Combining Overall equipment Efficiency (OEE) and productivity measures as drivers for production improvements

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Combining Overall Equipment Efficiency (OEE) and Productivity Measures as Drivers for Production Improvements

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ABSTRACT

To compete on a globalized market companies need to constantly improve the performance in their manufacturing systems. Production performance measures can be used for different purposes, by practitioners they are commonly used for follow-up and reporting purposes. Two of the most commonly used performance measures are Overall Equipment Efficiency (OEE) and productivity. Between these two productivity exhibits the far most variety in definition. Even if OEE and productivity are strongly affected by improvement work, they are seldom used to drive the improvement efforts. The purpose of this paper is to present definitions of productivity suitable as improvement drivers, and to discuss the need for a combined set of performance measures to drive productivity improvements. Finally some experiences from industrial improvement work are viewed.

Keywords: Performance measures, operations, OEE, productivity, Improvement drivers

1. INTRODUCTION

The economic wealth and growth of a nation is dependent on the prosperity of the industrial sector. However, an increased globalization implies growing challenges regarding competition for every manufacturing company. Common global issues as the present environmental situation will put pressure on the manufacturing industry to constantly reduce the use of energy and other natural resources. To be able to maintain and develop the ability to compete on a global market, manufacturing companies need to be successful in developing innovative and high-quality products with short lead-times, as well as designing robust and flexible production systems implying the best preconditions for operational excellence [1]. The concept of Lean Production is implemented worldwide in order to cope with many of these challenges. The Lean concept could be considered the best way known today of how to create opportunities for developing resource efficient manufacturing systems. With the increasing focus on economic, environmental and social sustainability [2], more dimensions are added to the complexity of designing and operating a production system in a resource-efficient way. Lean and green manufacturing is a terminology currently adopted by some researchers and companies describing both the goals and means related to resource efficiency within manufacturing [3].

Due to the overall challenges, manufacturing companies continuously need to improve the performance of their production systems. Manufacturing output in terms of quality, cost, speed, dependability and flexibility, defined as performance objectives by Slack & Lewis [4] should reflect the dynamic market requirements. Consequently, the production system needs to be both designed and operated in such a manner that the determined performance objectives are fulfilled. On a level above that, the production strategy should concern the long-term decisions of how to develop the capability of the production system and resources in alignment with the corporate and business strategy.

A well-known and widely spread concept of improving the production performance is Total Productive Maintenance (TPM) founded by Nakajima [5]. As stated by Ahuja et al. [6] *"TPM is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets through the use of employee involvement, linking manufacturing, maintenance and engineering."* As defined by Nakajima, Overall Equipment Effectiveness (OEE) is an important part of the TPM concept [5]. OEE is traditionally used as an operational measure, but can also be used as an indicator of process improvement activities within a production context.

Productivity is another operational measure of general importance to production. Productivity shows an output-input relation of the targeted production process while OEE combines performance, availability and quality level of the targeted process. Productivity is often linked to the OEE measure in literature and by practitioners. In fact, OEE could be considered as a subset of productivity since OEE improvements also improves the productivity level. Like the OEE measure, a productivity measure could also be used to drive production improvements.

In this paper we intend to show the potential of using OEE and productivity measures in combination as fundamental drivers for improvements on process level within manufacturing industry.

2. RESEARCH DESIGN

There are a number of challenges regarding definition, introduction, and utilization of OEE and productivity as performance measures. These measures could be used for the purpose of monitoring, follow-up and control of performance within production. Even more challenges could be found when using the measures as improvement drivers. Many of the challenges are of change management nature, such as what approach to use, how to structure the working procedure, and awareness, training and involvement of management, team leaders and operators in production. The measures are relevant on shop-floor level but could also be consolidated to higher system levels like site level. However, the consolidation can sometimes be difficult, and needs to be analysed carefully.

In order to fulfil the objective of showing how the combination of OEE and productivity measures could be used for production improvement purpose and what issues that are involved with this approach, two basic research questions are formulated:

- *RQ1:* How does the OEE measure capture productivity changes, and in case of shortages – what productivity measures need to be added in order to achieve full control of productivity changes of a production process?
- *RQ2:* How could OEE and productivity measures be defined and used as drivers for improvements, and what are the criteria for successful industrial implementation?

