Reformatted version of paper originally published in:
Journal of Quality in Maintenance Engineering

Original reference:

Stenström, C., Parida, A., Kumar, U. and Galar. D. (2013) Performance indicators and terminology for value driven maintenance. Journal of Quality in Maintenance Engineering, vol. 19, no. 3, pp. 222-232.

<http://dx.doi.org/10.1108/JQME-05-2013-0024>

Performance indicators and terminology for value driven maintenance

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Abstract

Purpose – Value driven maintenance (VDM) is a fairly new maintenance management methodology based on four maintenance value drivers and the formula of net present value (NPV) to calculate the value of different maintenance strategies. However, the dependability of the engineering assets needs to be assessed in order to make an estimation of the NPV. Therefore, the purpose of this paper is to critically analyse standardised indicators to find the most essential indicators for the four value drivers and for estimation of the NPV. Terminology containing performance drivers and killers are common in the field of asset management, but not many publications can be found for their detailed descriptions. One section in this paper is therefore dedicated to review these terms. A comprehensive description and classification of performance killers and drivers, and of indicators for VDM are presented in this paper.

Design/methodology/approach – Review of literature for technical terminology and review of standards for identification of indicators for maintenance performance measurement and NPV of maintenance. Findings ? Common description of technical terminology, as used by researchers, and identification of the most important indicators for maintenance performance measurement and the NPV of maintenance. Indicators classified under economic, technical, organizational and health, safety and environment (HSE) perspectives from EN 15341 standards are discussed and identified.

Originality/value – Description of emerging terminology in maintenance performance measurement adds to the consistency in communication of researchers and business stakeholders. Also, the identified maintenance performance indicators can facilitate performance measurement of organisations new to the process of measuring and analysing their performance.

Keywords – Maintenance, Maintenance engineering, Measurement, Performance, Costs, Drivers, Indicators, Standards, Net present value, Value driven maintenance

Paper type – Research paper

1 Introduction

Value driven maintenance (VDM) is a maintenance management methodology developed about four value drivers in maintenance, which are; asset utilisation, resource allocation, cost control and HSE (health, safety and environment) [4]. These four drivers are used to calculate the value of maintenance strategies using the formula of net present value (NPV). However, an effective maintenance performance measurement (MPM) system is needed to build up knowledge of the four drivers and to be able to make an estimation of the NPV. The European standard on maintenance key performance indicators (KPIs) EN 15341 is providing a battery of indicators for this purpose [1]. However, due to the ratio-based construction of the indicators, even the common indicators of the standard can be challenging to implement in an organisation without previous experience in data collection and analysis. The most essential indicators and easiest to implement is therefore the indicators found in the numerators and denominators of the KPIs in the European standard.

In this paper, the indicators of highest importance for organising a MPM system for the four value drivers of VDM have been extracted from EN 15341 standards.

Terms like value drivers, performance drivers, etc. are commonly used in the field of physical asset management, but descriptions are mostly missing. Therefore, the paper starts with a review on the use of this terminology. No standards have been found for the terms; performance driver and performance killer. The review is therefore focused on authors that are using the terms.

This paper is based upon Stenström et al. [18], but the current paper has been revised with regard to text, figures and tables for their improvement.

2 Performance drivers and killers

Kaplan and Norton [8, 9] use the term performance driver in their work with the balanced scorecard (BSC), which complements financial measures of past performance with operational measures of the future performance. Thus, financial measures are considered as lagging indicators, i.e. output, or outcome measures; whereas operational measures are considered as leading indicators, i.e. input measures. A description agreed upon by other researchers as well. Parida and Kumar [15] describes indicators measuring inputs to a process as leading indicators and indicators measure the outputs to a process as lagging indicators. With this background, performance drivers can be interpreted

as the inputs to a process, whereas performance killers are the inputs that obstruct the performance.

The financial perspective of the BSC consists mainly of output measures, while the other perspectives of the BSC are more of input measures and thus drives the performance. One example given by Kaplan and Norton [9] is measures of on-time delivery; such a measure will be a useful performance measure for customer satisfaction and retention.

