Maintenance Value Drivers, Killers and their Indicators

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***Abstract*— Value driven maintenance (VDM) is a fairly new maintenance management method based on four maintenance value drivers and to calculate the discounted present value (DPV) of the maintenance strategy. However, the dependability of the engineering assets needs to be assessed in order to make an estimation of the DPV. Therefore, the European standard EN 15341 has been studied, in order to find the most essential indicators for the four value drivers and for estimation of the DPV. Terminology containing drivers and killers are common in the field of asset management, but definitions are scarce. One section in this paper is therefore dedicated to review these terms.**

***Keywords*— performance, killers, drivers, VDM, MPM, maintenance, indicators, PI, KPI, HSE**

I. Introduction

Value driven maintenance (VDM) is a maintenance management method developed about four value drivers in maintenance, which are; asset utilisation, resource allocation, cost control and HSE (health, safety and environment) [1]. These four drivers are used to calculate the value of the maintenance strategy using the formula of discounted present value (DPV). However, a maintenance performance measurement (MPM) system is needed in order to build up knowledge of the four drivers and to be able to make an estimation of the DPV. The European standard on maintenance key performance indicators (KPIs) EN 15341 is providing a battery of indicators for this purpose [2]. However, due to the ratio-based construction of the indicators, even the most general 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 the 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 the EN 15341 standard.

Terms like; value drivers, performance drivers, etc. are commonly used in the field of asset management, but definitions are mostly missing. The paper is therefore starting 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 concentrated on authors that are using the terms.

II. Performance Drivers and Killers

Kaplan and Norton [3, 4] use the term performance driver extensively in their work with the Balanced Scorecard (BSC), which complements financial measures of past performance with operational measures of the future performance. Financial measures are commonly considered as lagging indicators, i.e. output, or outcome measures. Therefore, performance drivers can be interpreted as the inputs to a process, whereas performance killers are the ones that are performing badly.

Indicators measuring inputs to a process are often considered as leading indicators [5]. Thus, lagging indicators measure outputs.

The financial perspective of the BSC constitutes mainly of output measures, while the other perspectives of the Balanced Scorecard have more performance drivers within them. One example given by Kaplan and Norton is measure of on-time delivery; such a measure will be a useful performance measure for customer satisfaction and retention [3].

To Tsang [6, 7] the term performance drivers are equivalent to lead indicators, which have the ability to predict future outcome. Parida and Chattopadhyay [8, 9] agree that a lead indicator can be a performance driver which acts like an early warning system. However, the authors do not state that performance drivers are lead indicators. Patra et al. [10] have the same stance of policy, i.e. a lead indicator can be a performance driver.

Markset and Kumar [11] states that performance killers are 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 and Kumar [8, 12] 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.

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A. *Cost Drivers*

Horngren [13] defines cost driver in accounting as any variable that causally affects costs over a given time span. Markeset and Kumar [11] 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 [14] used Horngren's definition and defined cost driver in a railway management context, as an analogous to unpunctuality driver, which in turn are defined as any factor that affects unpunctuality. Espling [15] gives some examples of cost drivers in railway infrastructure management; labour, labour overtime, spare parts and infrastructure failures. Furthermore, Nissen [16] considers the actions taken after inspection of railway switches and crossings as cost drivers, since they could be omitted if the switches and crossings were more reliable. This can be interpreted as unreliability of engineering assets is a cost driver.

B. *Conclusion 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 references and previous reasoning, performance killers and cost drivers are similar, but not necessary the same. Both impair process outputs, but a performance killer can reduce the revenue, while the expenses are the same, i.e. it does not have to increase costs. Quality is an example of performance killer and cost driver. Bottlenecks are another example, defined by Oxford Dictionaries as a situation that causes delay in a process or system.

Nyström [14] used Horngren's definition and defined cost driver in a railway management context, as analogous to unpunctuality driver. A common indicator in accounting is the capacity utilisation, often calculated as the actual output over the potential output. Another essential aspect in any process is the quality of the output. Deduced from previous reasoning, any factor that reduces capacity, quality, punctuality, etc. can be a performance killer or cost driver of the outputs.

The definitions and descriptions of the terms discussed in the identified literature are brought together in Table I and the input-process-output model (IPO-model) in Fig. 1.

As can be seen in Fig. 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. Soft measures are the same as qualitative indicators, 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 discounted present value (DPV), as the four value drivers are terms in the formula for calculating the value of all future cash flows. See Eq. 1 in the next section.

