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PS1: Life cycle asset management

NAGOYA 2015

Information and Risk-based Strategies for Lifetime Asset Management

Ravish P.Y. MEHAIRJAN[1, 2], Nicolaie L. FANTANA[3], Johan J. SMIT[1],
[1)] High Voltage Technology & Asset Management, Delft University of Technology, the Netherlands
[2)] Asset Management, Stedin, the Netherlands
[3)] ABB Corporate Research, Germany

Risk based management (RBM) is seen as a guiding principle for lifetime asset management for T&D infrastructures at utilities supported by PAS55 and ISO 55000. Increasingly utilities recognize lifetime management as a strategic issue, however, utilities still lack straightforward strategies or frameworks to know what information is required in guiding the selection of an appropriate lifetime management regime, which can include sustainable maintenance concepts, condition monitoring or predictive health indexing. In this contribution a solid foundation for data management and case studies related to risk based-based decision-making are presented. This paper is supported by investigations of CIGRE working group B3.06 and B3.34 on substation management and practical experiences from the electric power industry in the Netherlands.

Keywords-; asset management; information; risk management; maintenance; data; strategy

INTRODUCTION

The practical implementation of a risk-based lifetime asset management in utilities has to be supported by a sound information and data foundation. In other words, risk-based integrated decision processes require data in mixed strategies [1]. This means matching technical, economic and social data from a holistic point of view. Utilities require a data management model that is capable of linking them to the risk management decision-making model. WG B3.06 (TF05) investigates in filling the gap between data management, through information strategies, and the link with risk based decision-making. This work has been published in CIGRE TB 576 [2]. A model, referred to as an *hourglass model*, is proposed. This model should assist T&D utilities to be aware of a potential data and information gap and make a link between risk management (decision-making requirements) and data management (data and information requirements). This model comprises of two essential parts, which are:

- *Risk management*: this helps in utilizing and addressing the requirements on asset data.
- *Data management*: this supports the decision making process through constructing a system to acquire, warehouse and transmit data.

Data management as a solid foundation for lifetime asset management is discussed in the first part of the paper and in the second part practical experiences with risk-based decision-making is presented.

SOLID FOUNDATION FOR RISK BASED MANAGEMENT

Sustainable asset management decisions require the right information at the right time. The required information is typically a combination of processed and unprocessed data stemming from multiple sources. This data has to be collected over time, stored for different time periods, analysed and processed, condensed and ready to be used on demand, e.g. on events, for operation or for asset planning or asset management decisions. The data and information aspects and the related processes, tools and strategies are considered a key element for asset management, and the availability of the right data is one of the major challenges in an utility and for implementation of asset management systems. The information requirements to support asset management decision in general and risk based approaches in special have to consider and make available for decision making phase, data from the *technical*, *economic* and *social data* categories. The *technical data* is the one typically considered by engineers and is related to asset and network aspects such as: asset condition, failure probability, technical impact of asset on the system, equipment base inventory, technologies, spare parts, maintenance procedures and maintenance history, climatic aspects such as temperatures etc. The

ravish.mehairjan@stedin.net, nicolaie.fantana@de.abb.com, j.j.smit@tudelft.nl

technical data exist in various technical systems in utilities such as the network operation system, maintenance management system, in various automation systems, SCADA, protection devices, monitoring systems, in the geographic information system, asset inventory, but also in ERP systems and life cycle management systems. A systematic IT strategy can help to continuously and cost-effectively consolidate and recognize across systems the same piece of equipment and bring easily together all the related asset information and dependencies. *Economic data* contains financial details related to the equipment, but also related to the network and energy delivery and implications in case the equipment fails. These asset related economic aspects can be investment cost, maintenance and repair costs, diagnose and monitoring or scrapping costs. Due to its position in the network consequential costs may result if an asset is not functional. These could be for example penalties but also damage by reputation loss, impact on share price, loss of customers. If the failure leads to environmental damage more negative financial or even legal consequences, depending country's laws and regulations, can be expected. The *social data* category is reflecting the social impact of an asset management decision, of an asset failure, an outage or an event, on both private and industrial users. The failure and outage aspects are strongly linked to the duration of outage and losses produced to the community. The highest visibility and impact have the public image of the utility, safety aspects, the environmental damage.
To achieve an optimized asset management decision, targeting a reduced risk, a combination of all relevant *technical*, *economic* and *social* data, available at a certain moment in time, has to be considered. This has to be combined considering the knowledge and experience from previous cases, the utility risk strategy, regulatory constraints, social, environmental and safety aspects.
A generic information processing architecture and also processes to be consistently in the IT strategy of utilities has been developed [1, 2], employing a systematic collection, consolidation, analysis and processing, integration and condensation to relevant information for decision, shown in figure 1.

