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The use of engineering tools and methods in maintenance organisations: mapping the current state in the manufacturing industry

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Abstract

Digitalisation is the future of the manufacturing industry, and it will entail production systems that are highly automated, efficient, and flexible. The realisation of such systems will require effective maintenance organisations that adopt engineering approaches, e.g. engineering tools and methods. However, little is known about their actual extent of use in industry. Through a survey study in 70 Swedish manufacturing companies, this study shows to what extent engineering tools and methods are used in maintenance organisations, as well as to what extent companies have maintenance engineers performing work related to engineering tools and methods. Overall, the results indicate a potential for increasing the use of engineering tools and methods in both the operational and the design and development phase. This increase can contribute towards achieving high equipment performance, which is a necessity for the realisation of digital manufacturing.

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Keywords: Digitalisation, Manufacturing, Maintenance, Tools, Methods

1. Introduction

The manufacturing industry is currently undergoing changes that will shape its future. The reason is digitalisation. Within 20 years, the implementation of the Internet of Things will realise the digitalisation of the manufacturing industry, which is spurring governmental initiatives all over the world. In Germany, this initiative is referred to as "Industrie 4.0", and the American equivalent is known as "Industrial Internet Consortium". The production systems in the digital factories of the future are envisioned as highly automated, flexible, and efficient. Expectations are clearly high, but there is a fundamental prerequisite for the realisation of such systems: the highly complex and automated equipment must deliver high performance. Naturally, maintenance organisations play a key role in fulfilling this prerequisite.

Although digitalisation is a common goal for the manufacturing industry, companies are struggling with low equipment performance. In order to measure equipment performance, Overall Equipment Effectiveness (OEE) has been widely used in industry [1], and OEE figures of 85% are often considered world-class [2]. However, low OEE figures of around 40-60% have been consistently reported during the past two decades [3,4]. Ljungberg [5] presents extensive OEE data with an average of 55%; refers to other studies with similar results, and comments that it "does not seem unusual to have low OEE" (p. 505). Likewise, more recent publications argue that OEE figures are commonly 15-25% below the targeted level, thus constituting one of the largest problems in industry today [6]. Clearly, this situation is incompatible with the prerequisite of high equipment performance in future digital production systems.

To achieve high enough equipment performance in future systems, working towards reduction of all types of equipment losses is essential in every life-cycle stage. However, this work requires engineering approaches within maintenance organisations. One indicator of such approaches is the use of engineering tools and methods, but there is unfortunately a

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lack of studies showing the actual use of them in industry.

Engineering tools and methods in this paper are interpreted in a wider sense. Tools are understood as means to accomplish certain objectives, which include for example Failure Mode and Effects Analysis (FMEA) [7] and Fault Tree Analysis [8]. Methods are understood as systematic procedures to accomplish certain objectives, and include for example preventive maintenance planning (e.g. [7]) and maintenance prevention [9].

The aim of this paper is to identify the current state of the use of engineering tools and methods in maintenance organisations. The study intends to answer the following two questions:

(1) To what extent are engineering tools and methods used?
(2) To what extent are engineers performing work related to engineering tools and methods?

To answer the two questions, a web-based survey study in the Swedish manufacturing industry is used, where empirical data are collected from over 70 companies. Increasing the use of engineering tools and methods within maintenance could be a first step towards achieving equipment performance levels sufficient for the realisation of future digital factories. Tools and methods can act as an important link between the operational and design and development phases, where increased knowledge of the factors affecting equipment performance can be used to improve both existing and future production systems.

2. Literature review

In this section, various engineering tools and methods applicable in maintenance organisations are presented, which are considered useful for the work towards improved equipment performance.

2.1 Models of maintenance management

In literature, numerous models for maintenance management have been proposed. When reviewing the published literature on this topic, Fraser et al. [10] found that the three most popular models are Total Productive Maintenance (TPM), Condition-Based Maintenance (CBM), and Reliability-Centered Maintenance (RCM) (note that TPM is a more holistic company-wide model, while RCM and CBM can be used as integrated parts in a company's maintenance model. For further review of these three models, see [11]) However, Fraser et al. [10] observe that out of several thousand articles published on TPM, RCM, and CBM, only 82 papers provided empirical evidence or links to practice. Therefore, a gap between theory and practice in regard to these models is proposed, where the authors conclude that "maintenance theory, in many respects, is de-coupled from practical applications." (p. 655).

