BEST PRACTICES IN MAINTENANCE PERFORMANCE MEASUREMENT AT THE NETHERLANDS ARMED FORCES

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Abstract

It is of decisive importance that maintenance performance indicators are presented in a clear and transparent manner. Indicators are valuing and visualizing important information for organizations in order to achieve a required utilization level. In this paper a structured two-level approach is proposed to process available data and provide the information required for maintenance decision support. The framework is then applied to three practical cases to demonstrate its benefits. Finally, the best practices obtained from this project, both for the development process and the developed tool itself are summarized.

1. Introduction

Maintenance performance indicators are important tools for companies to control their maintenance processes and achieve the required utilization level of their assets. The main challenge is to combine and analyze all data collected within the company, transform it into useful information and present it in a clear and transparent manner. Being performed in close cooperation with representatives of the Royal Netherlands Army, Air Force and Navy, this two year project aimed for defining a structured methodology for asset data analysis. In several practical cases, data was analysed and the way of working resulted in a new framework. The proposed framework is elaborated in section 2. Application of the framework in several practical cases is discussed in section 3. This application provided the users with improved insight of the performance of their asset and maintenance organisation. Finally, the best practices derived from this project are described in section 4.

2. Framework

A survey of maintenance scorecards (EFNMS; SMRP, 2011), (Haarman & Delahay, 2004), (Muchiri, Pintelon, Gelders, & Martin, 2011), (Weber & Thomas, 2005) indicates that there is common sense about what the objectives of a maintenance policy should be. The main purpose of any maintenance policy is to achieve a sufficiently high functionality level of the system, which is often specified in terms of availability. At the same time, the aim is to minimize the costs associated to achieving that functionality. Maintenance scorecards used in industry generally entail mainly lagging indicators, and in some cases also a limited number of leading indicators. A lagging indicator typically reports what has been achieved in the (recent) past, like realized availability and costs. A leading indicator has more predictive power, as it characterizes a certain aspect of the process itself. For example, if the queue of open work orders is small, the maintenance process is well-controlled and the future performance is expected to be good. This combination of leading and lagging parameters is summarized in Table 1. Clearly, the lagging indicators specify some cost-effectiveness objective that typically can be achieved by maximizing the leading indicator, e.g. by complying to the maintenance policy.

<table>
<thead>
<tr>
<th>Leading indicator</th>
<th>Functionality</th>
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<tr>
<td>e.g. availability</td>
<td>Resource costs</td>
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<tr>
<td>e.g. repair costs</td>
<td>Maintenance policy</td>
</tr>
<tr>
<td>compliance</td>
<td>e.g. # work orders finished in time</td>
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Table 1 Leading and lagging maintenance performance indicators

Related work of the authors is focusing on the inference of models to relate the leading and
lagging indicators (Rijsdijk & Tinga, 2015). For that reason, two construction rules for maintenance performance indicators, that appear often violated in the practice of maintenance performance measurement, are proposed:

- Avoid redundancy, i.e. every maintenance performance indicator is instantaneously observable and built on unique evidence (recording routines). This to avoid definitional dependencies between performance indicators.
- Choose a sampling rate that allows to reconstruct the original signal, i.e. the variation in the signal rather than its average value allows analysts to learn about the system behaviour.

Based on these considerations, a framework is proposed now, following a two-level approach. The first level of the framework provides a fleet-wide overview of the most important performance indicators, whereas the second level provides more detailed information on the individual system and component level. Moreover, on both levels three main performance indicators are calculated, quantifying (i) system availability, (ii) costs and (iii) maintenance process control. The input for both levels of the analysis tool is a set of work orders from a Computerized Maintenance Management System (CMMS). A schematic representation of the framework at the fleet level is shown in Figure 1. The figure clearly shows the three indicators, the required inputs and the information that is provided as output.

