POLITECNICO DI TORINO

Master's Thesis in Engineering and Management

Overall equipment effectiveness (OEE) analysis in CHEP

Supervisor:

Professor: Giulia Bruno

Department of Management and

Production Engineering

Candidate:

Siyavush Juraev

Company:

CHEP ITALY S.R.L.

Academic Year 2021/2022

Contents

ABSTRACT

The thesis focuses on the concept of overall equipment effectiveness by implementing productivity improvement strategies across CHEP. In October, November, and December of 2021, the research was completed that had been started.

Total equipment effectiveness has been designed as a conceptual framework to analyze the impact of qualitative and performance-related losses on a system or equipment. Following this, a survey is conducted on a small portion of the entire process, and the findings are analyzed using Excel.

Researchers are using a theoretical model in their quest for ways to increase overall equipment effectiveness. To assist Lean Manufacturing and Total Productive Maintenance (TPM), the OEE is a critical performance measure that is commonly implemented. While the OEE depicts a process in a static manner, it does not portray the actual variety of lean manufacturing [1]. There were organizational and availability-related losses discovered during the research. Single Minute Exchange of Dies (SMED) is a strategy for shifting internal events (setups and changeovers) to external events to reduce the number of poorly planned events that occur. Even during manufacturing, it has been shown that OEE values may be considerably improved by eliminating all the related issues.

Equipment malfunction, unscheduled, and absence of personal output were three of the most common causes of unplanned losses. It may be easier to define, assess, and propose possible cures. It may be easier if the losses were broken down into three distinct categories.

In certain cases, costs are recorded as "no reason code" since the personnel did not offer any information or no data input was gathered. This indicates that the entire team, not just the device users, must be educated, trained, and made aware. Thus, the entire business has developed a strong feeling of responsibility and loyalty. Using the "5 whys"[2] approach or a sophisticated fishbone diagram, we are able to identify the root cause of the issue.

ACKNOWLEDGEMENTS

Professor Giulia Bruno, Department of Industrial and Information Engineering, Turin Polytechnic University, Italy, has been a tremendous mentor and help to the author during this thesis project. Alisher Ruzikulov, my supervisor and plant manager at CHEP, has been a tremendous source of inspiration and support for our project. This endeavor would not have been feasible without his encouraging guidance, sound advice, and never-ending motivation. This study would not have been possible without the help and cooperation of everyone at CHEP, Turin, Italy, and we are grateful for that.

INTRODUCTION

In recent decades, manufacturing enterprises have fought against the threat of being forced out of the market by customer retention. For this to happen, there must be a desperate tendency to eliminate industrial waste while increasing production efficiency. Instead of focusing on reducing operating costs by reducing economic loss, manufacturers avoid increasing prices and exerting strain on customers.

$$\mathbf{TP = P*Q-TC}$$

TP = total profit

P = Price of the product

Q = Quantity of product

TC = Total cost of the product

Increasing the price of a product or reducing the overall cost of a product can both increase profit. Decreasing overall expenses is much more vital than raising prices, which might lead to a loss of customers. Through Total Productive Maintenance (TPM), infrastructure production could be raised while maintenance costs are lowered. Total Productive Maintenance will be used to evaluate six preventable wastes in further depth.

Background

[3]

In order to increase output in any industry, efficiency and effectiveness must be strictly enforced in today's highly competitive market. For the time being, success can only be measured in terms of rising profitability. Identifying and eliminating hidden waste and bottlenecks in every manufacturing environment requires an efficiency metric that measures the overall performance of equipment against its theoretical potential [4]. Analysis of industries indicated that they needed to modify their performance evaluations or use the appropriate measurements in the correct manner [5]. With these measures, the following must be considered:

1. What to measure and

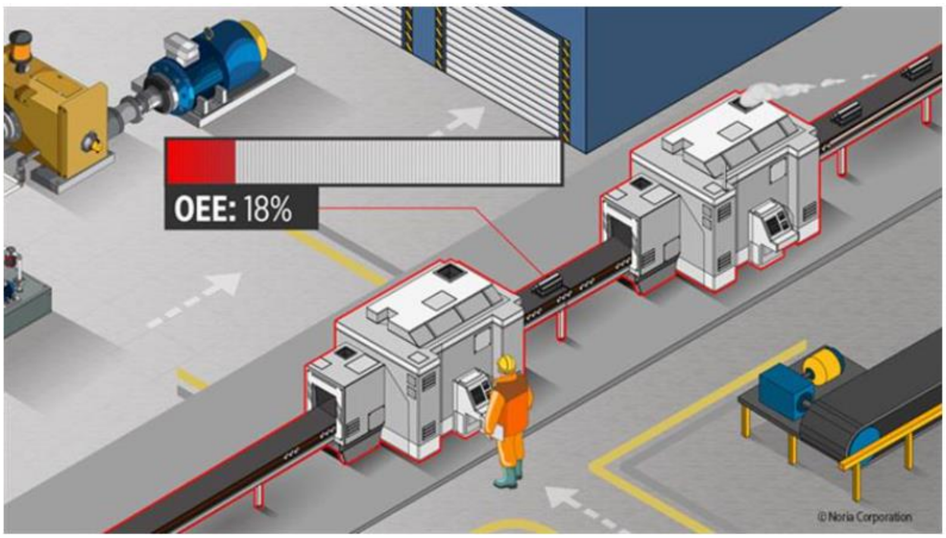
2. How to measure

Available and productive production facilities are the only way for manufacturing sectors to remain competitive in a highly competitive industry [6]. To do this, they must first focus on increasing and optimizing their efficiency, which means seeking out and reducing unnecessary production losses. As a result, production costs are reduced, companies stay competitive, and customers' needs are met [7].