2.1 Engineering tools and methods

Within the three most popular maintenance models, as well as in other maintenance literature, the use of various engineering tools and methods are emphasised. These tools and methods aid in identifying, analysing, and evaluating various types of risk, and thus contribute to improved decision-making for reduction of equipment losses.

To identify hazards and risks, suitable qualitative tools are e.g. Hazard and Operability studies (HAZOP) and FMEA, whilst FTA and Event Tree Analysis (ETA) are quantitative alternatives [8]. Decision Tree Analysis (DTA) can be used for maintenance policy selection [12], and Variation Mode Effects Analysis (VMEA) is useful for finding critical areas in terms of the effects of unwanted variation [13]. Further, Root Cause Analysis (RCA), which is normally supported by Fishbone Diagrams, is important for analysing problems down to their root causes instead of merely addressing their symptoms [14]. These tools can be used for many different purposes, e.g. FMEA which is useful for hazard and risk identification [8], deterioration and failure analysis [15], and preventive maintenance planning [7].

For a manufacturing company, the occurrence of equipment failures and their consequences are fundamental to manage. However, reliability analysis not only deals with failure modes (i.e. *how* equipment fail using e.g. FMEA) but also with failure rates (i.e. the *frequency* in which it fails, using e.g. Weibull analysis [16]). Furthermore, engineering tools are vital for a proactive approach to safety risks [17], and managing safety risks in essential in maintenance. Production disturbances often results in direct accident risk for maintenance workers [18], and the European Agency for Safety and Health at Work (EU-OSHA) [19] reports that 10-15% of all fatal accidents within the 'working process' area are related to maintenance. Lind and Nenonen [20] describe several risk-increasing factors for maintenance workers such as operating under the pressure of time, performing independent maintenance work during night shifts, as well as poor work practices, work guidance, and risk analysis. To review job procedures and practices, identify hazards, and determine risk-reducing measures, Job Safety Analysis (JSA) is a suitable tool [21]. Further, even simple and quick tools can provide useful information, where one example is What-if analysis (for a discussion of situations where such simple tools are justified, see [22]).

Academic research within the field has focused on enhancing the capabilities of individual tools [23]. Authors have proposed both developed versions of individual tools, e.g. cost-based FMEA [24], as well as combinations of several tools, e.g. combining RCA, FMEA and Fuzzy Methodology [25] or FMEA-aided LCC [26]. However, some engineering tools are academic and therefore seldom used by maintenance practitioners [23]. Moreover, many tools are deemed time-consuming. For instance, Takata et al. [15] claims that FMEA is not extensively used in industry, and argues that this due to its high requirement in terms of expertise and time. To reduce the time-consumption and thus improve the usefulness of tools, computer supported versions have been proposed (e.g. Computer-Aided FMEA [27] or Automatic Generation of FMEA [28]). In fact, Zio [29] advocates for the development of user-friendly software to implement reliability engineering methods in the future.

2.2 Engineering tools and methods in design and development

The cost of failures can be avoided if their consequences are addressed early [13]. Therefore, addressing reliability and maintainability during the design and development phase is crucial [30,31]. In this phase, it is also possible to reduce the maintenance requirement through changes in the equipment or process design. This reduction of maintenance requirement can be achieved through Maintenance Prevention (the fifth pillar of TPM), which is based on analysing equipment data in search of failure trends, failure rates and root causes of failures [9]. Similarly, Life Cycle Costing (LCC) is a tool to influence the life cycle cost at an early stage [15]. In addition, tools like HAZOP and FMEA can be used at this stage to design safe and environmentally friendly production processes and maintenance activities [32]. In fact, Sandberg [33] emphasise that knowledge gained from failures and other incidents should be used for actions to make improvements in not only the current, but also the next generation of production systems (e.g. in specification, purchasing and installation).

2.3 Previous survey studies

Previous survey studies in maintenance organisations have been reported. Jonsson [30] conducted a survey regarding maintenance management and indicated e.g. that analysing reliability data is not highly prioritised. Ylipää and Harlin [34] focused on Production Disturbance Handling and concluded e.g. that tools such as FMEA and Fishbone diagrams have low user satisfaction. Alsyouf [12] identified characteristic maintenance approaches, including e.g. analysing equipment failure causes and effect, use of failure data, and recording of failure frequencies. Further, he argues that industries are aware of the role of maintenance in improving reliability and maintainability of production systems during the design and development phase. Although Alsyouf [12] touches upon the use of tools, e.g. that few companies use FMEA or DTA for maintenance policy selection, none of these studies specifically investigated the use of engineering tools and methods. This motivates the need for further studies.

