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GOOD SOLUTIONS

Analysis of Overall Equipment Effectiveness (OEE) within different sectors in different Swedish industries.

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Product and process development
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ABSTRACT

In this thesis, concepts about overall equipment effectiveness (OEE), through total productive maintenance (TPM) practices across the Swedish industries are discussed. The work has been carried out during the whole spring and autumn of 2014 at Good Solutions AB, Gothenburg, in Sweden and at Mälardalen University campus. At Good solutions AB, data was obtained through their OEE tool called RS-Production and used to report results based on various Swedish industries.

A theoretical framework is developed to determine the influence of OEE on Swedish industries, since it measures the effect of performance and quality related losses in a system or equipment. It is then followed by a survey-based research on a sample of Swedish industries grouped into four categories (food and beverages, mechanical workshop, polymeric and other automated discrete production industries), as well as analysing the outcome of this survey using EXCEL.

The aim of the thesis is to identify related OEE (Overall Equipment Effectiveness) losses and possible improvements in accordance with theoretical framework. It is noticed that planning factor related and availability related losses were the highest in all of the four categories. Eliminating unplanned events requires getting its root cause while reducing planned (setups and changeovers) events need a strategy known as SMED (Single Minute Exchange of Dies) for shifting internal events to external events. It has also shown OEE values can significantly improve if all the planned related factors are eliminated especially during production time.

A common weakness of the system was that unplanned losses were grouped into equipment breakdown and unplanned production. Considering the fact that some significant percentage losses were recorded, splitting them into two separate losses could help identify, analyse and provide potential solutions.

Other losses are stated as “no reason code” due to the fact that operators did not provide any information or no data input is recorded. This requires educating, training, and awareness of the whole staff and not only the operators operating the machines. As such, it creates a sense of total responsibility and commitment within the entire industry. A simple and powerful tool called “5 whys” technique or complex fishbone diagram are used for shading light on the root of this problem once and for all.

Keywords: Overall equipment effectiveness, Single minute exchange of dies, 5 whys, Cause-Effect diagram.

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1. INTRODUCTION

This chapter leads to an introduction phase of the thesis. It covers a background description, problem formulation, project limitations, presentation of company as well as its aim and research questions.

For the past decades especially after the last global economic recession, manufacturing industries resist from being kicked out of the market by remaining competitive. For this to happen, this creates a desire to improve on eliminating production wastes while optimizing its productivity. Manufacturing companies avoid putting pressure on customers by increasing prices and instead by instead focus on minimizing manufacturing cost of products by the elimination of losses during production.

$$TP = Pq - TC$$

Where;

TP ; Stands for Total Profit.

P ; Price of product.

q ; Quantity of product.

Pq ; Revenue.

TC ; Total cost for product.

From an economic point of view, total profit can be increased by either reducing the total cost or increasing the price of a product. It is relevant to focus on reducing the total cost rather than increasing the price which might lead of customer lost.

Total Productive Maintenance (TPM) aims at increasing equipments' productivity with reduction in maintenance investment. Total Productive Maintenance (TPM) helps in identifying six preventable losses that will be explained further in this thesis. Ahlman (1993) has shown that the overall utilization of installed capacity is closed to 60 percent within a number of Swedish industries but according to Nakajima (1989), it is likely possible to increase this level of overall utilization from 60 to 90 percent by the implementation of total productive maintenance (TPM). Ljungberg (1998) presented a better approach but only focused on three major concepts of TPM instead of the latest TPM model with nine equipment losses.

This thesis focuses on how to improve productivity within a number of Swedish manufacturing companies using the application of Total Productive Maintenance (TPM). It will group Swedish manufacturing industries into four namely; metal, plastic, other automated discrete production and food.

1.1. Background

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

In today's competitive market, efficiency and effectiveness need to be enforced in order to be more productive in any industrial sector. Success at this point is having an increase in total sales leading to more profit. A request over inefficiencies, unidentified losses during any production environment must be detected and eradicated. Empirical study carried out on industries needed a change in their performance measurements or they ought to used the right measures and in a correct manner (Schmenner and Vollman, 1994). When dealing with these measures, the following questions need to be raised:

1. What to measure and
2. How to measure

Manufacturing industries can only stay in a competitive market if their production facilities are available and productive (Fleischer *et al.,* 2006). For this to happen, improving and optimizing their productivity is the basic necessity and therefore must be considered searching for unnecessary production losses as well as eliminating them. This helps reduce cost of manufacturing products, remaining competitive and meeting customer demand (Huang *et al,.* 2003).

In the 1980s, the total productive maintenance (TPM) philosophy, launched by Nakajima (1988), lead to a metric called overall equipment effectiveness (OEE). Overall equipment effectiveness is a measurement tool used in identifying and measuring productivity machines in an industry. OEE is simply made up of three elements known as performance rate, availability rate and quality rate. It is a performance measurement tool which presents an updated status of any production with the least details in terms of calculations. It helps identify potential losses and how corrective actions could be used to reduce it. Such measurements could be done on machines, men, material leading to higher productivity. OEE provides a world-class status as;
1. It reduces equipment downtime and maintenance costs leading to a better management of equipment's life cycle.
2. It increases labour efficiencies while increasing productivity. There is an improvement in visibility into operations as operators are empowered.
3. Productivity is increased as bottlenecks are easily indentified.
4. It creates less rework of products, reduces scraps leading to an increase in the rate of quality.

It has been widely used since it supports and improves equipments' effectiveness and widens productivity in semiconductor-manufacturing activities (Huang *et al.* 2003). In a beverage industry in Nigeria, the implementation of OEE increased its value by 50% and helped in the reduction of losses while improving equipment uptime (Olayinka and Leramo, 2012). The implementation of overall equipment effectiveness as a primary production measure at Airbags International Ltd(AIL), highlighted a number of losses and enabled new levels of performance measurements (Dal *et al.,*2000).
The richness of OEE metric has nevertheless been deployed totally as revealed by academics since its application range in a real world remains void according to literature review.

1.2. Problem formulation

Swedish companies have the duty to improve in their products but efficiency of their outcome depends on identifying and elimination of non-value added activities. These activities basically called losses can simply be traced using OEE which shows performance and quality related losses either within a system or equipment.

In recent years, there has only been performed a few general analysis of Overall Equipment Effectiveness (OEE) within Swedish manufacturing companies (Almström & Kinnander , 2012; Hagberg & Henriksson, 2013). Kinnander *et al.* (2011), highlights the importance of increasing utilization of production equipment in electronic manufacturing industry but assumes its outcome could be valid in other high-cost countries. However, these have been limited in scope and only demonstrated as a mean of Overall Equipment Effectiveness and not on what the underlying losses of OEE are.
Performance analysis of Overall Equipment Effectiveness (OEE) could not show the differences made in different sector within difference types of Swedish companies, neither could it present what they have in common. It is therefore vital to identify the potential losses and where they affect the factors of OEE.

1.3. Aim and Research questions

This thesis is aimed at exploring the benefits of overall equipment effectiveness based on its theoretical concept. OEE literature is developed and reported within the context of performance measurement. It is then followed by analysing overall equipment effectiveness (OEE) measurements and the underlying losses from Swedish manufacturing industries to demonstrate the strength of OEE as a tool for all departments in an organization for prioritizing and monitoring improvements. These Swedish industries would be placed into four categories namely;

- Food and beverage
- Mechanical workshop
- Polymer (Rubber and plastics) and
- Other automated discrete production companies

As a framework that supports research, the following research questions are brought forward;

Question 1. Is there a normal OEE?

Basically, world class overall OEE is 85.0% with availability at 90%, performance at 95% and quality at 99, 9%.

Research question 2. What is the difference in OEE between different types of industry?

Research question 3. What is the best and worst parameter for OEE?

1.4. Project limitations

Data gathered is used in the Overall equipment effectiveness calculations. This study is limited since it does not provide an equal proportion of data being collected within the four types of industries stated. Some of the data were unable to be processed due to approval while some were incomplete.

The analysis presented in the thesis is based on data obtained within a period of six months (October 2013 to March 2014) creating lots of product variations, limitations of some machines during the analysis since it could influence the conclusion.

Last be not least, there is a challenge on how product designs complexity and operator skill can influence the OEE results.

2. RESEARCH APPROACH

This Chapter presents how the methodology of the project was planned and performed. Various research methods are described followed by the best method being chosen for this study. It also presents a clear view how data were collected through literature, observations, interviews and discussions. Research approaches are often classified into two main types namely quantitative and qualitative. These methods of research is a step-by-step plan of action giving direction to thoughts and efforts that would conduct a systematic research and on schedule to produce quality and detailed report. It has to do with staying focused, a reduction in frustration, a better quality while saving time and resources. Both methods would be carried out in this study.

Choosing an appropriate method for collecting data is another essential issue to be cleared out when initiating a research. Most scientific research could differentiate two data collection techniques into quantitative and qualitative (Bryman & Bell, 2007).

2.1. Quantitative method

Primarily, this method deals with numerical information being generated and emphasized. This method is a collection of limited variables known as group sample and from a representing sample, comparing with a few variables in the group of samples (Darmer & Freytag, 1995). It is more objective and presents a better understanding between research and theory. Aliaga and Gunderson (2000) define it as an "*Explaining phenomena by collecting numerical data that are analysed using mathematically based methods (in particular statistics)*".

A quantitative study based on overall equipment effectiveness (OEE) was chosen and well explained in details. This is also in relation to total production maintenance (TPM) concept designed by Seiichi using overall equipment effectiveness (OEE) as a quantitative metrics for measuring productivity of each manufacturing machine in a factory.

2.2. Qualitative method

Qualitative research according to Gummeson (2000) is focused on collection of more variable information from the individual and is usually connected with using of non-numerical data for deeper understanding of the characteristics of the research area.
This method is aimed at creating an understanding of underlying reasons and motivations. This gives a holistic view on how to approach potential problems or dealing with large numbers of variables within a group sample. Darmer & Freytag (1995) talk of a high degree of flexibility and adaptability to individuals while managing quantitative research and vice versa, or implemented in parallel. Qualitative data captures information that is not numerical in nature. These types of information can be placed in three major categories namely;

Table below shows a clear understanding between Quantitative and Qualitative methods

Qualitative Data Collection	Phases in the Process of Research	Quantitative Data Collection
• Purposeful sampling strategies. • Small number of participants.	Sampling	▪ Random sampling. ▪ Adequate size to reduce sampling error and provide sufficient power.
• From individuals providing access to site. • Institutional review boards. • Individuals.	Permissions	▪ From individuals providing access to sites. ▪ Institutional review boards. ▪ Individuals.
• Open-ended interviews. • Open-ended observations. • Documents. • Audiovisual materials.	Data sources	▪ Instruments. ▪ Checklists. ▪ Public documents.
• Interview protocols. • Observational protocols.	Recording the data	▪ Instruments with scores that are reliable and valid.
• Attending to field issues. • Attending to ethical issues.	Administering data collection.	▪ Standardization of procedures. ▪ Attending to ethical issues.

Table 1: ***Similarities between Qualitative and Quantitative Methods*** **(Creswell, et al., 2007)**

2.3. Case study design

This project was initially developed by Good Solutions. They could gather data through their software system called RSproduction. . In this report, **RSProduction** is a real time series production system that is put in place in data collection and automatic calculation of Overall Equipment Effectiveness. Installations of this system was quiet easy and simple to understand. Below is a holistic view of how the whole process is connected and carried out.

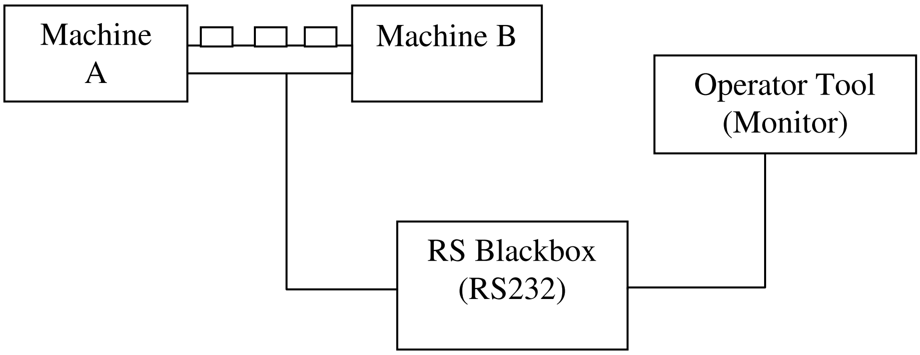


Figure 1: ***Installation layouts (RSProduction)***

Figure 2.2.1 shows how the system is connection and how data is collected. An RS black box (RS232) is connected between two machines. In most installations, the RS-Black Box collects a series of hardware events. Signals Machine is mainly used for the identification of operation/downtime and bill of quantity produced. Mechanical signals may also be used for other needs of the production monitoring.

· Cycle Signal
· Operating Signal
· Scrap Signal
· Signal Processing
· Automatic Coding Signal

The operators use the operator tool (monitor) to specifically specify reasons for any disturbances during production.
Data collected from the operator tool are then loaded to the internet via enternet (http) in different servers. Office tools are used in order to view, collect and evaluate these data. These data is then transferred to EXCEL for further calculations, analysis and for getting results.

Idea Generation: The overall ideas are to help various Swedish companies using OEE as their tools for improvement, understand the underline losses as well as making their processes more efficient. The figure below presents a holistic view for this project's action plan.

