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Towards a unified reliability-centered information logistics model for production assets

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Abstract. Reliability-centered maintenance for production assets is a well-established concept for the most effective and efficient disposition of maintenance resources. Unfortunately, the approach takes a lot of effort and relies heavily on the knowledge of individuals. Reliability data in Computerized Maintenance Management System (CMMS) is scarce and almost never used well. An automated risk assessment system would have the potential to contribute to the dissemination and effective use of risk information and analysis. The individuality of production setting, however, prevents current systems from being practically relevant for most industries. The presented approach combines ontologies to store and link knowledge, an information logistics model displaying the various information streams, and the Internet of production to take the different user systems and infrastructure layers into account. The provided model of a reference digital shadow for risk information and a detailed information logistics model will help software companies to improve reliability software, standardize and enable assets owners to establish a customized digital shadow for their production networks.

Keywords: risk analysis system, asset management, criticality analysis, intelligent support system, risk management, information logistics model, Internet of production, digital shadow.

1 Introduction

The percentage of productive maintenance work is stated by *WIREMAN* at 25 to 35 percent [1], which corresponds to about 9 hours of productive maintenance work in a continuous shift system per day per full time equivalent (FTE). Reliability-centered approaches in maintenance provide a powerful tool to identify the right maintenance strategy for each asset, choosing the most effective improvement projects and giving comprehensive guidance for operational disposition. The approach was introduced in the 1960s aircraft industry and published by *NOWLAN and HEAP* in 1978 [2]. *BLOOM* states that only 40 percent of the introduced reliability concepts in production plants are successful. In addition, a high percentage of these implementation attempts are very superficial and therefore the real success rate is much lower [3]. Within the following

paragraphs, five main reasons are given why the implementation of a more than 40 year old concept is still a big challenge. First, however, the next paragraph provides a brief introduction to reliability and risk for production assets.

1.1 Reliability and risk in production and maintenance

There is currently no generally valid definition of risk in the literature, as the broad range of the term allows for a wide variety of perspectives [4]. In terms of asset reliability, risk is closely linked with the performance of the assets. For example, POLLANZ defines risk as "negative influence on the achievement of objectives" [5]. Consequently, risk in maintenance management can be described as the product of the probability of occurrence and the impact on the effectiveness of the plant or asset [6].

$$\text{Risk} = \text{probability of occurrence} \times \text{impact on the effectiveness} \quad (1)$$

The task of maintenance is to identify the reasons for these deviations and to take countermeasures [7].

1.2 Holdbacks for the implementation of reliability concepts

The holdbacks for the implementation of reliability-based approaches can be clustered into five groups: Increasing system complexity, complex failure modes, subjective risk identification, complex risk aggregation, and insufficient data. In the following sections, these clusters are briefly explained.

Increasing system complexity: The concept of the value chain defined by Porter in 1985 [8] no longer holds true for today's companies and is transforming more and more into complex value-added networks [9]. This means that companies can have many different value-added chains within the same production plant, which, in addition to generating various potentials, leads to different, interconnected and more complex risks [10]. The increasingly close networking of different systems and production areas resulting from Industry 4.0 also adds new and complex risks for manufacturing companies [11].

Complex failure modes: Reliability concepts deal with the individual error causes of each component and can therefore define the ideal action to be taken instead of just having to replace the component regularly [2]. Limitations exist if the error mechanism or the overall system is not properly understood [2], which is more and more difficult given the increasing complexity of assets. These patterns cannot be predicted for a single asset, but can only be predicted by looking at reference plants [12].

Subjective and dynamic risk identification: In many cases, a risk determination is only possible post ex, since the multitude of risks cannot be estimated and data for easily comparable investments do not exist. This not only means that in most cases only a risk diagnosis is possible, as risks cannot be predicted. But also that risks that have

already occurred are heavily over or underestimated (recall bias, illusory correlation etc.) [13]. Since vulnerability is not static, it is even more difficult to measure risk [14]. For example, age and quality of maintenance have an enormous influence on how susceptible a production asset is to failure [12].

Complex risk aggregation and interdependencies: The difficulty lies in the coupling of effects, since individual events can represent an acceptable risk, but are extremely intensified by a coupling effect [15]. It is not possible to estimate overall risks, thus procedures for risk aggregation are necessary [16].

Insufficient data: However, many risks cannot be predicted for the individual asset and can only be predicted by looking at reference plants [12]. This makes applying failure data from one system to another difficult even for identical standard systems [17]. Hence, it is necessary to have a huge amount of data and find an adequate way to take variations in the environment, process and so on into account. The assessment of risks is usually expressed in language, which makes it even harder to analyze [18].