The research methodology used is a theoretical review of current OEE and productivity definitions, assessment and frameworks, and a case study at a manufacturing company within the automotive industry developing and supplying products for the heavy vehicle business. The case study methodology as defined by Yin [8] was found relevant for the purpose of studying this broad phenomenon of utilizing OEE and productivity within an industrial context. The data collection was based on multiple sources of evidence such as shop floor observations, studies of documentation, participation in workshops and cross-functional working meetings.

The case study implied active involvement and participation in a 2.5 year long development and implementation process of measures, structured working procedures and tools performed as a project at the case study company. The project was initiated as a pilot at a semi-automatic assembly line, but further replicated within assembly and machining at the company. Due to the authors' participation in the pilot, the research approach could be considered being of action research character. The active involvement implied an excellent opportunity to follow the upcoming issues as well as improvements related to the utilization of the developed measures and methods.

3. LIST OF SYMBOLS

A	Availability	%
C_P	Production Part Cost	currency/unit
C_U	Total utilization cost	currency
E_S	Effectiveness	
E_Y	Efficiency	
I_{mr}	Manufacturing resources	currency/unit
N_{DP}	No. of delivered parts from a manufacturing process	unit
N_{RFT}	No. of products manufactured right first time	unit
O_A	Actual output	number
O_E	Expected output	number
P	Performance	%
P_i	Definitions of Productivity	--
P_P	Production Pace	time/unit
Q	Quality	%
R_{EC}	Expected resource consumption	number
R_{AC}	Actual resource consumption	number
t_{IA}	Ideal assembly time	Time
t_{VA}	Value-adding time	time
t_{WT}	Total work time	time
T_{plan}	Planned production time	time
V_a	Value added	currency/unit

4. FRAME OF REFERENCE

A performance measurement system comprising financial and operations measures as developed and used by a manufacturing company, should be related to the manufacturing strategy, include non-financial measures, vary between locations, change over time, be simple and easy, give fast feedback and aim to teach rather than to monitor as stated by Maskell [8]. Slack et al. [4] identify speed, quality, cost, flexibility and delivery as five general performance objectives. White (1996) presents lists containing more than a 100 different performance measures divided in five categories. One purpose of applying performance measures is to set targets for improvement activities in alignment with the company strategic goals and objectives. In this section definitions and implementation aspects of OEE and productivity are presented. These measures are most commonly analysed by researchers and used by practitioners. However, there is still potential for further development for full industrial utilization of the measures..

3.1 OEE – definition and implementations

The original definition of OEE developed by Nakajima [5] comprises the six big losses divided into the three categories of Availability, Performance and Quality, see Figure 1. OEE is abbreviation for Overall Equipment *Effectiveness* [10],[11],[12] rather than Overall Equipment *Efficiency*. Generally, effectiveness describes the external efficiency, i.e. doing the right things, while efficiency refers to internal efficiency, or doing things right.

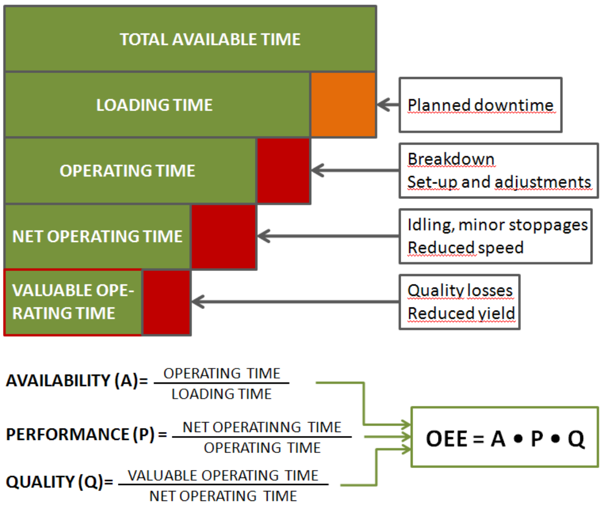

Figure 1: Definition and computation of OEE (own processing based on [5]).