The Japan Institute for Plant Maintenance (JIPM) was the first to create it, and it is now extensively utilized across a wide range of sectors. In addition, it provides the foundation of performance improvement approaches such as TQM and Lean Production. The phrase "total productive maintenance" (TPM) was coined by Nakajima [8], who went on to create the concept of "overall equipment effectiveness" (OEE). Overall equipment effectiveness may be used to find and quantify the company's most efficient machinery. OEE's three components of an assessment are performance, availability, and quality. With a few mouse clicks, you can see the status of any product in real-time. When prospective losses are detected and remedies are put in place, they are significantly reduced. Such observations might be made on equipment, people, and materials, resulting in an improvement in productivity. World-class status is provided by OEE in the following ways:

- Minimizing infrastructure downtime and maintenance costs are two ways to approach equipment product lifecycle management.
- It boosts output whilst simultaneously improving worker efficiency. Visibility into operations improves as controllers acquire greater power.
- As a result of the ease with which bottlenecks may be located, productivity increases.
- Consequently, the end product's quality improves.

In semiconductor production, it has been widely employed since it supports and enhances the efficiency of equipment and expands productivity [7]. The deployment of OEE in Nigeria's beverage sector resulted in a 50% rise in its value and a decrease in waste while increasing equipment uptime [9]. New levels of performance measurements were discovered and emphasized by Airbags International Ltd.'s (AIL) application of total equipment efficacy as a major production measure [10]. According to a literature review, the OEE metric's application range in the real world remains unexplored, notwithstanding researchers' demonstration of its depth.



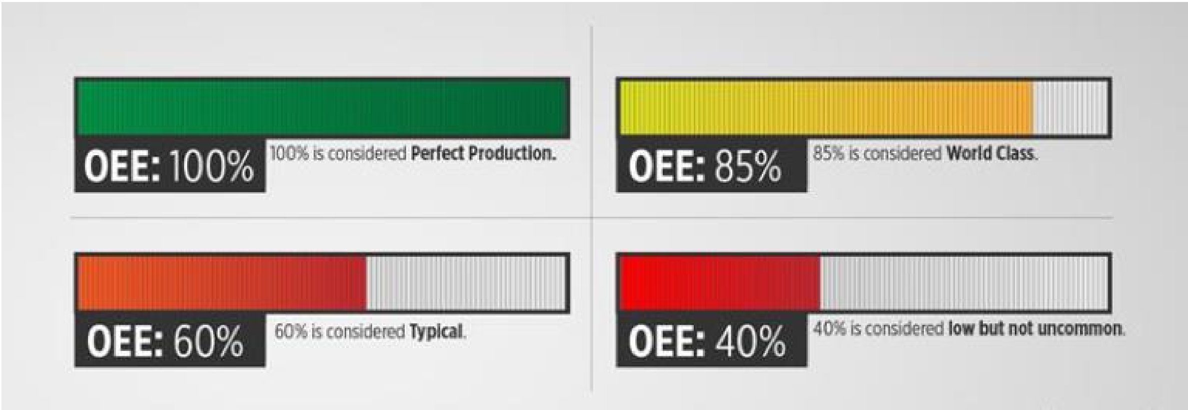
[11]

OEE provides both a standard and a baseline for measuring performance [12]:

- An output resource's OEE might be evaluated against industry standards, equivalent in-house assets, or the results of different shifts working on the same asset.
- OEE may be used as a baseline to measure progress in reducing inefficiency on a specific production asset over the course of time.

OEE Benchmarks

What is regarded as a "good" OEE score as a benchmark? What is considered a world-class OEE score in the context of this discussion?



[13]

- Only high-quality components are being produced at a high rate of speed with no stoppage if your OEE score is 100%.
- OEE of 85% is regarded as world-class in the context of independent manufacturers. It's a good long-term objective for many businesses.
- 60% OEE is a good benchmark, but there is a lot of space for development in this industry.
- If you're a new manufacturing company, 40 percent OEE is not out of the question. You can increase it with simple actions like recording stop time causes and tackling the biggest drivers of downtime one-by-one, but it's still a poor grade.

Problem formulation

While CHEP has a duty to enhance its goods, identifying and removing non-value-added processes is essential to maximizing productivity. Using OEE, a system or equipment's functionality and quality-related losses may be easily spotted, allowing you to identify these processes as losses. The OEE performance study is essential to identify the possible losses and where they influence the OEE variables.

It's common for issues to develop in collecting the data needed for an OEE study and/or adapting the loss categorization structure to meet unique industry needs. Muchiri and Pintelon's [14] latest study provides a comprehensive literature review of these difficulties, which have resulted in a broad range of inventive solutions.

Aims and research questions

This thesis investigates the advantages of overall equipment efficacy, relying on its theoretical concept. When it comes to OEE literature, performance assessment plays an important role. The OEE measurements and underlying losses from CHEP are then examined to show the usage of the OEE method, via which a company's department can schedule and track changes.

Considering these concerns, it appears that OEE calculations should incorporate volatility analysis. Starting from the primary determinants of waste's PDF [1], OEE is handled as a stochastic random variable and an approximate statistical technique is utilized to create its pdf. Even the selection of an appropriate data collection period may be substantially simplified in this manner, allowing one to readily analyze the OEE's mean and standard deviation (i.e., the variability). Consolidation of data for the OEE can be done on a monthly or quarterly basis, for example, whereas the plant's operating lifecycle can be viewed as the acceptable timescale for data collection. Reliability and durability of outcomes are guaranteed without sacrificing or sacrificing crucial information about production variability.