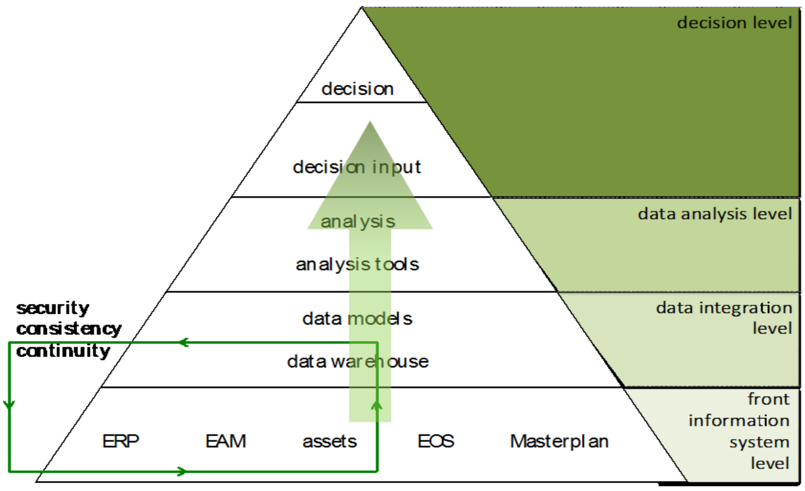


Figure 1: *Generic information architecture and information generation for asset management decisions[2].*

The largest amount of available data is pretty heterogeneous and distributed in various enterprise systems and other sources. Typical data available are from resource planning, asset management and inventory, geographical information, network operation and maintenance management system. To this data also environmental, weather and social information can be added. Important aspects to consider are data quality, data amount and integration and consistent correlation of information across systems.
In asset management decisions it is important to identify the data referring to an individual equipment, to distinguish between the "function to perform", e.g. breaker, and the "individual", physical, component described by serial number, make, age, material and technology used, etc. These two views of an asset have to be considered in the integration layer. The asset identification and tracking across systems and over lifetime needs to be solved, and it is important to allow on view and consistent use of available data. In terms of IT systems an integration in for example a data warehouse can be done. The integration has to overcome the internal organization barriers, consider access rights and allow a consistent view of available information from all IT systems and the seamless association with the asset or situation of interest. Complex analysis and processing done to derive additional details, and

information such as on condition of the asset, safety, technical risk, etc., and may calculate and derive a set of new variables and indicators usable further in the decision process. The condensed and integrated information is used then in the decision layer. The decision layer may use a set of additional tools to derive recommendation for decision making. A decision input preparation layer can be followed by the final decision part, which is on the top of the information pyramid. Tools that derive final decision recommendations are not yet commonly used in the power electric industry, however analysis and decision support tool are used providing condensed and specific information to a human decision maker to support his activity. The information delivered to the decision maker should be understandable, transparent and comprehensible and allowing a ranking and prioritization of the actions by e.g. using the overall risk.

RISK LINKED RCM FOR POWER TRANSFORMERS

This case study describes a risk-based decision making model for maintenance management on the premises of using different sources of information to assess the optimal risk-based maintenance concepts. In doing this multiple, technical, financial and social corporate business values are incorporated into the model. The model, *Risk* linked *Reliability Centered Maintenance (RCM)* is developed and applied at a Dutch DNO. In this method, the traditional *Risk Priority Number (RPN)* has been expanded in order to deal with the consequences of asset failure modes on multiple corporate business values. The goal was to develop a practical method for risk-based maintenance management. A complete and extensive description can be found in [3]. Here the application and some results of this method is shown. The extended version of the RPN formula, which has been used in our practical application, is given:

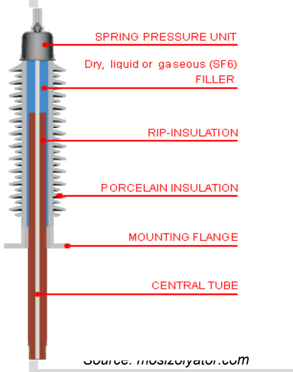
$$\boldsymbol{RPN_{worst\ case} = S_{business\ value} \times \left(O_{business\ value} \times O_{failure\ mode}\right)_{worst\ case} \times D} \qquad (1)$$

$$\boldsymbol{RPN_{most\ likely} = S_{business\ value} \times \left(O_{business\ value} \times O_{failure\ mode}\right)_{most\ likely} \times D} \qquad (2)$$

S= Severity, O=Occurrence, D= Detection

The RPN calculations are made using unified risk management ranking tables for each parameter *(S, $O_{business\ value}$, $O_{failure\ mode}$, D)*. Once the RPN's are calculated, failure mode can be individually ranked from high to low risk. This ordering of RPN's will provide a priority ranking for choosing maintenance tasks to mitigate and control the occurrence of failures. It is desirable to revise the initial risk assessment based on the assumption (or the fact) that the recommended maintenance actions have been completed [3, 5]. Therefore, revised RPN's are calculated with revised ratings of *severity*, *occurrence* and *detection* for each failure mode. The *initial* RPN's can be compared to the *revised* RPN's. This offers an indication of the usefulness of certain maintenance actions. In addition, an assessment can be made of the implications on risk exposure when certain maintenance tasks are not performed (i.e. in case of OPEX budget cuts). As a practical application of the developed method, this model is applied on a case study for 150 kV transformers. Here an example for HV bushings (oil filled condenser type) is summarized and shown in table 1.

Table 1: Typical FMEA results for high voltage transformer bushing for a failure mode [3].

Component Hierarchy	*Function*	*Functional Failure*	*Failure Mode*	*Failure Effect*
	Provide an isolated connection between the transformer windings and cable termination.	Short circuit between transformer tank and conductor.	Low oil level, which can be caused by not on time filling or leakage due to a leaking gasket.	Short circuit will lead to disconnection of the transformer from the grid. Loss of the bushing and possibility of fire.

A recent failure of a transformer bushing is used to assess this method. An analytical assessment of the impact of such a failure (the failure mode described in table 1) on each business value can be done by calculating an initial RPN. For this study, two failure scenarios were identified by experts:

- Worst case: *Power transformer burn, major injury, article in local newspaper.*
- Most likely: *Transformer is switched off by protection, bushing explodes, burn damage on the transformer, transformer repairable, no injuries (nobody present).*
-

The experience of the actual failure is used to make an estimation of the *occurrence* of the failure mode (1 time in 30 years). Originally, there is no *detection* measure for the failure mode and therefore the detection is ranked as no detection. With the $O_{failure\ mode}$, $O_{business\ value}$, S and D, the RPN's for each business value are calculated. For mere study purposes, we have developed an inspection task (yearly) for the oil levels of the high voltage bushing. With the oil level inspection, the failure mode can be detected preventively. With this revised detection possibility, the *revised* RPN for the most likely scenario is calculated. In figure 2, a combination of *initial* and *revised* RPN's is shown.

