Value-driven maintenance planning: Application to a gasification plant

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ABSTRACT: The challenge for maintenance planning is to identify appropriate objects and tasks for preventive maintenance and ensure that there are sufficient provisions for any necessary repair actions. In this paper we will present a maintenance planning approach, called value-driven maintenance planning, to emphasize the fact that the objectives of the company are the reference points for judging; (a) the functional requirements for the equipment and systems, and (b) the acceptable cost-benefit ratio for controlling functional failures. The three basic phases of the value-driven maintenance planning approach are:

• the definition of the fundamental and means objectives of the production plant,
• the classification of equipment into maintenance classes, each associated with a functional requirement specification, and
• the selection of maintenance tasks (including timing) for equipment assigned to the equipment locations.

This paper focuses on the two first points, detailing the analysis logic within the context of a case study on a gasification plant in Finland.

1 INTRODUCTION

The primary reasons why company and plant managers are (or should be) interested in maintenance performance goal-setting and measurement is the continuous improvement of plant and maintenance performance with respect to the fundamental, strategic and maintenance objectives defined by the corporate, plant and maintenance management. To better support the incorporation of asset values in maintenance planning, compared to the standard IEC-60300-3-11 on Reliability Centred Maintenance (RCM) (IEC 60300-3-11, 1999), a maintenance planning approach has been developed, called value-driven maintenance planning. The development is based on extensive experience from R&D on maintenance and operating experience analysis and case studies with the Nordic nuclear power industry (Laakso et al. 1993, Laakso et al. 1995a, Laakso et al. 1995b, Laakso et al. 1999, Unga 1999). The main differences of the presented approach and the standard RCM are:

• the definition of plant and maintenance objectives with respective (key) performance indicators,
• the definition of maintenance classes to reflect differences in importance of equipment with respect to effects on key and maintenance performance indicators,
• the extensive use of expert judgment on plant and maintenance performance based on systematically collected operating experience, failure and maintenance data.

2 PROCESS DESCRIPTION OF VALUE-DRIVEN MAINTENANCE PLANNING

The process diagram of value-driven maintenance planning is given in Figure 1. The output of value-driven maintenance planning is the maintenance programme for the equipment of the plant systems. The expert panels define and annually update the value-tree, goals and constraints related to the plant and maintenance performance indicators. The expert panels also define the maintenance classification of equipment, the related reliability requirements, and finally select the maintenance tasks, their timing and the maintenance resources needed. The assessments made by the expert panels are based on the information obtained from follow-up analyses of maintenance data and operating experience. In the remainder of the
paper, we will focus on the first two phases of the process diagram in Figure 1: ‘Value structuring’ and ‘Maintenance classification’.

3 VALUE STRUCTURING OF THE OBJECTIVES OF THE GASIFICATION PLANT

The objectives of the company may be structured as a hierarchical value-tree (Keeney 1996), depicting the relationship between the generic fundamental objectives of the company, the strategic objectives at the plant level, and the maintenance objectives (means objectives using the terminology in Keeney (1996)) for the plant’s maintenance organisation. A value-tree linking company, plant-level and maintenance objectives of a gasification plant is shown in Figure 2. Leading key performance indicators (KPI) (Liyange & Kumar 2003) and maintenance performance indicators (MPI) (Laakso et al. 1995a) are also shown. Some of the numerical values of the plant KPIs have, however, been deleted for reasons of confidentiality. It should be noted that some of the PIs are related to equipment reliability and thus statistical in nature whereas some PIs are deterministic (e.g. related to operational strategy).

4 MAINTENANCE CLASSIFICATION FOR THE GASIFICATION PLANT

For the gasification plant, three maintenance classes are defined: Maintenance class 1 (MC1) reflects the most risk significant class and is assigned the most stringent reliability requirements that the equipment in the equipment location must meet. A functional failure in an equipment location leading to a violation of a leading KPI will imply a classification of the corresponding equipment as MC1; Maintenance class 2 (MC2) reflects an intermediate class and is assigned a more relaxed reliability requirement in comparison to MC1. A functional failure in an equipment location leading to a violation of a leading MPI (see below) only will imply a classification of the equipment into MC2. The equipment locations with no risk importance will be assigned as maintenance class 3 (MC3): ‘Breakdown maintenance’.