Tsang [19, 20] describes that performance drivers can be explained as lead indicators, which have the ability to predict future outcome. Parida and Chattopadhyay [12, 13] agree that a lead indicator is a performance driver which acts like an early warning system. Patra, Kumar and Larsson-Kråik [16] have the same stance of policy, i.e. a lead indicator is a performance driver. Concluding, a lead indicator is a performance driver, and, a performance driver can be a lead indicator. Whether an indicator is a lead or lag depends on the perspective and is subjective. As an example, a lag indicator may be a lead indicator when used for planning.

Markeset and Kumar [10] describe performance killers as factors/issues that reduce performance without being strong enough to stop a process. The authors give a number of examples of performance killers: equipment that is critical with respect to uptime, health, safety and environment; bottlenecks in capacity, administration and inventory; incompetence; lack of proper tools and facilities; faulty procedures and checklists; inadequate information and communication flow; etc. Furthermore, Parida, Kumar and Chattopadhyay [14, 13] have discussed a number of performance killers, which are unavailability of resources, materials, spares, personnel, IT support, project support, time etc., i.e. a performance killer can be non-availability of resources. This confirms the presumption that performance killers are process inputs that leads to poor performance.

2.1 Cost drivers

Horngren, Foster and Datar [5] describes cost driver in accounting as any variable that causally affects costs over a given time span. Markeset and Kumar [10] have listed examples of cost drivers; unplanned maintenance, process bottlenecks, equipment with high energy requirements, potential liability issues, operational and/or maintenance costs, training costs, facility costs, disposal costs, etc.

Nyström [11] used Horngren's description to explain cost driver in a railway management context, as analogous to unpunctuality driver, which in turn are described as any factor that affects unpunctuality. Some examples of cost drivers in the context of railway infrastructure management have been

given by Espling and Kumar [3] as; labour, labour overtime, spare parts and infrastructure failures.

Consequently, a cost driver can be interpreted as an element that affects cost, or an element that increases costs considerably.

2.2 Conclusions on drivers and killers

Deduced from Kaplan and Norton's description of the Balanced Scorecard, a performance driver is an input to a process. Similarly, a performance killer is an input to a process that performs badly or hinders performance. According to the review and previous reasoning, performance killers and cost drivers are similar, but not the same. Both impair process outputs, but cost driver are tangible since they affects costs, i.e. more visible as it is a cost object, while a performance killer is less tangible; since, it does not directly affect costs, it hinders performance, e.g. inappropriate tools and clothing, faulty procedures, poor communication and bottlenecks.

A common indicator in accounting is the capacity utilisation, also called efficiency, often calculated as the actual output over the potential output. Another essential aspect in any process is the quality of the output. Therefore, any factor that reduces capacity, quality, punctuality, etc. can be a performance killer or cost driver.

The descriptions of the terms discussed in the reviewed literature are brought together in Table 1 and the input-process-output model (IPO-model) in Figure 1.

As can be seen in Figure 1, coincident indicators and soft indicators are mentioned as well. Coincident indicators measure events at the same time as they occur, compared to leading and lagging indicators which measure future events, or events that already have occurred. Preventive maintenance indicators, e.g. from inspections and sensors, can be interpreted as coincident indicators, giving indication of the actual condition of engineering assets. Another perspective is that these indicators are leading indicators since they control the output, and thus the lagging indicators. Inspections and sensors facilitate for proactive actions before failures occur.

Soft measures (Figure 1) are the same as qualitative indicators, measuring intangible values, which can be used to measure customer satisfaction etc. In this context the customer is the user and maintainer of the engineering assets.

Regarding the term 'maintenance value drivers', used in VDM, the origin comes from the net present value (NPV), as the four value drivers are terms in the formula for calculating the value of all future cash flows. See Equation 1 in next section.

Table 1: Description of terms.

Term	Description
Process	<p>A process is a series of activities or steps, with required input elements taken, to achieve or produce a desired product or service output.</p> <p>Note: all the inputs together form and drive the process or business performance, i.e. a process is all the inputs working together.</p>
Performance driver	A supporting input element to a process, driving the process or business performance.
Performance killer	<p>An input element to a process that performs poorly or hinders performance.</p> <p>Note: similar to cost driver but more intangible since it does not directly affect costs.</p>
Cost driver	<p>An input element to a process that causally affects or drives costs.</p> <p>Note 1: a cost driver is tangible, as it is a cost object.</p> <p>Note 2: a cost driver can be interpreted as an element that affects cost, or an element that increases costs considerably.</p>
Bottleneck	<p>An element that limits the performance of a process or system.</p> <p>Note: a bottleneck is a performance killer.</p>
Leading indicator	<p>Indicator measuring the inputs to a process, giving indication of future events.</p> <p>Note 1: Preventive maintenance indicators, e.g. inspections and sensors, can be interpreted as leading indicators since they control the outputs, and thus the lagging indicators.</p> <p>Note 2: Whether an indicator is leading or lagging is subjective and depends on the perspective.</p>
Lagging indicator	Indicator measuring the outputs of a process, giving indication of events that have already taken place.
Coincident indicator	<p>Indicator measuring events at the same time as they occur.</p> <p>Note: Maintenance inspections and sensors can be interpreted as coincident indicators, giving indication of the actual condition of engineering assets.</p>