Additionally, the suggested technique provides the opportunity to detect and assess the impact of various remedial measures in terms of both efficiency and efficacy, which is a significant benefit. It is widely accepted that a manufacturing process is considered successful if it achieves the desired results and efficient if its outputs are obtained with the fewest assets. Instead of focusing on outputs to determine if a process is effective, efficiency measures inputs to determine how well a process functions.

Is OEE a typical occurrence? The overall equipment effectiveness is 85 percent, with 90 percent availability, 95 percent performance, and 99,9 percent quality.

Objectives of OEE

- To increase the overall performance and reliability of an asset by focusing on a specific machine or piece of equipment.
- Underperformance or failure to meet expectations can have several causes. OEE serves as a starting point for prioritizing improvement efforts and identifying fundamental causes.
- To keep tabs on the advancement or deterioration in equipment efficiency over a period.
- To prevent an unbalanced flow by concealing or tapping into unused industrial capability.
- Since "maintenance" alone can't enhance OEE by itself, asset operations, maintenance, buying, and system design must work together to discover and remove (or minimize) the root causes of poor performance.

Project limitations

It's a tool for evaluating a machine's overall performance. Data gathered outside the targeted plant isn't evenly distributed in this investigation. As a result, some of the data could not be processed, while others were insufficient.

The data obtained throughout three months (October, November, and December 2021) resulted in a wide range of product variances and machine limitations, which might affect the results of this thesis study. How sophisticated product designs and operator expertise affect OEE outcomes is also a question.

RESEARCH APPROACH

Another important aspect to consider before beginning a research project is choosing a suitable strategy for gathering data. Quantitative and qualitative data collection approaches are used in the majority of scientific research [15].

Quantitative method

The creation and reliance on statistical information is the major focus of this technique. Each subject is represented by one or more samples, which are then compared to a small number of variables. It is more objective and shows a better understanding of research and theory. By gathering numerical data and analyzing it using mathematically based methodologies (such as statistics), one may interpret the phenomenon [16].

It was decided to conduct a quantitative study referring to the total efficiency of the equipment. As part of Seiichi's total production maintenance (TPM) strategy, which employs OEE as a quantitative indicator for assessing the efficiency of each manufacturing unit in a plant, this is relevant.

[17]

Qualitative method

According to Gummeson [18], non-numerical data is widely employed in qualitative research to gain an in-depth understanding of the characteristics of the research topic. The goal of this strategy is to discover the underlying causes and motives of a given scenario. There are many factors in a group sample, and this gives a full grasp of how to handle things or deal with them. When doing quantitative research, Darmer and Freytag describe a high degree of flexibility and adaptability for individuals, or when conducting both quantitative and qualitative research at the same time. The distinction between quantitative and qualitative data is crucial.

This section includes three primary forms of information:

Qualitative Data Collection	Phases in the Process of Research	Quantitative Data Collection
1. Purposeful sampling strategies 2. Small number of participants	Sampling	1. Random sampling 2. Adequate size to reduce sampling error and provide sufficient power
1. From individuals providing access to site 2. Institutional review boards 3. Individuals.	Permissions	1. From individuals providing access to sites 2. Institutional review boards 3. Individuals
1. Open-ended interviews	Data sources	1. Instruments

2. Open-ended observations 3. Documents 4. Audiovisual materials		2. Checklists 3. Public documents
1. Interview protocols 2. Observational protocols	Recording the data	1. Instruments with scores that are reliable and valid
1. Attending field issues 2. Attending to ethical issues	Administering data collection	1. Standardization of procedures 2. Attending to ethical issues

Similarities between Qualitative and Quantitative Methods [19]

Literature study

Detecting and eliminating waste is another technique to boost output. Total Productive Maintenance is a technique for ensuring the long-term viability of equipment and machinery. The information used comes from resources at Google Scholar, SSRN, ScienceDirect, ResearchGate, and IEEE, as well as other Social Science Research Networks (SSRN).

Literature as a tool for research: Three months of real-time data were collected from a variety of equipment, including their significant losses, OEE values, production times, change-over and setup times, and cycle times. The data came from a variety of machines. The brainstorming method was used to conduct all the interviews and discussions that took place throughout the course of the project. They were detained during this time. As a consequence of this, several of the queries in the literature study were answered.

The collection of information and the method used to collect it are crucial since OEE evaluation is completely reliant on them. To have a solid foundation for further research, the facts must be gathered in a logical order. Consequently, it must be truthful and objective without being skewed by bias. Research techniques in this project may be divided into two categories: quantitative and qualitative. Without measurement [14], there will be no improvement in performance metrics or growth over time. By hand, the operators gathered this information. According to Jonsson and Lesshammar[4], manual data collection is less reliable, especially when reporting short malfunctions or unavailability, which can be easily ignored.

Analysis

Attending CHEP requires you to provide both quantitative and qualitative information (interview material, difficult to measure). Qualitative data, on the other hand, gives a more in-depth understanding of the statistical underlying results.

It is during this phase of the analysis that challenges and possibilities are continuously explored. When it becomes difficult to understand what analyses may be performed or how judgments and actions can be taken, the accuracy and usability of assessments may be questioned. Careful planning was necessary when the project had to be completed on time. Rescheduled many times due to unforeseen events. Improvements in the scope of work demanded more time for comprehension and execution. Because of this, Microsoft Project creates a Gantt chart that provides a clear picture of the whole project. No interruptions were made due to the inclusion of both scheduled and unscheduled meetings with supervisors in this Gantt chart. This is merely a summary of the project since a record was kept of all the tiny details and activities that took place during it. When it comes to data, this plant's management team is efficient. Consequently, the project was able to run well because of the peaceful and understanding environment that was created.