All equipment of the plant should be classified into one of the maintenance classes. This ensures that:

(i) every equipment location is ranked according to its risk importance for the valued assets,
(ii) every equipment is assigned a requirement specification in terms of reliability that is matched with the risk importance of the equipment location.

The decision flowchart in Figure 3 shows the decision logic of the maintenance classification. The answer to the question ‘Does a functional failure of equipment have consequences on plant objectives?’ leads to a chain of ‘bottom-up’ inference, ending at a maintenance class for the assessed equipment. In the value-driven maintenance planning approach, the most severe but still probable failure mode and mechanism of an equipment location is typically assessed for its maintenance classification. If the plant strategic objectives are not affected by a functional failure, the effects on the MPIs (typically cost effectiveness) need also to be assessed based on the most recurring
failure mode and mechanism. Risk matrix techniques may be utilised to support answering the questions in the decision nodes in Figure 3 (in relation to statistical PIs). The risk matrices shown in Figure 4 have been developed for the equipment of the gasification plant in the case study.

In the appendix A, a table documenting the expert judgements on the likelihoods and consequences for input to the risk matrices, and the classification of some equipment related to the aluminium process of the gasification plant, are found. As can be seen for the equipment location HV7861 and HV7862 in the functional location SA0313, the consequence on the safety KPI prescribes a classification of the equipment to MC1, albeit a borderline case. For the equipment HV7859 and HV7873 no KPIs are violated. The expected plant unavailability costs are, however, due to delayed shutdowns, high enough for a prescription to the maintenance class MC2. For the above equipment, the equipment damages stay at a lower level: a half and one tenth or less, of the respective expected production losses. These particular examples have been indicated in the table by circling the maintenance classes.

5 MAINTENANCE TASK SELECTION FOR THE GASIFICATION PLANT

Once all equipment locations have been classified, the maintenance task selection to secure the reliability of equipment and prevent functional failures can be performed. This is done according to the decision logic principle of Reliability Centred Maintenance (compare with standard IEC-60300-3-11) and by utilisation of experience data and expert knowledge. The selection of maintenance tasks and their timing for equipment should be such that the requirement specification of the equipment is met. The information is documented in the maintenance programme which is the main output of the value-driven maintenance planning cycle. A further discussion of the maintenance task selection phase is, however, out of the scope of this paper.

6 DISCUSSION

The practical implementation of the value-driven maintenance planning approach relies on the availability of experienced personnel for the expert workshops.
Does a functional failure of the equipment place affect plant objectives?

Does a functional failure contribute to a violation of leading MPIs?

Does a functional failure violate leading safety KPIs?

Does a functional failure violate leading emission KPIs?

Does a functional failure violate leading plant availability KPIs?

Risk matrices for statistical KPIs

Risk matrices for statistical MPIs

MC1: ‘No functional failures during operating period’

MC2: ‘Functional failures allowed z times per year on average’

MC3: ‘No reliability requirements, but follow-up of maintenance costs’

Figure 3. Maintenance classification flowchart developed for a classification into three maintenance classes. Each maintenance class (MC) is associated with a requirement specification in terms of reliability (within citation marks).

Figure 4. Risk matrices for determining the maintenance classes of equipment of a gasification plant. Risk matrix (a) relates to unavailability costs of plant downtime due to functional failure of equipment, whereas risk matrix (b) relates to equipment damage costs. The integers in the matrices indicate the maintenance class to be selected for the assessed equipment. The 1’s in Figure b are circulated to indicate that in practice the corresponding risks cause also plant shutdowns and are thus analysed in conjunction with the risk matrix in Figure a.

Personnel from the operation and maintenance organisations discuss possible discrepancies between the leading and the lagging KPIs and MPIs. Also the relevance of the defined MPIs to support the achievement of KPIs have to be regularly reviewed: How sensitive is the positive correlation between them, and how much does experience data support the judgements? To be able to answer such questions, multidisciplinary
expertise has to be available during the assessment. Risk analysts can facilitate the expert workshop and document the arguments and the conclusions.