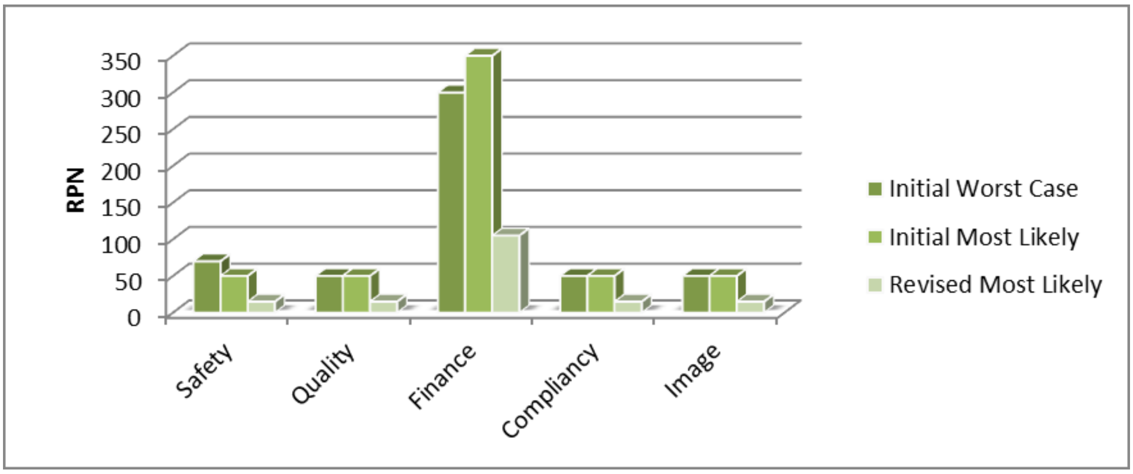


Figure 2: Business value for initial (both scenarios) and revised RPN's [3].

With this, the benefit in terms of business value risks for a maintenance or inspection task can be assessed. In practice, this developed tool is immensely improving the RCM team in addition to preventing solely technical judgements to prevail the follow-up maintenance strategies. Moreover, we find that the technical experts are actually, gradually, developing an improved social-technical understanding of re-examining the traditional maintenance beliefs.

CONDITION MONITORING FRAMEWORK FOR ASSET MANAGEMENT

Condition monitoring technologies form an essential part in risk management and are developing rapidly and are slowly becoming more financially attractive for deployment. Nevertheless, utilities are carefully and reluctantly implementing them. There are several reasons for this [4, 6]:

- The asset population is usually large and thus a wide scale implementation of condition monitoring is difficult to justify economically.
- Lack of in-depth knowledge of failure modes of the wide range of assets which are present in the networks and the complexity to assess these.
- Lack of existence of clear processes and concepts for the integration of operational technology (OT) and information technology (IT).
- Uncertainty with aspects such as cybersecurity implications when deploying condition monitoring. Also, uncertainty and lack of experience regarding the reliability of condition monitoring systems compared to the primary network assets.
- The challenge with the big amount of data that will come once deployed largely.

In order to, objectively, select out of condition monitoring technologies, maintenance decisions should be informed by a number of knowledge or data streams, such as described in section 1. The most crucial of these is knowledge of how assets functions and could fail. On system level and for risk based purposes, it is also required to have knowledge of the consequences of failures (whether an unacceptable risk is present). The latter is important because due to the high number and wide variety of assets in electricity networks, the application of condition monitoring will be most effective on high risk and critical systems or components. The in-depth knowledge of failure modes, stress factors, ageing mechanisms, historical failure statistics, predicted failure rates, material knowledge, expert knowledge and risk levels will form key information streams within the framework for selecting amongst condition monitoring technologies. In practice there is still a lack of straightforward frameworks to link the data required as input for selecting amongst condition monitoring technologies. In the developed framework (figure 3), the asset manager has to make a decision between corrective or preventive maintenance tasks for a certain failure mode resulting from a FMEA. Such an approach has been described in [3]. In the case of a preventive maintenance action, the choice for a condition-based approach can be decided by having knowledge of the ageing models behind the failure modes.

