
Managing OEE to Optimize Factory Performance

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1. Introduction

"If you can not measure it, you can not improve it."(Lord Kelvin)

It is a common opinion that productivity improvement is nowadays the biggest challenge for companies in order to remain competitive in a global market [1, 2]. A well-known way of measuring the effectiveness is the Overall Equipment Efficiency (OEE) index. It has been firstly developed by the Japan Institute for Plant Maintenance (JIPM) and it is widely used in many industries. Moreover it is the backbone of methodologies for quality improvement as TQM and Lean Production.

The strength of the OEE index is in making losses more transparent and in highlighting areas of improvement. OEE is often seen as a catalyst for change and it is easy to understand as a lot of articles and discussion have been generated about this topic over the last years.

The aim of this chapter is to answer to general questions as *what to measure? how to measure?* and *how to use the measurements?* in order to optimize the factory performance. The goal is to show as OEE is a good base for optimizing the factory performance. Moreover OEE's evolutions are the perfect response even in advanced frameworks.

This chapter begins with an explanation of the difference between efficiency, effectiveness and productivity as well as with a formal definition for the components of effectiveness. Mathematical formulas for calculating OEE are provided too.

After the introduction to the fundamental of OEE, some interesting issues concerning the way to implement the index are investigated. Starting with the question that in calculating OEE you have to take into consideration machines as operating in a linked and complex environment. So we analyze almost a model for the OEE calculation that lets a wider approach to the performance of the whole factory. The second issue concerns with monitoring the factory performance through OEE. It implies that information for decision-

making have to be guaranteed real-time. It is possible only through automated systems for calculating OEE and through the capability to collect a large amount of data. So we propose an examination of the main automated OEE systems from the simplest to high-level systems integrated into ERP software. Even data collection strategies are screened for rigorous measurement of OEE.

The last issue deals with how OEE has evolved into tools like TEEP, PEE, OFE, OPE and OAE in order to fit with different requirements.

At the end of the chapter, industrial examples of OEE application are presented and the results are discussed.

2. Fundamentals of OEE

Overall equipment efficiency or effectiveness (OEE) is a hierarchy of metrics proposed by Seiichi Nakajima [3] to measure the performance of the equipment in a factory. OEE is a really powerful tool that can be used also to perform diagnostics as well as to compare production units in differing industries. The OEE has born as the backbone of Total Productive Maintenance (TPM) and then of other techniques employed in asset management programs, Lean manufacturing [4], Six Sigma [5], World Class Manufacturing [4].

By the end of the 1980's, the concept of Total Production Maintenance became more widely known in the Western world [7] and along with it OEE implementation too. From then on an extensive literature [8-11] made OEE accessible and feasible for many Western companies.

3. Difference between efficiency, effectiveness and productivity

Confusion exists as to whether OEE has indeed been an effectiveness or efficiency measure. The traditional vision of TMP referred to Overall Equipment Efficiency while now it is generally recognized as Overall Equipment Effectiveness. The difference between efficiency and effectiveness is that effectiveness is the actual output over the reference output and efficiency is the actual input over the reference input. The Equipment Efficiency refers thus to ability to perform well at the lowest overall cost. Equipment Efficiency is then unlinked from output and company goals. Hence the concept of Equipment Effectiveness relates to the ability of producing repeatedly what is intended producing, that is to say to produce value for the company (see Figure 1).

Productivity is defined as the actual output over the actual input (e.g. number of final products per employee), and both the effectiveness and the efficiency can influence it. Regarding to OEE, in a modern, customer-driven "lean" environment it is more useful to cope with effectiveness.