The OEE measure is commonly used for production performance monitoring as part of a company's performance measurement system. The OEE measure could be used both for internal benchmark quantifying improvements made, for internal comparison of performance, and for identifying worst machine for TPM focus Dal et al. [10]. The main application area of OEE is automatic and semi-automatic processes mainly due to the cycle time parameter [13]. Another application aspect stated by Garca-Reyes et al. [14] is that OEE is normally used in high volume processes where capacity utilization is a high priority and disruptions are expensive implying high capacity lost. The compound effect of availability, performance and quality provides surprising results of the OEE calculation, as visualized by e.g. Louglin [15], see figure 2. World class level of OEE is in the range of 85 % to 92 % for non-process industry Bicheno [16]. A real challenge within industry is to achieve a stable and robust performance level as indicated by a stable OEE.

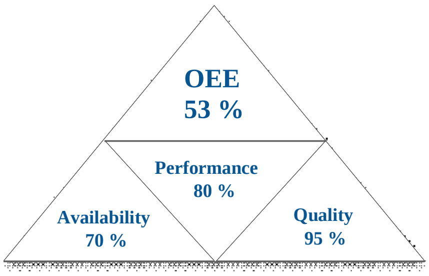

Figure 2: The OEE micro pyramid [15]

Although OEE is a very good performance measure die to its triple factor combination, it has some shortages. The definition of OEE anticipates that there is a fixed (at least in the short term) ideal cycle time of each machine that controls the maximum processing rate, i.e. capacity, and it does not consider the number of people working in the process [17]. From a productivity perspective this means that the possibility to improve productivity by reducing the cycle time or the resources (input) is not fully covered in the OEE measure. Rather, the OEE takes a more reactive approach by reducing or eliminating disturbances and deviations as a way to improve the capacity. The productivity on the other hand could be used in a proactive way by considering cycle time reductions as well as reduction of resources put into the process. The conclusion is, therefore, that OEE does not fully capture productivity improvements. Hence, the OEE measure needs to be combined with complementary measures if a complete picture of the productivity is to be achieved.

3.2 *Productivity related definitions*

Despite the fact that productivity is an extremely common measure, it is rarely well defined or explained. The high industrial implementation rate has lead to many examples of productivity definitions, basically all are emanating from the same general productivity definition by Sumanth [18]:

$$\mathrm{Pr}oductivity = \frac{Output}{Input} \quad (1)$$

The productivity measures can according to Sumanth be divided in three different categories depending on what is included in the measure:

- Partial productivity measures – the output is related to one source of input
- Total factor productivity measures – total output minus purchased services and goods in relation to associated labor and capital input
- Total productivity measures – the output is related to all sources of input.

A variety of partial and total productivity measures is used in industry. The benefit of a partial productivity measure is the simplicity, since finding one input and one output is usually trivial. The drawback is that the impact from only one parameter is viewed, which might lead to false indication about the overall productivity [19], [13]. A manufacturing process usually needs more than one input parameter to operate. It is also common for a manufacturing process to deliver multiple outputs.

To provide an overall picture of the process productivity, measures that integrate a multiple set of input and output is required. Drawbacks of using all-encompassing productivity measures in practice are i.e. the effort of collecting adequate data and the fact that every parameter might not have the same unit. This is probably the reason why companies usually focus on partial productivity measures with labor as an input parameter. Thus the risk of using a partial productivity measures is that the improvement efforts will only considers one parameter. With the use of labor productivity measures, the only feasible improvement activity is to maintain the production with a reduced workforce or increase the production with a maintained workforce capacity. Using this types of productivity leads to limited improvement opportunities, and does not promote the use of all features in a production system to be competitive.

The following definition proposed by Aspén et al. [20] (from [13]) can be used as both a partial or total measure, dependent on the interpretation of the parameters included in the definition:

$$P = \frac{V_a}{I_{mr}} 100 \quad (\%) \tag{2}$$

V_a = value added (unit = currency) and I_{mr} = input of manufacturing resources (unit = currency). The definition in equation 2 involves monetary parameter, while Sink & Tuttle [20] proposes a productivity definition involving efficiency E_Y and effectiveness E_S:

$$P = E_S \cdot E_Y \tag{3}$$

As discussed, there are different opinions on the meaning of the terms efficiency and effectiveness. Hill [21] states that efficiency means doing things right and effectiveness means doing the right things. Doing things right refers to the internal manufacturing system and its performance while doing the right things means doing what the customer wants to buy (external). This differs from the definition in equation 3 and 4 where [21] means that efficiency is related to an input to a process and effectiveness is related to its output.