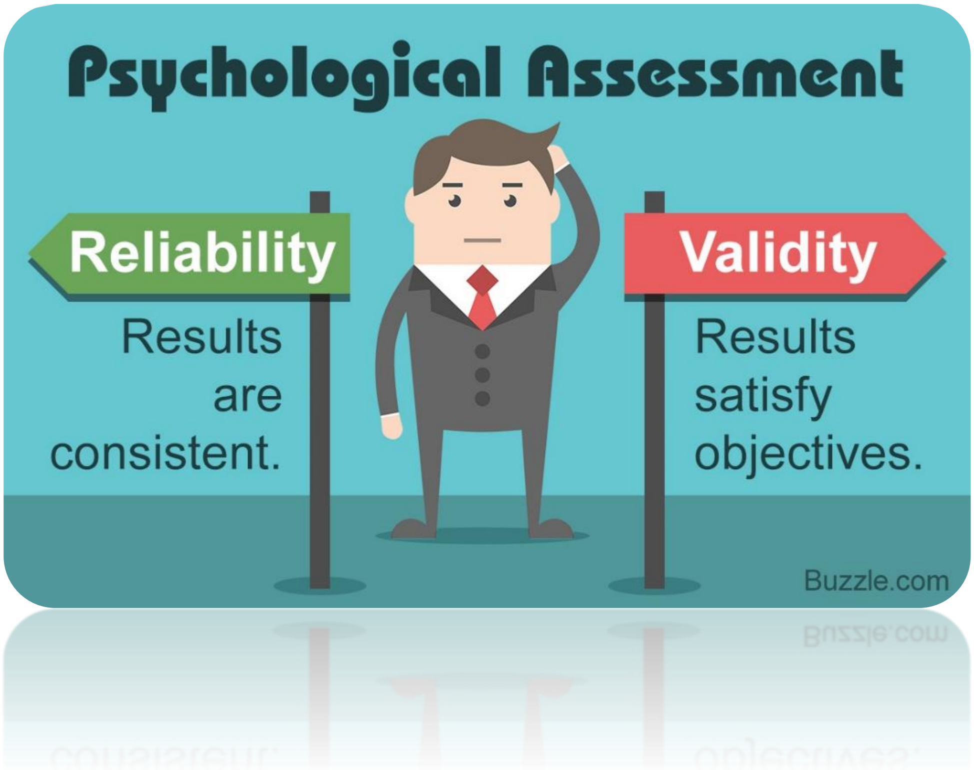
Week	Task
1-3	Introduction of the project
4-8	Project planning and literature studies
9-11	Data collection and literature studies
12-13	Analysis and thesis

Draft table of project planning

Validity and Reliability

It is not enough for research to be effective or relevant to all areas of the primary subject to be considered a good study. So the study's validity and reliability must be evaluated as a result. When it comes to obtaining reliable and accurate information, the questionnaire structure and question design play a critical role. In order to eliminate wrong answers, its primary purpose is to reduce the likelihood of subjective question construction [20].

Procedures were implemented at every stage of the investigation, including data analysis and interpretation, and hypothesis formation, in order to ensure the reliability and validity of the data. The use of a questionnaire-based technique helps assure data accuracy and validity. It was also possible to increase the accessibility of the research by employing raw data analysis, descriptive, and regression analysis approach.



[21]

	Reliability	Validity
What does it tell you?	How well outcomes are repeatable if they are conducted again under similar settings.	To what degree are they able to measure what they are meant to measure.
How is it assessed?	By ensuring that the outcomes are consistent throughout time, between observers, and inside the test itself.	By evaluating how closely the findings match up with existing theories and other methods of assessing the same subject.
How do they relate?	A reliable measurement is not always valid: the results may be repeatable, but that doesn't mean they're accurate.	A valid measurement is generally reliable: reproducibility is an indicator that a test yields accurate findings. [22]

Key points to differentiate reliability and validity

Validity: uniform work is required for the whole sector, allowing for thorough communication among personnel. Worker participation and responsiveness to deviations in manufacturing processes are established under this framework [23]. As stated by Freivalds [24], the validity of efficiency gains and reducing the risk of new workers making errors are both dependent on a homogenous working environment. Validity may be established in a variety of ways.

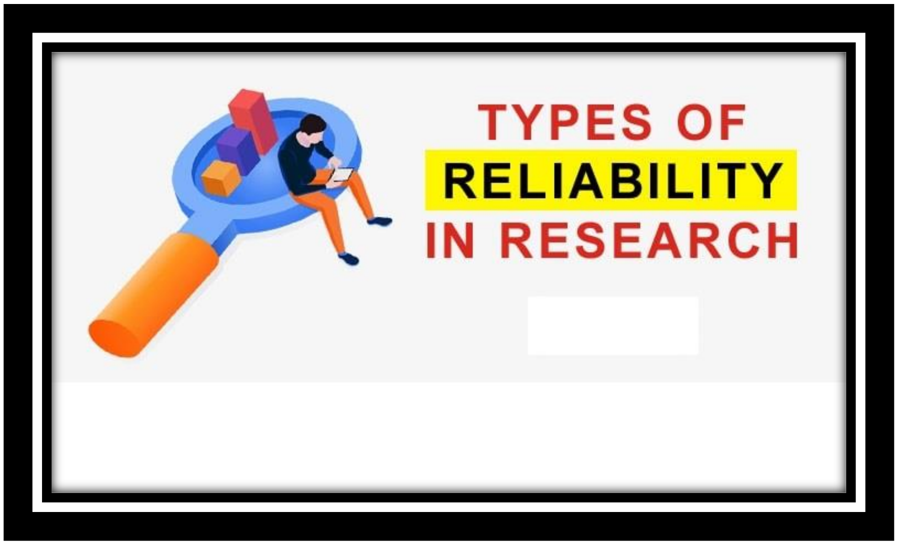
[25]

