Improving maintenance by profit indicators

H. Rødseth¹, O. Myklebust², R. Eleftheridis¹ & P. Schjølberg¹
¹Department of Production and Quality Engineering, Norwegian University of Science and Technology, Norway
²SINTEF Raufoss Manufacturing AS, Norway

Abstract

With the challenges of “silo thinking” in production and manufacturing, several disciplines and departments perform activities that affect each other, which can lead to suboptimal results in production with respect to extra costs and lack of production assurance. For maintenance management, silo thinking may result in unplanned maintenance activities, which may impede production plans. As a remedy to avoid this challenge, a key performance indicator (KPI) for maintenance management has been developed and is denoted as profit loss indicator (PLI). The purpose of this research was to investigate how this indicator can be further developed with more perspectives of concepts of Toyota Production System and Six Sigma. In particular, this PLI is evaluated for a relevant example in the industry with a case study. Results from both literature and case study are used to build further on the PLI concept.

Keywords: profit loss indicator, maintenance management, zero defects.

1 Introduction

When the production department provides feedback to the maintenance department, there arises a need for an integrated planning (IPL) concept, which avoids the two departments’ functioning as “silos.” This phenomenon occurs when an asset with several disciplines and departments performs activities that affect each other [1]. Owing to poor coordination between the maintenance and the production department, the overall result may be suboptimal in terms of production volume, safety, and costs. A key performance indicator (KPI) has been developed for operating IPL. This KPI, denoted as profit loss indicator (PLI) is based on a structured approach for measuring the financial loss due to a hidden factory in production [1].
Hidden factory is an analogy for time losses in production and is calculated for the maintenance KPI of overall equipment effectiveness (OEE) [2]. These time losses, denoted as six large losses, are categorized into availability losses, which include (1) machine breakdown, (2) waiting period, (3) performance loss in terms of minor stoppages, (4) reduced speed, (5) quality loss in terms of scrap, and (6) rework [3]. In particular, quality losses were of interest in this research. Although the PLI concept has been partly tested in a case study for the saw mill industry [4], quality losses have not been tested and demonstrated [4].

In production, industry needs to meet specific requirements of its stakeholders – market and authorities. One particular requirement of different stakeholders is compliance with zero defect manufacturing (ZDM). In fact, the requirement relates to the quality of not only products but also management systems [5]. This has been coped with in traditional quality management programs such as the Six Sigma methodology, which systematically gets as near as possible to “zero defects” (ZD) [6]. However Wang [7] claims that this is not sufficient for reaching ZD in manufacturing. The reason is limitation in the program in dealing with complex and dynamic data sets. This can be partly explained by the dynamic and complex nature of current production. It is, therefore, necessary to have a toolbox that can gather and process data and present the processed data in real time. The result is faster and better decision-making in production. However, aiming for the application of real-time data is not in conflict with existing management programs, and should be regarded as inclusive instead.

The aim of this article is to evaluate how ZDM is related to the concept PLI, partly based on literature study and partly based on discussions with managers in the machine tool and smelting plant industries. It is common to these industries that they have both worked systematically with approaching ZDs in production.

The structure of the remaining article is as follows: In Section 2, the concept of ZDM is discussed in detail and its relation to Toyota Production System is provided. Further, in this section, the hidden factory is presented with the maintenance KPI OEE and how it is related to ZDM is discussed. In Section 3, PLI is evaluated on the basis of discussions in the industry, and the final conclusion is drawn in Section 4.

2 Toward ZDs and minimizing PLI

In addition to the concept of Six Sigma, the concept of ZDs is found in other traditional concepts such as total productive maintenance (TPM) [2], quality management, and ZDM. Quality measurement can be provided by statistical indexes like process capability index and minimum process capability index typical of statistical process control (SPC). SPC is based on the idea of monitoring a variation in a feature to distinguish between natural variability and variation due to assignable causes; the detected variation due to assignable causes is meant to be eliminated and provides hints for further process improvements. As its name reveals, SPC is based on statistics and requires a certain number of measurement values/products to achieve statistically significant statements on which decisions can be based.
Therefore, companies that produce in small batches struggle to provide demanded statistical indexes and assure the quality of small-batch production; to help these companies in coping with these issues the process needs to be stable. A stable process is one that is only subject to random causes or one in which the controlled quality feature follows a time-invariant distribution. Second, a process is capable if a stable process has demonstrated to realize a quality feature that fulfils the requirements. The application of control charts is a common method to keep a process capable.