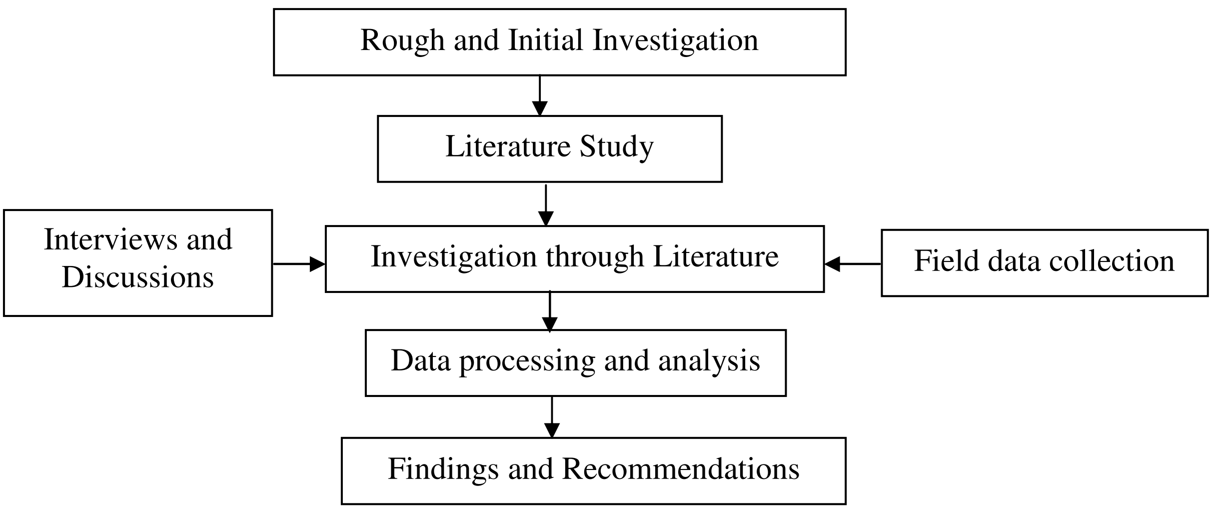


Figure 2: ***Case study design***

2.4. Literature study

Another way of improving productivity is to identify and eliminate losses. Total Productive Maintenance (TPM) is one concept for maintaining machines or equipments with the help of Overall Equipment Effectiveness (OEE). Information used was taken from books and articles through databases at Mälardalen University library, Google scholar, Social Science Research Network (SSRN), ScienceDirect, and IEEE.

Investigation through literature: Real time data were collected in the RSproduction system made up of the various types of industries, types of machines, their first five big losses, overall equipment effectiveness values, production times, their change over and set-up times, as well as their cycle times during a six months period (October 2013 to March 2014).
Throughout the project, interviews and discussions were made in a process called brainstorming. They were held before and after analysis were carried out. This helped in answering some of the research questions that were stated in this project.

Source of data being collected and how it is being collected are important aspects needed since OEE measurement totally depends on. There must be gathered in a reasonable order so as to have a good basis for a wider study in the subject matter. Therefore, it has to be accurate without being biased. The method for collecting data in this project can be grouped into two types (Quantitative and Qualitative) as described in Table 2.3. Performance measurement and continuous improvement from the data being collected will only be improved if measured (Muchiri &Pintelon, 2008). Collection if these data were done both manually by the operators and automatically by the RSproduction system. According to Jonsson and Lesshammar (1999), manual collection of data is less accurate especially when recording minor stoppages or downtime as there can easily be forgotten.

Data process, analysis, findings and recommendation will be covered at the later part of this paper.

2.5. Analysis

Quantitative (expressed in numbers) as well as quantitative (interview material, difficult to quantify) data is obtained and gathered from the participating Swedish companies. Quantitative data is much easier to work within the analysis but qualitative data provides a better understanding of the quantitative underlying results.

The analysis stage is characterized by a follow up and identification of problems and opportunities. Accuracy and usability measurement could be questioned when it is hard to realize what analysis could be made or what decisions or actions could be taken.

Planning was necessary in order to attend the time frame of the project (within 20 weeks). It was rescheduled several times due to some modifications. These modifications needed more time for understanding and processing the whole project as a whole. For this reason, the author used Gantt chart in Excel to have a well planned view of the entire project. This Gantt chart contained both planned and unplanned meetings with supervisors, making sure no interruptions are being compromised.

Table 2 presents the time spent during the entire project. This is just an overview plan of the project since a diary was written so as to include the very little details or activities that occurred during the entire project. This management team at Good Solutions are quiet helpful in making sure the author gets the required and available data. By doing so, it created a calm and understanding environment needed to make the project run smoothly. The author's supervisors from Mälardalen University are quiet helpful in making sure the written part of the project goes as planned.

Week	Task
1	Introduction of the project (by Good Solutions)
2	Project planning and Meeting with Good Solutions
3-4	Literature studies
5-6	Meetings, data collection and literature studies
7-8	Meetings, data collection and literature studies
9-14	Meetings, analysis and thesis
15-20	Thesis.

Table 2: ***Draft table of project planning***

2.6. Validity and Reliability

An acceptable research study most not only be good or that the results are applicable to all areas of the main field. It is therefore necessary to consider the validity and reliability of the study being described. Validity and reliability of the data collected rely very much on the questionnaire structure and questions design. Its main objective is to reduce the possibility of being subjective in creating the questions and consequently reducing wrong answers (Saunders et al., 2009).
Reliability and validity of data was achieved by applying controls on each step of the research process, data collection and interpretation, and conclusion development. Focus based on questionnaire is put in place in order to maximize the validity and reliability.
In addition, methods of analysis of raw data, descriptive and regression analysis helped enhance transparency of the research while reducing the setbacks.

Validity: A standardized work is necessarily for the entire industry bringing room for a comprehensive communication between employees. This provides a framework on how employees are involved and also defines the reaction to deviations in the production processes (Spear & Bowen, 1999). A standardized working environment as stated by Freivalds (2008) is vital for the validity of efficiency improvements as well as reducing the risk for new employees in doing mistakes. Validity can be established in several ways;

- **Face validity:** Which is an essential intuitive process where people often with experience or expertise in the field are asked whether or not the measure seems to be based at the concept in focus.

- **Concurrent validity:** Here, the researcher employs a criterion on which cases are known to differ and that is relevant to the concept in question. This is relevant for this study.
- **Predictive validity:** With this type of validity, the researcher takes future levels of absenteeism as the criterion against which the validity of a new measure of job satisfaction would be examined.
- **Construct validity:** Which is recommended by some writers. Here, the researcher is encouraged to deduce hypotheses from the theory that is relevant to the concept.
- **Convergent validity:** This view by some methodologists, consider measure that ought to be gauged by comparing it to measures of the same concept developed through other methods.

There are quite similar principles even if researchers formulate different ways for validity. In this study, this was also applied in order to establish validity. Frequent meetings were held in order to understand how the system was measuring machine inactivity, operators constantly assisted by engineers like evaluating the validity of cycle times, changeover times for all the machines.

Based on observations, Saunders et al. (2000) highlights a number of limitations during the collection of data. Data collection can be time consuming, have different degree of conflicts or bias, slow or expensive to collect. Based on this study, data collection needed approval from the industries which was denied in a few cases.

Interviews are necessary so as to avoid being bias in qualitative interviews. This required a perfect understanding and vital in the follow up process. Throughout this study, full collaboration between all the parties concerned helped in gaining relevant information.

Reliability: It refers to the consistency of a measure of a concept and has three prominent factors involved when considering whether a measure is reliable (Bryman and Bell, 2007). It includes availability of the machines with least down time. If the mean time between failure (MTBF) is more, it indicates machines are available for its desired performance. Attempt should be made to reduce the mean time to repair (MTTR) and improve (MTBF).

- **Internal reliability:** They key issue is whether or not the indicators that make up the scale or index are consistent or whether or not respondents' scores on any one indicator tend to be related to their scores on the other indicators.
- **Stability:** This is about asking whether or not a measure is stable over time, so that the degree of confidence that the results relating to that measure for a sample of respondents do not fluctuate. In other words, having a very little variation over time from the results obtained when administering a measure to a sample and then re-administering.
- **Inter-observer consistency:** When a great deal of subjective judgment is involved in such activities as the recording of observations or the translation of data into categories and where more than one 'observer' is involved in such activities, there is the possibility that there is a lack of consistency in their decisions. This can arise in a number of contexts, for example: in content analysis where decisions have to on how to categorize media items; when answers to open-ended questions have to be categorized; or in structured observation when observers have to decide how to classify subjects' behaviour.

3. THEORETIC FRAMEWORK

This chapter presents all the possible theoretical references used during the project. It involves a method known as Total Productive Maintenance (TPM) which aims at involving machine operators in the preventive maintenance of their machines. TPM's main objective is elimination of losses which includes, equipment downtime, defects, scraps, accidents, wasted energy, and inefficiency of labor. A metric tool that gauges TPM performance known as Overall Equipment Effectiveness (OEE) is carried out both theoretically (its evolution over time) and practically in this study. This metric helps in the identification of losses and classify them according to its three major factors namely availability, performance and quality.

3.1. Introduction

In an ideal factory, one would expect equipment to operate at 100 percent of the time, with 100 percent capacity and an output of 100 percent good quality. This isn't the case in real life since losses are the difference between ideal and actual situations. Total productive maintenance (TPM) defined in 1971 by the Japan Institute of Plant Maintenance (JIPM) is a wide strategy to increase effectiveness of any production environment through methods of increasing equipment effectiveness (Amasaka, 2009). The value of OEE is taken from the Japanese model. This model first developed by the automobile Toyota founded in the 1930s along with other automakers, produced beneficial outcome within the assembly line that Henry Ford developed. Severe recession followed after the second war world in the Japanese economy and industries were forced to streamline their manufacturing processes.
Total productive performance measurement method for discovering potential losses within equipment is overall equipment effectiveness (OEE). Measurement according to Ljungberg & Larsson (2001), is required since it answers a list of motives and benefits of measurements since

- Measurements clarify the relation between effort and result.
- Measurement creates a common language.
- Measurement motivates.
- Measurement is vital for continuous improvement.
- Measurement gives a motive for change.
- Measurement eases delegation.
- Measurement identifies problems.
- Measurements lead to focused management.
- Measurements allow comparison.
- Measurement prepares for action.
- Measurement answers the question where? and whither?

Measurement using OEE can be used at different levels within manufacturing environment since it measures initial performance of an entire manufacturing plant which creates a benchmark for management in decision making (Bamber et al, 2003).

3.2. Total Productive Maintenance (TPM)

Preventive maintenance (PM), productive maintenance (PM) and other concepts developed in the USA were modified by the Japanese concept today called Total Productive Maintenance. One of their aims was to make it suitable to match up with their industrial environment. The founder of this philosophy gathered activities in order to optimize efficiency through maintenance with the help of operators in the form of a group work (Nakajima, 1989). According to Brah & Chong (2004), employee empowerment and top management commitment must work as a group in order to reduce waste as well as striving for continues improvement. This in turn disregards division of labour to maintenance teams responsible for all factory maintenance (Nakajima 1989). Disturbances are also avoided during processes at its lowest possible cost if all co-workers are fully committed and involved (Salonen, 2007). With TPM, operators aim at having zero break downs, zero accidents, zero defects, zero dust and dirt which was not the case before.

A more meaningful explanation of Total Productive Maintenance is as follows;

Total, that stands for;

- Involving all the employees. Increased awareness of a skilled team of operators and sharing of knowledge create a problem solving attitude. This needs a total collaboration known as team work including and the administration (top management).
- Elimination of accidents, defects and breakdowns.

Productive

- Specific activities are performed during production.
- Difficulties during the production period are minimized.
- Production goods or services should always meet or exceed the customers' expectations.

Maintenance

- Restoring equipments or machines in original condition. This in turn prolongs life span of the machines. This includes, replacement of worn out parts, repairing damaged parts, cleaning or lubricating.

From the Japan Institute of Plant Maintenance (JIPM)'s TPM pillar initiatives, Ahuja et al. (2008) presented eight pillars approach for TPM implementation.

Development management

- Requiring minimal problems and running in time on new equipment.
- Utilize learning from existing systems to new systems
- Maintenance improvement initiatives.

Office TPM

- Improve synergy between various business functions
- Remove procedural hassles
- Focus on addressing cost-related issues
- Apply 5S in office and working areas

Safety, health and environment

- Ensure safe working environment
- Provide appropriate work environment
- Eliminate incidents of injuries and accidents
- Provide standard operating procedures

Education and training

- Imparting technological, quality control, interpersonal skills
- Multi-skilling of employees
- Aligning employees to organizational goal
- Periodic skill evaluation and updating

Quality maintenance

- Achieving zero defects
- Tracking and addressing equipment problems and root causes
- Setting 3M (Machine/Man/Material) conditions

Planned maintenance

- Planning efficient and effective PM, and TBM systems over equipment life cycle
- Establishing PM check sheets
- Improving MTBF, MTTR

Focused improvement

- Systematic identification and elimination of 16 losses
- Working out loss structure and loss mitigation through structured why-why, FMEA analysis
- Achieve improved system efficiency
- Improved OEE on production system

Autonomous maintenance

- Fostering operator ownership
- Perform cleaning – lubricating – tightening – adjustment – inspection – readjustment on production equipment.

3.3. Introduction to Overall Equipment Effectiveness (OEE)

Overall equipment effectiveness was initially used by Seiichi Nakajima in the 1980s. It aimed as a quantitative metric for measuring productivity of individual production equipment in a factory. This metric has significantly gained popularity in recent years as it turns to reveal and measure hidden or irrelevant costs related to a piece of equipment (Nakajima, 1988).
In any industry, equipments would be expected to yield good quality products with an expected capacity of 100 percent but improvement cannot be carried out without measurement. OEE concept is well known in maintenance and used as a tool for measuring the effectiveness of machines. This cannot always happen all the time in reality because of other factors affecting the equipments. So long as there are being used, so are their life span, present value,

effectiveness and efficiency reduced. Therefore, the difference between the initial and the current situation of the equipment are caused by losses.