With the definitions of efficiency and effectiveness by Sink & Tuttle equation 3 can be expressed as:

$$P = \frac{O_A}{O_E} \cdot \frac{R_{EC}}{R_{AC}} \tag{4}$$

See the list of symbols for parameter explanation. Peterson elaborates further on the definition in Eq. 4 and defines productivity for manual assembly as:

$$P = E_S \cdot E_Y = \frac{t_{VA}}{t_{IA}} \cdot \frac{t_{IA}}{t_{WT}} = \frac{t_{VA}}{t_{WT}} \cdot 100 \quad (\%) \tag{5}$$

The various definitions of productivity is both presented mathematically (as the examples in Eq. 1 – 4) and verbally. Examples of verbal productivity definitions are:

- Productivity is defined as the ratio of what is produced to what is required to produce it. Productivity measures the relationship between output such as goods and services produced, and inputs that include labor, capital, material and other resources [22].
- Productivity is a comparison of the physical inputs to a factory with the physical output from a factory [23].
- Productivity means how much and how well we produce from the resources used. If we produce more or better goods from the same resources, we increase productivity. Or if we produce the same goods from lesser resources, we also increase productivity. By Resources we mean all physical and human resources i.e. the people who produce the goods or provide the services, and the assets with which the people can produce or provide the services [24].

The present confusion regarding performance measurement can be illustrated by i.e. the different opinions by Grünberg [24] and White [9]. Grünberg notes that performance measures sometimes turn out to resemble productivity measures, sometimes making it difficult to identify weather a measure is a performance measure or productivity measure. This is in contradiction to White [9] who includes several productivity measures his array of performance measures.

All of the mathematical and verbal definitions listed above (and most of the definitions left out in the list) are based on the general definition by Sumanth [18], and they do not provide definitions clear enough to be used as improvement drivers. Even if the input parameter primarily consists of a multiple set of factors there is no agreement on what individual factors that should be included and on what level in the operation the definition is valid or suitable to use.

3.3 The use of Productivity as improvement driver

There are numerous researchers discussing performance measurement. However, proposals of how to implement them in the industrial context as improvement drivers are rarer to be found. The most common use of productivity by practitioners is for monitoring of process performance at different levels of aggregation in an organization. .

Cosmetanos & Eilon [26] presents a theoretical analysis of how a partial productivity definition based on labor as the input variable can lead to widely divergent results, but their study does not present any implementation results.

Grünberg [25] presents a seven step method to support performance improvement in industrial operations. The seven steps building up the method are; Planning, Pre-study, Process mapping, Process measurement, Analyze and Evaluation. The suggested factors influencing the performance listed for measurement in the Performance measurement step are lead-time, queue-time, tact-time, capacity, downtime, staffing, scrap, rework, reset-time, inventory, process inflow and outflow. Actually neither OEE nor productivity is found in the list of performance measures to be concerned. Even if the method provides a structured procedure of working with improvements, there is a lack of definitions of KPI´s to be used as improvement drivers. The purpose of the evaluation step is to track change and document the lessons learnt. To track change is not enough to evaluate the success of an implemented improvement. An evaluation of expected or set goal and an alternative plan if the goals are not reached should be included in an evaluations step.

Even if productivity represents one of the most important basic variable governing economic production activities [27], measurement and improvement regimes are often built without clear understanding of what is being measured and improved. This can be regarded as simply a pragmatic approach to improvement, or missed opportunities to fully understand – and then optimize – important factors relating to competitiveness and success [28].

This paper aims to clarify the definition of productivity and discuss the benefits of using productivity combined with OEE as improvement drivers.

5. DEFINITION OF PRODUCTIVITY AT SHOP FLOR LEVEL

Using productivity as an improvement driver requires a productivity definition including a set of parameters that could contribute to an overall productivity improvement.

The general definition of productivity is found in Equation 1. The use of productivity as an improvement driver requires a clear and comprehensive definition encompassing the necessary parameters to work with overall productivity improvement. The majority of existing productivity measures is based on labor as the input parameter, a too narrow definition to provide any real improvement opportunities. A broader definition of input is necessary to secure that hidden opportunities do not receive any attention.