Figure 1: IPO-model with integral MPM system. Indicators and measures are synonymous.

3 Indicators for value driven maintenance

The value drivers; asset utilisation, resource allocation, cost control and HSE of VDM, represent the core of the maintenance function in organisations; see Figure 2.

Maintenance managers must balance the importance of the value drivers in order to maximise stakeholders' value. A business that experiences a high market demand may want asset utilisation to be increased and will therefore put more money on maintenance and resource allocation. On the other hand, a declining market does not require as high asset utilisation and the focus is therefore to control costs. Whereas, a business providing health care may put more focus on HSE.

Haarman and Delahay [4] have put together a formula to calculate the cash flows from the value drivers based on discounted cash flows. Recalling the discounted present value with multiple cash flows and by using the value drivers, the value of maintenance is:

Figure 2: Maintenance value drivers. Adapted from [4].

$$NPV_{Maint} = \sum_{t=0}^N F_{HSE,t} \frac{CF_{AU,t} + CF_{CC,t} + CF_{RA,t} + CF_{HSE,t}}{(1+r)^t} \quad (1)$$

Where:

- NPV = Net present value
- CF_t = Future cash flow at time t
- $F_{HSE,t}$ = Compliance with HSE regulations, $\in [0,1]$
- AU = Asset utilisation
- CC = Cost control
- RA = Resource allocation
- r = Discount rate

After ascertaining the required asset utilisation and consulting involved engineers, e.g. reliability and performance measurement engineers, the maintenance and resource allocation objectives and strategies need to be adjusted. Equation 1 can be used to estimate the monetary value of alternative strategies, but this requires data to be collected, which has large costs and equally large savings associated to it. The most important performance indicators (PI) are therefore to be identified in order to know what data to collect for

building up a maintenance performance measurement system. There are two major standards for this, the European standard EN 15341 and the North American SMRP Best Practice Metrics [1, 17]. The value for an organisation to use standardised indicators or metrics, such as the indicators from the standard EN 15341 or the SMRP metrics are [7]:

- Maintenance managers can rely on a single set of predefined indicators supported by a glossary of terms and definitions
- The use of predefined indicators makes it easier to compare maintenance and reliability performance across borders
- When a company wants to construct a set of company indicators or scorecard, the development process based on predefined indicators will be simplified
- The predefined indicators can be incorporated in various CMMS software and reports
- The predefined metrics can be adopted and/or modified to fit the company's or the branch's special specific requirements
- The need for discussion and debate on indicator definitions is ended and uncertainties are eliminated

EN 15341 has been used in this paper to find and connect the most relevant standardised indicators to the four maintenance value drivers of VDM. The standard consists of 71 key performance indicators (KPIs) categorised into three groups and three levels. The groups are economic, technical and organisational indicators, and the levels are going from general indicators to more specific ones. HSE indicators can be found in the technical group. The most simple connection can be done by connecting the three groups of indicators to the value drivers, see Figure 3. The indicators have been given letters and numbers for identification in the standard.

Each KPI has been constructed by taking the ratio of two or more factors, PIs or parameters, i.e. data are need for at least two PIs in order to be able to calculate any of the KPIs in EN 15341. This makes even level 1 indicators challenging to calculate for organisations where this practice is new. Therefore, the factors in the numerators and denominators can be seen as level 0 indicators, easiest to calculate and most essential to have. Out of the level 0 PIs, the easiest to calculate and most essential PIs have been deduced from EN 15341 and are presented in Figure 4 and Table 2.

Indicator names ending with .1 and .2 are referring to the numerator and denominator, respectively. The third number refers to first or second term in the numerator or denominator. The in indicators T16.2(2), T16.2(3),

Figure 3: EN 15341 indicator groups connected to the value drivers of VDM.