3.4. Definitions of OEE

Overall Equipment Effectiveness is part of total productive performance (TPM) concept launched by Seiichi Nakajima in the 1980s'. It is regarded as a measurement tool under TPM and at aimed identifying production losses related to equipment (Williamson, 2006). Initial performance of an industry can be used as "benchmark" helping the management team compare OEE values between initial and current so as to improve. Known as a quantitative metrics, Nakajima (1989) classified these losses into six in order if it had to be eliminated and does not consider all the factors reducing capacity utilisation such as planned downtime, lack of material, labour etc. The losses are;

1. Breakdown (Equipment failure)
2. Set-up and adjustment
3. Idling and minor stoppages
4. Reduced speed or speed losses
5. Quality defects and
6. Rework

Nakajima (1988) earlier suggested ideal values of OEE at 85% (known to be as a world class value) for a component measure as;

- Availability rate at 90 percent
- Performance rate at 95 percent and
- Quality rate at 99 percent.

Further researches have been carried out in order to clarify the appropriate levels of availability, performance and quality. Kotze (1993) presents an OEE value greater than 50 percent as a more evident and reality figure and more helpful as an acceptable benchmark. Ljungberg (1998) presents an acceptable OEE value of between 60 percent and 75 percent while (Ericsson, 1997) gives a value that varies between 30 percent and 80 percent.

Although (Ljungberg, 1998) mean percentage of OEE from his sample cases was 55 percent, results of mean availability was 80 percent which closely attends the 90 percent availability rate stated by Nakajima (1988).

The average performance rate was 68 percent according to (Ljungberg, 1998) which is far below the 95 percent rate stated by Nakajima (1988). This low performance rate of 68 percent is attributed to idling and losses due to minor stoppages while most of the major losses were attributed to availability related losses.

Ljungberg (1998) average quality rate was 99 percent which coincides with the 99 percent as suggested by Nakajima (1988).

3.5. The Purpose of OEE

Due to the fact that OEE measurement can be implemented within different levels in an industrial environment, it value can be used as a "benchmark" for further measurements of any manufacturing plant. Previous and future results of OEE can be examined so as to quantify and qualify the improvement made (Bamber *et al*, 2003).

OEE value from one manufacturing line can be used to compare different performance lines across an industry. In an individual level, OEE measure can identify which machine performance is ineffective and required special attention (Nakajima, 1988).

OEE is not just regarded as a metric but provides a framework for improving a process. It can pinpoint specific aspects of a process that can be ranked for improvement. It is also based on identifying any losses that restricts equipment from achieving it maximum effectiveness.

3.6. Chronic and Sporadic disturbances

The OEE metric is designed to identify losses that reduce machine effectiveness while wasting resources with no value creation. These losses are manufacturing disturbances which are group into two (Jonsson and Lesshammar, 1999) namely;

- Chronic disturbances; and
- Sporadic disturbances.

Chronic disturbances according to Tajiri and Gotoh (1992), are quiet small, hidden and confusing since they are simply the result of many concurrent causes. They disturbances lead to low equipment utilisation with large costs since they occur repeatedly. Chronic disturbances are hard to identify since they can be seen at the normal state and are inherent in the system of manufacture. Its identification is possible through comparison of performance with theoretical capacity of equipment. According to the losses presented by Nakajima (1989), their characteristics could be placed under obvious and hidden losses are viewed in the table 2

Losses	Obvious losses	Hidden losses
• Sporadic breakdowns • Chronic breakdowns	✓	 ✓
• Setup and adjustment	✓	✓
• Idling and minor stoppages		✓
• Speed		✓
• Sporadic quality defects • Chronic quality defects	✓	 ✓

Table 2: ***Characteristics of loss*, (*Nakajima 1989*)**

Sporadic disturbances are easily identified quickly since its deviations are quite large from the normal. They do occur irregularly and their effects often lead to serious problems

Chronic and sporadic disturbances create different types of wastes with no value. OEE aims to identify these losses from an essentially bottom-up approach as stated by Nakajima (1988).

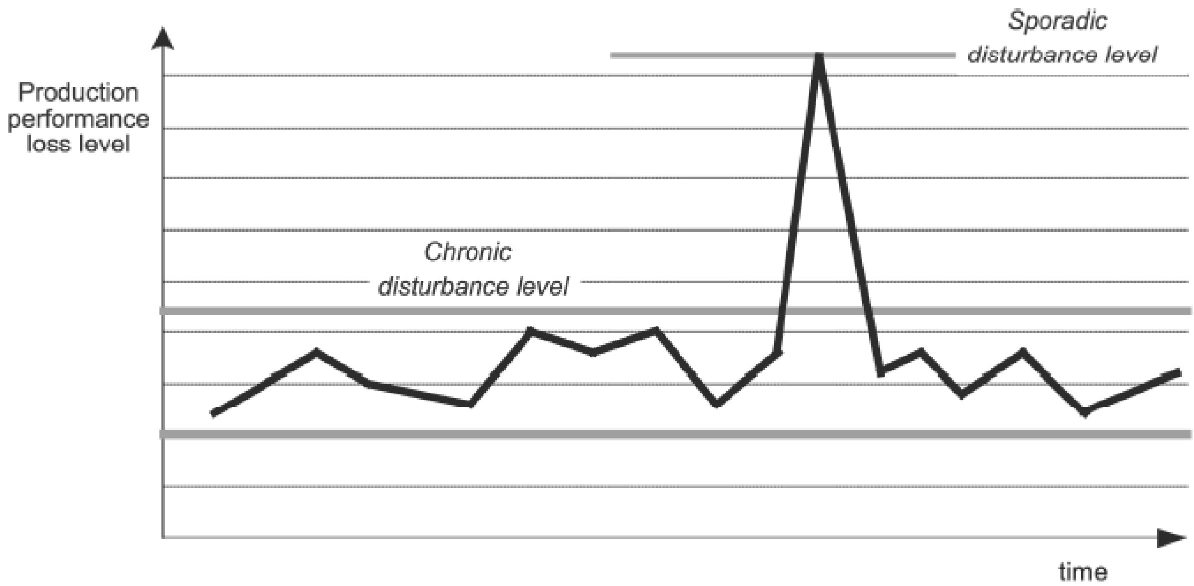


Figure 3: ***Production performance losses as a result of chronic and sporadic disturbances*** **(Bamber *et al.*2003)**

3.7. Six big losses of OEE

Nakajima (1988) launched of OEE as a measurement tool under the TPM concept which aimed at achieving a zero breakdown and zero defect of equipment. This led to an improvement in production rate, reductions in costs, reductions in inventory, and an eventual increase in labour productivity. The main purpose of the TPM concept according to Muchiri and Pintelon (2008) is on production equipments in view of the fact that they have a high control on quality, productivity, cost, inventory, safety and health, and production output.

Nakajima (1988) stated that losses from the manufacturing disturbances apply the bottom-up approach where an incorporated workforce strives to accomplish overall equipment effectiveness by eliminating six big losses. Based on his observation in Japan, Nakajima (1988) suggested the following six big losses:

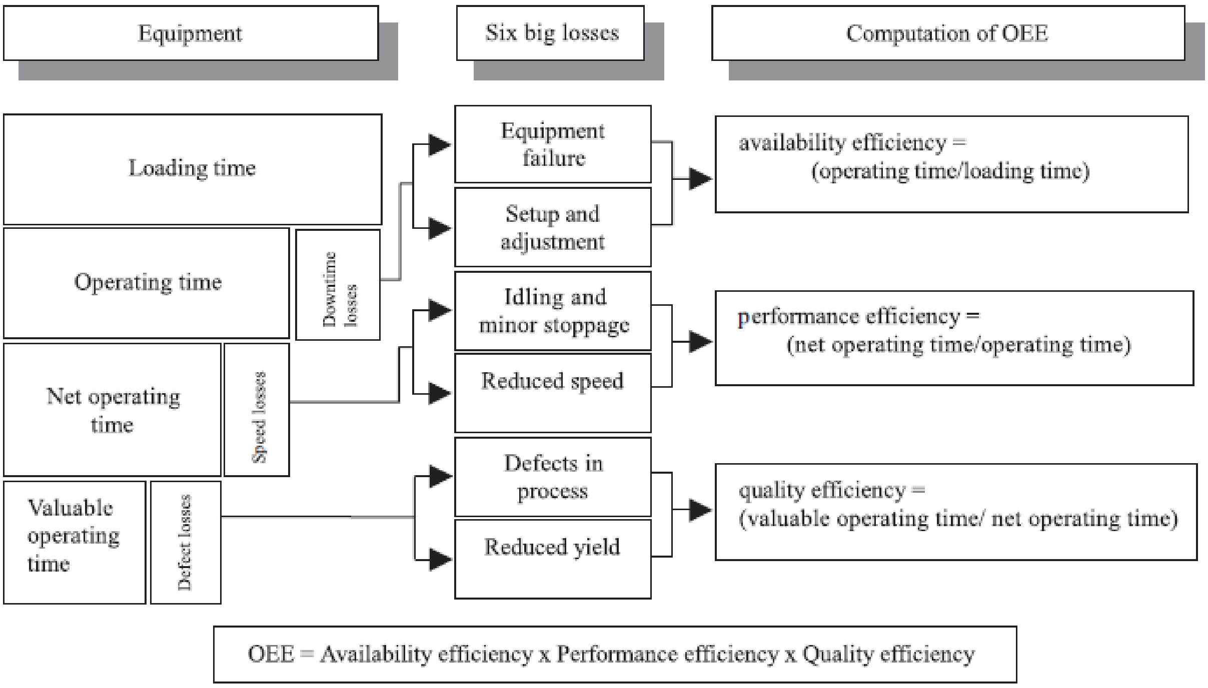


Figure 4: ***Overall equipment effectiveness and Computation procedure*** **(Nakajima, 1988)**

Unplanned downtime losses as a function of Availability

There are made up of the first two big losses presented below and are used to help calculate the true value for the availability of a machine in an industry.

1) Equipment failure: Breakdown losses are categorised as time and quantity losses caused by failure, breakdown or by defective products. In a brewery plant as analysed by Pintelon *et al.* (2000), a breakdown of palletizing plant motor led to downtime and thus production loss.

2) Set-up and Adjustment: These are losses that occur when production when production is changing over from requirement of one item to another. Still in the brewery plant, the type of losses encountered during the set-ups, were set-ups between different products, testing during start-ups and fine tuning of machines and instruments.

Speed losses as a function of Performance

Speed losses are required for calculating the true value for performance of a machine. It cannot be calculated during downtime of machines.

1) Idling and minor stoppage: These losses occur when production is interrupted by temporary malfunction or when a machine is idling. For example, dirty photocells on palletizing machines cause minor stoppages even though they are quickly fixed, due to their frequency, much capacity is lost.

2) Reduced speed: These losses refer to the difference between equipment design speed and actual operating speed. The use of unadapted pallets in a palletizing plant has presented by Muchiri and Pintelon (2008) led to longer processing times for the same number of bottles leading to speed losses.

Quality losses as a function of Quality

Quality losses affect the quality of the final product. This causes serious economical setbacks in a factory due to waste of resources or cost for recycling. They are based on;

1) Defect in process / rework: These are losses caused by malfunctioning of production equipment. In the case of pallets, some got stuck in between depalletizer and unpacker and are damaged.

2) Reduced yield: They are yield losses during start-up that occur from machine start-up to stabilization. Poor preparation for morning shift by night shift in the brewery led to problems with the filling taps and thus led to reduced yields.

This can be illustrated in the figure 5 presented below;

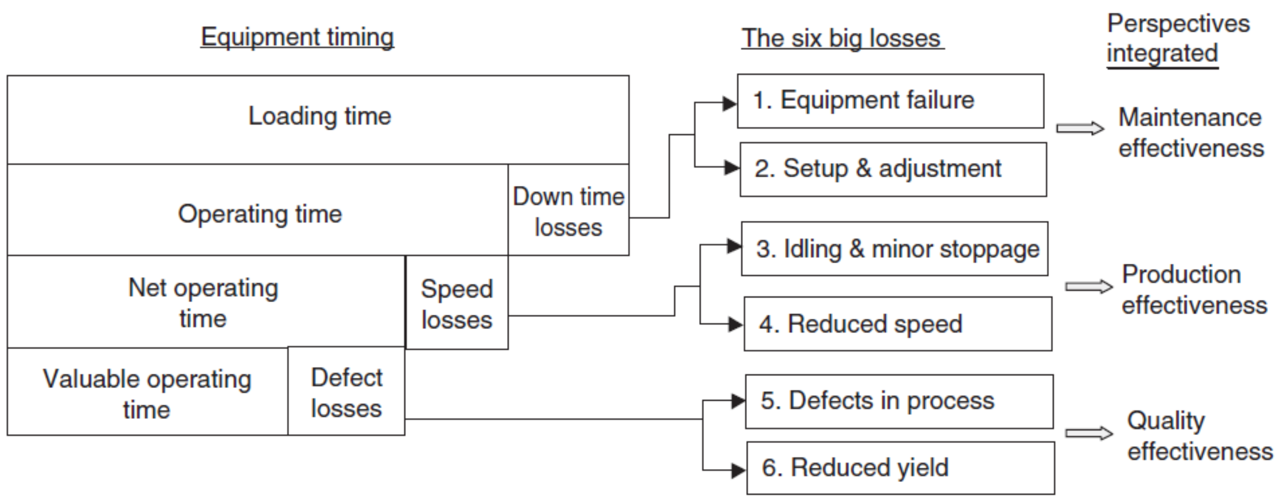


Figure 5: ***OEE measurement tool and the perspectives of performance integrated in the tool*** **(Muchiri & Pintelon, 2008)**

3.8. Evolution of OEE

Although the origin OEE was defined by Nakajima (1988), different definition between authors have evolved over the years which is now regarded as a primary performance metric (Muthiah *et al*. 2006). Fleischer et al. (2006) stated that the desire to remain competitive in any manufacturing industry depends on availability and productivity of its production facility while Jonsson and Lesshammar (1999) presents OEE as a tool that could identify losses due to manufacturing disturbances that are either chronic or sporadic. Huang et al. (2003) stated the popularity of OEE tool as an essential quantitative tool for measuring productivity limited at individual equipments. Additional causes of OEE losses such as preventative maintenance, holidays and off-shifts according to Jeong and Phillips (2001) were not considered to be appropriate for capital intensive industry as originally defined Nakajima (1988).