3. Methodology

A descriptive survey research approach was adopted [35], with the aim of increasing available knowledge of the use of engineering tools and methods in maintenance organisations. Through a web-based survey study, empirical data were collected within the Swedish manufacturing industry between March and April 2014. The respondents were asked about maintenance models, engineering tools and methods, software, and work performed by maintenance engineers. A pilot questionnaire was tested and evaluated by researchers and industrial experts [35], and the collected feedback resulted in improvements to the final questionnaire. Thereafter, invitations were sent by email to selected respondents, an open invitation was listed on the Sustainability Circle (SC) website, and an email newsletter was sent to SC members. SC is a none-governmental, maintenance-focused organisation with more than 50 member companies.

3.1 Selection of companies and respondents

A non-random judgement sample was chosen [35], with the intention to include an expert view from high a strategic level. Although non-random sampling limits the overall generalizability of the results, the authors are convinced that this study provides valuable information about the current state of engineering tools and methods.

In total, 62 out of the 82 selected respondents answered, resulting in a response rate of 75 per cent. Non-respondents received follow-up phone calls and up to three e-mail reminders, and the most common argument for non-response was lack of time. The open invitation resulted in 22 additional responses. Out of the total 84 submissions, the respondents who did not have a high strategic position were excluded, and the respondents with the highest management level were chosen at plant-level for each company.

The final selection consisted of 76 responses from 71 companies, mainly from the discrete manufacturing and process industries. In total, 62 per cent of the respondents are from the maintenance department, 25 per cent from production department, and 13 per cent from both. A varied sample was included, where company size range from small (<100 employees) to large (> 500 employees), the capital turnover range from <105 M€ to >1050M€, and a vast majority of the respondents have long experience (more than 40 per cent have 16 years or more of experience).

3.2 Structure of the questionnaire, and analysis and presentation of data

The questions were derived from literature review, where the selection of investigated tools and methods was not intended to be exhaustive. Nominal data regarding engineering tools and software were collected using checkboxes. Ordinal data concerning all other questions were collected using Likert scales adopted from [34]. In line with the descriptive research approach, the results are presented with descriptive statistics in the form of frequency and mode (marked with bold text in the figures).

4. Results

The results from the survey are presented in the section, which shows the use of engineering tools and methods in maintenance organisations.

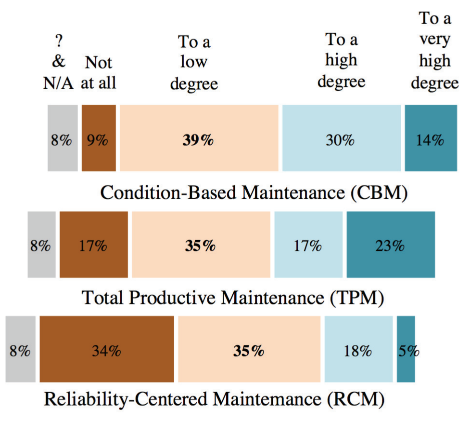

Figure 1: Maintenance models

The data in figure 1 shows to what extent the companies are working with the three maintenance models CBM, TPM, and RCM. It appears that CBM and TPM are the two most common models, and RCM the least common. This is indicated by that approximately twice as many respondents answered that CBM or TPM is used to a high or very high degree compared to RCM. However, it is important to note that none of the three models are used by a vast majority of the companies, suggesting that many companies have not yet fully implemented these models in their maintenance organisations.

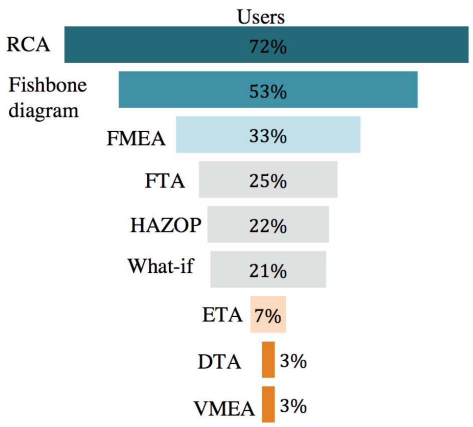

Figure 2: The use of engineering tools

Large variance in the use of the proposed engineering tools can be seen in figure 2. Clearly, RCA is the most commonly used tool, followed by Fishbone diagrams. In contrast to these two tools, the degree of use is rather low for all the others: FMEA is used by a third of the companies, while 6 out of the 9 tools are only used by one fourth or less of the companies.

