The Journey towards World Class Maintenance with Profit Loss Indicator

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Abstract. To have a maintenance function in the company that ensures a competitive advantage in the world market requires the world class maintenance (WCM). Though several different periods in history, maintenance has shifted from reactive maintenance fixing it when it breaks towards more systematic analysis techniques in terms of root cause analysis. With the onset of digitalisation and the breakthrough technologies in from Industry 4.0 more advanced analytics are expected in WCM. In particular the indicator profit loss indicator (PLI) has shown promising results in measuring e.g. time losses in production in a monetary term. Further, this indicator has also been proposed to be included in predictive maintenance. However, it is not pointed out clearly which role PLI will have in WCM. The aim of this article is therefore to investigate the trends of WCM as well as how PLI can be included in this journey.

Keywords: Profit Loss Indicator, Maintenance Management, World Class Maintenance

1 Introduction

With the global competition and the need for improving the manufacturing performance, the focus of improving the maintenance function in the company has also increased [10]. This is supported by the maintenance expert Wireman who is addressing the importance of maintenance in order to being competitive in the market [17]. It seems that the concept world class maintenance (WCM) is referring to the maintenance function in a company that ensures a competitive advantage in the world market [7,17].

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To evaluate if a company actually is at a WCM level, specific maintenance indicators are applied in the evaluation and is denoted as WCM indicators [7]. An example of such an indicator is annual maintenance costs as a percent of replacement asset value of the equipment. In addition, WCM should also strives to reduce the hidden factory which is quantified in terms of time losses and the indicator overall equipment effectiveness (OEE). It is pointed out by Nakajima that measurement of equipment effectiveness is value added to production through the equipment [11], and should therefore be regarded as a WCM indicator as well. Although this indicator has demonstrated improved results in terms of reducing the hidden factory and time losses in the industry, it is of interest to investigate in the profit loss due to the hidden factory [15]. The indicator profit loss indicator (PLI) measures this property of the hidden factory and should be included as a WCM indicator. Although several demonstrations have been conducted by PLI both at a strategic level [13] as well as at an operational level [15], it is a need to investigate more in detail how PLI will contribute in the journey towards WCM.

Today with the breakthrough technologies from Industry 4.0 [8], new opportunities has emerged in WCM. In particular the concept Smart Maintenance is expected to contribute in Industry 4.0 formalized through standardisation work and strategic roadmaps in Industry 4.0 [3].

In light of the opportunities in Industry 4.0, the aim of this article is to investigate the trends of WCM as well as how PLI can be included in this journey.

The future structure in this article is as follows: Section 2 elaborates some trends in WCM, whereas Section 3 further elaborates how maintenance management will influence the value chain as a specific trend in WCM. Section 4 further presents PLI and proposes a new structure of PLI. Future aspects of PLI is discussed and concluded in Section 5.

2 Trends in World Class Maintenance

Table 1 presents some examples of trends in manufacturing and WCM inspired from several literature studies of maintenance trends as well as own experiences. In particular trends in WCM is discussed in this article.

The structure of the trends in maintenance is based on an earlier structure [14]. Likewise in manufacturing there has in maintenance been a evolvements of the maintenance function. The content of the trends within maintenance is meant to be examples and not a complete list. Instead, the trends should aid how PLI can be a part of the journey towards WCM.

The time up to 1980 can be regarded as a period of cost focus where in maintenance it was reactive maintenance in terms of corrective maintenance, ad-hoc planning as well as ad-hoc analysis.

Further in the period 1980-2010 it was a shift towards quality focus where concepts such as Toyota Production System (TPS) influenced the period. In this period the maintenance function could be classified as Maturing maintenance where the concept total productive maintenance (TPM) [11] was getting implemented with different

degrees of success. This also included the application of the WCM indicator OEE and should be considered to be a systematic approach in reducing the hidden factory in terms of time losses in production. Also in this period the maintenance management loop [12] was developed enabling the company to ensure continuous improvement based on the principles from the Deming cycle. In this management loop, application of analysis methods such as root cause analysis (RCA) and life cycle cost (LCC) was performed. By considering the maturity matrix in predictive maintenance [5], the condition monitoring methods in terms of visual inspections, instrument inspections and real-time condition monitoring could be positioned in period of Maturing maintenance.