The insufficiency of OEE tool has led to modification and has widened to fit a much broader perspective in the manufacturing systems. This has not only been modified in the literature and in practice, but has been followed by modified formulations. Some modifications being limited to effectiveness at equipment level such as planned equipment effectiveness (PEE) and total effective equipment performance (TEEP), others have been enlarged it to factory-level effectiveness such as, overall throughput effectiveness (OTE), overall plant effectiveness (OPE), and overall assembly effectiveness (OAE).

3.9. Total Effective Equipment Performance (TEEP)

The concept of total effective equipment performance (TEEP) was proposed by Ivancic (1998) which is very similar to OEE by Nakajima (1988). The main difference lies in the inclusion of planned downtime in the total planned time horizon. There is a clear distinction made between planned downtime and unplanned downtime as it clearly shows how maintenance is contributed to the bottom line productivity of the plant. Maintenance goal is aimed at minimizing unplanned shutdown sometimes known as technical downtime. Pintelon *et al,* (2000) explain how downtime is a function of various breakdowns within a specified period of time and relates measures such as mean time between failures (MTBF) and mean time to repair (MTTR).

According to Ivancic (1998), TEEP helps in the measurement of both planned and unplanned downtime. Equipments availability can be improved through a thorough analysis of these two downtimes by either increasing the MTBF or reducing the MTTR. Speed and quality related losses included in TEEP match that of OEE. In figure 6 below, TEEP is calculated by dividing the valuable operating time (VOT) with the total available time (T_T) while figure 7 as shown below, presents an analysed and measure constituent elements in TEEP.

Just like in OEE measurement, TEEP measure is limited to equipment-level productivity which can also be applicable to a processing plant or a flow of shop where production process can be regarded like a single production entity.

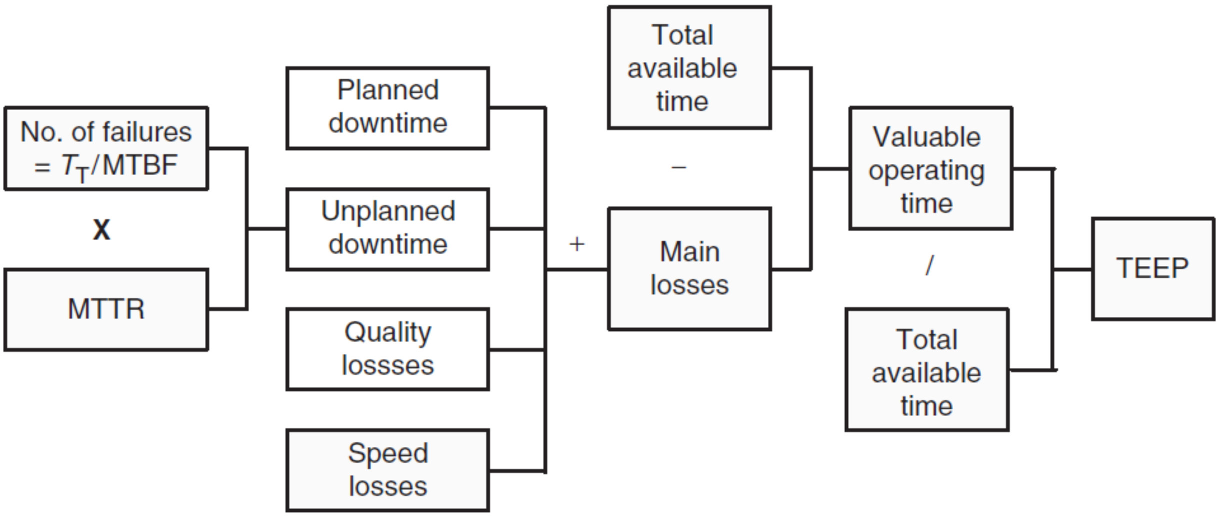


Figure 6: ***Constituent elements used in the calculation of TEEP*** **(Muchiri & Pintelon, 2008)**

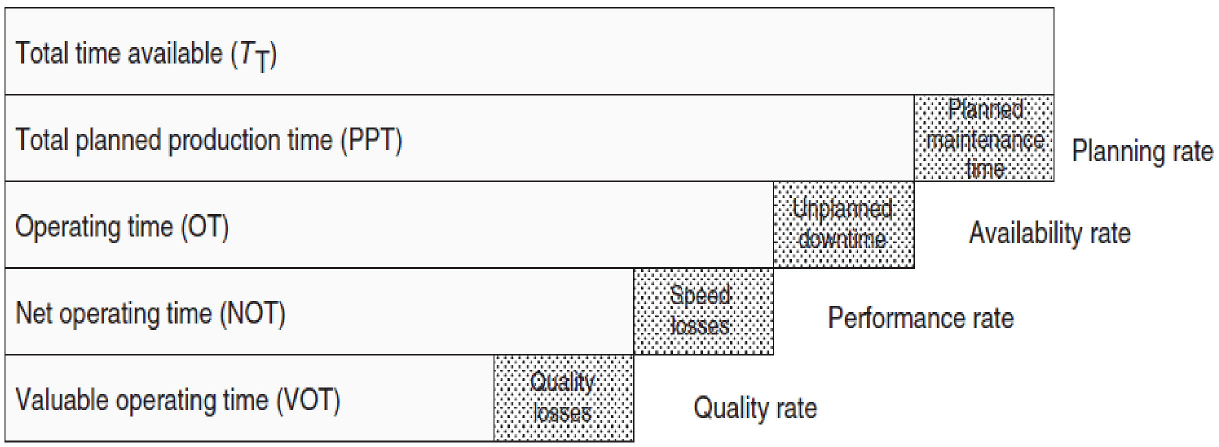


Figure 7: ***Constituent elements in TEEP*** **(Muchiri and Pintelon, 2008)**

3.10. Four underlying metrics of OEE

The factors of OEE (availability, performance and quality) are totally independent of another. The six big losses in relation to the machines are divided into the three factors of OEE[1]. From previous remark, a basic definition of OEE is:

OEE = Valuable operating time

[1] http://www.oee.com/oee-factors.html, 2014-08-04

Loading time

Where;

- Valuable operating time is the defined as 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).

Planning factor (Pf)

Another relevant element when calculating availability is the loading time. This is a portion of the TEEP metric representing the percentage of total calendar time that is actually scheduled for operation. According to Dal *et al.* (2003), loading time is the length of the shift after any deduction for planned downtime where planned downtime includes activities such as:

- No labour available due to operator shift changes and breaks;
- Planned maintenance activities;
- Operator training;
- Equipment trials and process improvements activities;
- Machine cleaning and general operator maintenance;
- Waiting time due to completion of current orders;
- Shortage of personnel;
- Holiday;
- Line overhaul;
- Production modification;
- Inspections;
- Engineering activities;
- Security drilling;
- Problems with external or internal material; and
- Personal time.

Planning factor presents time loss due to planned stops and does not affect equipment effectiveness. Due to increase of both planned and unplanned losses, the value of planning factor will inevitably decrease

$$\text{Planning factor} = \frac{\text{Scheduled time} - \text{Planned related stops}}{\text{Scheduled time}}$$

Total OEE can also be calculated as follows:

$$\text{Total OEE} = \text{OEE} \times \text{Planning factor}$$

Availability factor (A)

This has to do with the time the equipment was available and running and not just the time the machine was available. Availability factor of OEE measures total stoppage time from unscheduled downtime, set-up and changeovers, and other unplanned stoppages. This in order terms can be defined as changes in actual production time to planned operating time and taking theoretical production time into account against highlighted unplanned stoppages.

Availability calculation does not take into account planned preventive maintenance since it might lead exceedingly long activities or excessive process set-up times (Dal *et al.* 2003). OEE value still appears to be low even as planned preventive maintenance is omitted which still required the need to decrease planned maintenance activities by implementing TPM.

Therefore downtime activities included in availability activities are;

- Set-up and change over times;
- Minor stoppages; and
- Unplanned maintenance such as breakdowns of machines.

Thus availability factor can be formulated as follows;

$$\text{Availability} = \frac{\text{Planned production time} - \text{Unplanned stop time}}{\text{Planned production time}}$$

Performance factor (P)

As the second element of the OEE calculation, performance is the product of the net operating rate and operating speed rate. According to Nakajima (1988), it measures a fixed amount of output which indicates actual deviation in production in time from ideal cycle time. De Groote (1995) instead focuses on fixed time and calculates the deviation in production from that planned.

Over a given period of time, net operating rate measures the achievement of a stable processing speed. It do not take into consideration whether the actual speed is faster or slower than the design standard speed but focuses only on a given period of time, for examply a production shift of 8 hours. Losses resulting from recorded, and unrecorded stoppages such as small faults and adjustments can be calculated. A performance of 80 percent implies a Speed Loss of 20 percent. Performance can be calculated by using the equation below.

$$\text{Performance rate (\%)} = (\text{Net operating rate x Operating speed rate}) \text{ x } 100$$

Where

$$\text{Operating speed rate} = \frac{\text{Theoretical cycle time}}{\text{Actual cycle time}}$$

And

Net operating rate = Number produced x Actual cycle time / Operation time

$$\text{Net operating rate} = \frac{\text{Number produced} \times \text{Actual cycle time}}{\text{Operation time}}$$

Quality factor (Q)

This factor is the last regarding the calculation of the OEE as quality rate. It highlights the proportion of defective production to the total production volume. These defects are usually on a specific machine or production line and occur only in designated stage of production.

$$\text{Quality rate} = \frac{\text{Total number produced} - \text{Number Scrapped}}{\text{Total number produced}}$$

3.11. OEE formulation

According to Nakajima (1988), overall equipment effectiveness is the product of three factors and it is being calculated in percentages. The formula is given below as;

(OEE)= Availability (A) x Performance (P) x Quality (Q) x %

A world class[2] value of OEE is expected to be 85.0% comprising of;

Availability 90.0 %
Performance 95.0%
Quality 99.9%

Regarding planned working hours, overall equipment effectiveness is formulated as;

(Planning factor OEE) = (Planning factor) x Availability rate x Performance rate x Quality rate

[2] http://www.oee.com/world-class-oee.html, 2014-08-04

3.12. Data collection

Collection of data refers to the registration of values for a certain variable. Questions need to be put in place as to what data should be registered, how and when. Data can be registered manually or automatically and in some cases there can be done simultaneously. Ljungberg and Larsson (2001) suggest automatic measures used to collect information are probably relevant in the long run.

The method used in the collection of data is a vital aspect needed in the calculation of OEE. Data collection can vary from manual to much automated, as correct input of parameters acquired from the production system is essential for OEE calculations (Ericsson, 1997). Manual data collection which mainly happens in low-tech industries consists of a registry, where operators are required to fill in the causes and duration of breakdowns as well as reliable comments about minor stoppages and speed losses. In high-tech industries, an automatic OEE calculation system is governed by sensors linked to the equipment, automatically recording the start time and duration of stoppages while prompting the operator to make available the system with correct information about their specific downtime causes. With automatic method, opportunities are made available for operators to set up lists of potential downtime causes, scheduling the available operating time and constructing an automatic OEE calculation for any specific time period. So long as the data input are provided in the system, it is not only possible to provide OEE results but makes it easier to retrieve a variety of reports of production performance and visualization of the performance results from the system.

However, too much information in the system can be a waste of time for the operators and they will have to search for each downtime cause. Reluctance against data collection from operators and foremen are some of the major challenges faced by many industries. Ljungberg (1998), finds it necessary to convince operators as some do believe that some disturbances have a major impact on efficiency which later measurements shows that to be completely wrong.

With automatic data collection, the system is quiet expensive, complex and is collected at an aggregated level. On the contrary, manual data collection can be very detailed as losses can be fully examined.

It is necessary to introduce both manual and automatic data collection methods coupled with training of the operators of OEE as a performance measure, and on various parameters affecting the OEE outcome. Main reasons for this would be to qualify the quality of input data in line with an increase in the competence of operators and creating a better involvement of the operators in identifying potential performance loss factors as well as providing system with accurate information.

Quantitative measurements for the OEE calculation were collected from a large number of machines in the various industries under a period of three months. Machine stops were registered with a use of computer by the help of the operators as suggested by Ljungberg (2000).