- Face validity: It's necessary to use face validity, an intuitive approach in which people with expertise in one of the questions is whether the measure appears to be grounded in the hypothesized concept.
- Concurrent validity: Using a criterion that is known to vary across examples and is important to the notion of the problem, the researcher employs this kind of validity. This is relevant to our investigation.
- Predictive validity: A novel measure of job satisfaction may be judged on its predictive validity, in which future absence levels are used as the criteria for measuring its validity.
- Construct validity: There are writers that advocate constructing validity. Scientists are advised to formulate hypotheses that are in line with the argument.
- Convergent validity: According to certain methodologists, the validity of a measure should be evaluated by comparing it to other measures of the same concept obtained by other approaches.

Diverse approaches to evaluating validity have been developed, but the fundamental ideas remain the same. This research also relied on this method to verify its results. Machine idleness was often discussed in meetings, and operators were assisted by engineers in activities such as verifying cycle times and changeover times on all machines.

According to Saunders[23], there are certain limitations to data collection. Data collection can be time-consuming, fraught with conflict or prejudice, and slow or expensive. For the most part, industry approval was provided for data acquisition.

It is the solution's capacity to reliably measure something that determines its level of trustworthiness. There are three key aspects to examine when determining the reliability of measurement [15]. It's a great option in terms of dependability and downtime. The greater the mean time between failures, the more readily available machines are to achieve their targeted efficacy. There should be efforts to reduce the time it takes to fix and improve the quality of repairs (MTBF).



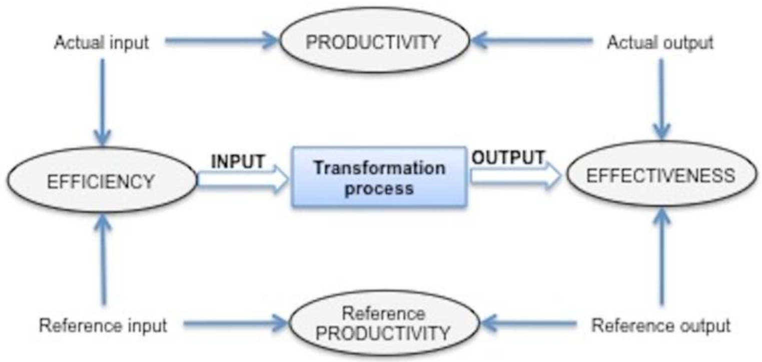
[26]

- Internal reliability: When conducting surveys, it's crucial to determine if a certain indicator correlates with other indicators, or if the results are consistent.
- Stability: If a measure has a high degree of stability, it means that the results of that measure for a sample of respondents will not alter over the course of time. When providing a test to a sample and then re-administering it, there should be very little variation in the results.
- Inter-observer consistency: when several observers are engaged in duties such as recording observations or translating data into categories, there's a possibility that their findings may be contradictory if they have different interpretations of the data. When making judgments on how to classify media objects, such as in a literature review or when answering critical questions, this might happen. It can also happen in observational research when researchers must choose how to classify participants' behavior.

Efficiency and Effectiveness

When it comes to measuring efficiency and effectiveness, there is a lot of misunderstanding. Current TMP jargon uses the phrase "overall equipment effectiveness" instead of the earlier word "overall equipment efficiency". Efficiency is the existing input over the reference value, whereas effectiveness is the actual output over the reference result [27]. Equipment efficiency refers to an equipment's capacity to function at a cheap cost. Production and business objectives are no longer related to the efficiency of the equipment. An industry's capacity to consistently provide the goods and services it needs is defined by the idea of Equipment Effectiveness (E.E.) [27]. To put it another way, being effective means undertaking the right things, but being efficient means doing the right things the right way every time.

To measure productivity, we look at how many finished items a person produces compared to how many hours he or she spends at work. A contemporary "lean" workplace is better served by a focus on efficiency than OEE.



[28]

THEORETICAL FRAMEWORK

Throughout the project, this chapter includes all the theoretical sources that were utilized. TPM, or Total Productive Maintenance, is an approach to preventive maintenance that involves machine employees. This includes downtime caused by equipment defects and waste, as well as lost electricity and unproductive personnel. TPM may be used to reduce these losses. TPM score is determined theoretically and practically using a method called Overall Equipment Effectiveness (OEE). This statistic is used to define losses based on their availability, performance, and quality indicators.

Introduction

In an ideal factory, one would expect all of the equipment to be running at 100% capacity and all of the output to be of high quality at all times. Because losses are what separate ideal and actual conditions in real life, this is not true. The Japan Institute of Plant Maintenance's (JIPM) whole productive management approach, first outlined in 1971, is a broad approach to improving the efficiency of any industrial environment by enhancing the efficacy of machinery [29]. The Japanese model is used to calculate OEE. In the early 1930s, Toyota and other manufacturers devised a model that worked well in Henry Ford's production line, which was based on this model. Following the Second World War, Japan's economy was devastated by a severe recession, and businesses were obliged to reduce their operations. By measuring total system efficacy, you might be able to find any possible losses in the equipment. As stated by Ljungberg & Larsson [30], measurements are essential as they address the following reasons and benefits:

- Measurement of effort-to-outcome correlations is crucial.
- Having a common language makes communication much simpler.
- Measurement is a powerful motivator.
- Keeping an eye on the numbers is essential to ensuring long-term progress.
- Measurement is a driving force for improvement.
- Delegation is easier when there is a clear measure of success.
- Problems may be discovered by measuring them.
- Measurements help managers concentrate their attention.