4.1 Production Pace

One of the most important performance measures is speed [9],[4] since production speed determines the amount of products, i.e. capacity that the production system “delivers” per time unit. Examples of factors related to the speed found in the literature are lead time and delivery. When focusing on production processes more specific time parameters could be found like throughput time, set-up time, operation time etc. The ideal speed in a production system, for example in a machining cell or an assembly line, is determined by the ideal cycle time in the bottleneck process. This ideal speed is often reduced due to various reasons. Nakajima [5] was the first to describe how these disturbances affect the equipment performance, see figure 1. The real production speed is thus influenced by both the ideal cycle time and the performance of the equipment. To capture these in a productivity measure the following productivity measure called *Production Pace* was developed within the introduced project within the case study company:

$$P_p = \frac{N_{RFT}}{T_{plan}} \qquad (6)$$

The output parameter N_{RFT} is defined as the number of products that are produced right the first time. Since this productivity definition is intended to measure the efficiency of the processing units, it should not encompass products that does not meet the quality criteria and hence cannot be directly delivered to the customer. Products that are scrapped or reworked should therefore not be included in the N_{RFT} parameter.

The input parameter in equation 5 is defined as planned production time T_{plan}. The purpose of Production pace (P_P) is to serve as a productivity measure that can be used for improvements of the production processes rather than measuring to what extent the production capacity is utilized. This is the reason why planned production time is chosen as the input parameter instead of total available time. Both N_{RFT} and T_{plan} are parameters that are often monitored in a production system. The number of parts produced right first time is the total number of products minus the number of scrapped and/or reworked products during a chosen time interval of for a chosen batch.

There is a problem to create an atmosphere of “sense of urgency” if there is excessive capacity in the production system. It is a great management challenge to focus on productivity improvement during times when production volumes are going down due to less customer orders. The choice of planned production time instead of total available time, facilitated the chosen improvement approach of the project. Although the total manufacturing capacity was considered as being an important parameter to balance against customer tact, the objective to drive improvement activities on the assembly line required setting another input parameter then total available time that was possible to affect on process level. Planned production time at the process was, therefore, the choice.

In general sense, a performance measure should be easy to understand, and the parameters needed to calculate is should be easy to collect. Jonsson and Lesshammar [11] state that too many or too complex measures might lead to a reactive system controlling and checking the past, eventually ending up being even ignored or discharged. The opposite was to be created in the project described, where the purpose was improvements rather than control. One of the principles guiding the development work was that using a measure just for collecting data is nothing but pure waste.

4.2 Production Part Cost

Another general and important performance measure is cost, one out of the five productivity objectives presented by e.g. Slack [4]. When developing a cost measure with the potential of being a useful improvement driver it was obvious to the project team that it needed to be both clear and comprehensive and comprise a limited set of parameters that could capture a complete productivity change. Since the improvement activities was focused on the production process, the parameters needed to be measurable within any generic production process, either in assembly or machining.

The productivity measure called *Production Part Cost* is relating process input, i.e. the costs associated with keeping the processes running, to process output. The definition is based on the manufacturing part cost model presented by Jönsson et al. [29]:

$$C_P = \frac{C_U}{N_{DP}} \quad (7)$$

The output was defined as the parts delivered from the process, N_{DP}, i.e. the sum of approved parts and reworked parts.

The utilization cost C_U comprises all the costs associated with keeping the equipment in operation and was further defined as “the sum of all costs that have a direct impact on resources needed to utilize the equipment. If any of these resources are removed the manufacturing unit looses the ability to produce parts.” Nine different cost parameters influencing the total utilization cost was identified:

- Operator cost, C_{OP} – determined by the number of operators and their wage cost.
- Material supply cost, C_{MS} – determined by the number of material suppliers, their wage cost and the cost of necessary material supply equipment
- Maintenance cost, C_{MT} - determined by time spent on maintenance, the number of maintenance operators, their wage cost
- Rework cost, C_{RW} - determined by time spent on rework, the number of rework operators, their wage cost and the cost of exchanged parts
- Scrap cost, C_S - determined by the number of scrapped part and the raw material cost
- Material cost, C_M - determined by the number of approved parts and the raw material cost
- Equipment and operating cost, C_{EO} - determined by utilized time, yearly equipment cost and total available time.
- Tool cost, C_T – tool cost, renovation cost, renovation interval and change interval.
- Other cost C_O – costs not explicitly related to one of the previous cost items