3.13. Set-up time

Taiichi Ohno, the former president of Toyota in the 1950s was unhappy since cars were produced for stock in his company. This waiting of cars for customers at parking lot was a waste and was caused by manufacturing components and final products in excessively large series. Van Goubergen and Van Landeghem (2002) present the importance of reducing

machine setup time by the implementation of lean manufacturing since it had significant impact on manufacturing costs caused by decreased sizes of series orders. This is the time when a machine is inactive because of certain preparations needed for the next production product to begin. In order words, it can be referred to as losses occurring after breakdowns. Such preparations might be removal of previous tools, cleaning program loading, loading of new tools, settings, inspection and testing, etc until machine is activated for the next product to start producing. This is an important downtime factors that affects machines. It is omitted at times in the calculation of OEE by some industries since; it is classified as a planned activity which is required. Others view it as important in OEE calculation since it is actually a downtime loss and which could be reduced. It is divided into long and short set-up times. There is no specific time allocation for both set up times since machines vary as their changeover times too. In normal cases, unplanned changeover for some unknown reasons must be included in OEE calculation since the required setup is exceeded.
Other causes for machine stop can be listed below

- Program failure
- Tool change
- Waiting for container (missing pallets)
- Missing tools (Searching or waiting)
- Machine failure
- Cleaning (Maintenance)
- Material loading
- Setup (tools)
- Inspections

According to Van Goubergen & Van Landeghem (2002), reduction of machine setup time increases flexibility (offer customers more products in their variants in smaller series), increases higher throughput due to reduction of setup times of bottleneck machines and increases machine efficiency which leads an increase in company income.
Setup reduction as stressed by Suzaki (1987) is essential as factory operation becomes flexible enough to react to the changing market demand. Industries regularly compete with each other in offering a greater variety of products to satisfy specific customer needs. By applying standardized fixtures for processing a number of items on a machine, create ways of reducing setup time and contribute to the learning transmission between items (Pratsini, 1998). Single Minute Exchange Of Dies (SMED) provides basic steps in setup time reduction through standardized procedures (Shingo, 1985).

For simplicity, the following parameters used in order to facilitate calculations on setup times are shown in the data collection section.

3.14. Cycle time

Cycle time corresponds to the time required to produce a product under continuous production. According to Ljungberg (2000), it is considered as the operating speed per hour calculated as time per item. It is also divided into long and short cycle times but it is often considered long if products are being rejected after production and therefore referred to as looses. Cycle times are affected by the design speed, initial optimal situation and change with regards to a product (Nakajima, 1989).

3.15. Single Minute Exchange of Dies (S.M.E.D)

Single minute exchange of dies was developed in the 1950s by Shigeo Shingo. The need due to higher degree of smaller production lot sizes in Japan in meeting customer demand required flexibility. It aims at reducing waste in manufacturing processes by providing fast and efficient way of converting current product to running the next product (Shingo, 1985). Single minute exchange of dies was developed in the 1950s by Shigeo Shingo. The need due to higher degree of smaller production lot sizes in Japan in meeting customer demand required flexibility. It aims at reducing waste in manufacturing processes by providing fast and efficient way of converting current product to running the next product (Shingo, 1985). The term "single minute" refers to the time less than 10 minutes being needed for all changeovers and startups.

Benefit of Setup reduction.

Below are the following benefits applying SMED;

- Scrap and inventory reduction leading to lower cost.
- Improvement in quality after changeover (rapid change).
- Improvement in flexibility.
- Reduction of impact on equipment utilization.
- Improvement in throughout.
- Reduction in batch sizes.
- Improvement of repeatability
- Improvement in changeover time.

Setup or changeover is therefore defined as the preparation or post adjustment that is performed once before and once after each lot is processed (Shingo, 1985). It is divided into two parts:

- Internal setup, which can only be implemented when the machine is shut down and,
- External setup, which can be done when the machine is still running.

SMED system can be applied in any type of setup based on the following steps (Shingo, 1985):

Step 1: Identifying and separating internal and external setups.

The step single-handedly can help reduce setup time by 30-50 percent. External setups are activities that are carried out while the machine is running and is performed ahead of time in order to gain time when setting up the machine. Internal setups are activities are performed only when the machine is stopped or on hold and can only take place when the machine has finished its previous operation. Operators must be able to complete all the external setups and ready to fulfill internal setups for the next product before the machine is done processing a product.

Step 2: Converting internal setups to external setups.

It is time consuming on both setups but improving or transferring some of the internal activities to external activities increases the running time of the machine from one product to the other. Most of the external setup activities are unseen within the internal set up time such as cleaning, material handling and product, gathering tools and fixtures, preheating, etc.

Step 3: Reorganizing all aspects of setup.

The working environment has to be organized properly, locating tools to their nearest point of use, and making sure machines and fixtures are functioning properly. Adjustments that assist in minimizing internal setup activities should be simplified and put into practice such as using quick fasteners and locator pins, preventing alignment rework with the help of preceding desired settings.

Step 4: Performing parallel setup activities.

Standardization of components, parts and raw materials can improve and even get rid of setup activities. A continuous practice of setup processes can be documented as it is vital for workers and engineers for the task of setup time reduction. It can be referred to as principles once ideas generated are studied and put into place. These principles can then be practiced until improvements can be done.

3.16. 5 WHY'S analysis

This analysis is a question-asking technique used to explore the cause and effect relationships underlying a particular problem. It is needed to identify the root cause of a problem or defect (Slack et al. 2010). It is not a problem solving technique but one that analysis one or several root causes that ultimately identify the reason why a problem was originated. This has to begin initially by clearly stating the problem since a defined problem is half resolved.

This method can be used for simple issues with or without knowledge and experience, reoccurring issues, issues with human interaction basically caused by operator error or procedure not followed through. It is root cause analysis tool that is simple, effective, comprehensive, flexible, engaging and inexpensive to use. An example can be presented below;

Statement: The machine keeps failing.

- **Why 1**

Why did the machine fail? Because of circuit board burnt out.

- **Why 2**

Why did the circuit board burn out? Because of overheat.

- **Why 3**

Why did it overheat? Because it wasn't getting enough air.

- **Why 4**

Why was it not getting enough air? Because the filter wasn't changed.

- **Why 5 and Root cause**

Why was the filter not changed? Because there was no preventive maintenance scheduled in place informing the operator to do so.

3.17. Fishbone (Cause-Effect) Diagram

The Fishbone diagram (also referred as Ishikawa diagram) is a tool for identifying the root causes of quality problems. It was credited to Kaoru Ishikawa, who pioneered the use of this chart in the 1960's (Juran, 1999).

It is an analysis tool that provides a systematic way of searching at effects and causes that create or contribute to those effects. It presents a suggestive view of the relationship between effects and its multiple causes. This structure encourages and benefits group participation by utilizing group knowledge of the process through structural brainstorming sessions (Slack et al. 2010). As a fishlike skeleton diagram, simple bevel line segments leaning on a horizontal axis suggests the distribution of multiple causes and sub-causes through completed quantitative and qualitative approaches (Ciocoiu, 2008). Headings such as machinery, manpower, materials, methods, and money can be structured used to identifying possible causes. Practically, any category could be covered in comprehensive way for possible causes. The figure below is an example which shows the Cause-effect diagram of unscheduled returns identifying causes for spares shortages.

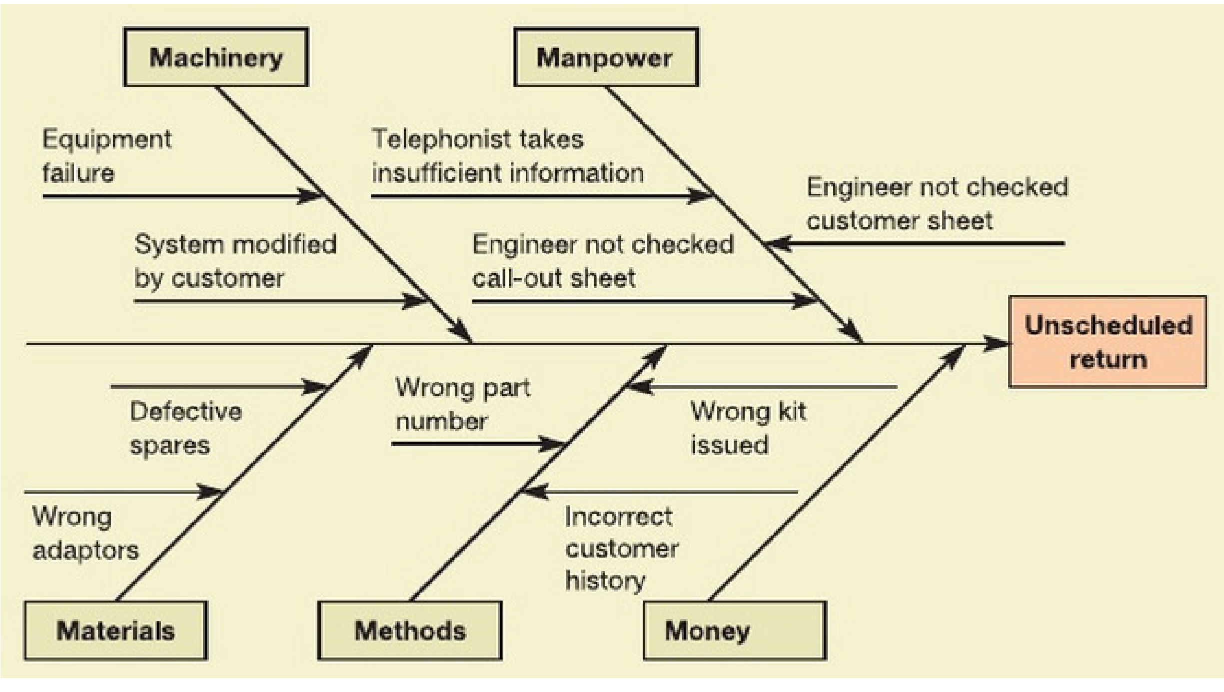


Figure 8: ***Fishbone diagram of unscheduled returns, (Slack et al. 2010)***

4. DATA COLLECTION BY EXCEL SHEET

This study carried out at Good Solutions plant in Gothenburg, Sweden. A systematic approach is used to collect data of all the manufacturing machines within the different types of industries. Data collected is studied while measurements, observations and interviews were employed on weekly basis.

The data collected from Swedish industries were OEE values, downtime looses, total scheduled production times, actual production times, types of machines, cycle times, and number of pieces per order. The industries were grouped into four main categories namely;

Type of industry	Data collected
1. Food and beverage	244
2. Mechanical workshop	347
3. Polymer (Rubber and plastics)	157
4. Other automated discrete production	119
Total	867

Table 4: ***Four groups of Swedish industries Vs data collected***

Total scheduled production time	357190 hours
Total operation time	170925 hours
Total downtime	186265 hours

Table 5: ***Total time registered***

Types of Set-up (Changeover) times	Number of pieces
Single set-up time	Less than 5 pieces
Short set-up time	5-25 pieces
Medium set-up time	25-200 pieces
Long set-up time	Greater than 200 pieces

Table 6: ***Setup/Changeover times per piece.***

Types of Cycle times	Time
Single cycle time	Less than 2 seconds
Short cycle time	2-60 seconds
Medium cycle time	1-5 minutes
Long cycle time	Greater than 5 minutes

Table 7: ***Cycle time recorded ranges***

Average OEE value for all the Swedish industries

Total Availability	47,9 %
Average Availability	49, 7 % without considering Total schedule production time.
Average OEE	43, 5 % without considering Total schedule production time.

Table 3: ***Total Availability and Average OEE for the Swedish industries.***

Results of downtime losses and their stoppage reasons where down time losses for the all the industries were obtained and calculated are as follows;

Downtime losses (Aggregate Stoppage Reasons)	Time	Percentages of Looses
Setup/Changeovers	17591 hours	28,4%
Machines/Techniques	9354 hours	15,1%
No reason code	/	/
Shift changes and breaks	3641 hours	5,9%
Unplanned production	13669 hours	22,1%
Planned service/Maintenance	4277 hours	6,9%
Other planned stops	1946 hours	3,1%
Lack of accessories	549 hours	0,9%
Lack of personals	4631 hours	7,5%
Micro stoppages	2985 hours	4,8%
Personal time	82 hours	0,1%
Problems with internal material	1535 hours	2,5%
Problems with external materials	1041 hours	1,7%
Quality issues /reworks	634 hours	1,0%
Total	61933 hours	100%

Table 4: Aggregated stoppage reasons and time of downtime losses.

Result of OEE values between different types of industry.

Type of industry	Average OEE values
1. Food and beverage	49,9%
2. Mechanical workshop	49,8%
3. Polymer (Rubber and plastics)	38,7
4. Other automated discrete production	43,3%
Total	100%

Table 5: Average OEE values for the Swedish industries

Results show that average quality is the highest parameter as a whole. The table below clearly shows average quality value compared with the other OEE parameters.

Type of industry	Average Availability	Average Performance	Average Quality
1. Food and beverage	58,76%	82,60%	100%
2. Mechanical workshop	55,98%	89%	100%
3. Polymer (Rubber and plastics)	44,70%	89,70%	95,90%
4. Other automated discrete production	44,90%	96,20%	99,8%

Table 6: Highest average OEE parameter for the Swedish industries

Result of parameters that give a low OEE. Results show that average availability accounts for lowest OEE value.

Type of industry	Average Availability	Average Performance	Average Quality
1. Food and beverage	58.76%	82.60%	100%
2. Mechanical workshop	55.98%	89%	100%
3. Polymer (Rubber and plastics)	44.70%	89.70%	95.90%
4. Other automated discrete production	44.90%	96.20%	99.8%

Table 7: Lowest average OEE parameter for the Swedish industries

5. RESULTS

In this paragraph, discussions on what has been done and how is done are presented. An evaluation is carried out on how it could have been done better and what factors may have affected the work and the possible sources of errors. It presents all the results of the OEE measurement carried out in the case study. This is in relation to the theoretical framework that was previously presented as the problems are identified and exposed.