REFERENCES


Appendix A. The maintenance classification of equipment according to consequences on key performance indicators related to functional failure (examples).

Process: Aluminium processing

Consequences on KPI related to safety (S), environment (E), process availability (A)

<table>
<thead>
<tr>
<th>Function location or protection function</th>
<th>Equipment location</th>
<th>Description</th>
<th>Equipment type</th>
<th>Process media/ or safety function</th>
<th>Functional failure</th>
<th>Failure mechanism</th>
<th>Description of consequences on the KPI</th>
<th>Criticality of effects (YES/NO) on criteria S and E</th>
<th>S</th>
<th>E</th>
<th>ISD*</th>
<th>DSD**</th>
</tr>
</thead>
<tbody>
<tr>
<td>SÄ0313</td>
<td>HV7861</td>
<td>SÄ0313 Gas removal valve 1/2</td>
<td>Pneumatic shut-off valve (of a ball type)</td>
<td>Steam/aluminium product, nitrogen, product gas</td>
<td>Leaks through (internal leak towards the gas exchange vessel)</td>
<td>Solid impurities (coal dust, aluminium, sand) stick to the ball surface, which damages the valve seals or causes excessive wear</td>
<td>Steam flow to the gas exchange vessel where steam may get into contact with aluminium; hydrogen is formed, which may ignite and explode (S)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>SÄ0313</td>
<td>TI7612</td>
<td>SÄ0313 Temperature measurement of the gas removal line 1</td>
<td>PT100 measurement</td>
<td>HV7618, HV7736, HV7793, HV7794, HV7897, HV7900</td>
<td>Too low indication; does not trigger the safety function from high temperature</td>
<td>Temperature sensor mounting or adjustment error</td>
<td>Risk of aluminium temperature rising in the gas removal line SÄ0313 (so that it escapes operator’s notice) due to the disturbance increases =&gt; Risk of fire, etc.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>SÄ0313</td>
<td>HV7859</td>
<td>SÄ0313/SÄ0314 Shut-off valve of the inlet side</td>
<td>Pneumatic shut-off valve (of a spherical segment type)</td>
<td>Aluminium product, nitrogen, product gas</td>
<td>Valve seal leakage; pressure in the vessel remains too low</td>
<td>Solid impurities (coal dust, aluminium, sand) stick to the ball surface, which damages the valve seals or causes excessive wear</td>
<td>Gas exchange is disturbed; the redundant gas exchange vessel must be taken into use (A)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>SÄ0313</td>
<td>HV7865</td>
<td>SÄ0313/SÄ0314 Shut-off valve of the outlet side</td>
<td>Pneumatic shut-off valve (of a spherical segment type)</td>
<td>Aluminium product, nitrogen, product gas</td>
<td>Valve seal leakage; pressure in the vessel remains too low</td>
<td>Solid impurities (coal dust, aluminium, sand) stick to the ball surface, which damages the valve seals or causes excessive wear</td>
<td>Gas exchange is disturbed; the redundant gas exchange vessel must be taken into use (A)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

* Immediate shutdown, ** Delayed shutdown.
### Process: Aluminium processing

Consequences on KPI related to safety (S), environment (E), process availability (A)

<table>
<thead>
<tr>
<th>Effects of criteria A</th>
<th>Plant unavailability cost [k€]</th>
<th>Shutdown frequency</th>
<th>Expected loss of production [#/10 yrs]</th>
<th>Equipment damage cost [k€/10 yrs]</th>
<th>Expected overall costs [k€/10 yrs]</th>
<th>Maintenance class</th>
<th>Remark</th>
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<tbody>
<tr>
<td>20 (A)</td>
<td></td>
<td></td>
<td>1 (S)</td>
<td>100</td>
<td>30,00</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 (A)</td>
<td>200,0</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td>2</td>
<td>8,0</td>
<td>0,3</td>
<td>0,83</td>
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<tr>
<td>4</td>
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<td>4,0</td>
<td>4,40</td>
<td>2</td>
</tr>
<tr>
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<td></td>
<td></td>
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<td>4,40</td>
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