From TPM perspective, Nakajima [2] stated that ZD is a US concept that is an individual activity and became popular in Japan in 1965. The first Japanese firm to implement it combined it with Japanese-style quality circle and small group activities. Japan Institute of Plant Maintenance (JIPM) endorses small groups that are autonomous based on the ZD model advocated by Professor Emeritus Kunio Odaka of Tokyo University [8]. This is also in accordance with recent literature study of TPM by Ahuja and Khamba [9], who support autonomous maintenance as a TPM pillar. In addition, they list quality maintenance as another pillar that fosters an operator’s skills in terms of achieving ZD. Therefore, it should be no surprise that in the concept of ZDM, a methodology has been developed that considers the manufacturing industry as a sociotechnical system [10]. The methodology, called SEISMIC (stabilize, evaluate, identify, standardize, monitor, implement, and control), has been tested successfully for a complex automotive part; it significantly reduced defect rates and produced anecdotal results in terms of greater job satisfaction and ownership of work.

In ZDM approach in manufacturing, it is important to specify the terminology for the word “defect.” It has been claimed that the definition of ZD is zero failures during operations in the field, but not necessarily zero imperfections, blemishes, or nonconformities [11]. This is also supported by Tils, who explains ZDs as products without perceptible failure or malfunction during operation by the end user [12]. The word “failure” has been defined according to IEC 50191 [13] as the termination of the ability of an item to perform a required function.

Six Sigma can be regarded as a philosophy and a statistical method. The philosophy comprises a proven, data-driven suite of improvement methodologies, where tools support this philosophy with measurements and improvement tools for both processes and products [6]. The term sigma is a statistical term that indicates how far a process deviates from the desired measure. An important essence in Six Sigma Philosophy is that by reducing this variation, one can eliminate defects in production. The consequences of a successful application of Six Sigma in production are increased customer satisfaction, reduced operating costs, and reduced time loss in rework, which provides a bottom line of increased profit. If a company actually reaches a statistical six sigma level, the production process produces less than 3.4 Defects Per Million Opportunities (DPMO) and is considered to be a target in Six Sigma. Obviously, some variables in the industry may influence the realism of this target. One recent project that mainly focused on ZDM is the EU project IFaCOM (intelligent fault correction and self-optimizing manufacturing systems).
In Fig. 1, the IFaCOM concept is shown, which is adapted for the maintenance of an asset. Cognitive signal analysis, simulation, and behavior support the maintenance function of a company.

The framework is operationalized at the following three levels:
1. Short term: Closed-loop control based on in-process real-time measurement
2. Medium term: Process tuning and optimization
3. Long term: Machine system optimization

The framework also specifies that IFaCOM is vital for providing accurate and rapid feedback to maintenance. Overall, several maintenance types and maintenance concepts should be developed together with IFaCOM to establish the best practice in maintenance management in order to be a world-class maintenance company. The ZDM system in IFaCOM enables new opportunities in different approaches of maintenance by providing technological opportunities with real-time access to data from sensors. It also bears a clear relationship with Toyota Production System regarding wastes in production. One important type of waste is defects [14]. When a defect occurs, this might require repair or rework of the product and wasteful handling in terms of extra inspection.

The metaphor “hidden factory” can be traced to Nakajima, a former Vice Chairman of JIPM, who stated that OEE is a measure for “unlocking the hidden factory” [15] and provided a specific calculation approach for OEE [2]. In recent times, the OEE has been associated with a similar metaphor “hidden machine,” promoted by Koch [3]. Koch extends the definition to argue that availability losses
should also comprise planned downtime such as breaks and preventive maintenance. Although this updates the OEE calculation, it should still be considered a part of the “hidden factory”. This category comprises time losses when an equipment is stopped for planned maintenance. An overview of different classifications of time losses in the hidden factory is shown in Table 1 [3].