Table 1. Trends in manufacturing and World Class Maintenance

Cost Focus	**Quality Focus**	**Customization Focus**
-> 1980	1980 – 2010	2010 ->
Mass Production	*Lean Production*	*Smart Manufacturing*
Push policy Gantt charts Motion & time study Assembly line Statistical sampling Inventory optimization PERT/CPM MRP	Just-in time Pull policy Electronic data interchange TQM Baldrige award Kanban	Economies of scope Global manufacturing Agile manufacturing Internet-based manufacturing IoT, Data Analytics Cyber Physical System & Industry 4.0
Reactive maintenance	*Maturing maintenance*	*Smart Maintenance & Maintenance 4.0*
Corrective maintenance Ad-hoc planning Ad-hoc analysis	TPM & TPS CMMS LCC OEE RCA Maintenance mgt. loop Condition monitoring: - Visual inspection - Instrument inspection - Real-time condition monitoring	Predictive Maintenance 4.0 LCP Remaining useful life (RUL) Green Maintenance Wireless sensors Miniaturisation PLI Maintenance planning with a system perspective Digital competence and social competence Value driven maintenance

From 2010 and into the future it seems to be a shift towards customization and evolvement of the period Smart Maintenance and Maintenance 4.0. The enhancement of Smart Maintenance is in particular addressed in the German standardization roadmap within Industry 4.0 [3]. In this standardization roadmap it is pointed out that Smart Maintenance is an “enabler” of Industry 4.0 where it is responsible for ensuring

that the cyber-physical systems are kept available and efficient. The concepts of Smart Maintenance and Maintenance 4.0 is also included in Norwegian industry through e.g. the project CPS Plant. In this project it is pointed out the importance of PLI as a central part as Maintenance 4.0. When considering the maturity matrix in predictive maintenance [5] the concept Predictive Maintenance 4.0 is emerging in this period. This concept includes continuous real-time monitoring of the asset with on alerts based on predictive analytics such as machine learning. This will as a result estimate the remaining useful life (RUL) of the asset. With the trends within and sustainability [16] and circular economy leads to the concept of Green Maintenance. As an example, renovation projects of the asset will no longer accept disposal of old parts but rather remanufacture and re-use the parts. Another important element in this period will be miniaturization where reduction in size of computer devices combined with wireless sensors ensures that the same computer capability can be performed by an e.g. smart phone instead of a computer in a control room. This can enable new services in terms of remote maintenance.

It is also expected that PLI would be a suitable indicator within Smart Maintenance. For example, it has been demonstrated that this indicator can be applied in predictive maintenance and is also relevant of maintenance planning [14]. The importance of maintenance planning is also pointed out to be essential in future digital maintenance where maintenance planning with a system perspective is a probable scenario [2]. The aim of this type of maintenance planning is to optimize the performance of the entire manufacturing system by considering both the technical condition of the machine as well as the system perspective in terms of bottlenecks. Also, the competence in the future will require more digital competence such as data analytics as well as social competence in terms of interdisciplinary collaboration. Finally, it is expected that in future it will be a more value focus of the maintenance function where the value creation and contribution to profit is systemized and quantified [4]. The next section will more evaluate the relationship between maintenance management in the value chain.