Downtime reasons for the combined industries are presented in the graph below;

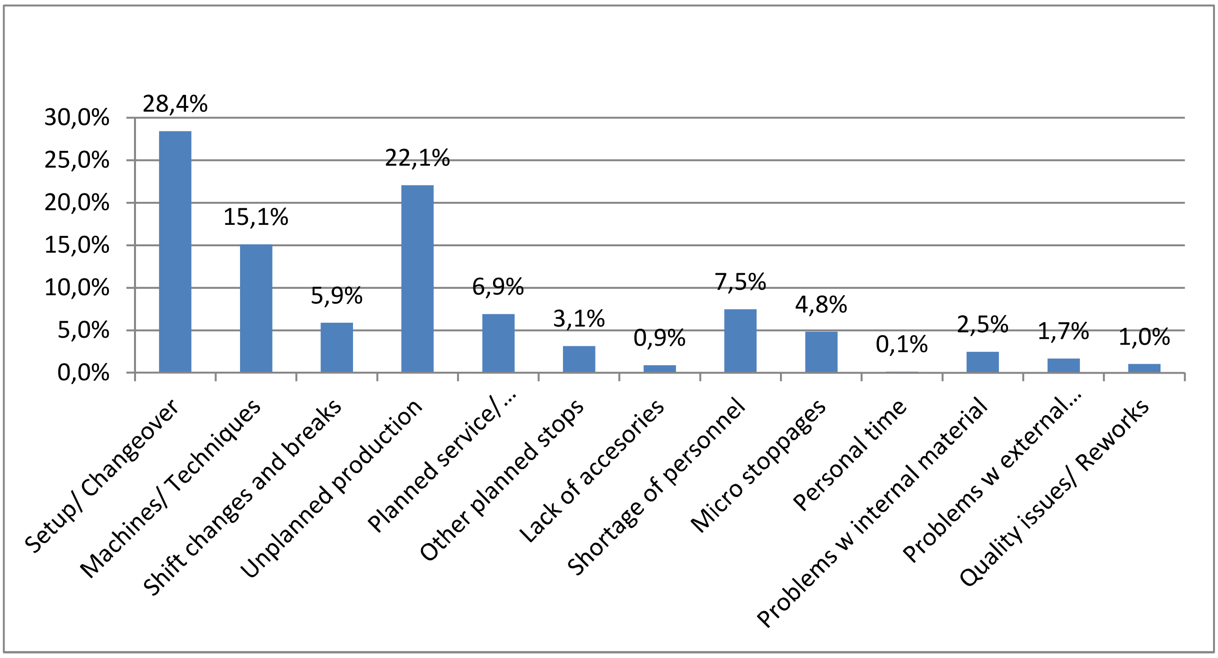
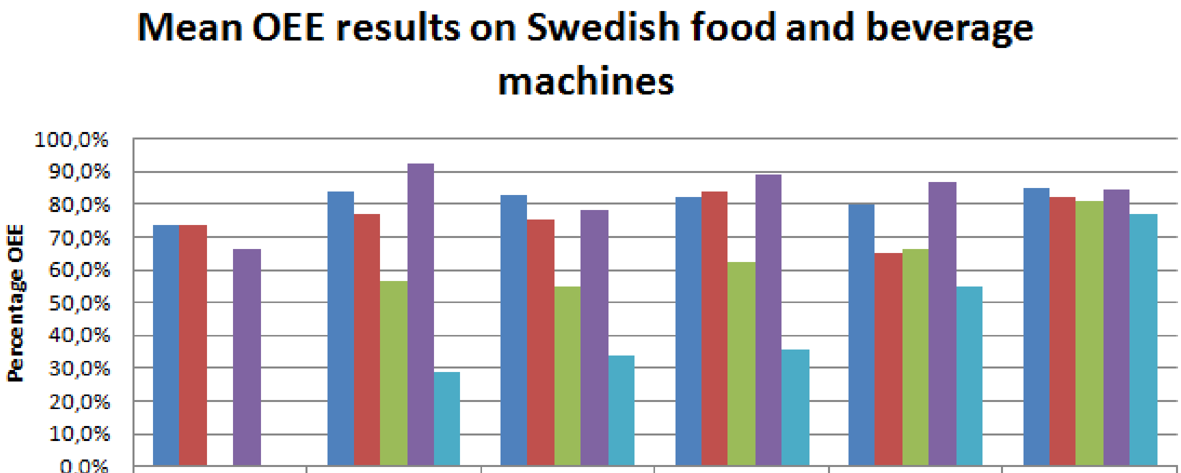


Figure 9: ***Major Percentage looses within all the type of industries.***

An aggregated loss reasons within the Swedish industries is shown in the figure above. Availability related losses were the biggest due to setup/changeover (28, 4 percent) and breakdowns/Unplanned production (22, 1 percent) making it a total of 50, 5 percent.
This was followed by planning related losses caused by machines/Techniques (15,1 percent), shortage of personnel (7,5 percent), planned service/maintenance (6,9 percent), shift changes and breaks (5,9 percent), other planned stops (3,1 percent), problems with internal material (2,5 percent), problems with external material (1,7 percent) and lack of accessories (0,9 percent) making a total of 43 percent.
Performance related loss were micro stoppages with just 4, 8 percent while quality related losses were recorded to be just one percent.

5.1. Swedish food and beverage machines



	October	November	December	January	February	March
FB 14	73,5%	83,7%	82,7%	82,3%	80,1%	85,1%
FB 15	73,6%	76,8%	75,3%	83,9%	65,3%	82,1%
FB 44	0	56,8%	54,6%	62,4%	66,2%	81,0%
FB 40	66,3%	92,3%	78,0%	88,8%	86,7%	84,3%
FB 46	0	29,0%	34,0%	35,7%	54,8%	76,8%

Figure 10: ***OEE results over time for different Swedish food and beverage machines***

OEE analysis of different Swedish food and beverage machines between the month of October, 2012 and March 2013 shows a significant increase in their individual average OEE values on machines FB 14, FB 15, FB 44, FB 40 and FB 46. It should be noted that only five out of sixty one machines were chosen for the analysis. Machines FB 44 and FB 46 had an outstanding increase in their OEE results from 0% in the month of October to 81percent and 76 percent respectively.

Variations of OEE values within these months are caused as a result of losses which were either planned (planned factor), availability related losses known as unplanned losses, performance and quality related losses. Performance and quality had higher OEE values in the food and beverage machines.

Aggregated results of the sixty one machines loss within the Swedish food and beverage industries were conducted. The table below shows the percentage of aggregated losses that occurred within the different factors of OEE and their machines.

24 percent of the losses were planned related which were caused by machines/techniques, shift changes and breaks, planned service/maintenance, problems with external material, other planned stops.

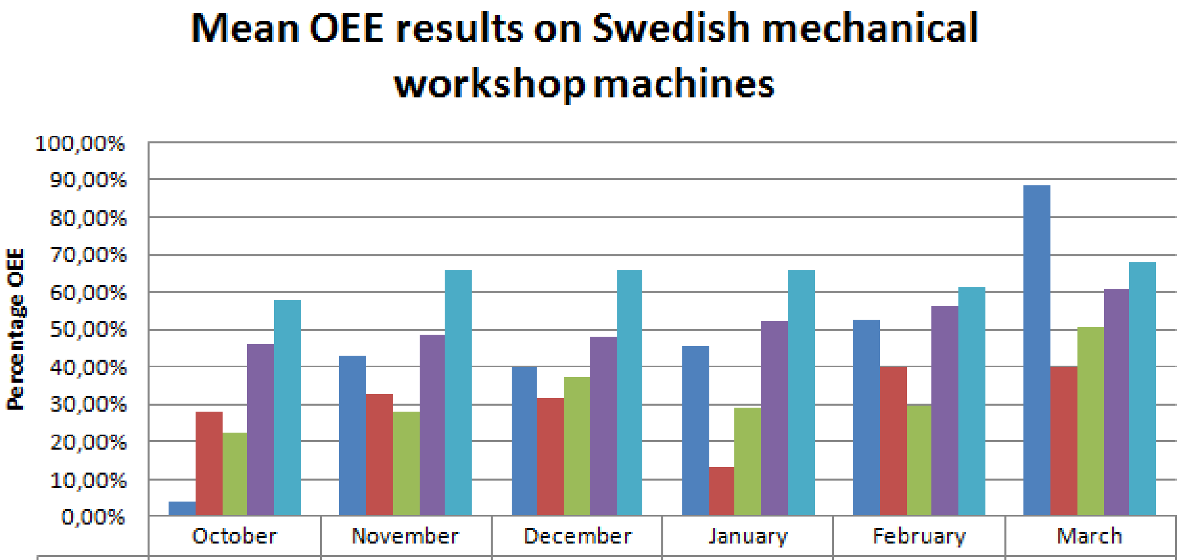
Availability related stops were unplanned losses caused by equipment breakdown/unplanned production and setup/changeover. These losses are made up of 24 and 14 percent, making a total of 38 percent out of the total percentage of losses.

Performance related losses caused only 2 percent and was caused by minor idling losses known as micro stoppages. There was no quality related losses within the Swedish food and beverage machines which is similar to the world class quality value of OEE.
35 percent of the losses were unknown or not recorded. This creates a lot of concern as it can easily alter our OEE results. The table below shows the summary of the related losses that occurred.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	10%
		Shift changes and breaks	1%
		Planned service/Maintenance	5%
		Other planned stops	2%
		Lack of accessories	0%
		Shortage of personnel	2%
		Personal time	0%
		Problems with internal material	4%
		Problems with external material	0%
Total			**24%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	24%
		Setup/Changeover	14%
Total			**38%**
Performance	Minor idling losses	Micro stoppage	2%
Quality	Defect and rework	Quality issues/Reworks	0%
No reason code	Unknown losses	Unknown	36 %

Table 8: ***Average downtime losses for Swedish food and beverage industries.***

5.2. Swedish mechanical workshop machines



	October	November	December	January	February	March
MW 6	3,90%	43,10%	39,70%	45,50%	52,70%	88,30%
MW 40	28,2%	32,6%	31,6%	13,1%	39,8%	40,0%
MW 39	22,4%	27,9%	37,3%	29,0%	29,7%	50,7%
MW 21	45,8%	48,8%	47,8%	52,2%	56,0%	60,8%
MW 29	57,6%	66,0%	65,7%	66,0%	61,3%	67,8%

Figure 11: ***OEE results over time for different Swedish mechanical workshop machines***

For the Swedish mechanical workshop industries, there was an increase in OEE values within some of their machines. Among the sixty five machines, results of OEE values on machines MW 6, MW 40, MW 39, MW 21 and MW 29 were significantly higher. Machine MW 6 shows the best increase in OEE value from 3, 9 percent in the month of October to 88, and 3 percent in March. This is then followed by machine MW 39 which rises from 22, 4 percent to 50, and 7 percent.

These OEE values differ among the months and are less than 100 percent. Aggregated losses in the Swedish mechanical workshop machines are defined and classified.

Planned related losses amounted to 25 percent which were caused by machines/techniques, shift and breaks, planned service/maintenance, other planned stops, lack of accessories, shortage of personnel, and problems with internal and external material.

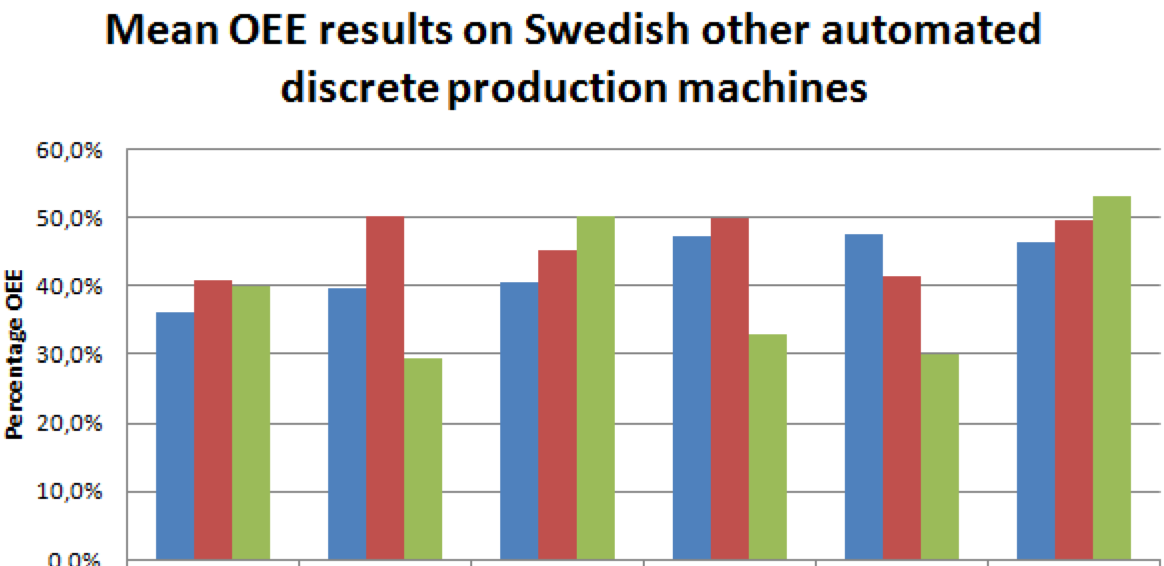
Availability related stops were unplanned losses caused by breakdown/unplanned production and setup/changeover. These losses amounted to 16 percent of which 3 percent is related to breakdowns and 13 percent, related to setup/changeover.