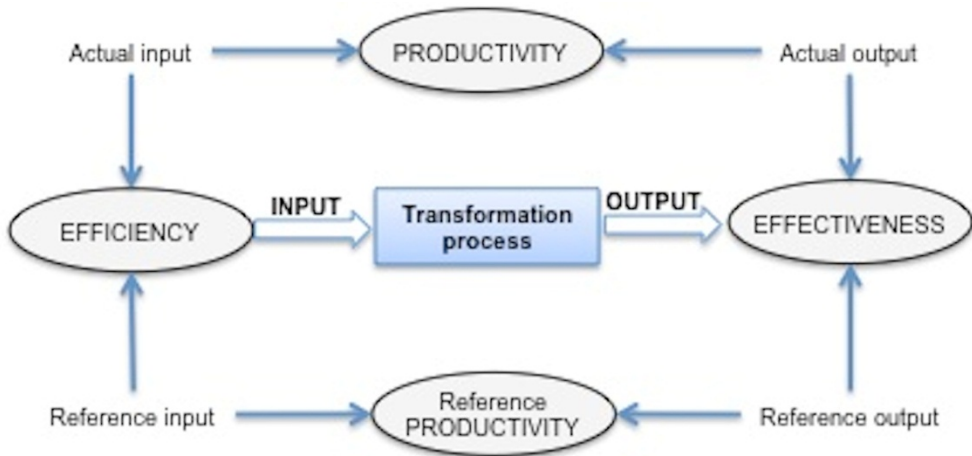


Figure 1. Efficiency versus Effectiveness versus Productivity.

4. Formal definition of OEE

According to the previous remark a basic definition of OEE is:

$$OEE = \frac{\text{Valuable Operating Time}}{\text{Loading Time}} \quad (1)$$

where:

- Valuable Operating Time is the net time during which the equipment actually produces an acceptable product;
- Loading Time is the actual number of hours that the equipment is expected to work in a specific period (year, month, week, or day).

The formula indicates how much the equipment is doing what it is supposed to do and it captures the degree of conforming to output requirements. It is clearly a measure of effectiveness.

OEE is not only a metric, but it also provides a framework to improve the process. A model for OEE calculation aims to point out each aspect of the process that can be ranked for improvement. To maximize equipment effectiveness it is necessary to bring the equipment to peak operating conditions and then keeping it there by eliminating or at least minimizing any factor that might diminish its performance. In other words a model for OEE calculation should be based on the identification of any losses that prevent equipment from achieving its maximum effectiveness.

The OEE calculation model is then designed to isolate losses that degrade the equipment effectiveness.

5. Losses analysis

Losses are activities that absorb resources without creating value. Losses can be divided by their frequency of occurrence, their cause and by different types they are. The latter one has been developed by Nakajima [3] and it is the well-known Six Big Losses framework. The other ones are interesting in order to rank rightly losses.

According to Johnson et al. [12], losses can be chronic or sporadic. The chronic disturbances are usually described as “*small, hidden and complicated*” while the sporadic ones occur quickly and with large deviations from the normal value. The loss frequency combined with the loss severity gives a measure of the damage and it is useful in order to establish the order in which the losses have to be removed. This classification makes it possible to rank the losses and remove them on the basis of their seriousness or impact on the organization.

Regarding divide losses by their causes, three different ones can be found:

1. machine malfunctioning: an equipment or a part of this does not fulfill the demands;
2. process: the way the equipment is used during production;
3. external: cause of losses that cannot be improved by the maintenance or production team.

The external causes such as shortage of raw materials, lack of personnel or limited demand do not touch the equipment effectiveness. They are of great importance for top management and they should be examined carefully because their reduction can directly increase the revenues and profit. However they are not responsible of the production or maintenance team and so they are not taken into consideration through the OEE metric.

To improve the equipment effectiveness the losses because of external causes have to be taken out and the losses caused by machine malfunctioning and process, changeable by the daily organization, can still be divided into:

- **Down time losses:** when the machine should run, but it stands still. Most common down-time losses happen when a malfunction arises, an unplanned maintenance task must be done in addition to the big revisions or a set-up/start-up time occurs.
- **Speed losses:** the equipment is running, but it is not running at its maximum designed speed. Most common speed losses happen when equipment speed decrease but it is not zero. It can depend on a malfunctioning, a small technical imperfections, like stuck packaging or because of the start-up of the equipment related to a maintenance task, a setup or a stop for organizational reasons.
- **Quality losses:** the equipment is producing products that do not fully meet the specified quality requirements. Most common quality losses occur because equipment, in the time

between start-up and completely stable throughput, yields products that do not conform to quality demand or not completely. They even happen because an incorrect functioning of the machine or because process parameters are not tuned to standard.

The framework in which we have divided losses in down time, speed and quality losses completely fits with the Six Big Losses model proposed by Nakajima [3] and that we summarize in the Table 1:

Category	Big losses
DOWNTIME	- Breakdown - Set-up and adjustments
SPEED	- Idling, minor stoppages - Reduced speed
QUALITY	- Quality losses - Reduced yield

Table 1. Six Big Losses model proposed by Nakajima [3].