- Measurements are useful because they allow for comparisons.
- Measuring helps us plan for the future.
- Measurement answers the inquiry, "Where?" and "Whither?"

In the production context, OEE may be utilized at several stages since it assesses the initial performance of a complete production facility, which provides a standard for the company to improve when making decisions [31].

Total Productive Maintenance

TPM is a Japanese term for an alternative to the US-based approaches of preventative maintenance, efficient maintenance, and other ideas known as "total productivity". It was one of their goals to make it compatible with its industrialized surroundings. It was the inventor of this theory who grouped tasks to maximize efficiency via maintenance with the assistance of operators in the form of group work [8]. According to Brah and Chong [32], workers and managers must work together to decrease waste and pursue continuous improvement. Maintenance teams are responsible for all manufacturing repairs, and this ignores their distribution of tasks [8]. It is also feasible to keep disruptions to a minimum throughout procedures if all employees are completely dedicated and participating. To achieve zero downtime, accidents, faults, dust, and filth prior to the introduction of TPM, operators use TPM.

More information on TPM may be found in the following paragraphs:

Total, that stands for:

- Every employee should be involved. Problem-solving attitudes are fostered by raising awareness of a capable crew and disseminating information. The administration, as well as the entire team, must work together to accomplish this goal (top management).
- The elimination of errors, malfunctions, and breakdowns.

Productive

- Various duties must be completed during the manufacturing process.
- There are fewer problems during the manufacturing process.
- Customers' expectations of the final product or service should always be met or exceeded during production.

Maintenance

- Restoring machinery or equipment to its original state. As a result, machines have a longer lifespan. Restoration of worn-out or broken components, as well as cleaning or lubrication, are all included in this service.

Ahuja [33] offered an eight-pillar strategy for TPM implementation based on the TPM pillar efforts of the Japan Institute of Plant Maintenance (JIPM).

Development management

* Operating smoothly and on time with little issues with new equipment.

* Innovate new systems based on learning acquired from present ones.

* Projects to enhance maintenance.

Office TPM

* Simplify a variety of business processes.

* Get rid of bureaucratic hurdles.

* Concentrate on resolving issues relating to costs.

* Utilize the 5S method at the office.

Safety, health, and the environment

* Ensure a safe working environment.

* Create a suitable working environment.

* Eliminate incidents of injuries and accidents.

* Make available standard operating procedures.

Education and training

* The provision of technical, quality inspection, and interpersonal abilities education and training.

* Multi-skilling of employees.

* Bringing the organization's aims into alignment with those of its employees.

* Periodic and up-to-date skill assessment.

Quality maintenance

* Getting rid of all errors.

* Determining the underlying causes of machine breakdowns and addressing them.

* Assembling a 3M (Machine/Man/Material) system.

Planned maintenance

* Equipment longevity is ensured through long-term planning and TBM systems.

* Creating a set of project management checklists.

* Enhancing MTBF and MTTR.

Focused improvement[33]

* Systematic identification and elimination of 16 losses.

* Structured why-why, FMEA analysis for determining loss structure and loss reduction.

* Achieve improved system efficiency.

* Improved OEE on the production system.

Autonomous maintenance

* Encouraging a sense of personal ownership among operators.

* Clean, lubricate, tighten, adjust, and examine manufacturing equipment. Re-adjust if necessary.

Overall Equipment Effectiveness

Seiichi Nakajima was the first to coin the phrase "overall equipment effectiveness" in the 1980s. Measurement of machine productivity in production was its major objective [14]. Over the last several years, this metric has become more popular since it identifies and evaluates any hidden or unnecessary expenses associated with a particular piece of equipment [8]. A top-quality product and a capacity of 100 percent are required in any sector, but improvements can't be made without measurements. In maintenance, the OEE concept is well-known and utilized as a tool for monitoring equipment efficacy. Other considerations impacting the equipment mean that this is not always possible in practice. These items have diminishing returns when they are utilized more frequently, and their usefulness diminishes as well. Because of this, the gap between the equipment's initial state and its present state is due to losses.

Definition of OEE

In the 1980s, Seiichi Nakajima introduced the Total Productive Performance (TPM) paradigm, which includes the notion of overall equipment effectiveness. Under TPM, it serves as a measuring tool for identifying equipment-related production losses. Senior management might use the initial performance of an organization as a "reference point" to evaluate OEE levels between the initial and current enhanced levels. Assuming these losses were to be eliminated, Nakajima [8]has broken the losses down into six categories, which does not consider all the variables that impact operating efficiency, such as scheduled downtime, shortage of material, manpower, etc. The following are the losses:

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

For a component metric, Nakajima[8] specified optimum values of OEE at 85 percent (known as a "world-class number"):

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

The research was conducted to identify the minimum requirements for availability, performance, and quality. According to Kotze [34], a higher than 50% OEE is more realistic and useful as an acceptable benchmark. Ljungberg [30] provides an appropriate OEE value of between 60% and 75%, but (Ericsson) [35] provides a value that ranges from 30% to 80%. OEE was found to be 55% in his sample instances, while the mean availability was found to be 80%. This is quite close to Nakajima's claim that 90% of his equipment was available (1988).

According to Ljungberg [30], the average performance rate was 68 percent, which is significantly lower than the 95 percent figure indicated by Nakajima [8]. Idling and small stoppage losses are to blame for the 68 percent low-performance rate, whereas the majority of the significant losses were attributable to accessibility losses. Ljungberg [30] reported an average quality rate of 99 percent, which is in line with Nakajima's prediction of 99 percent [8].