Figure 4: Level 0 PIs deduced from EN 15431.

T21.1(2) and T21.1(3) are indicators not found in the standard, but considered important to have in a MPM-system. T16.2(2) and T16.2(3) are the number of corrective work orders and preventive work orders respectively. T21.1(2) is the repair time (RT), a measure of maintainability. T21.1(3) is here called waiting time (WT), a measure of maintenance support [6].

Table 2: PIs deduced from the KPIs in EN 15341.

Economic indicators		
$E1.1 = \sum \epsilon_{Cost}^{Maint}$	$E3.2 = \sum \#_{Output}^{Prod}$	$E7.1 = \sum \epsilon_{Value}^{Maint\ inventory}$
$E8.1 = \sum \epsilon_{Cost}^{Maint\ personnel}$	$E10.1 = \sum \epsilon_{Cost}^{Maint\ contractor}$	$E11.1 = \sum \epsilon_{Cost}^{Maint\ mtrl}$
$E15.1 = \sum \epsilon_{Cost}^{CM}$	$E16.1 = \sum \epsilon_{Cost}^{PM}$	$E21.1 = \sum \epsilon_{Cost}^{Maint\ training}$
Technical indicators		
$T1.1 = \sum t_{Up\ time}^{Prod}$	$T1.2.2 = \sum t_{Down\ time}^{Maint}$	$T6.2.2 = \sum t_{Down\ time}^{Failures}$
$T7.2.2 = \sum t_{Planned}^{Maint}$	$T11.2 = \sum \#_{Failures}$	$T16.2 = \sum \#_{WO}^{Maint}$
$T16.2(2) = \sum \#_{CM\ WO}^{Maint}$	$T16.2(3) = \sum \#_{PM\ WO}^{Maint}$	$T21.1 = \sum t_{Restoration}^{Item} = TTR$
$T21.1(2) = \sum t_{Repair}^{Item} = RT$		
Organisational indicators		
$O1.1 = \sum \#_{Personnel}^{Maint}$	$O1.2 = \sum \#_{Personnel}^{Tot\ internal}$	$O21.1 = \sum t_{Overtime}^{Maint}$
$O23.1 = \sum t_{Training}^{Maint}$	$O21.1(3) = \sum t_{Waiting}^{Item} = WT$	
HSE indicators		
$T5.1 = \sum \#_{Injuries}^{Maint}$	$T11.1 = \sum \#_{Injuries}^{Failures}$	$T12.1 = \sum \#_{Pot\ injuries}^{Failures}$
$T13.1 = \sum \#_{Envir\ dmg}^{Failures}$	$T14.1 = \sum \#_{Pot\ envir\ dmg}^{Failures}$	

Notes: CM, corrective maintenance; PM, preventive maintenance; WO, work order; TTR, time to restoration; RT, repair time; WT, waiting time; Item, system or component; Maint, maintenance; E1.1, total cost of maintenance; E3.2, total number of output; T1.1, total uptime of production; T21.1, total time to restoration.

Indicator T21.1, time to restoration (TTR), is the sum of WT and RT. The TTR can be further divided into smaller parts, but this may not be needed for basic requirements. Monitoring WT and RT can still be in alignment with standards, See Figure 5. High requirements, or high maturity, are according to IEV and EN 13306 [6, 2]. In basic requirements, technical delay is considered as zero, or part of the repair time. The waiting time is administrative and logistic delay added together.

For high requirements, or high maturity:

For basic requirements (corrective maintenance):

Figure 5: Morphology of an item under operation. High requirements, or high maturity, are according to IEV and EN 13306 [6, 2].

The extracted PIs can be used to calculate some of the level 1-3 KPIs. This has been carried out and is presented in Table 3 and Figure 6. These KPIs are considered to be the easier to calculate and most important indicators following the level 0 indicators. Three additional indicators within parenthesis can also be seen in Table 3 and Figure 6, which requires the asset replacement value (ARV) and maintenance inventory value. These have been added, since they give valuable inputs, but may not be the first indicators to be implemented by an organisation.

Table 3: Level 1-3 indicators based on the Level 0 indicators.

