of these systems typically depends on the production rate, implying that the deterioration process can be controlled by adjusting the production rate. This applies, for instance, to wind turbines gearboxes and generates that deteriorate faster at higher speeds.

We study a multi-unit system with condition monitoring and economic dependencies. The system is modeled as a markov decision process and optimal policies that minimize the long-run average cost are derived by backward induction. In particular, we are interested in the structure of the optimal policy, i.e., when to adjust the production rate of an unit in order to postpone or advance its maintenance moment to improve the efficiency of clustering.

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Damian Rommel
University of Twente.
Session 2B – Technical Session

Predictive Maintenance in Wind Turbine Main Power Train based on Physical Models

Abstract

One of the recent trends in predictive maintenance is the attempt to predetermine the component life time at a stage where the component is still "healthy". A promising approach to reach this objective is the usage of physical models. Hereby, both the behavior of the components themselves and the loads acting on these components are described by models. The present work will show how applying a physical model-based approach to wind turbines. The approach consists of two crucial steps: i) selection of critical parts / components and the associated physical models, and ii) quantification of the relevant loads acting on these parts, as will be discussed next.

Firstly, the life assessment of the critical components or parts of a complex system like a wind turbine must follow a modular concept. Typically the number of critical components is rather large, which would require a huge amount of work in developing the models. Therefore, the number of physical component models are ideally reduced to only a few, which could be achieved when the component models are usable for different wind turbine sub-systems (modular concept).

Secondly, applying the approach of physical models to wind turbines does not only require the specification of the critical components but also the load spectra description at the different component interfaces. Every wind turbine component has at its input and output specific loads. These loads must be known rather precisely in order to calculate the life time. As the component interface loads depend also on the wind turbine design, loads are also application dependent. This means that the modular concept can only be applied to the load models to a limited extent, as the load spectra include both design-dependent and design-independent loads.

Heletjé van Staden
KU Leuven
Session 2B – Technical Session

Optimization of condition based and periodic maintenance policies for partially observable systems

Abstract

While the value of condition based maintenance is widely known, its application is not as widely adopted yet. In this paper, we formulate and analyze the joint optimization of both condition based and periodic maintenance for a system of multiple components, by means of a partially observable Markov decision process. To demonstrate the advantage of condition based maintenance and to encourage the adoption thereof, we consider a setting that consists of one continuously monitored component, whose exact condition is only partially related to the received deterioration data and whose belief state is updated at discrete decision epochs, and a number of unmonitored components in the same system. Given an optimal periodic maintenance interval for the unmonitored components, we prove the optimality of the maintenance policy for the monitored component and instances when it is optimal to adapt the periodic maintenance interval. The optimal policy is characterized by three definite thresholds. Firstly, we prove that there exists a time threshold between periodic maintenance actions after which it is optimal to accelerate the periodic maintenance interval should the system be interrupted for condition based maintenance. Secondly, the remaining two thresholds are based on the perceived condition of the monitored component and determine when to combine maintenance of the monitored component with maintenance of the unmonitored components, or not. In addition to these three thresholds, we obtain extra thresholds dependent on both the time to the next periodic maintenance action and the perceived condition of the monitored component, the number of which is limited to the number of decision epochs between the time threshold and the next scheduled periodic maintenance action, due to the nonlinear increase in periodic maintenance costs over time. We illustrate the results with a numerical experiment based on data from an OEM that show potential cost savings over existing suboptimal policies.

Co-authors: Nishant Mishra, KU Leuven

Dimitrios Karampelas
University of Twente.
Session 2B – Technical Session

Failure mechanism identification expert system

Abstract

Although maintenance tries to prevent them, failures regularly occur in practice. Prevention prerequisites insight on the "how" a failure occurs. Failure mechanisms (FM) describe how components fail. However, operators or technicians as the first people to deal with a failure, normally lack the knowledge to access FM that act on a material level. Current failure reporting is typically done by entering a failure type/failure mode/cause manually or selecting from a drop-down menu. However, this process has been reported as problematic by several industries. Thus, this study proposes the use of an Expert System (ES) as an app in mobile devices to assist operators in assessing the appropriate FM. The basic idea behind the ES is simply that failure analysis expertise is transferred from a human to a computer in the form of heuristics. This knowledge is then stored in the computer and users call upon the computer for specific advice as needed. The computer asks questions regarding failure diagnostic characteristics, makes inferences and arrives at a specific conclusion. Then, like a human consultant, it gives advices on the most probable FM and explains, if necessary, the logic behind the advice. The ES is based on an extensive study of failure diagnostic characteristics and their contribution to FM. In contrast to failure modes, the proposed FM approach enhances the decision making upon proper remedial actions. The ES can help standardize failure mechanism identification for a given set of characteristics, unify failure terminology, and codify and document the failure investigation procedure.

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Discussion Panels

Dr. ir. Bob Huisman
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Maintenance Management

Dr. ir. Rob Bosman
University of Twente.
Maintenance Technology

Prof. dr. Erik Skov Madsen
Southern University of Denmark
Maintenance and Service Logistics

Notes