On the base of Six Big Losses model, it is possible to understand how the Loading Time decreases until to the Valuable Operating Time and the effectiveness is compromised. Let's go through the next Figure 2.

CALENDAR TIME	
LOADING TIME	
OPERATING TIME	
NET OPERATING TIME	
VALUABLE OPERATING TIME	
Planned downtime	Breakdown Set-up and adjustments
Minor stoppages Reduced speed	Quality losses Reduced yield

Figure 2. Breakdown of the calendar time.

At this point we can define:

$$Availability (A) = \frac{Operating Time}{Loading Time} \tag{2}$$

$$Performance (P) = \frac{Net Operating Time}{Operating Time} \tag{3}$$

$$\text{Quality (Q)} = \frac{\text{Valuable Operating Time}}{\text{Net Operating Time}} \quad (4)$$

Please note that:

$$\text{OEE} = \frac{\text{Valuable Operating Time}}{\text{Loading Time}} \quad (5)$$

and

$$\text{OEE} = \frac{\text{Operating Time}}{\text{Loading Time}} \times \frac{\text{Net Operating Time}}{\text{Operating Time}} \times \frac{\text{Valuable Operating Time}}{\text{Net Operating Time}} \quad (6)$$

finally

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (7)$$

So through a bottom-up approach based on the Six Big Losses model, OEE breaks the performance of equipment into three separate and measurable components: Availability, Performance and Quality.

- **Availability:** it is the percentage of time that equipment is available to run during the total possible Loading Time. Availability is different than Utilization. Availability only includes the time the machine was scheduled, planned, or assigned to run. Utilization regards all hours of the calendar time. Utilization is more effective in capacity planning and analyzing fixed cost absorption. Availability looks at the equipment itself and focuses more on variable cost absorption. Availability can be even calculated as:

$$\text{Availability} = \frac{\text{Loading Time} - \text{Downtime}}{\text{Loading Time}} \quad (8)$$

- **Performance:** it is a measure of how well the machine runs within the Operating Time. Performance can be even calculated as:

$$\text{Performance} = \frac{\text{Actual Output (units)} \times \text{theoretical Cycle Time}}{\text{Operating Time}} \quad (9)$$

- **Quality:** it is a measure of the number of parts that meet specification compared to how many were produced. Quality can be even calculated as:

$$\text{Quality} = \frac{\text{Actual output (units)} - \text{Defect amount (units)}}{\text{Actual output (units)}} \quad (10)$$

After the various factors are taken into account, all the results are expressed as a percentage that can be viewed as a snapshot of the current equipment effectiveness.

The value of the OEE is an indication of the size of the technical losses (machine malfunctioning and process) as a whole. The gap between the value of the OEE and 100% indicates the share of technical losses compared to the Loading Time.

The compound effect of Availability, Performance and Quality provides surprising results, as visualized by e.g. Loughlin [13].

Let's go through a practical example in the Table 2.

Availability	86,7%
Performance	93%
Quality	95%
OEE	76,6%

Table 2. Example of OEE calculation.

The example in Table 2 illustrates the sensitivity of the OEE measure to a low and combined performance. Consequently, it is impossible to reach 100 % OEE within an industrial context. Worldwide studies indicate that the average OEE rate in manufacturing plants is 60%. As pointed out by e.g. Bicheno [14] world class level of OEE is in the range of 85 % to 92 % for non-process industry. Clearly, there is room for improvement in most manufacturing plants! The challenge is, however, not to peak on those levels but thus to exhibit a stable OEE at world-class level [15].

6. Attacking the six big losses

By having a structured framework based on the Six Big Losses, OEE lets to track underlying issues and root causes. By knowing what the Six Big Losses are and some of the causes that contribute to them, the next step is to focus on ways to monitor and correct them. In the following let's see what is the way:

- **Breakdown:** eliminating unplanned downtime is critical to improving OEE. Other OEE factors cannot be addressed if the process is down. It is not only important to know how much and when down time equipment is but also to be able to link the lost time to the specific source or reason for the loss. With down time data tabulated, the most common approach is the Root Cause Analysis. It is applied starting with the most severe loss categories.
- **Set-up and adjustments:** tracking setup time is critical to reducing this loss. The most common approach to reduce this time is the Single Minute Exchange of Dies program (SMED).
- **Minor stoppages and Reduced speed:** minor stoppages and reduced speed are the most difficult of the Six Big Losses to monitor and record. Cycle Time analysis should be utilized

to point out these loss types. In most processes recording data for Cycle Time analysis needs to be automated since the cycles are as quick as they do not leave adequate time for manual data logging. By comparing all cycles to the theoretical Cycle Time, the losses can be automatically clustered for analysis. It is important to analyze Minor stoppages and Reduced speed separately because the root causes are typically very different.