The purpose of OEE

It is possible to utilize the OEE evaluation as a "benchmark" for future measures of any manufacturing plant since it may be performed at numerous levels in the enterprise environment. It is possible to evaluate previous and future OEE findings to determine how much progress has been achieved [31].

It is possible to compare the performance of many production lines within a given industry by using the OEE value of a single manufacturing line. OEE metrics may be used to discover which machines are underperforming and need more attention [8].

In addition to being a measurement, OEE is also a foundation for improving processes. It is able to pinpoint the aspects of a process that require improvement. An important part of the process is discovering and preventing equipment from operating at its full potential.

Chronic and Sporadic disturbances

The OEE measure is intended to detect inefficiencies that waste resources without adding any value to the machine. According to Jonsson and Lesshammar [4], there are two types of industrial disruption that are responsible for these losses.

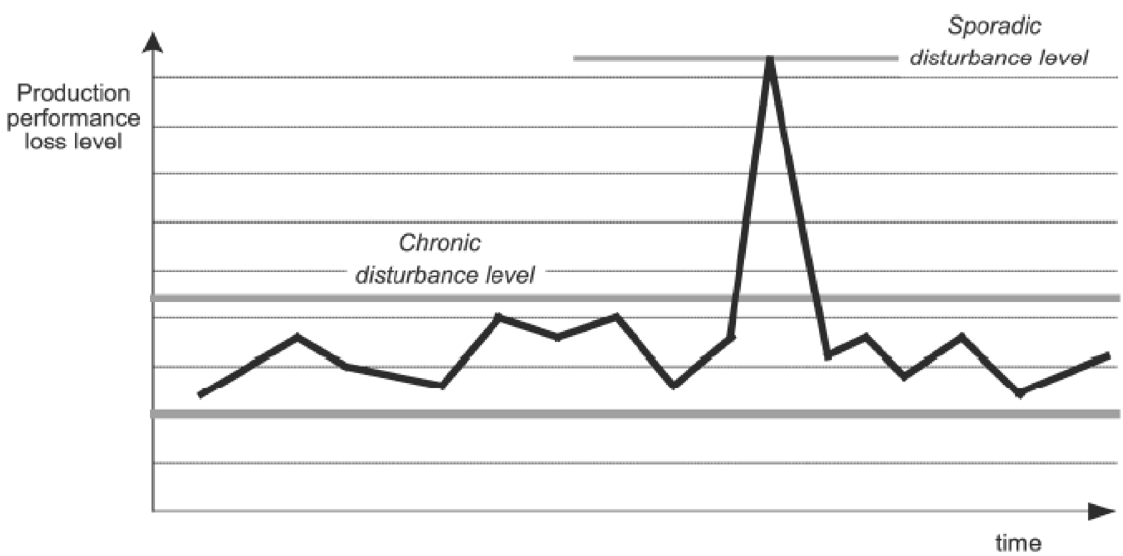
- Chronic disturbances
- Sporadic disturbances

Chronic disruptions are defined by Tajiri and Gotoh [36] as small, hidden, and confusing as a consequence of technological concurrent causes. Since they occur often, the disruptions result in poor equipment utilization and high expenses. Chronic problems are difficult to spot since they can be observed in their normal condition and are a part of the manufacturing process itself. A comparison of actual performance to overpotential might help in identifying it. Following Nakajima (1989), the features of the losses may be categorized into evident and concealed losses.

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

Characteristics of loss, (Nakajima 1989)

It is easy to identify sporadic disruptions since their departures from the norm are considerable. They are rare, but the effects may be terrible once they do happen. Continual and occasional disruptions produce a variety of waste products that have no use. A bottom-up strategy, as Nakajima indicated, is being used to discover these losses (1988).



Chronic and sporadic disturbances resulted in production performance losses (Bamber, [31]***)***

The OEE losses classification structure

The fraction between what was actually created and what might have been perfectly produced may be defined as any "E" effectiveness metric, or as the percentage of time equipment operates at its full working capability [1]. Analytically, this notion can be summarized as follows:

*E = Actual output/ Theoretical output = (Cycle time * Valuable time)/ (Cycle time * Theoretical time) = Valuable time/ Theoretical time*[1]

Where the *Valuable Time* is the amount of time during which equipment performs at its best and the T*heoretical Time* is the greatest amount of time that may be productively used.

It is simple to create three effectiveness measures using various *Theoretical Time* values based on the loss's categorization structure in the formula above.

Net utilization = Valuable time/ Operating time

Operation Effectiveness = Valuable time/ Loading time

Overall equipment effectiveness = Valuable time/ Net loading time[1]

Only the inefficiencies that may be directly attributed to equipment are included in OEE, whereas Net Utilization considers other types of losses. OEE is a merchandise measure designed to complement the work of the production staff (such as maintenance operators and production engineers), but it focuses solely on the efficacy of individual equipment, instead of the overall factory performance [37]. Net Loading Time is used to calculate OEE because it includes both external and internal losses that cannot be clearly attributed to a single piece of equipment, such as blockage and hunger, as well as the time it takes to load and unload products (i.e. equipment independent losses). However, it is true that this method is right since the equipment-independent losses cannot be avoided by corrective actions extended to the entire production system, such as plant layout change, machine balancing, and buffer size re-dimensioning.