In regard to the use of software for risk or reliability analysis, none of the respondents answered that their company use any of the exemplified specific software, e.g. @Risk, Relex, or Reliasoft. However, two respondents clarified that they use a “Self developed risk software” or “Risk-Based Work Selection”. Further, 37 respondents answered that another type of software is used. Out of these respondents, 6 clarified that they do use that type of software, and 31 referred to their Computerized Maintenance Management System (CMMS).

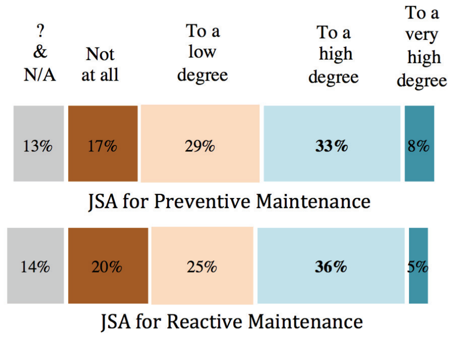

Figure 3: Job Safety Analysis (JSA)

Figure 3 illustrates to what extent JSA is used to analyse the safety of preventive and reactive maintenance activities. Small differences can be observed in the use of JSA between the two types of activities, and the answers are rather evenly spread between low and high degree of use. It can be seen that approximately 40% of the respondents answered that their company use JSA to high or very high degree for both types of activities, whilst around 45% instead answered to a low degree or not at all.

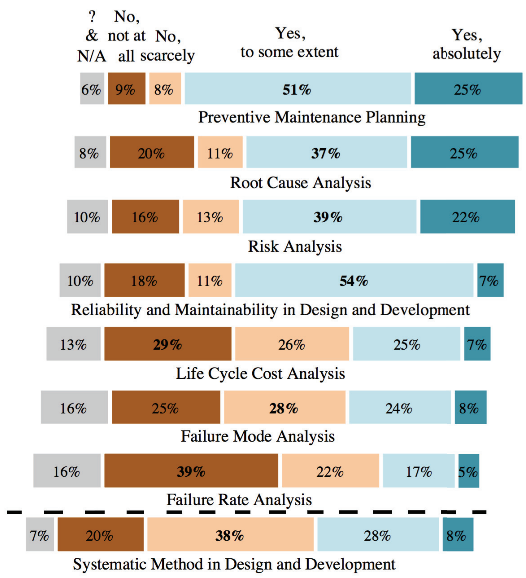

Figure 4: Work performed by maintenance engineers

Figure 4 shows to what extent the companies have engineers in the maintenance department performing work related to engineering tools and methods. The data suggests that preventive maintenance planning, root cause analysis, and risk analysis are rather common, indicated by that approximately 20-25% of the respondents answered that their company absolutely have engineers working with this. In contrast, calculating Life Cycle Costs, or analysing failure modes or failure rates seem to be less common, shown by that approximately 25-40% of the respondents instead answered their company not at all have engineers for this purpose.

Further, it can be observed in figure 4 that a majority of the companies seem to be working to some extent with reliability and maintainability in the design and development phase. A systematic method for performing this type of work, e.g. Maintenance Prevention, is however only absolutely or to some extent used in slightly more than one third of the companies. Finally, a rather clear division between the eight questions can be seen. It is noted that in regard to the top three questions, more than 20% of the respondents chose the answer alternative "Yes, absolutely", in contrast to less than 10% for the bottom five. This implies that within the companies in this study, the bottom five are work areas that maintenance engineers are not heavily focusing on.

5. Discussion

This study adopted a web-based questionnaire to identify the current state of the use of engineering tools and methods in maintenance organisations. Overall, the results illustrate a potential to increase the use of engineering tools and methods in both the operational and design and development phase.

None of the three most popular models for maintenance management CBM, TPM or RCM [11] are used to a high degree by a majority of the companies (figure 1). These findings lend further support to Fraser et al.'s [10] notion about the gap between theory and practice in regard to these models.

Large variance in the use of engineering tools is reported (figure 2): a positive observation is that a vast majority of the companies use RCA [14]. However, overall, a rather low use of engineering tools is observed. The results indicating low use of FMEA (33% of the companies in this study) is consistent with the findings of Alsyouf [12] and the claim of Tanaka et al. [15]. Still, the explanation behind the low use of engineering tools remains indefinite. Although possible-contributing factors might be that some are deemed too academic [23] or time-consuming [15] it should be noted that even simple tools such as What-if [22] are only used by one fifth of the companies.