Micro stoppages known as performance related losses amounted to 5 percent while quality issues/reworks which are quality related losses were 2 percent. Unknown losses were recorded to be 52 percent. The table below illustrates the results of aggregated losses.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	9%
		Shift changes and breaks	6%
		Planned service/Maintenance	4%
		Other planned stops	1%
		Lack of accessories	1%
		Shortage of personnel	2%
		Personal time	0%
		Problems with internal material	1%
		Problems with external material	1%
Total			**25%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	3%
		Setup/Changeover	13%
Total			**16%**
Performance	Minor idling losses	Micro stoppage	5%
Quality	Defect and rework	Quality issues/Reworks	2%
No reason code	Unknown losses	Unknown	52%

Table 9: ***Average downtime losses for Swedish mechanical workshop industries.***

5.3. Swedish automated discrete production machines



	October	November	December	January	February	March
AU 9	36,2%	39,6%	40,5%	47,4%	47,5%	46,3%
AU 10	40,8%	50,2%	45,1%	49,9%	41,5%	49,5%
AU 19	40,0%	29,5%	50,2%	32,8%	30,0%	53,1%

Figure 12: ***OEE results over time for other Swedish automated discrete production machines.***

OEE results of different Swedish automated discrete production machines between the month of October, 2012 and March, 2013 were recorded. There was a significant increase in their individual average OEE values on machines AU 9, AU 10 and AU 19. A total of twenty one machines were registered. From the figure above, OEE results from the three machines were improved but only machines AU 19 and AU 10 but around 50 percent. Machines AU 9's OEE values was 46, 3 percent in the month of March but was significantly higher as compared with its value in the month of October.

Aggregated result of each of the twenty one machines losses within the Swedish automated discrete production were caused machines/techniques, shift changes and breaks, planned service/maintenance, other planned stops, shortage of personnel, problems with external material, equipment breakdown/unplanned production, setup/changeover and micro stoppages. Planned related losses (planning factor) amounted to 37 percent, availability related losses (unplanned factor) amounted to 26 percent with equipment breakdown (5 percent) while setup/changeover was 21 percent.

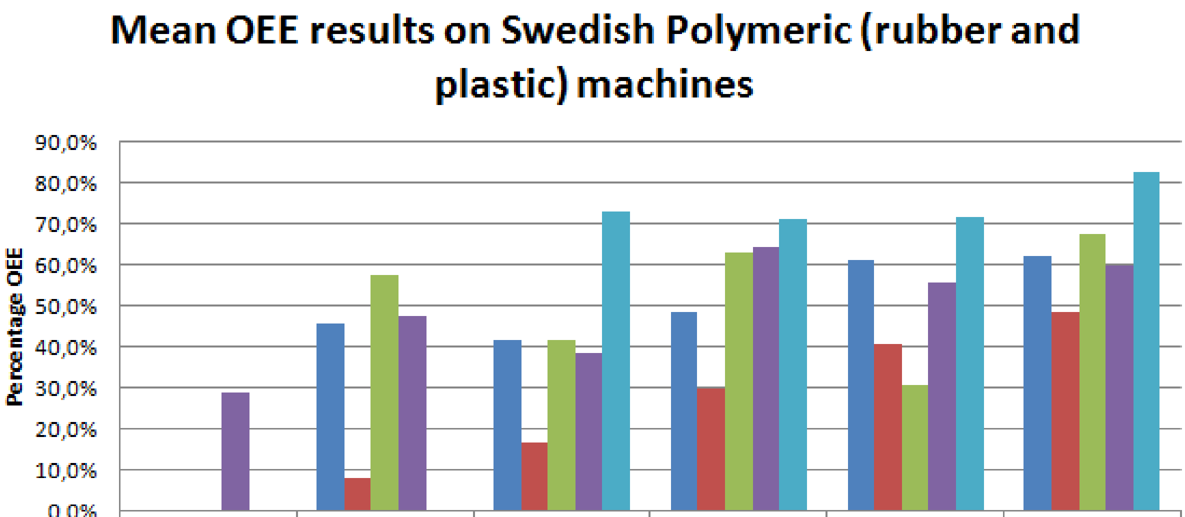
Performance related loss was micro stoppage with 3 percent. No quality related losses were identified. Apart from the losses that occurred, the remaining 34 percent were unknown as shown

.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	12%
		Shift changes and breaks	4%
		Planned service/Maintenance	6%
		Other planned stops	4%
		Lack of accessories	0%
		Shortage of personnel	10%
		Personal time	0%
		Problems with internal material	0%
		Problems with external material	1%
Total			**37%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	5%
		Setup/Changeover	21%
Total			**26%**
Performance	Minor idling losses	Micro stoppage	3%
Quality	Defect and rework	Quality issues/Reworks	0%
No reason code	Unknown losses	Unknown	34%

Table 10: ***Average downtime losses for other Swedish automated discrete production industries.***

5.4. Swedish polymeric (rubber and plastic) machines



	October	November	December	January	February	March
308	0	45,9%	41,6%	48,5%	61,3%	61,9%
184	0	8,0%	16,7%	30,1%	40,8%	48,7%
149	0	57,5%	41,6%	63,2%	31,0%	67,5%
S3	29,1%	47,5%	38,3%	64,2%	55,8%	59,8%
E6	0,3%	0	72,8%	71,0%	71,7%	82,7%

Figure 13: ***OEE results over time for Swedish polymeric***

In the Swedish polymeric industries, a total of 35 machines were recorded. Out of them, machines 308, 184, 149 S3 and E6 had significant increase in their OEE values within the months of October till March. The value “0” in the figures indicates that no values of OEE were registered. There was an increase in OEE values in machine 184 but it was still below 50 percent while machines 308, 149, and S3 had values just above 50 percent. The most significant improvement on OEE value is on machine E6 with a value of 0, 3 percent in the month of October to 82, and 7 percent in the month of March.
Although improvements were made leading to increase in their OEE values, some losses were identified to be the factors negatively affecting these values.
Planned related losses amounted to 11 percent which were caused by machine/techniques, planned service/maintenance, other planned stops, shortage of personnel and problem with external material.
That of availability related losses were unplanned caused by equipment breakdown/unplanned production and setup/changeover. They amounted to 24 percent of which 13 percent is related to breakdowns and 11 percent related to setup/changeover.
There were no performance or quality related losses making it a zero percent while unknown losses amounted to 65 percent.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Machines/Techniques	4%
		Shift changes and breaks	0%
		Planned service/Maintenance	1%
		Other planned stops	1%
		Lack of accessories	0%
		Shortage of personnel	4%
		Personal time	0%
		Problems with internal material	0%
		Problems with external material	1%
Total			**11%**
Availability	Unplanned Losses	Equipment breakdown/ Unplanned production	13%
		Setup/Changeover	11%
Total			**24%**
Performance	Minor idling losses	Micro stoppage	0%
Quality	Defect and rework	Quality issues/Reworks	0%
No reason code	Unknown losses	Unknown	65%

Table 11: ***Average downtime losses for Swedish polymeric industries.***

6. ANALYSIS AND SCOPE OF IMPROVEMENT

In this part, discussions regarding the results based on the big losses will be presented as well as possible solutions or countermeasures needed to address them. The solutions are taken from theoretical knowledge, observations, interviews, company and personal knowledge. Based on the four factors of overall equipment effectiveness (i.e. planning factor, availability factor, performance factor, and quality factor), degrees of losses were attributed.

In order to improve on OEE results, focuses has to be put on the major losses and looking for ways on how to eliminating them rather than smaller losses.

Type of industry	Amount of Unknown losses (%)
1. Food and Beverage	36%
2. Mechanical workshop	52%
3. Polymeric (Rubber and plastics)	**65%**
4. Other automated discrete production	34%

Table 12: ***Unknown losses for the four types of industries.***

Unknown losses could affect our results since it is not used in calculating the OEE values in the individual industries. This is a serious problem with most performance measurement systems among industries. Schmenner and Vollmann (1994) showed in an empirical study that they often include too many different measures, which might be difficult to understand or might be unsure of using the right measures in correct ways. From the unknown losses, other automated discrete production industry has the lowest of all. This helps us understand the need of automated systems to be implemented. It is also noted that these unknown losses could dramatically affect OEE results different from the main results since it is unpredictable.

6.1. Swedish food and beverage industries

Average OEE value for the Swedish food and beverage industries is 49, 9%. This is influenced by its average availability and performance rates with 58, 76% and 82, 60% respectively while average quality is 100%. It should be noted that few individual machines had good OEE results meanwhile most of them were affected by planned losses with a total of 24%. Some of the planned losses that can be eliminated are;

- Planned service/Maintenance with 5%, which can be scheduled out of the production time.
- Shortage of personnel with 2%, which is certainly a lack of planning.
- Problems with internal material with 4%. Verification and pre-testing should be carried in advanced before the production time begins.

Another the major loss is recorded as “unknown” with a total of 36%. It is actually the lowest unknown loss registered after the Swedish automated discrete production industries. This raises concern since it is actually not attributed to any of the factors of OEE. In order words, this could to alter our results in different ways. Some of the reasons given by operators are that they were unsure of the reason that could be attributed or system failure. Some could actually forget giving reasons based on being negligent, reluctant, too much work or procrastination. Education and training of operators is required in solving this problem and ensuring that they fully understand the importance of accounting to these losses.

Availability related losses as seen in table 8 are the highest and thus contributes negatively in their OEE results. A total of 38 percent of the total losses are availability related losses were equipment breakdown/Unplanned production and setup/changeover has 24 and 14 percent respectively. Again, equipment breakdown should have been separated from unplanned production so has to know the exact percentage losses attributed to each. Setup/changeover can be reduced with the help of Single Minute Exchange of Dies (S.M.E.D) program. Equipment breakdowns have 24 percent of the availability related losses. Root cause analysis such as Cause-effect diagram can be implemented so as to help identify and eradicate these losses.

A total of 24 percent of the total losses are planning related. These were due to other planned stops, shortage of personnel, problems with internal material, shift changes and breaks, and machines/techniques. Root-cause analysis such as 5 whys can be implemented in order to identify to attribute the reasons for each loss.

6.2. Swedish mechanical workshop industries

Its average OEE value 49, 8%, which is similar to that of the Swedish food and beverage industries. It is again influenced by its average availability and performance rates with 55, 98% and 89% respectively while average quality is 100%. It should be noted that few individual machines had good OEE results meanwhile most of them were affected by planned losses with a total of 25%. Some of the planned losses that can be eliminated are;

- Shift changes and breaks with 6% which can be minimized by good planning.
- Planned service/Maintenance with 4%, which can be scheduled out of the production time.
-
- Shortage of personnel with 2%, which is certainly a lack of planning.

The highest incurred losses were again attributed to “unknown” with 52 percent. As seen in table 12, it is the highest unknown loss after the Swedish polymeric industries. The remedy for this problem is education and training of operators. Another major loss in the Swedish mechanical workshop was planning related with 25 percent of the total losses. The reasons for these losses could be identified with the help of five whys. Shift and breaks with a 6 percent loss could be reduced or more operators could be added into the plant so as to maximise the planning factor. Unplanned losses (equipment breakdown) can be improved with the help of Cause-effect diagram while setup/changeover would need the S.M.E.D program.

6.3. Swedish automated discrete production industries

Average OEE value for the Swedish automated discrete production industries is 43, 3%. This is influenced by its average availability with 44, 90% while performance rates 96% and quality 99, 8%. Again, few individual machines had good OEE results meanwhile most of them were affected by planned losses with a total of 37%. Planned losses are recorded as the highest compared to the other types of Swedish industries. Some of the planned losses that can be eliminated are;

- Shortage of personnel with 10%, which is certainly a lack of planning.
- Planned service/Maintenance with 6%, which can be scheduled out of the production time.
- Other planned stops which is not well detailed. 5whys could be used to trace the causes for these stops.

"Unknown" loss as seen in table 12 is the lowest in all the major industries with 34 percent. Its elimination could highly influence the results in a positive way. This is in accordance to the benefits of an autonomous system where losses are either recorded both manually and automatically or automatically.
In the automated discrete production industries, the biggest losses that decreased the OEE values planning related. They took up to 37 percent of the total losses incurred. An important root cause program to apply would be the 5 whys for example shortage of personnel with 10 percent or shift and change over with 4 percent.
Other major losses were unplanned due to breakdowns and setup/changeover with 26 percent. As early stated in other Swedish industries, improving breakdowns with require the Cause-effect diagram program while setup/changeover will require the S.M.E.D program.

6.4. Swedish polymeric industries

With an average OEE value 38, 7%, which is the lowest value compared to the other Swedish industries. Simply influenced by its average availability and performance rates with 44, 70% and 89, 7% respectively while average quality at 95, 9%. Again, that few individual machines had good OEE results meanwhile most of them were affected by planned losses with a total of 11%. Some of the planned losses that can be eliminated such as

- Shortage of personnel with 2%, which is certainly a lack of planning.

The highest loss under the Swedish polymeric industries as seen in table 12 is "unknown" with 65 percent. It is actually the highest loss among all the other type of industries. On the other hand, planned related losses are the lowest in all the different types of industries with only 11 percent. Major improvement could be done in order to reduce planned loss due to shortage of personnel (4%). Availability related with equipment breakdown (13 percent) and setup/changeover (11 percent). Improvement programme called Cause-effect diagram could be implemented in equipment breakdowns while S.M.E.D program on setup/changeover.
The second big losses are planning related with a total of 35 percent and the lowest the lowest loss compared to the other types of industries (35 percent). An initial 5 whys method could be applied so as to improve and eliminate these losses. The performance factor was the best with 0 percent as compared to the other types of industries.

7. CONCLUSIONS AND RECOMMENDATIONS

This thesis carries out a thorough analysis of overall equipment effectiveness within four types of industries by identifying all the losses. OEE provided a holistic view of how efficient different processes within the four types of industries are performing and how easy one type could affect another. Decision makers could know the causes of stops and their various times obtained from data provided in this thesis.