- **Quality losses and Reduced yield:** parts that require rework of any kind should be considered rejects. Tracking when rejects occur and the type is critical to point out potential causes, and in many cases patterns will be discovered. Often a Six Sigma program, where a common metric is achieving a defect rate of less than 3.4 defects per million opportunities, is used to focus attention on a goal of “zero defects”.

7. OEE evolution: TEEP, PEE, OAE, OFE, and OPE

During the last decades, both practitioners and researchers have raised the discussion about OEE in many ways. One of the most popular has led to modification and enlargement of individual original OEE tool to fit a broader perspective as supposed important for the companies [16]. With the evolution of OEE, different definitions have also come up in literature and in practice, coupled with their changed formulations. Some of these formulations (TEEP and PEE) are still at the equipment level, while the others (OAE, OFE and OPE) extended OEE to the factory level. Let’s go through the main features of each formulation.

TEEP stands for **Total Equipment Effectiveness Performance** and it was proposed firstly by Invancic [17]. TEEP is a performance metric that shows the total performance of equipment based on the amount of time the equipment was present. So OEE quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run. TEEP measures OEE effectiveness against Calendar Time, i.e.: 24 hours per day, 365 days per year.

$$TEEP = \frac{\text{Valuable Operating Time}}{\text{Calendar Time}} = OEE \times \frac{\text{Loading Time}}{\text{Calendar Time}} \quad (11)$$

OEE and TEEP are thus two closely related measurements. Typically the equipment is on site and thus TEEP is metric that shows how well equipment is utilized. TEEP is useful for business analysis and important to maximize before spending capital dollars for more capacity.

PEE stands for **Production Equipment Efficiency** and it was firstly proposed by Raouf [18]. The main difference from OEE is that each item is weighted. So Availability, Performance, and Quality don’t have an equal importance as it happens for OEE.

At the level of the factory we found **Overall Factory Effectiveness (OFE)**, **Overall Production Effectiveness (OPE)**, and **Overall Asset Effectiveness (OAE)** metrics. OFE is the most widespread and well known in literature. It covers the effort to export the OEE tool to the whole factory. The question is what kind of method should be applied to OEE values from all pieces of equipment, to derive the factory level metric. There is no standard method or metrics

for the measurement or analysis of OFE [19]. Huang [20] stated that the factory level metric can be computed by synthesizing the subsystem level metrics, capturing their interconnectivity information.

OPE and OAE are extensively implemented in industry under different formulations. They involve a practical approach developed to fit the specific requirements of different industries.

8. OEE for the factory

As mentioned in the previous section equipment operates in a linked and complex environment. So it is necessary to pay attention beyond the performance of individual tools towards the performance of the whole factory. According to Scott and Pisa [21], the answer to this requirement is the OFE metric, which is about combining activities and relationships between different parts of the equipment, and integrating information, decisions, and actions across many independent systems and subsystems. The problem is that a specific and unique method to calculate OFE does not exist. There many methodologies and approaches, with different level of complexity, different information coming from and different lacks.

A first common-sense approach is to measure OEE at the end of the line or process. Following this approach we can see OEE as

$$OEE = \frac{(Actual\ output - Defect\ amount) \times theoretical\ Cycle\ Time}{Loading\ Time} \quad (12)$$

and

$$OEE = \frac{Effective\ output\ (units)}{theoretical\ output\ (units)} \quad (13)$$

Here OEE measures effectiveness in term of output that is easy to be taken out at factory level too. So OFE becomes:

$$OFE = \frac{Effective\ output\ from\ the\ factory\ (units)}{Theoretical\ output\ from\ the\ factory\ (units)} \quad (14)$$

It is not always ideal. The complexity of OEE measurement arises where single or multiple sub-cells are constrained by an upstream or downstream operation or bottleneck operation. The flow is always restricted or limited by a bottleneck operation, just as a chain is only as strong as its weakest link. So according to Goldratt [22] we can measure OEE in real time at the bottleneck. Any variations at the bottleneck correlate directly to upstream and downstream process performance. Huang et al. [23] proposed a manufacturing system modeling approach, which captures the equipment interconnectivity information. It identifies four unique subsystems (series, parallel, assembly and expansion) as a basis for modeling a manufacturing system, as shown in Figure 3.