The definition in Eq. 8 could hence be expanded into the following definition:

$$C_P = \frac{C_{OP} + C_{MS} + C_{MT} + C_{RW} + C_S + C_M + C_{EO} + C_T + C_E}{N_{DP}} \quad (8)$$

The definition of cost must include each of the presented cost items, since there might be interdependencies between two or more of them. A change of work-piece material to a cheaper one might cause an increased tool wear and/or increased speed losses. An increase in material handling support leads to increased cost for material supply, and might lead to substantial decreases in speed loss. The elimination of grease leads to a dramatic decrease in the use of paper and protective gloves, i.e. other costs. These are all examples of interdependencies between the different input parameters. Equation 8 contains the necessary amount of parameters to encompass different aspects of productivity improvement in any production process.

6. A COMBINED SET OF PERFORMANCE MEASURES

To emphasize the operations performance in a production system, the improvement efforts can be divided into two different focuses. The first action is to improve the stability in the production processes. A concept called *Process stability* was developed with the purpose to decrease or eliminate disturbances or deviations in the production process. Since the general purpose of OEE is to achieve high equipment utilization and high quality rates, the OEE is an excellent driver for stability improvements, if implemented in a clear and structured way. Even if the objective to achieve process stability does not have a direct productivity improvement focus, an indirect result will be that the productivity increases if the improvements are made without any input of new resources.

After gaining a high and stable OEE measure, the next target is to improve productivity by changing the equipment constrains, operator setup or any other factor affecting both process input and output. The improvement focus should again be on the production process..

Many researchers refer to OEE as a productivity measure OEE. Even if it is true that OEE and productivity are closely linked together, the OEE measure cannot be categorized as a true productivity measure, since it doesn´t fit into the general definition of productivity as being the result of output divided by input. There are also reasons why OEE alone cannot be used as a productivity improvement driver. As previously stated there are different views among researchers considering the definition of the term productivity. According to theory increased productivity can be achieved by:

- Producing more with the same amount of input, or
- Producing the same amount of output with less resources, or
- Producing more with less resources

If a company has implemented successful stability improvements as visualized by a stable OEE, but is in the need of increased capacity in the existing equipment, it is necessary to consider whether the improvement focus should be shifted from improving OEE - by means of increasing the performance, availability or quality parameters - to a decrease in ideal cycle time of the bottleneck instead. It means that a traditional lean approach could be used trying to identify when it would add more value (i.e. increased capacity) to reduce cycle time instead, i.e. to shift from OEE as an improvement driver to the productivity driver. The following industrial example illustrates why OEE does not work as an improvement driver in a particular situation like this.

A semi-automatic assembly line containing a total of 14 assembly steps out of which 4 are manually operated is shown in figure 3.

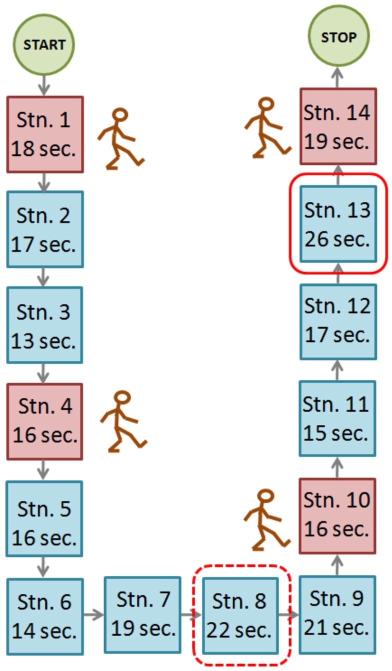

Figure 3: Example of a semi-automatic assembly line.

The bottleneck process is one of the automatic assembly stations, ideal cycle time is 26 sec. The line balancing is fairly good, and the second-highest ideal cycle time is 22 sec in one of the automatic stations. The bottleneck process is a test of certain functions in the product. By changing the test scheme and introducing new equipment that will operate faster the existing one, the ideal cycle time in the bottleneck process is reduced with 5 sec. The improvement activity has increased the theoretical output from 138 units/hour to 164 units/hour (with the ideal cycle time of 22 sec. for the new bottleneck process).