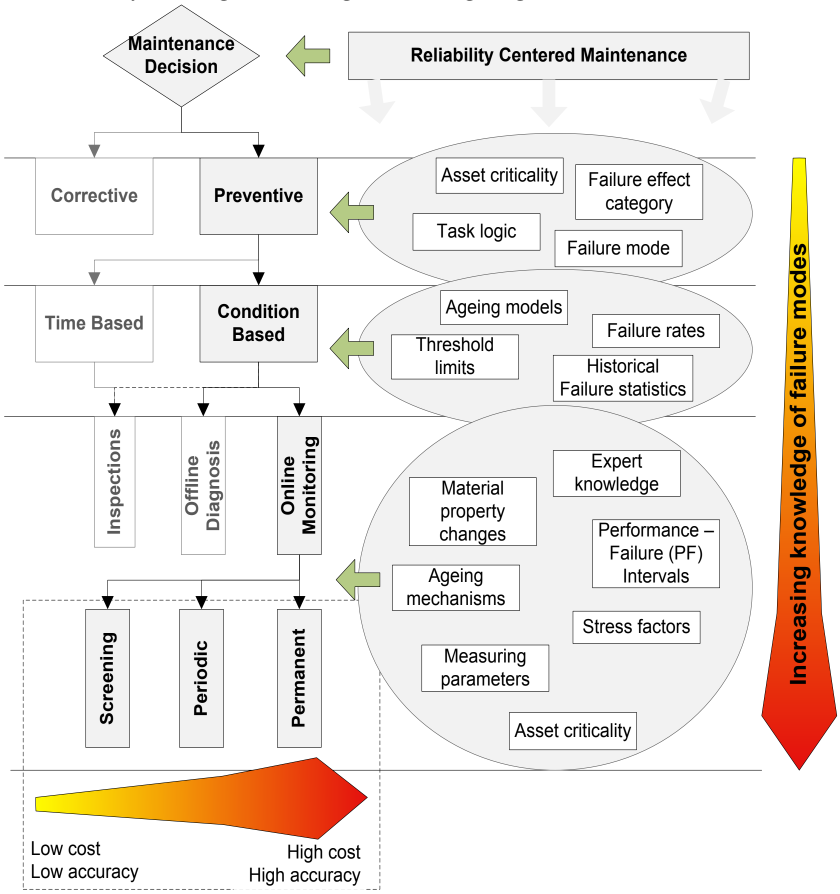


Figure 3: Framework for selection of condition monitoring [6].

If there is an increasing ageing or deteriorating parameter that is related to the failure mode and can be predicted based on condition measurement, then condition monitoring can be a viable and effective option. After the selection of a condition-based task, a method for measuring the parameters that indicate the condition and state of the asset must be selected. Different classes are available ranging from:

- Inspections with human senses (touch, sight, smell and hearing) or through simple tools (which is also categorized as screening tools in figure 1 under online monitoring).
- Offline diagnosis, which are well developed methods requiring the asset to be taken out of service.
- Online monitoring, which do not require the asset to be taken out of service (depending on the safety regulations and ease of installation).

In order to select amongst inspections, offline or online, in-depth knowledge is required such as, the stress factors that play a role, the ageing mechanisms, material properties, measurement parameters, performance-failure intervals and usually specific expert knowledge. Part of this knowledge cannot be derived from direct measurements in the field, but require measurements on model samples in laboratories. In laboratory experiments, destructive tests can be performed and stress models can be investigated in more detail. Together with the other sources of knowledge, it can be used to derive more understanding of the condition of insulation systems. In the case of online condition monitoring the asset manager can decide which degree of accuracy and time-scale is needed. At this point, information regarding the age of the asset, the operational environment, criticality and other business values (e.g. image, finance, quality of supply, etc.) should be used as input. For this purpose, a three stage condition monitoring approach can be followed [4]:

- ***Stage 1 "Screening"***: The condition of the asset scanned by means of simple tools such as handheld partial discharge tools, thermography tools, and acoustic measurements. The results from stage 1 can be used as input for selecting amongst stages 2 or 3 or for direct maintenance actions based on the condition.
- ***Stage 2 "Periodic Monitoring"***: In this stage, based on, for instance, the information from stage 1 or other detailed information (age of component, historic inspections, lab results, failure data, location in the grid, etc.), it can be decided to trend a certain condition indicating parameter for a specific period of time.
- ***Stage 3 "Permanent Monitoring"***: In stage 3, an advanced stage, the most critical locations are known because of previous stages 1 and 2. Therefore, the asset manager can decide to deploy permanent online condition monitoring systems to trend and locate defects in advance in order to allocate preventive maintenance actions based on the condition of the asset under monitoring.

CONCLUSIONS

Risk-based lifecycle asset management requires a sound foundation for IT strategies, processes and models for decision-making. This is in line with the requirements of PAS55 and ISO55000, which aims at "Better understanding and usage of data and information to provide informed and consistent decisions". Beside technical information, important are economic aspects and social impact and implications. A sound data and information foundation allows to extract effective knowledge on failure occurrence and equipment behaviour and to use this for multiple business value decision-making for asset management. Moreover, different sources of information can be used in frameworks as a guide to assist asset management in identifying the relationship between failure modes, ageing processes and consequences to select amongst condition monitoring regimes. The lack of a sound information foundation to support risk-based decision-making can lead to risky and suboptimal decisions resulting in financial drawbacks and organisation ineffectiveness regarding lifecycle asset management.

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