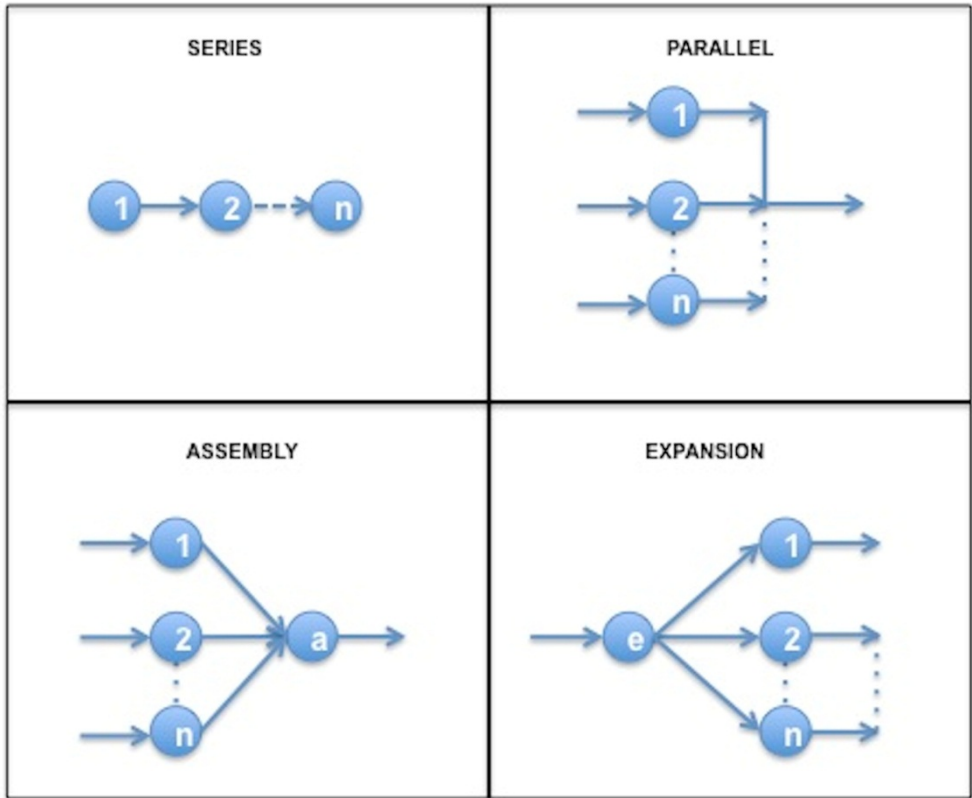


Figure 3. Types of manufacturing subsystems.

Muthiah et al. [24] developed the approach to derive OTE metrics for these subsystems based on a “system constraint” approach that automatically takes into account equipment idle time.

Other methods are based on modeling the manufacturing systems. Some of these notable approaches are queuing analysis methods [25], Markovian methods [26], Petri net based methods [27], integrated computer-aided manufacturing definition (IDEF) method [28], and structured analysis and design technique (SADT) [29]. In addition to them there are several commercial tools that have been reviewed and categorized by Muthiah and Huang [30].

9. What is OEE for?

OEE provides simple and consolidated formulas to measure effectiveness of the equipment or production system. Moreover Dal et al. [31] point out that it can also be used as an indicator of process improvement activities since OEE is directly linked to the losses as well as OEE can

be even used to compare performance across the factory highlighting poor line performance or to quantify improvements made [31]. Moreover improving can be pursued by:

- Backtracking to determine what loss reduces effectiveness.
- Identifying bottlenecks as not only the slowest machine, but as the machine both slower and less effective.