1.3 Derivation of research needs

Production risks are mostly determined in a manual, workshop-like process, which takes place a few times in the life cycle of the assets. The gathered information of these workshops are subjective, scattered across information silos and difficult to compare. Modern information systems offer the possibility to make generalizations based on large data sets and to derive recommendations for action. The possibility of learning from data represents a great potential not only within the own organization, but also beyond. This potential is not used in current organizations and information systems. The various internal and external data silos must be linked and in order to do so, use cases have to be derived from actual business needs. Risk assessment is one of the most crucial concepts for maintenance management. An automated risk modelling could further dissemination and enable a more efficient and effective maintenance organization. For the establishment of a comprehensive risk modeling, there needs to be a data logistics model to fuse the different data types and needs together.

2 Risk modelling and knowledge preservation

ROMEIKE identifies two groups of methods for risk identification, analysis and evaluation. The search methods (e.g. checklists, loss databases, SWOT analysis) are particularly suitable for already known or trivial risks. The search methods are suitable for complex and unknown risks and are further subdivided into analytical methods and creativity methods. In the context of this work, the analytical methods will be considered in the following, as they are suitable for "identifying future and previously unknown risk potentials". [19] The creativity methods are therefore not suitable for this task, as the aim of this paper is to lay out a foundation for an automated determination

of risks. Current information systems are not suitable for a creative performance, but are very capable of finding patterns in huge sets of data [20].

The most commonly used and broadly accepted as the tool of choice for risk assessment is the Failure Mode and Effect Analysis (FMEA), which considers a wide range of factors and delivers compelling results. FMEA considers the severity (S), occurrence (O) and detection (D) ratings to determine the risk priority number (RPN) [21].

$$\text{Risk Priority Number (RPN)} = \text{Severity (S)} \times \text{Occurrence (O)} \times \text{Detection (D)} \quad (2)$$

KÖNIG adapted the method, which originally came from quality management, in order to be able to effectively prioritize risks. With the Risk Mode and Effect Analysis (RMEA) approach, the risks are combined into a risk cube, which consists of different risk classes according to the probability of occurrence and detection. [22] There are many other approaches to risk measurement and aggregation like Failure Mode, Effect and Cause Analysis (FMECA) [23], Socio Technical Reliability Analysis (STRA) [24], Fuzzy Fault Tree Analysis (FFTA) [25], Monte Carlo Simulation (MCS) [26] and evaluation laboratory (DEMATEL) [27].

The weak point of all those models still prevails. They all rely on the estimation of the failure rates for the assets [28] or simulate random numbers (e.g. for MCS). In addition, they presume that all possible failure modes are known to the asset owner. It is therefore necessary to develop a data model for risk identification and comparison between companies and production sites. Current ontology-based approaches are limited in the level of detail they provide and do not include a sufficient digital reference shadow for asset risk information.

3 Information logistics model for risks of production assets

The current state of the ontology-based risk model is presented in this section, which starts off with a brief description of risk in ontology. Subsequently, the transfer of one example into the information logistics model notation gives an outlook on the results.

3.1 Risk management ontology for production assets

The application of an ontology-based risk management is not yet sufficiently extended to production assets because of a lacking depth of detail for a reference architecture and comparison of different assets. For example, the models do not take environmental conditions into adequate account, although they are an important factor influencing the wear and tear and the functional efficiency of a machine [29].

For the definition of the risk management ontology for production assets (Fig. 1), the procedure following *STUCKENSCHMIDT* was chosen [30]. The functions of an information system are implemented according to *KRCMAR*: Collect, structure, process, provide, transform, communicate and use data, information and knowledge [31]. The ontology notation of *MILVICH* is used for Fig. 1 [32]. Accordingly, classes are displayed as dark grey ellipses. Related terms are represented by lighter grey ellipses and are connected by a straight, continuous grey arrow. In order to keep the ontology

readable, the classes have been divided into sub-concepts only to the extent necessary for understanding the approach. Accordingly, not every class has assigned terms. Furthermore, in Fig. 1, information containers are displayed with a rectangular grey frame. These are connected to a class by a dotted grey arrow and describe an identification property (displayed on the connection) and its type (string, value, array, and so on). The name and type can be filled with the corresponding values of the application when using the ontology.