The strength of OEE is to improve competitiveness in any manufacturing industry by creating a better return on investment (ROI) and producing increased productivity. A world class value of overall OEE is 85 percent where availability is expected to be 90 percent, performance 95 percent and quality 99, 9 percent. This value is greatly influenced by potential losses since it is the difference between ideal and actual states. However, according to Williamson (2006) there is no specific world class value which is also the case based on the empirical study carried out on the different sectors of Swedish industries. Setup and adjustment time increases accordingly with the product mix in manufacturing industries and will of course have an adverse effect on OEE value. The only OEE parameter that suits this value is the average quality factor. The average OEE values are affected by their average availability and performance rates. Swedish automated discrete production industries is the most have the best overall OEE parameter than the other Swedish industries based on their average performance and quality rates with 96,2 and 99,8 percent respectively. Generally, the worst overall OEE parameter is the average availability in all the Swedish industries. This is highly affected by their overwhelming losses or based on limitations based on the unknown losses that were not recorded.

Though quality related losses have been the lowest within the Swedish industries corresponding to the suggested world class quality value of OEE, the biggest losses in Swedish industries are recorded as "unknown" and therefore create a sense of irresponsibility between all the industries which is of great significance since it could affect average OEE value for the different sectors. This calls for an awareness and possible training all parties on the importance of information within all the different sectors within the industries. The reasons for measurement are important since it helps in decision making and help creates a benchmark for potential improvements. There is need for finding out why stoppage reasons were not being provided and this research could be extended in answering this.

As a matter of fact, average OEE on these Swedish industries have been poor. This indicates that they are not working according to the OEE concepts and employing fundamental principles of its theory. Potential reasons could be;

- That they think(through guessing) they have a better equipment efficiency than they actually have and see no direct need to measure their processes
- That untrained operators do not understand how the system put in place is used.
- That the system is too complex (so many stoppage reasons) and difficult to understand.
- Based on procrastination.
- Because operators think it could be used in measuring their own performance instead.
- That the system itself is not functioning properly.
- Those operators do not really care about the system or its benefits towards them.
- That previous data were not used by the management and it is not really relevant.
- Based on change on management and so much change of systems.

- Misunderstood and misused.
- It is not really being used for future improvement but simply book keeping.

Potential difficulty in personnel's resistance to change can be overcome by devoting great efforts towards internal communication and making messages understood. This can improve current performance to gaining sustainable competitiveness.

The simple tool known as 5 whys or fishbone diagram for complex systems could be used in acquiring possible reasons to the loss related events which could be caused by machines, humans, process, material or method. This also raises an issue on data accuracy as the reliability of OEE values depends highly on. It is therefore important to invest in automated supervision system which could improve data credibility and reliability in a frequent manner.

Companies increasingly acquire and rely on costly equipment and new technologies. Since this is vital for operations, reliance on new technologies and equipment has eventually led to create probability for a critical system to fail. These resulting unbudgeted losses can be extremely costly, and in some cases, create a bigger impact on the ability of operators to operate. The benefits of OEE would enhance;

- Accuracy of information through automatic data collection.
- Efficiency and effective usage of their existing equipment and facilities.
- Visible and clear reporting to inform decision making.
- Energy efficiency and quality monitoring facilities.

In all the four types of industries, availability related losses played the greatest part for a low OEE. Setup and changeover was the major loss than any other which calls for the implementation of SMED. Introducing SMED will reduce cost of inventory as well as meeting customer demand.

Since one can only control what is measure, OEE improvement within the Swedish industries will therefore increase availability, speed and quality since it is a technical ratio related to equipment effectiveness.

7.1. Future recommendations

Future recommendation would be informing all the operators and personnel before any of these solutions are implemented. Since people are sometimes resistant to change, the need to motivate as well as providing a clear reason for these changes should first be brought forward. Training and empowering the staff creates awareness and promotes a sense of responsibility on their part. A system should also be designed in other to fit the specific process in any industry. Qualitative research can be carried out in gathering data based on interviews (through phone or face-to-face), through questionnaires addressed to operators and the entire management teams. Data from a build cross-functional team work could help create a more reliable and valuable data.

Further unplanned measures due to breakdowns of machines might require preventive maintenance, or vibration analysis.
Future research may be done to explore;

- Operation and production design.
- The dynamics of translating equipment effectiveness or loss of effectiveness in terms of cost.
- Machine design or mechanical design.
- Frequency studies on man hours (Human OEE).

7.2. Further research

One important aspect that could further improve the work already carried out in this thesis would be quantitative research. Some of the difficulties encountered during this work were;

- Unavailability of data from some industries limiting the research.
- Incomplete data from some industries.

Due to the fact that this research had a short time frame, it is recommended that a quantitative research should be applied to as to gather more quantitative data. This can be done in the form of questionnaires either open-ended, closed-ended or a combination of both. Contact methods may gather information through mail, telephone or personal interview. Questionnaire consists of a set of questions presented to the various industries so as to get their own interpretation (answers). This will help answer some of the questions that might help solve the OEE problem in return. High quality can be established due to effectiveness and efficiency due to effort put by man, machine, method and material.

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9. APPENDICES

9.1. Presentation of Company

Good Solutions[3] is a Gothenburg based software company. The company was founded in 2005 and has since the beginning only indulged in production monitoring in various forms. After a few years of searching, they founded the 2007 definition of product RS -Production when they received the first orders for solutions to stop time monitoring and OEE measurement. Its proprietary product RS-Production used by manufacturing companies that focuses on high production efficiency and increased profitability. In addition to the software offered services to assist client companies to achieve the full potential of the software. This often involves coaching services in different ways to mature in its improvement.
The software RS -Production is an accessible tool for practical improvements and real-time visualization of production status against plan. An important basic feature is the automatic identification of production disruptions and visualization of transient causes' impact on production efficiency. This is done in clear and easy user interface so that all can participate.
The company is driven by a clear goal of establishing a standard product in both Sweden and in other geographic markets. Getting there by committed employees who are in dialogue with its customers, they develop a scalable product with the help of modern techniques mostly from Microsoft. In the background is an experienced and financially stable ownership structure.
It has over 90 customers both in Sweden and worldwide.

The company is divided four main areas, as shown in Figure 2.4 below.

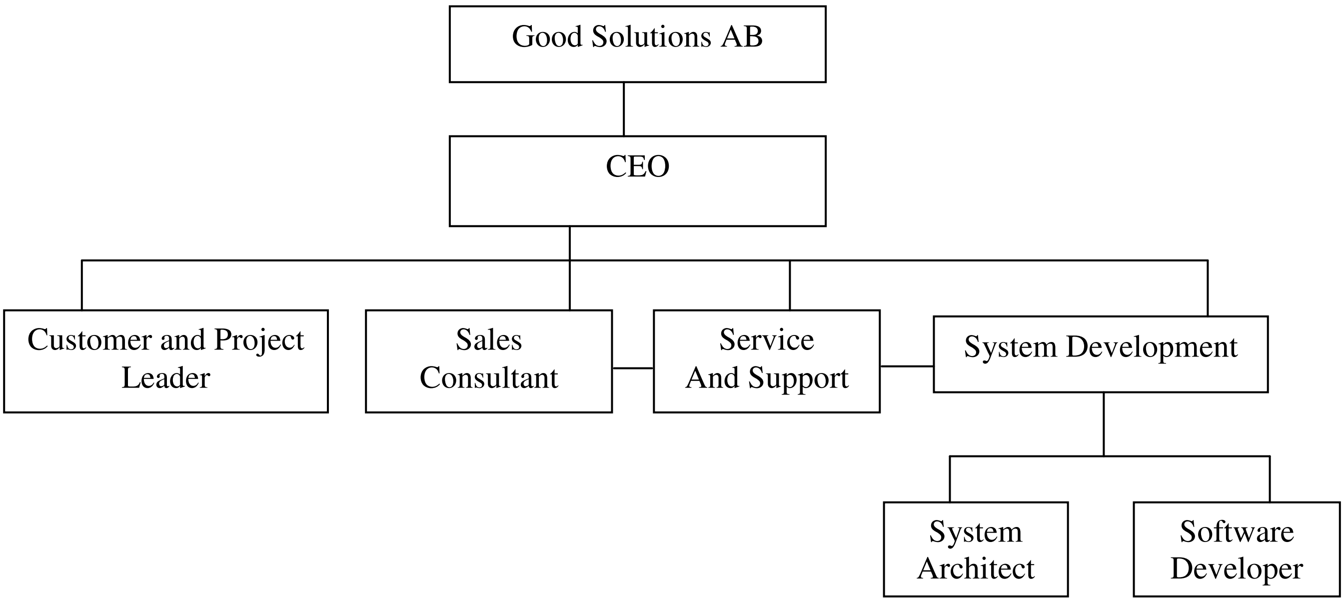

Figure 9.1 Organization Chart Good Solutions AB

[3] http://www.goodsolutions.se/

9.2. Average OEE for other automated discrete production machines

Other automated discrete production (Machines)	Average OEE
AU 11	27,6%
AU 12	41,5%
AU 13	27,9%
AU 1	28,5%
AU 22	28,2%
AU 14	21,2%
AU 15	48,3%
AU 16	49,2%
AU 17	53,7%
AU 2	73,6%
AU 3	13,1%
AU 4	65,5%
AU 18	47,6%
AU 8	59,5%
AU 9	42,9%
AU 10	46,2%
AU 5	36,1%
AU 6	27,6%
AU 7	29,4%
AU 19	39,3%
AU 20	5,7%
AU 21	22,8%
Total	**38,0%**

9.3. Average OEE for Mechanical workshop machines

Mechanical workshops (Machines)	Average OEE
MW 5	36,0%
MW 21	51,9%
MW 6	45,5%
MW 7	37,0%
MW 20	45,9%
MW 12	80,9%
MW 13	78,2%
MW 36	28,5%
MW 10	58,0%
MW 30	43,9%
MW 31	68,1%
MW 42	65,5%
MW 43	28,6%
MW 32	53,1%
MW 11	42,8%
MW 37	30,1%
MW 44	15,2%
MW 66	18,4%
MW 34	63,8%
MW 33	63,3%
MW 8	71,1%
MW 14	48,0%
MW 15	66,8%
MW 45	61,5%
MW 22	85,3%
MW 23	72,7%
MW 24	71,5%
MW 47	42,8%
MW 48	51,0%
MW 49	48,0%
MW 50	50,8%
MW 51	38,2%
MW 52	20,8%
MW 53	37,0%
MW 54	44,8%
MW 46	29,6%
MW 9	21,2%
MW 1	38,1%
MW 2	20,0%
MW 3	34,3%

MW 38	15,7%
MW 55	12,9%
MW 56	30,1%
MW 39	32,8%
MW 25	76,0%
MW 16	71,5%
MW 40	30,9%
MW 41	24,2%
MW 57	23,1%
MW 58	22,5%
MW 17	51,2%
MW 59	62,5%
MW 60	53,7%
MW 61	58,4%
MW 62	63,6%
MW 63	52,4%
MW 26	74,2%
MW 27	79,3%
MW 28	64,1%
MW 29	70,3%
MW 64	52,4%
MW 35	63,0%
MW 65	2,1%
MW 18	40,7%
MW 4	58,5%
MW 19	73,4%
MW 66	66,6%
Total	**48,3%**

9.4. Average OEE for food and beverage machines

Food and beverages (Machines)	Average OEE
FB 47	31,8%
FB 34	59,6%
FB 35	74,4%
FB 36	80,6%
FB 37	91,6%
FB 38	92,1%
FB 2	51,5%
FB 29	51,0%
FB 1	37,3%
FB 48	28,1%
FB 49	32,2%
FB 3	43,2%
FB 4	49,4%
FB 50	27,1%
FB 50	29,9%
FB 6	40,1%
FB 7	60,5%
FB 8	49,0%
FB 9	40,0%
FB 10	51,0%
FB 51	27,7%
FB 11	61,6%
FB 52	30,7%
FB 12	49,1%
FB 53	47,9%
FB 54	45,7%
FB 12	44,0%
FB 13	59,5%
FB 14	81,2%
FB 15	76,2%
FB 16	68,8%
FB 17	29,7%
FB 18	73,1%
FB 19	65,6%
FB 39	73,2%
FB 40	82,7%
FB 41	92,3%
FB 42	81,8%
FB 43	90,2%
FB 30	71,7%

FB 31	64,3%
FB 32	70,1%
FB 33	47,2%
FB 20	13,5%
FB 21	22,6%
FB 22	25,5%
FB 23	34,4%
FB 24	17,6%
FB 25	28,8%
FB 55	16,8%
FB 56	13,7%
FB 26	21,0%
FB 56	14,8%
FB 57	16,5%
FB 58	1,6%
FB 27	30,6%
FB 28	35,6%
FB 44	59,2%
FB 45	41,6%
FB 46	46,0%
Total	**48,2%**

9.5. Average OEE for polymeric (Rubber and plastic) machines.

Polymeric (Rubber and Plastics) Machines	Average OEE
17	54,3%
139	43,9%
140	56,6%
148	42,9%
149	52,2%
150	56,9%
154	63,8%
155	37,0%
161	56,2%
162	20,3%
164	52,5%
166	42,2%
167	37,1%
168	27,7%
169	61,3%
170	26,9%
171	65,0%
173	80,2%
176	18,5%
178	31,0%
179	45,5%
183	85,0%
184	28,8%
189	47,4%
190	22,3%
195	34,6%
308	51,8%
309	11,9%
577	12,2%
E6	59,7%
S1	26,9%
S12	52,0%
S14	49,2%
S3	49,1%
S4	42,7%
Total	**44,2%**