All these goals need of an approach based on the Deming Cycle [32]. It is an improvement cycle to increase the plant OEE rating until the target goals and world class manufacturing status are achieved (Figure 4)

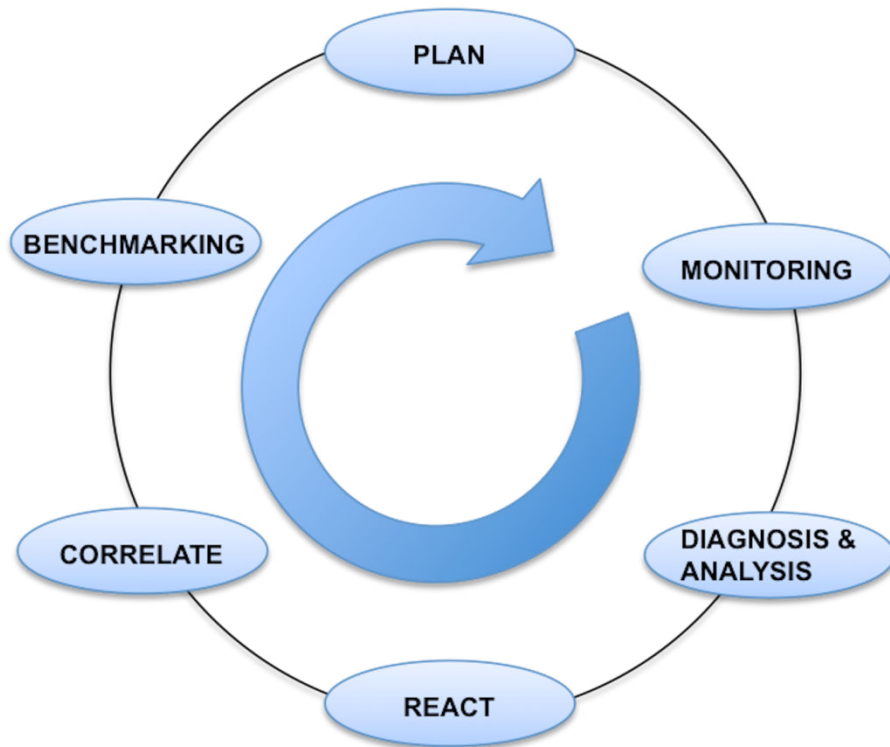


Figure 4. Improvement approach to increase the plant OEE.

This approach requires a large amount of data that can be provided both in a static or dynamic way. In the first case data are picked up only at the end of a certain period and used in the Diagnosis & Analysis stage.

There is another way to use OEE and it is to know exactly what is happening in real time through a continuous monitoring to immediately identify possible problems and react in real-time using appropriate corrective actions. Information on OEE items (maintenance and

operational equipment effectiveness, product data accuracy, uptimes, utilization, bottlenecks, yield and scrap metrics, etc.) is really valuable in environments where making decisions in near real-time is critical. This second approach requires then a data collection system completely automatized and moreover the Diagnosis & Analysis stage should be automatic.

In the next sections we will take into consideration different strategies to acquire data and we will illustrate main automated tool for the OEE integration.

10. Data collection strategies

The OEE calculations should be based on correct input parameters from the production system as reported by Ericsson [33]. Data acquisition strategies range from very manual to very automated. The manual data collection method consists of a paper template, where the operators fill in the cause and duration of a breakdown and provide comments about minor stoppages and speed losses. It is a low-tech approach. On the contrary a high-tech approach runs through an automatic OEE calculation system that is governed by sensors connected to the equipment, automatically registering the start time and duration of a stoppage and prompting the operator to provide the system with information about the downtime cause. An automatic approach usually provides opportunities to set up lists of downtime causes, scheduling the available operating time and making an automatic OEE calculation for a time period. A variety of reports of production performance and visualization of the performance results are even possible to retrieve from the system.

Two approaches have to be compared through opportunity and cost both, in a quantitative as well as in a qualitative way. Regarding cost, the main figures in case of the manual approach are derived from the hourly wage cost of operators multiplied by time spent to register data on paper templates, feed them into a computer system and for generating reports and performing OEE calculations. In case of the automatic approach cost concerns a yearly license cost for an automatic OEE calculation system together with an investment cost for hardware. The introduction of both the manual and automatic data collection methods must be preceded and then associated with training of the operators on OEE as a performance measure, and on different parameters affecting the OEE outcome. The purpose of training the operators was twofold:

1. The quality of the input data is likely to increase in alignment with an increase in the competence of the staff;
2. The involvement of the operators in identifying performance loss factors is likely to create a better engagement for providing the system with accurate information.

Another issue to overcome is the balance between the efforts of providing adequate information in relation to the level of detail needed in the improvement process. In fact if a critical success factor in an improvement project driven by OEE is the retrieval of detailed information about production losses, however not all the improvement projects require a higher and really expensive data precision.