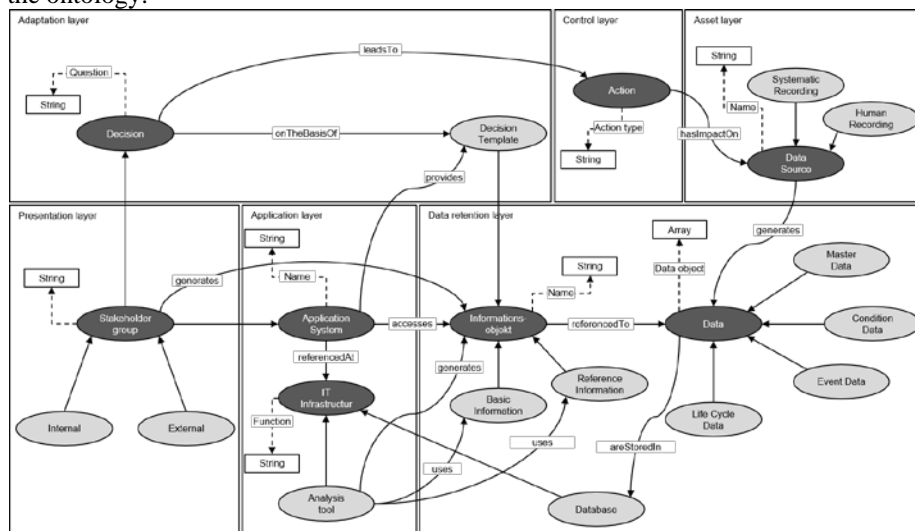


Fig. 1. Risk management ontology for production assets (top level excerpt)

3.2 Exemplary transfer into an information logistics model

For the implementation and future usage, the ontology needs to be transformed into an information logistics model. Fig. 2 displays an excerpt of the model for condition monitoring, which has an impact on the occurrence (O) as well as detection (D) of a risk.

The information logistic model notation of *NIENKE* was used for Fig. 2 [33]. It consists of roles that are characterized by the generation of information (source) and the use of or need for information (sink). A vertical line visually separates the two parts of a role. Each role has both elements. A special role is the decision role or target role, which has a certain need for information in order to decide. An oval shape characterizes the role with a dark edge. In addition, the decision questions of the target role are noted above the role. Information objects are exchanged between roles and systems through information flows. The information objects are described under a role or a system on the source side. To improve clarity and structuring, the data records are grouped together into information objects and listed accordingly. Fig. 2 displays the data transfer from the asset to a data base. The data base is then fed into an analysis system which derives a decision template to present to the specific role. With each step more data is considered, aggregated and analyzed. Since not all data is numerical, available and easy to

process, the focus must lie on the possibility to fill the gaps by reference assets. Even if it results in less accuracy for the analysis.

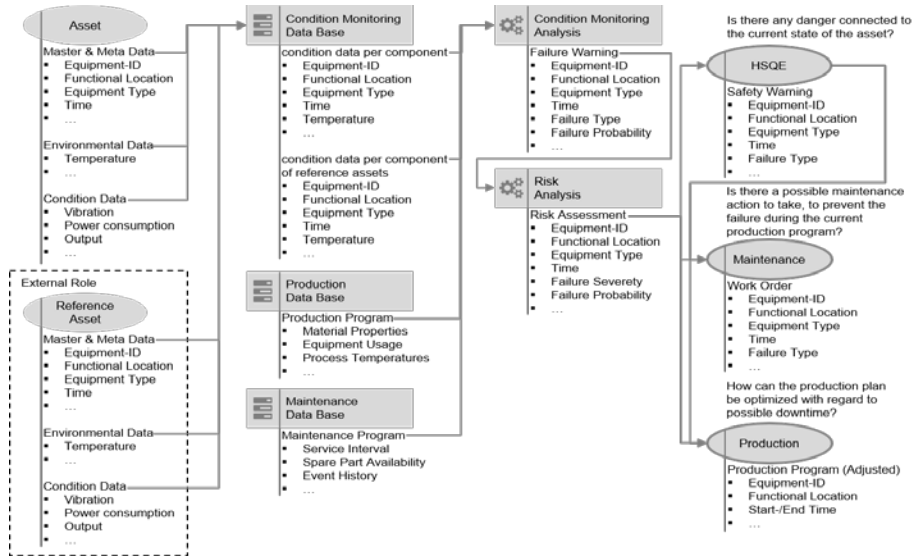


Fig. 2. Information logistics model for condition monitoring (excerpt)

4 Conclusion

Automated risk assessment systems have the potential to contribute to the dissemination and effective use of risk information and analysis. Especially in complex production environments, it provides an effective and efficient way to optimize maintenance and investment spending, as well as the effectiveness of the whole plant. The provided reference digital shadow for risk information linked to a detailed information logistics model will help software companies to improve reliability software, standardize and enable assets owners to establish a customized digital shadow for their production networks. The future goal should be to extend the model with a variety of functions and information. Therefore, further research and case studies need to be conducted. For the moment, the model's functions focus on the process industry, and other industries can be implemented in the future, as they have similar business requirements.

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