3 Maintenance management in the value chain

Through the four stages of industrial revolutions, industrialists have dramatically improved their level of performance. In addition, industrialist's view on maintenance has developed from seeing maintenance as an unnecessary evil, to an opportunity of gaining a competitive advantage [6], and utilizing the field of maintenance for improving value chain performance has become an important action for industrialists. A definition of value chain is given as follows [1]: "*The functions within a company that add value to the goods or services that the organisation sells to customers and for which it receives payment."* It is well-known, that maintenance has direct effect on the total operating cost of all manufacturing and production plants [6]. Thus, measuring maintenance performance is an efficient way for those aiming at increasing value chain performance. For measuring maintenance performance, Key Performance Indicators (KPIs) can be regarded as a suitable tool [10]. Based on experiences obtained

from a Norwegian process industry company, the following maintenance KPIs, as shown in Figure 1 is used for the abovementioned purpose.

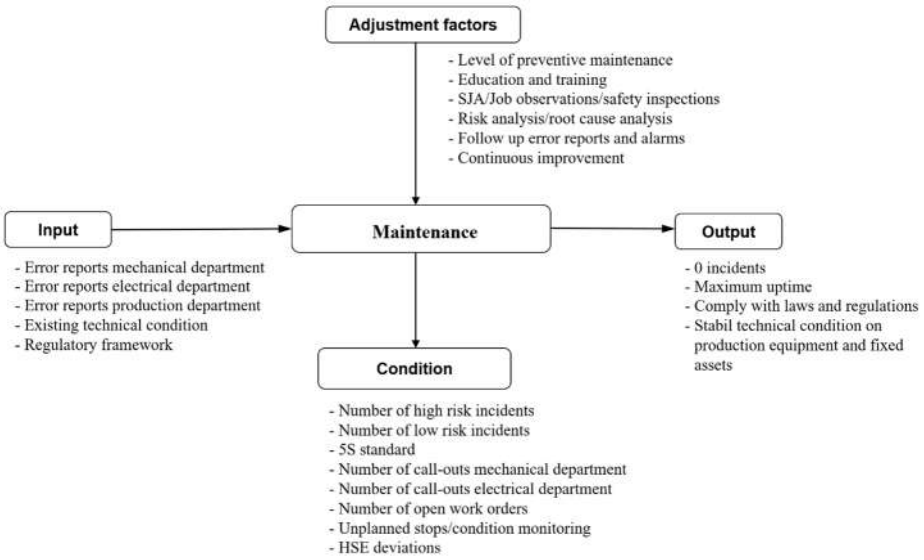

Fig. 1. Focus diagram for maintenance indicators supporting the value chain

As shown, the company divided maintenance indicators into four factors with appurtenant parameters of importance for the company. First, "Input" described the current situation. Second, "Adjustment factors" gave an overview of elements that affect the maintenance quality. Third, "Condition" presented status of critical parameters. Fourth, "Output" defined the parameters important for increasing the value chain performance of the company. Based on the definition of the value chain it is expected that several parts in the maintenance function will influence the value chain. However, it remains to investigate more in detail the relationship between the maintenance indicators and the performance of the value chain.

4 PLI and future applications

PLI has evolved from OEE where the need is to develop a monetary indicator of the hidden factory. A suitable approach for calculating PLI is to structure the elements of this indicator in three different dimensions.

Figure 2 presents the approach for calculating PLI in terms of the PLI cube [15]. The hidden factory will be divided in terms of time loss and waste, the accounting perspective as well as the perspective of the physical asset.