Generally there are many companies in which manual data collection is convenient. In other companies where each operator is responsible for a number of processing machines, timely and accurate data collection can be very challenging and a key goal should be fast and efficient data collection, with data put to use throughout the day and in real-time, a more desirable approach would be realized if each machine could indicate data by itself.

An automatic OEE data recording implies:

- better accuracy;
- less labor;
- traceability;
- integrated reporting and analysis;
- immediate corrective action;
- motivation for operators.

In any case the implementation of data collection for OEE has limited value if it is not integrated in a continuous work procedure, as a part of the improvement initiative. Daily meeting and sharing information both cross-functionally and bottom-up in the organization hierarchy become a prerequisite. As well as it is useful integrating OEE into an automated management system. OEE can be applied when using a total manufacturing information system providing the detailed historical information that allows thorough diagnoses and improvement plans but more importantly it gives the summary signals.

11. Automating OEE and integration of OEE into automated management system

Automating OEE gives a company the ability to collect and classify data from the shop floor into meaningful information that can help managers understand the root causes of production inefficiency. Therefore giving greater visibility to make more informed decisions on process improvement. An automated OEE system addresses the three primary functions of OEE:

- **Acquisition:** it concerns data collection that as discussed above data will be completely automatic.
- **Analysis:** it usually provides algorithms to calculate OEE and other items related to. Moreover it is often able to support downtime classification via reason trees and other technical analysis. The more sophisticated the package, the more analysis equipment is available.
- **Visualization:** OEE metrics are available through reports or they can be displayed even via a software interface directly to the operator.

There is a lot of commercial software that provide automated OEE system, but it is possible even to integrate OEE into general tools as ERP ones. They usually offer a wide range of

capabilities. They are able to gather and coordinate the operations of a plant and provide measurable information. The advantages are that database are completely integrated so the coordination among different functions involved is better. For example manufacturing can see the upcoming planned maintenance and maintenance can see the production schedules. Automated Management systems are naturally and inherently eligible for providing feasible decision support on plant profitability and establish a foundation for addressing other manufacturing challenges in the future.

12. OEE applications

At the end of the chapter, industrial examples of OEE application are presented to remark as different industries and different goals can be all involved through the OEE metric.

12.1. Case study 1

Sigma/Q [34] is a leading manufacturer of quality packaging in Northland Central America serving various markets across the globe. The company's primary goal was to improve plant performance and reduce operational costs.

The solution was to build a foundation for continuous improvement through OEE. The first step was to automate the data collection and analysis processes and introduce a real-time strategy. But the real key success factor was operator involvement in the performance improvement process. The company identified key contributors to reward them appropriately during performance reviews.

As a result, OEE increased by 40%, variability in run speed due to frequent starts and stops in the manufacturing process, was dramatically reduced and run speed was increased by 23%. Last but not least operators aspired to achieve higher levels of operational excellence, promoting a culture of continuous improvement across the various plants.

12.2. Case study 2

A global pharmaceutical company [35] has shown the will to understand if OEE as a metric could be used as an ongoing tool of improvement. It has chosen an off-shore plant and as pilot a packaging line running a full 144-hour weekly cycle and handling more than 90 products because it allowed the collection of data over both shifts. The line also had counters on most unit operations that could be easily utilized for the collection of quality data by the line operators. Twelve weeks of data was collected with operator buy-in. The test has shown that many of the current metrics were too high-level to extract the causes of issues and therefore target improvements to them. Therefore the more than 90 products routed through the test line were divided into six groups based on the highest pack rates. The continuous real-time monitoring was able to account the 90% of available run time for with little impact running the line.

12.3. Case study 3

A company providing a broad range of services to leading original equipment manufacturers in the information technology and communications industries [36] obtained three new plants from a major contract electronics manufacturer.