Economic indicators		
$E1 = \frac{\sum \epsilon_{Cost}^{Maint}}{ARV}$	$E3 = \frac{\sum \epsilon_{Cost}^{Maint}}{\sum \#_{Output}^{Prod}}$	$E7 = \frac{\sum \epsilon_{Value}^{Maint inventory}}{ARV}$
$E8 = \frac{\sum \epsilon_{Cost}^{Maint peronnel}}{\sum \epsilon_{Cost}^{Maint}}$	$E10 = \frac{\sum \epsilon_{Cost}^{Maint contractor}}{\sum \epsilon_{Cost}^{Maint}}$	$E11 = \frac{\sum \epsilon_{Cost}^{Maint mtrl}}{\sum \epsilon_{Cost}^{Maint}}$
$E12 = \frac{\sum \epsilon_{Cost}^{Maint mtrl}}{\sum \epsilon_{Value}^{Maint inventory}}$	$E15 = \frac{\sum \epsilon_{Cost}^{CM}}{\sum \epsilon_{Cost}^{Maint}}$	$E16 = \frac{\sum \epsilon_{Cost}^{PM}}{\sum \epsilon_{Cost}^{Maint}}$
$E21 = \frac{\sum \epsilon_{Cost}^{Maint training}}{\sum \#_{Personnel}^{Maint}}$		
Technical indicators		
$T1 = \frac{\sum t_{Up time}^{Prod}}{\sum t_{Up time}^{Prod} + \sum t_{Down time}^{Maint}}$ = Availability related to maint	$T17 = \frac{\sum t_{Up time}^{Prod}}{\sum \#_{Failures}}$ = MTBF	$T21 = \frac{\sum t_{Restoration}^{Item}}{\sum \#_{Failures}}$ = MTTR
$T21(2) = \frac{\sum t_{Repair}^{Item}}{\sum \#_{Failures}}$ = MRT		
Organisational indicators		
$O1 = \frac{\sum \#_{Maint}^{Personnel}}{\sum \#_{Employees}}$	$T21(3) = \frac{\sum t_{Waiting}^{Item}}{\sum \#_{Failures}}$	
HSE indicators		
$T5 = \frac{\sum \#_{Injuries}^{Maint}}{\sum t}$	$T5(2) = \frac{\sum \#_{Pot injuries}^{Maint}}{\sum t}$	$T11 = \frac{\sum \#_{Injuries}^{Failures}}{\sum \#_{Failures}}$
$T12 = \frac{\sum \#_{Pot injuries}^{Failures}}{\sum \#_{Failures}}$	$T13 = \frac{\sum \#_{Envir dmg}^{Failures}}{\sum \#_{Failures}}$	$T14 = \frac{\sum \#_{Pot envir dmg}^{Failures}}{\sum \#_{Failures}}$

Description: M, mean; TBF, time between failures. See also description in Table II.

Figure 6: KPIs based on the level 0 PIs, with exception for the PIs within parenthesis, which requires ARV and inventory value.

4 Discussion

Any process input that reduces the output, e.g. capacity, quality, punctuality, etc., is a performance killer or a cost driver, and vice versa regarding performance drivers. Leading indicators measure the process inputs, but also the indicators and the measurement system themselves can have performance drivers and killers, since they are inputs to assist in driving the process.

VDM uses the formula of NPV to estimate the monetary value of investments in maintenance, which requires assessment of the dependability of the engineering assets in question. Knowing what to measure and analyse is a key factor, since large costs and equally large savings are related to the activity. EN 15341 has been used to answer this question. The indicators of EN 15341 are constructed as ratios of factors, which can be hard to implement for an organization new to the process of measuring and analysing their performance. Level 0 indicators have therefore been extracted from the standard as the most essential and first indicators to implement into the maintenance function. This battery of indicators is powerful to help in understanding the assets, facilitate reliability studies and benchmarking, at the same time as they provide confidence due to their standardisation. Furthermore, the level 0 indicators can be used to calculate some of the Level 1-3 KPIs, as a second step in constructing a MPM-system for VDM and proactive maintenance

Figure 7: Identified PIs categorised according to leading, lagging, etc.

5 Conclusions

Emerging terminology in MPM has been reviewed and described as used by researchers, facilitating consistency and efficiency in communication of researchers and business stakeholders.

The most vital maintenance PIs for calculating the NPV for investments in maintenance and for monitoring of dependability have been identified, providing indicators simple to implement and based on standardisation for proactive maintenance and business safety.

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