As was mentioned before, the input for the tool is obtained from the CMMS. For the availability indicator, the up or down state of each individual system is required as input. For some systems within the Ministry of Defense, system availability can be directly obtained from an indicator in the CMMS (e.g. giving the status full / partly / non mission capable). For other systems this status is not available, and has to be derived from work order information. For example, it can be assumed that a system is down when at least one work order is open on that system. The input for the costs indicator can rather directly be obtained from the CMMS, e.g. the costs for spare parts, personnel or facilities required for certain maintenance tasks. Finally, the input for the process control indicator is typically information on the queue of open work orders or the time between maintenance, which can also be derived from the work order information. Using this basic input from the CMMS, also more advanced parameters like reliability and maintainability can be derived and real information on the system and maintenance process performance can be obtained.

The second level of the framework is very similar to the first level, but applies to individual systems or even components. Again the three main indicators are presented, but both the input and output is now more detailed. The work orders used as input already contain information on the specific system ID, maintenance location, specific subsystem or component involved, etc. This detailed information can now be used to create smaller subsets of the fleet, which can be compared. This may reveal performance differences between separate maintenance facilities or enables to generate a list of badly performing or costly subsystems or components. These performance killers and cost drivers can be used to prioritize improvements of the system or the maintenance process.

Application of the developed tool then consists of two steps. Starting on the fleet level, variations or deviations from the required or expected performance are easily detected by just monitoring the main indicators. Once an anomaly has been detected, it can be followed by more detailed analyses on level two. This will then reveal in more detail what the cause of the anomaly is, e.g. a badly performing maintenance facility, very demanding operating conditions (deployments) or components with a low reliability.

### 3. Implementation

To support the approach, NLR implemented the method in a software tool, offering insight into the factors affecting system availability in a user-friendly manner. In this prototype, the underlying raw data set was delivered by one of the
participants of the involved armed force. In a future version, the aim is to directly link the tool to the CMMS database. The two level approach was incorporated in the tool. After selection of the specific weapon system the user gets an overview of all indicators on Maintenance Performance at fleet level, see Figure 2.

![Figure 2 Screen dump of selection window](image)

Depending on the purpose of the analysis, the user selects one Maintenance Performance indicator and views more detailed information in a dash board where the results are presented with a daily frequency (if appropriate data is available). Anomalies can be further analyzed by making specific cross-sections of data sets, per system ID, failure code, or location.

The prototype tool has been tested by experts from the field. As this test was successful, the used algorithms and two level approach has now successfully been incorporated in an operational tool used by the Air Force.

The methodology and its software implementation have been applied to a number of cases, like helicopters, aircraft and vehicles, as will be discussed in the next section. These cases show that following the proposed structured approach, the reliability of both the complete fleet and individual assets can be easily monitored and availability killers or cost drivers can be identified more easily. The Netherlands Defence organization gathers a lot of data on their systems during the complete life cycle, from which potentially very valuable insights can be obtained. This data is stored in a Computerized Maintenance Management System (CMMS), but the way this data is captured and analyzed is not yet uniform across all operational commands. The proposed framework and tool can assist in considerably increasing the amount of information derived from that data.

4. Application and results

The developed method has been applied on several practical cases. Two more or less standard cases and one more advanced analyses will be discussed in this section to demonstrate the benefits of the tool.

In the first case, the reliability of a fleet of systems (level 1) is calculated based on a set of work orders (i.e. reported failures). The result is shown in Figure 3 as the dotted line. For this fleet, one of the systems was suspected to fail more often than others. For this reason, a level 2 analysis was performed, zooming into the individual system level. The reliability of one of the systems, Type X, is represented by the solid line in Figure 3, which is clearly considerably lower than the fleet average. With this information, actions directed at this specific system can be initiated to improve its performance.

![Figure 3 Fleet wide reliability versus reliability of a specific system](image)

In the second case, the focus will be on the maintenance process. Figure 4 shows the generation of new work orders during a certain period, as well as the queue of open work orders (difference between opened and finished work orders). It is clear that the queue size is limited (around 5) and rather constant in time, which indicates that the process is well-controlled.