Each plant had distinct ways of identifying and determining downtime, as well as their own preferred techniques and practices. The goals were then:

- Find a common metric to measure productivity across plants
- Standardized downtime reporting among plants

The manufacturer's issues were complicated by the fact it makes about 30,000 different products out of 300,000 different parts, and adds an average of 2,000 new products into its manufacturing mix every month. With this number of products, frequent changeovers are necessary. It also becomes vital to have a scientific method to be able to compare all the different lines. The company was searching for a common framework in order to compare its three newest plants. The solution was the identification of factors leading to assembly line downtime. Companies utilizing this information can make comparisons across plants and assembly lines to improve effectiveness. The results were:

- OEE increase of 45%
- Identified 25% more downtime not found with previous methods
- Reduced costs

12.4. Case study 4

The Whirlpool Corporation's Findlay Division manufactures dishwashers for many brands in the world [37]. The demand for product is at an all-time high. The goal was then how to get more out of the facility and its equipment without making huge capital investments? And more specifically how can the maintenance department support the needs of manufacturing to achieve the company goals?

To make these improvements, the Division used OEE as a measure of their current equipment efficiency. As the company started tracking individual pieces of equipment's OEE ratings, it became apparent that there was room for improvement. The combination of fundamental maintenance practices such as Root Cause Failure analysis and a preventive and predictive maintenance system, along with very strong support from Division leadership, enabled the Findlay Division to get off the ground with the Total Productive Maintenance program. Again "it was the people that made this change possible" (Jim Dray, TPM Facilitator). The Division has been able to increase production by 21%, without any significant capital costs.

The OEE measure is an excellent KPI for use on both strategic and operational levels, if it is used correctly. When an organization holds people with knowledge and experience of the typical shortages of OEE and its common implementation challenges, the probability of achieving the intended benefits of OEE will certainly increase. Based on using OEE as an improvement driver at the case study company, some success factors have been identified:

- A standard definition of OEE must be clearly defined and communicated at all levels within the organization since this is the foundation for its utilization. It is especially important to determine how the ideal cycle time and planned and unplanned downtime should be interpreted.
- Involving the operators in the process of defining production loss causes and configuring the templates and lists to be used for monitoring promotes operator commitment, understanding of the procedure and awareness of the frequency of sporadic and chronic disturbances.
- Driving the OEE implementation as a project with a predefined organization, a structured working procedure promoting cross-functional and shop floor involvement, and practical guidance on what activities to execute and in what order, implies resource allocation that forces management attention and puts OEE on the agenda.
- Viewing and communicating OEE as a driver for improvements rather than a management measure for follow-up and control of performance (although this is also the case) is one of the cornerstones for a successful OEE implementation.
- Active involvement of the support functions, especially production engineering and maintenance, is required, otherwise the level of improvements to increase OEE will not be enough and the speed of change will consequently be too low.
- Separating improvement actions into those directly having an impact on process stability, i.e. OEE, from those with indirect impact is necessary especially in the initial implementation phase to show quick results.
- Including reporting OEE and prioritized daily actions in the routines of daily follow-up meetings (from team level to department/site level) is an excellent way to integrate OEE as a driver for improvements in the operations management system.
- Results should be communicated, e.g. by graphical visualization of the OEE improvements on the boards. Visualizing OEE and process output together are illustrative and motivating.
- Including production performance in the company's overall production strategy and managing this with a continuous follow up of OEE as a KPI on different consolidation levels is the optimal driver for efficient management. When top management attention is continuously given to the process of achieving stable production processes the possibilities of reaching good results certainly increases.

13. Conclusion

There are many challenges associated with the implementation of OEE for monitoring and managing production performance, for example:

- how it is defined, interpreted and compared
- how the OEE data are collected and analyzed

- how it is monitored and by whom
- how it aligns with the overall production strategy
- how it could be utilized for sustainability purpose.

Moreover it is remarkable that setting high OEE goals in an environment with excessive capacity is of less value since it is not possible to utilize the equipment full time. OEE measure is less suitable as a target KPI, since OEE only measures the efficiency during the time the equipment is planned to be operating, while equipment and personnel drives manufacturing costs both when they are in operation and during downtime.

The purpose of measuring OEE can be questioned in the light of the financial crisis. There are some authors that have reported the need of further research work on linking OEE with financial measures. Dal et al. [31] asserts “there would appear to be a useful line of research in exploring the link between OEE and the popular business models such as balanced scorecard”. Muchiri et al. [16] suggests “Further research should explore the dynamics of translating equipment effectiveness or loss of effectiveness in terms of cost.” The authors agree with these statements, there is clearly a missing link between OEE and manufacturing cost. Jonsson et al. [39] presents a manufacturing cost model linking production performance with economic parameters. The utilization of this manufacturing cost model in developing industrially applicable productivity KPI’s will be elaborated on in future research.

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