Before the improvement the OEE was 86%, where the main losses were caused by station number 7, just before the new bottleneck. The real output for an OEE of 86% is 118 units/hour. After the improvement in station no. 7 continues to exhibit downtime. Since the ideal cycle time is reduced, the existing downtime is causing the OEE to drop to 79% after the improvement. However, the real output with OEE = 79% and the ideal cycle time 22 sec is 130 units/hour.

The example is very illustrative – at a certain point it is more value-adding activities to reduce cycle time since it increases the output, here defined as production pace, although it reduces the OEE at the same time. The OEE as a measure is consequently just a step towards improving the productivity.

The conclusion of the results is that the improvement activity has lead to both a decrease in OEE and an increase in productivity. This is the reason why the OEE measure is not sufficient as a productivity improvement driver. OEE is an excellent stability improvement driver if implemented in a structured way. Therefore the combination of OEE and the productivity measure P_P provides a set of production performance measures suitable for implementation as stability and productivity drivers on factory floor level. Figure 2 illustrates the development of these two parameters for the industrial example described above.

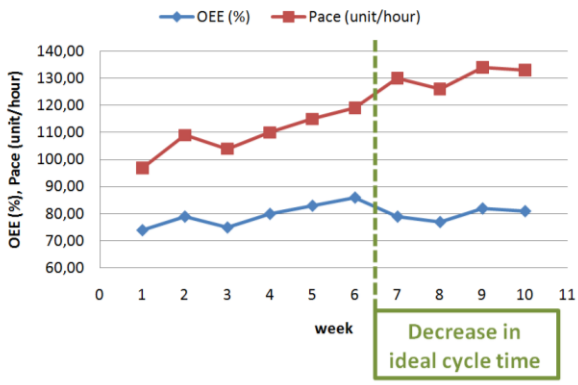

Figure 2: The weekly change in OEE and production pace during an improvement activity.

To alter the equipment constrains in the example presented above, an investment in new equipment was required. This imposes an increase in input. Since neither OEE nor production pace consists of any cost related parameters, there is a need for a productivity definition encompassing changes in input from a cost perspective. This is the reason for the development of Production Part Cost as the second productivity measurement driving production performance improvements. This KPI enables an analysis of the combined result of multiple input changes. Production Part Post also provides opportunities to analyze the productivity effects of different types of improvement suggestions.

The conclusion of the example above is that a set of performance measures are needed in order to capture the total effect of different activities like cycle time reduction and investments.

7. OEE AND PRODUCTIVITY AS IMPROVEMENT DRIVERS

There are both potentials and challenges associated with using OEE and productivity as improvement drivers. One issue is clearly how to define the measures. For OEE, the definition could be considered to be globally standardized, however, the interpretation of the factors of the standard definition is a common reason for variations between companies. The empirical findings show that e.g. the interpretation varies of what is calculated as planned/unplanned time, and what the ideal cycle time is set to. In order to compare between sites, the calculations must be made in a standardized way. However, a structured and correct implementation of OEE is a good driver for improvements in order to achieve process stability as further discussed in Andersson & Bellgran [30].

The existing productivity definition varies considerably between companies and system level – there is in fact no standard definition on detailed level in the same way as for OEE. Measuring relative productivity changes within a company rather than comparing companies is a way to handle the lack of standard definitions. On the other hand, the annual productivity change of a manufacturing company is very important both to monitor and to compare. Productivity indicates the profitability potential given the fact that most customers are forcing annual prize reductions.

To emphasize the operations performance in production at the case study company, process stability and productivity improvements were considered one at the time. The general approach was to start with the concept of improving process stability with OEE as a driver. When fairly good process stability had been achieved in the production process, as indicated by a stable OEE over time, the next step considered was to improve productivity by use of a set of performance measures as improvement drivers. For this purpose, standard definitions for the two productivity measures presented above were developed within the project.