In addition, almost none of the companies use specific software for risk or reliability analyses. This indicates two possible directions for further research: the underlying reasons to the low level of use, as well as the development of more user-friendly software [29].

Furthermore, this study observed an even spread of high and low use of JSA [21] to analyse the safety of reactive and preventive maintenance activities, as well as small differences between the two types of activities (figure 3). The observation that almost half the companies use JSA to a low degree or not at all, in combination with the results showing low use of typical safety tools like HAZOP, What-if, and ETA, highlights a potential for increasing the use of engineering tools oriented towards analysing the safety of maintenance activities. In fact, emphasising the use of safety tools within maintenance is necessary since maintenance is a particularly high-risk industrial activity [17,18,19,20].

This study has investigated to what extent engineers within maintenance organisations are performing work related to engineering tools and methods (figure 4). The present findings suggest that preventive maintenance planning, root cause analysis, and risk analysis are rather common, which is engineering work particularly important during the operational phase. However, Failure Mode Analysis or Failure Rate Analysis is found to be rather uncommon, which to some extent supports Jonsson's [30] findings that analysing reliability data is not highly prioritised. This may restrict companies' ability to understand the occurrence and consequences of failures, and therefore hinder the possibility to utilise this knowledge during the design and development phase. Therefore, this loss of knowledge might impede improvements to both the current and the next generation of production systems [33].

In fact, it is observed in this study that engineering work particularly important in the design and development phase is less common (figure 4). For example, few companies have maintenance engineers absolutely working with improving reliability and maintainability at this stage, or have a systematic method like Maintenance Prevention [9] to support this type of work. These are troublesome findings since this type of work is crucial [30,31]. It is still possible that Alsyouf's [12] argument holds true: that industries are aware of the role of maintenance in improving reliability and maintainability in the design and development phase. The findings in this study suggest that in practice, this is not as emphasised as it ought to be.

Overall, this study shows a fairly low use of engineering tools and methods within maintenance organisations in the manufacturing industry in both the operational and design and development phase. These tools and methods have the potential to support the work towards reduction of all types of equipment losses in every life cycle stage. A reduction of equipment losses is necessary to achieve high equipment performance, and low equipment performance has been a struggle for many companies for a long time [3,4,5,6]. This situation is incompatible with the prerequisites for high equipment performance in the digital factories of the future as envisioned in "Industrie 4.0" and "Industrial Internet Consortium". Therefore, increasing the use of existing engineering tools and methods could be a first step towards achieving high enough equipment performance, a situation necessary to realise digital manufacturing.

6. Conclusion

Based on a survey study in over 70 Swedish companies, this paper contributes with empirical data that identifies the current use of engineering tools and methods in maintenance organisations within the manufacturing industry.

The results show that none of the three most common models for maintenance management, CBM, TPM and RCM, are used to a high degree by a majority of the companies. Furthermore, large variance in the use of engineering tools is observed, where e.g. RCA is used to a greater extent than FMEA. However, a majority of the tools are used by less than one fourth of the companies. Moreover, in regard to the safety of maintenance activities, this study shows that the use of JSA is evenly spread between high and low use. In addition, almost no companies use specific software to conduct risk or reliability analyses. Overall, these results indicate a potential for increasing the use of engineering tools in maintenance organisations, which is of interest since maintenance is a particularly high-risk industrial activity, and plays a key role in achieving high equipment performance.

Further, this study indicates that having engineers in the maintenance department working with preventive maintenance planning, root cause analysis, and risk analysis is common. In contrast, having engineers working with LCC, failure mode analysis, or failure rate analysis is less common. Unfortunately, important engineering work in the design and development phase is missing in many companies. In particular, few companies absolutely address maintainability and reliability during the design and development phase, or have a systematic method for doing so. In general, this study has observed a lack of engineering work related to understanding the occurrence and consequences of failures during the operational phase, as well as a lack of engineering work and support from systematic methods related to addressing maintainability and reliability during the design and development phase. This may hinder companies' abilities to improve both current and next generation of production systems.

In conclusion, this study shows a potential to increase the use of engineering tools and methods within maintenance organisations in the manufacturing industry in both the operational and design and development phase. These tools and methods can support the work towards achieving high equipment performance equipment performance, which is a necessity for realising the digitalisation of the manufacturing industry.

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