<table>
<thead>
<tr>
<th>Time category</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>1. Machine breakdown</td>
</tr>
<tr>
<td></td>
<td>2. Waiting period</td>
</tr>
<tr>
<td>Performance efficiency</td>
<td>3. Minor stoppages</td>
</tr>
<tr>
<td></td>
<td>4. Reduced speed</td>
</tr>
<tr>
<td>Quality losses</td>
<td>5. Scrap</td>
</tr>
<tr>
<td></td>
<td>6. Rework</td>
</tr>
</tbody>
</table>

As described in previous chapter, Six Sigma focuses on the following improvement process of Define, Measure, Analyze, Improve and Control [6]. More specifically, Motorola identified and measured extra costs of defects in terms of rework for postrelease defects. Hence, Six Sigma has a financial measure for DPMO. It can be mathematically expressed as the relationship between OEE and DPMO [15]. More specifically, quality losses in OEE can be calculated as follows:

\[
\text{DPMO} = \frac{\text{Number of rejected parts}}{\text{Total number of parts produced}} \times 1,000,000, \tag{1}
\]

\[
\text{OEE}_{\text{Quality}} = 1 - \frac{\text{Number of rejected parts}}{\text{Total number of parts produced}} \times 1,000, \tag{2}
\]

\[
\text{OEE}_{\text{Quality}} = 1 - \text{DPMO} \times 10,000. \tag{3}
\]

3 Demonstrating PLI through ZDM strategy

The PLI concept has been developed and tested earlier partly in the saw mill industry [4]. In this article, the PLI cube is evaluated with an adopted version shown in Fig. 2. Further, in this section, PLI is evaluated on the basis of discussions with the industry related to the quality part of OEE.

ZDM is influenced by the maintenance function of a company. This is also supported by discussions with a maintenance manager within the machine tool industry. For this industry, a case study is performed for a machine, where PLI calculation is planned for demonstration. In this case study, unplanned downtime of a machine is evaluated. The result is corrective maintenance, and the following assumptions are made; a failure in a machine requires corrective maintenance, production personnel might be required to work overtime, time loss might cause
some delay in product delivery to the customer, and the downtime in the machine might affect other machines in the process.

From a maintenance perspective, this situation first affects the availability, part, and resource consumption of the PLI cube. The first aspect that calls for the calculation for PLI is labor costs for maintenance personnel and resource consumption in terms of spare parts and tools. The next aspect that might need to be looked into is standby cost for production personnel. This situation occurs when production personnel have no other tasks to perform during machine downtime. Furthermore, the downtime might cause a delay in production, which requires production personnel to work overtime. If, despite the overtime, the products are not made within the due date of delivery, a penalty might be imposed by the customer. This means that the customer would not be willing to pay the same price for the products and is then considered to be a turnover loss in availability.

The extent to which unplanned downtime is correlated to ZDs in manufacturing has been discussed. This depends significantly on the stage in which process unplanned downtime occurs. If this takes place in the first stage (i.e., the processing of raw material), this correlation is considered minor. At this stage, a machine has a robust system that does not cause a defect when unplanned downtime occurs. However, this situation is not the same in the end processes for finished goods. This correlation is believed to increase significantly in the end process. At this stage of the manufacturing process, unplanned downtime and corrective maintenance would be indicators of future defects in manufacturing.
Although ZDM is unique for a specific industry, the ZDM strategy has some synergies with other industries such as the process industry. In particular, discussions were carried out with a casthouse manager at a smelting plant and valuable feedback gathered. Overall, PLI is a valuable planning tool, but other tools are also necessary to cover the needs of the planning function. In addition, it is important to consider carefully how PLI will be applied together with existing KPIs in the company. In a ZDM strategy, it is necessary to have leading KPIs for PLI that are considered to be the drivers of the PLI value. In a process plant, process variability would be such a driver. In addition, it is important to understand the requirements in production. For a smelting plant, high volume is one of the requirements and must be balanced with the requirement to reduce defects in production.

4 Concluding remarks

In this article, the relationship between ZDM and the PLI concept has been evaluated. On the basis of literature study, the relationship between DPMO and OEE is clearly established. Furthermore, maintenance activities, such as machinery breakdown, might cause defects in production. In particular, discussions with a maintenance manager in a machine tool industry support this correlation. The process industry, for which the ZDM approach is also relevant in terms of having ZDs in production, might be pressurized to produce high volumes, which may compromise ZDs in production. Further research would require more field studies for these two industries, where PLI is demonstrated in combination with leading KPIs and drivers such as process variability.

Acknowledgments

The authors would like to thank the maintenance and production managers from the manufacturing and process industries who provided a qualitative demonstration of the PLI concept through discussions.

References