TABLE I
DESCRIPTION OF TERMS AND REFERENCES

Term	Description	Reference
Performance Driver	Input to a process	[3]
Performance Killer	Input to a process that performs badly or hinders performance. Note: Similar to cost driver but does not necessary effect costs, it can affect only revenue.	Deduced from performance drivers
	Factors and issues that reduce performance without being strong enough to stop a process	[11]
Cost Driver	Any variable that causally affects costs over a given time span	[13]
Bottleneck	A situation that causes delay in a process or system	Oxford Dict.
Leading Indicator	Indicator measuring the inputs to a process, giving indication of future events. Leading indicators are also called operational indicators.	Deductive reasoning
Operational Indicator	Driver of future financial performance. Note: See also leading indicator.	[4]
Lagging Indicator	Indicator measuring the outputs of a process, giving indication of events that have already taken place. Leading indicators are also called financial indicators.	Deductive reasoning

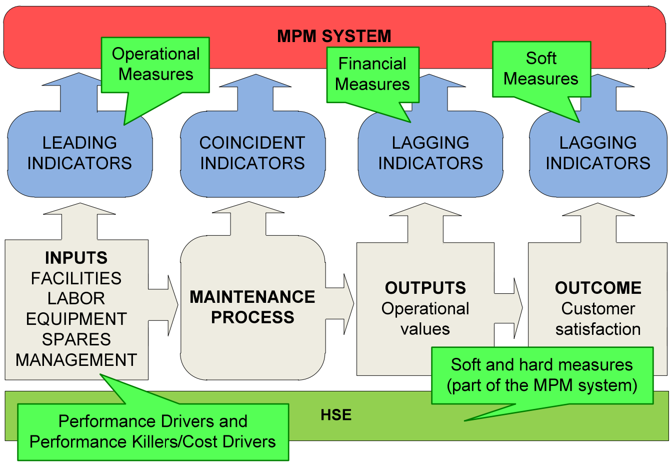

Fig. 1 IPO-model with integral MPM system.

III. 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 Fig. 2.

Maintenance managers must balance the importance of the value drivers in order to maximise the stakeholders' value. A business that experiences a high market demand may want

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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.

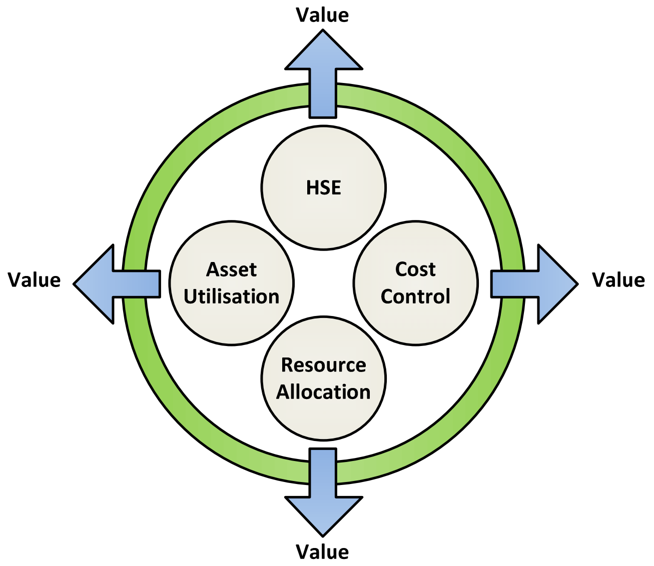

FIG. 2 MAINTENANCE VALUE DRIVERS. ADAPTED FROM [1]

Jonker and Haarman [1] have formulated 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:

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

Where:

DPV = Discounted present value (the origin to the term value drivers in this context)
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. This requires data to be collected, which have large costs and large cost savings associated with 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 SMRP Best Practice Metrics [2, 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 [18]:

- 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. The most simple connection can be done by connecting the three groups of indicators to the value drivers, see Fig. 3.

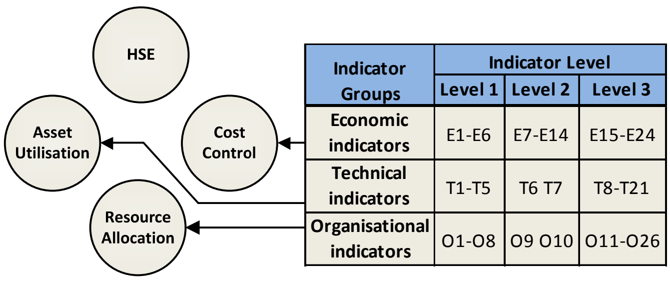

Fig. 3 EN 15341 indicator groups connected to the value drivers of VDM

Every KPI has been constructed by taking the ratio of two factors or PIs, i.e. data is 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 (numerators and denominators) can be seen as level 0 indicators, easiest to calculate and most essential to have.

Out of all the level 0 PIs, the easiest to calculate and most important ones have been heuristically deduced from the EN 15341 standard and are presented in Fig. 4 and Table II.