Another challenge when using OEE and productivity as improvement drivers is how to actually implement both the measures in a working procedure to enhance improvements at shop-floor level. To meet these challenges a concept of integrating the selected performance measures in a five step method supporting the practical improvement work. Some conclusions from the empirical findings from case studies implementing the five step methodology are the following:

- Extensive training concerning the standard definitions of the measures used, must be performed from shop-floor to management level.
- The operators are key the persons for logging necessary information about the disturbances and their causes in order to calculate OEE and for making improvements together with a cross-functional supportive team.
- When using KPI´s as drivers, it´s of great importance to base the calculations on correct input data. This requires support from software, templates or calculation sheets, and a structured approach towards identifying the potential causes of disturbance in the production processes.
- When using productivity as an improvement driver, the key persons are mainly production engineers and to some extent maintenance technicians. This is because the focus is on actions like reducing the cycle time which is often made through e.g. line balancing and new production technology.
- The approach of starting with OEE and continuing with productivity supports the need for an organization to grow in awareness and knowledge of how to work with improvements.
- Measuring KPI's without adding a structured approach for making improvements implies high risks of making ad hoc decisions and activities leading to a sustainable kaizen culture on shop-floor level.

The effort spent on the development and implementation of OEE and the productivity measures and working procedures is paid off many times as illustrated by increased production capacity and reduced production costs for producing the products at the case study company. This is essential for all industry, but especially for companies producing mature products.

Performance Measure	***Definition***	***Implementation***	***Limitation & Drawbacks***
OEE	$A \cdot P \cdot Q \ (\%)$	Performance monitoring Stability improvement driver	Does not capture improve-ments in ideal cycle time
Production Pace	$P_p = \frac{N_{RFT}}{T_{plan}} \left(\frac{unit}{time}\right)$	Performance monitoring Productivity improvement driver	Does not visualize equipment performance as Availability, Performance and Quality
Production Part Cost	$C_P = \frac{C_U}{N_{DP}} \left(\frac{currency}{unit}\right)$	Prioritizing among improvement suggestion Productivity improvement driver	Require a multiple set of input parameters. Does not capture equipment efficiency

Table 1: Suggested implementations, limitations and drawbacks for each performance measure

8. DISCUSSION AND CONCLUSION

The experience from working together with practitioners during both stability improvements and productivity improvements within the case study company, has indicated some success factors of generic interest.

The most important factor is to select a set of suitable KPI`s to drive the improvements. The KPI´s suggested in this study are presented in Table 1. Using KPI´s in an improvement project requires that goals are set and communicated to the employees involved. The goals should reasonable and possible to achieve, and can therefore be divided into gradual steps in order to motivate the staff instead of creating frustration. The KPI should be monitored before, during and after the improvement project. The values registered before the start of the project should be used as reference value for the setting of project goals. The values should further be monitored during and after the improvement activities in order to monitor progress and determine when the goals have been reached. During the improvement project the cost related KPI (Production part cost) could be used for prioritization between different suggested solutions. The presented set of KPI´s is used during phase two of the project where productivity improvements are in focus. The project start with measuring OEE, adding maybe also production pace to capture capacity improvements.

When using KPI´s as improvement driver (and for process monitoring) it is very important to base the calculations on reliable performance data retrieved from the production processes. This requires an implemented data collection procedure supported by user friendly templates or an automatic data collection and OEE calculation software.

Another success factor concerns resource allocation and management attention. The improvement work should preferably be organized in a structured work procedure involving a multidisciplinary project team, including e.g. operator, production engineers, and maintenance operators and operations management. The project should involve scheduled meetings and reviews of progression during a project limited in time. Some of the standard improvement methods (Lean-based projects and Six Sigma projects) does not usually have time as a restrictive parameter, therefore these projects sometimes tends to drag on. A structured and well defined methodology supported by tool templates and definitions creates speed in the improvement work.

The answer to RQ1 is hence that the OEE measure does not capture every change in productivity. The OEE measure cannot be used as the single driver of productivity improvements. For this purpose OEE has to be complemented by measures that capture changes in equipment constrains and e.g. equipment investments, to achieve full control over productivity changes.

The two productivity measures called Production Pace and production Part Cost partly provide answers to RQ2. A successful industrial implementation is facilitated by selecting suitable KPI´s to drive the improvement work, using reliable data collection methods, following a structured working procedure, receiving extensive management attention and appointing a cross functional project team that is extensively engaged for a targeted time period. The result is a potential for industrial growth due to release of latent production capacity within the manufacturing company, and increased potential for profitability due to cost reductions.

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