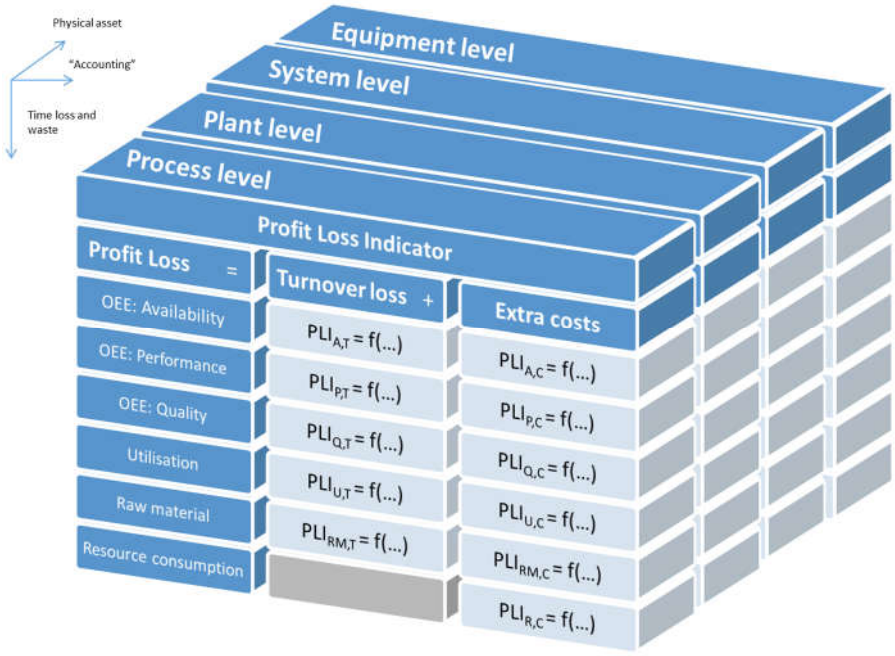

Fig. 2. The PLI cube [15].

Although calculation of PLI based on this cube has been demonstrated in several case studies, it is still of interest to investigate in alternative approaches for calculating PLI. Based on application of the DuPont [9] for profitability analysis as well as structuring of the contribution of OEE for return on asset [18].

Figure 3 presents a proposed structure of PLI inspired by this structure and could be related to the company level which will affect the value chain.

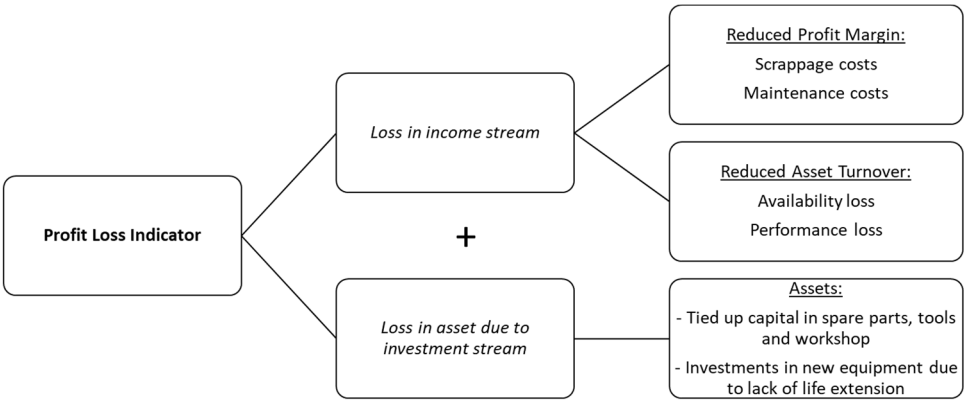

Fig. 3. Proposed structure of PLI, inspired from [9,18].

5 Future aspect of PLI and conclusions

The aim of this article was to investigate the trends of WCM as well as how PLI can be included in this journey. As shown in this article there are many elements of WCM and only some examples of elements in WCM has been presented.

The elements in WCM should aid PLI in the implementation. For example, the calculation of RUL based on machine learning can be combined with PLI and support as maintenance planning [14]. With the technologies developed from wireless sensors and the principle of miniaturisation it will be possible to have PLI in dashboards on small devices where PLI information is provided in real-time. By constructing a dashboard with both maintenance indicators relevant for the value chain and PLI can result in better and faster decisions in remote maintenance. This will also ensure that WCM is value driven.

More possible structures of PLI should be investigated. Although PLI has been tested in several case studies, the new approach of calculating PLI inspired from the DuPont model should be tested more in details since it can provide a new understanding of PLI at company level and how it will affect the value chain.

It is concluded that PLI should be included in WCM. Future research will require testing new approaches for calculating PLI in case studies as well as relate it to other maintenance indicators that affect the value chain.

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