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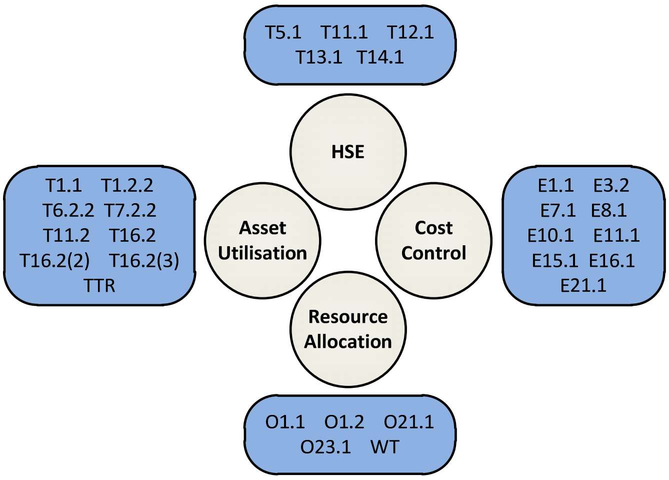

Fig. 4 Level 0 PIs heuristically deduced from EN 15431

TABLE II
LEVEL 0 INDICATORS EXTRACTED FROM EN 15341

Economic Indicators	
$E1.1 = \sum €^{Cost}_{Maint}$	$E3.2 = \sum \#^{Output}_{Prod}$
$E7.1 = \sum €^{Inventory\ value}_{Maint}$	$E8.1 = \sum €^{Personnel\ cost}_{Maint}$
$E10.1 = \sum €^{Contractor\ cost}_{Maint}$	$E11.1 = \sum €^{Mtrl\ cost}_{Maint}$
$E15.1 = \sum €^{CM\ cost}_{Maint}$	$E16.1 = \sum €^{PM\ cost}_{Maint}$
$E21.1 = \sum €^{Training}_{Maint}$	
Technical Indicators	
$T1.1 = \sum UT$	$T1.2.2 = \sum DT_{Maint}$
$T6.2.2 = \sum DT^{Failures}_{Maint}$	$T7.2.2 = \sum DT^{Planned}_{Maint}$
$T11.2 = \sum \#_{Failures}$	$T16.2 = \sum \#_{WO}$
$T16.2(2) = \sum \#^{CM}_{WO}$	$T16.2(3) = \sum \#^{PM}_{WO}$
$TTR = \sum t^{Item}_{Repair}$	
Organisational Indicators	
$O1.1 = \sum \#^{Personnel}_{Maint}$	$O1.2 = \sum \#_{Employees}$
$O21.1 = \sum t^{Overtime}_{Maint}$	$O23.1 = \sum t^{Training}_{Maint}$
$WT = \sum WT$	
HSE Indicators	
$T5.1 = \sum \#^{Injuries}_{Maint}$	$T11.1 = \sum \#^{Injuries}_{Failure}$
$T12.1 = \sum \#^{Pot\ injuries}_{Failure}$	$T13.1 = \sum \#^{Envir\ dmg}_{Failure}$
$T14.1 = \sum \#^{Pot\ envir\ dmg}_{Failure}$	

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), TTR and WT 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. TTR (time to repair) is a measure of maintainability. WT (waiting time) is a measure of the maintenance supportability or maintenance support performance. The definitions of maintainability, maintenance supportability and maintenance support performance are found in [19, 20].

TABLE III
LEVEL 1-3 INDICATORS BASED ON THE LEVEL 0 INDICATORS

Economic Indicators	
$E1 = \frac{\sum €^{Cost}_{Maint}}{ARV}$	$E3 = \frac{\sum €^{Cost}_{Maint}}{\sum \#^{Output}_{Prod}}$
$E7 = \frac{\sum €^{Inventory\ value}_{Maint}}{ARV}$	$E8 = \frac{\sum €^{Personnel\ cost}_{Maint}}{\sum €^{Cost}_{Maint}}$
$E10 = \frac{\sum €^{Contractor\ cost}_{Maint}}{\sum €^{Cost}_{Maint}}$	$E11 = \frac{\sum €^{Mtrl\ cost}_{Maint}}{\sum €^{Cost}_{Maint}}$
$E12 = \frac{\sum €^{Mtrl\ cost}_{Maint}}{\sum €^{Inventory\ value}_{Maint}} = \text{Warehouse turnover}$	
$E15 = \frac{\sum €^{CM\ cost}_{Maint}}{\sum €^{Cost}_{Maint}}$	$E16 = \frac{\sum €^{PM\ cost}_{Maint}}{\sum €^{Cost}_{Maint}}$
$E21 = \frac{\sum €^{Training}_{Maint}}{\sum \#^{Personnel}_{Maint}}$	
Technical Indicators	
$T1 = \frac{\sum UT}{\sum UT + \sum DT_{Maint}} = \text{Availability related to maintenance}$	
$T17 = \frac{\sum UT}{\sum \#_{Failures}} = MTBF$	
Organisational Indicators	
$O1 = \frac{\sum \#^{Personnel}_{Maint}}{\sum \#_{Employees}}$	
HSE Indicators	
$T5 = \frac{\sum \#^{Injuries}_{Maint}}{\sum t}$	$T5(2) = \frac{\sum \#^{Pot\ injuries}_{Maint}}{\sum t}$
$T11 = \frac{\sum \#^{Injuries}_{Failure}}{\sum \#_{Failures}}$	$T12 = \frac{\sum \#^{Pot\ injuries}_{Failure}}{\sum \#_{Failures}}$
$T13 = \frac{\sum \#^{Envir\ dmg}_{Failure}}{\sum \#_{Failures}}$	$T14 = \frac{\sum \#^{Pot\ envir\ dmg}_{Failure}}{\sum \#_{Failures}}$