![Figure 4 Generation of new work orders and resulting queue](image)

A similar plot for another department is shown in Figure 5. In this case the process is much less in control, as from day 450 the number of opened work orders is much larger than the number of closed orders, resulting in an explosion of the queue. This analysis on level 1 clearly shows an
anomaly, which calls for more detailed analyses on level 2. Possible reasons for the increase of the queue can be a reduced work force, logistic problems (supply of spare parts) or a sudden change in operational conditions that leads to more failures.

The final case concerns a more advanced analysis, aiming to validate the reliability estimates provided by the OEM in the procurement phase, for which the details can be found in (Rijsdijk & Tinga, 2016). Figure 6 shows for a specific system a 90% acceptance region of the OEM presumed cumulative failures (in black) as well as the actually observed cumulative failures (in red).

Still, one may seek for an explanation for the absence of failures after day 500. Currently, these explanations still follow from expert judgement but some attempts are being made to infer predictive models. As weapon systems become increasingly equipped with data loggers, explanatory variables for this maintenance performance indicator may become efficiently accessible. Rijsdijk & Tinga (2016) provide a more in depth discussion of this specific case.

5. Best Practices

The approach presented here was developed in a two-year programme by NLR and the Netherlands Defence Academy. Representatives of the Air Force, Army, and Navy were explicitly involved in the research to address user requirements and ensure commitment and adoption of project results. The best practices that could be derived form this project, both related to the development process and the developed tool, are summarized below.

1. Sharing information among project members
In a two monthly cycle, project members form different departments across the MoD came together to share results. Every project member shared his results with the group. This resulted in two effects:
   • Sharing of knowledge and experience;
   • Awareness of problems in other departments;

2. Hands-on support for participants
Participants, supported by staff members of the project, experimented with data related to failures,
repair time, repair costs, and general availability of systems and components. In this face-to-face interaction, ideas came up providing highly usable and intuitive information. This closed loop involvement of future users of the tool proofed to be a key success factor of the project.

3. Group control
The context of the reserach project and its time line enabled the project members on the one hand to spend enough time on experimenting in their own situation, but on the other hand also generated some pressure to come up with new results.

4. All armed forces involved
Since the re-organisation of de Defence organisation which evolved from a separated armed forces organisation into a single conducted/headed Defence organisation, the old departments are not yet fully integrated in the new organisation. As is the case for all organisational changes, the structure is relatively easy to realise. The culture change is a long term challenge and this will take years of exemplary behaviour of management and personnel. By doing this project jointly with participants of all armed forces, the new approach is adopted by all departments and will be known across the whole organisation.

5. Well-structured framework and clear definitions
The framework and tool developed in this project improved the analysis of all data available within the MoD. It appeared crucial to (i) clearly define what input data (and in what format) is required, and (ii) use clear and unambiguous definitions for the most important indicators (e.g. availability), as these appeared to vary across the organisation.

6. Conclusions
A framework for deriving Maintenance Performance Indicators from CMMS data in a Defence context is proposed. The framework is applied to several practical cases. The cases show that following a structured approach, the functionality (reliability / availability), costs and maintenance process control of both a complete fleet and individual assets can be easily monitored and analyzed. This research project was very successful because of the involvement of field engineers, which provided the requirements for the tool to be developed, but also could test several concepts and prototypes during the project.

This project was finalized in 2014 and will be succeeded by a new project focusing on the development of a scenario based approach to Life Cycle Management decision support. Based on the specific operational profile of a system and its failure behaviour, several possible scenarios are analyzed and projected into the future. This decision support system will give more insight in the consequences of a maintenance decision.

7. Acknowledgements
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8. References

EFNMS; SMRP. (2011). Global maintenance and reliability indicators; fitting pieces together.