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The extracted level 0 indicators can be used to calculate some of the level 1-3 KPIs. This has been carried out and is presented in Table III and Fig. 5. 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 III and Fig. 5, 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.

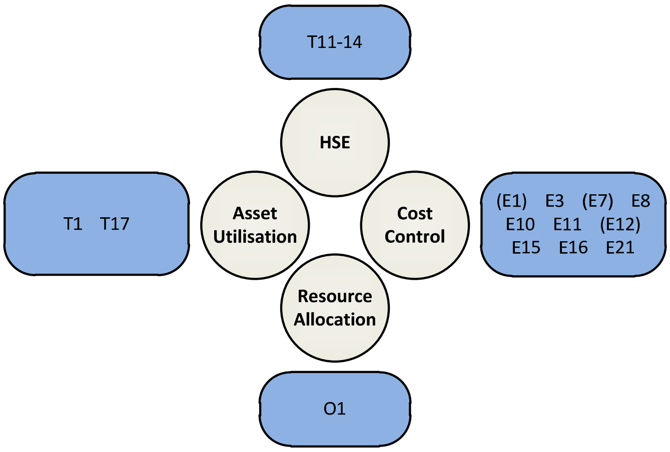

Fig. 5 KPIs based on the level 0 PIs, with exception for the PIs within parenthesis, which requires ARV and inventory value

The most important indicators to implement have been identified through EN 15341. Besides, connecting the indicators to the four value drivers of VDM, categorising according to leading and lagging indicators can as well be carried out. This has been shown as a last step in Fig. 6. E15.1-2 and E21.1 were put as leading indicators since they are measures of personnel training and maintenance policy.

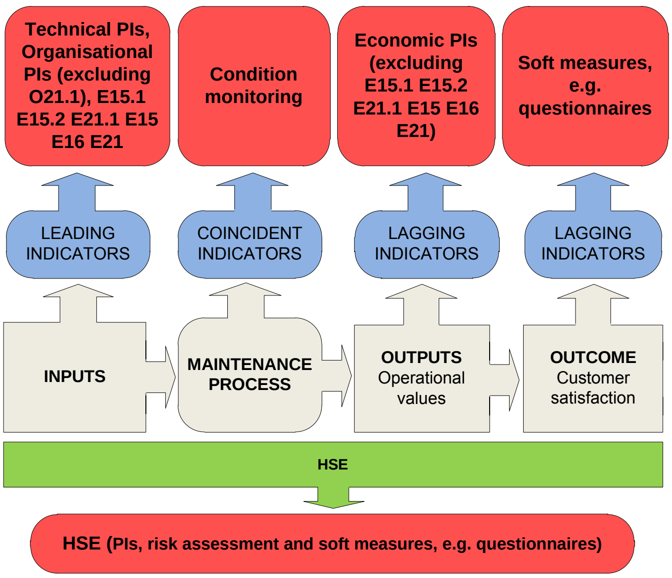

Fig. 6 Identified PIs categorised according to leading, lagging, etc.

IV. Conclusions

A review on killers and drivers related to asset management has been carried out and concluded in Table 1. Any input that reduces the output (capacity, quality, punctuality, etc.) is a performance killer or cost driver; and vice versa, regarding performance drivers. Leading indicators measure the inputs, i.e. driver and killers, but the indicators can as well be a driver or killer since the MPM system is built to assist in driving the performance.

VDM uses the formula of DPV to estimate the maintenance value, which requires assessment of the dependability of the engineering assets. Knowing what to measure and analyse is important, since large costs and large cost 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 analyzing 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 are still 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.

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