OEE = (NLT – DT – PLT – QRT)/ NLT [1]

NLT = Net Loading Time

DT = Down Time

PLT = Time wasted due to Performance Losses

QRT = Time wasted due to Quality Rate

*OEE = OpT/NLT * NOpT/OpT * VT/NOpT = (NLT- DT)/ NLT * (OpT-PLT) / Opt * (NOpT-QRT)/ NOpT = (NLT – DT) * NLT * (MI*CT)/OpT * DF/MI = A * P * Q* [1]

[11]

OpT = Operating Time

NOpT = Net Operating Time

VT = Valuable Time

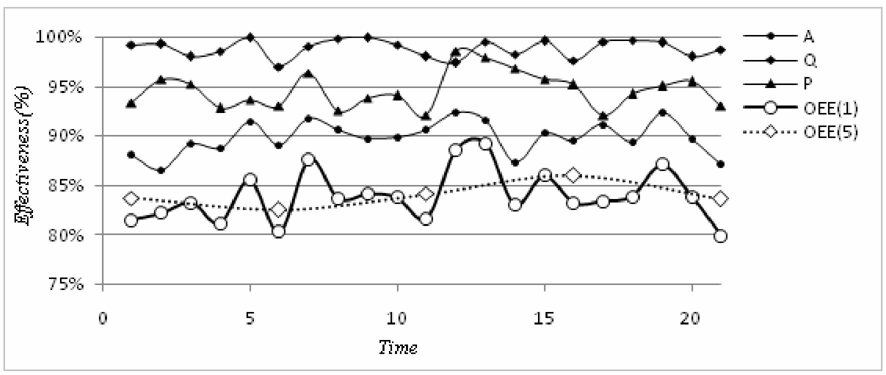
MI = Number of Manufactured Items

CT = Cycle Time

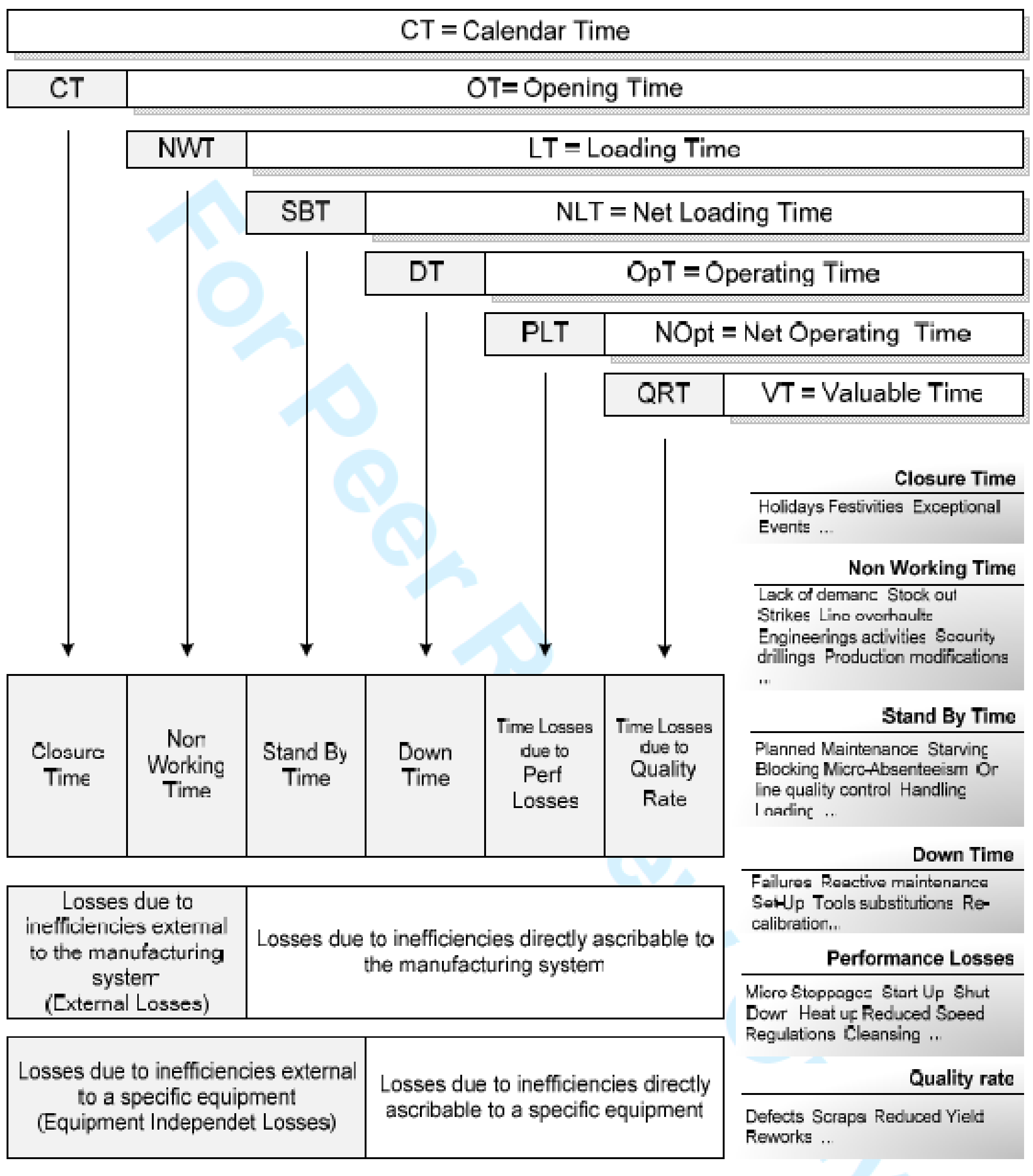
DF = Number of Defects

<u>*PLT = (OpT/ CT – MI) * CT = OpT – MI*CT*</u> [1]

<u>*QRT = (MI – DF) * CT*</u>



Effectiveness over time [1]



The OEE Losses Classification Structure [1]

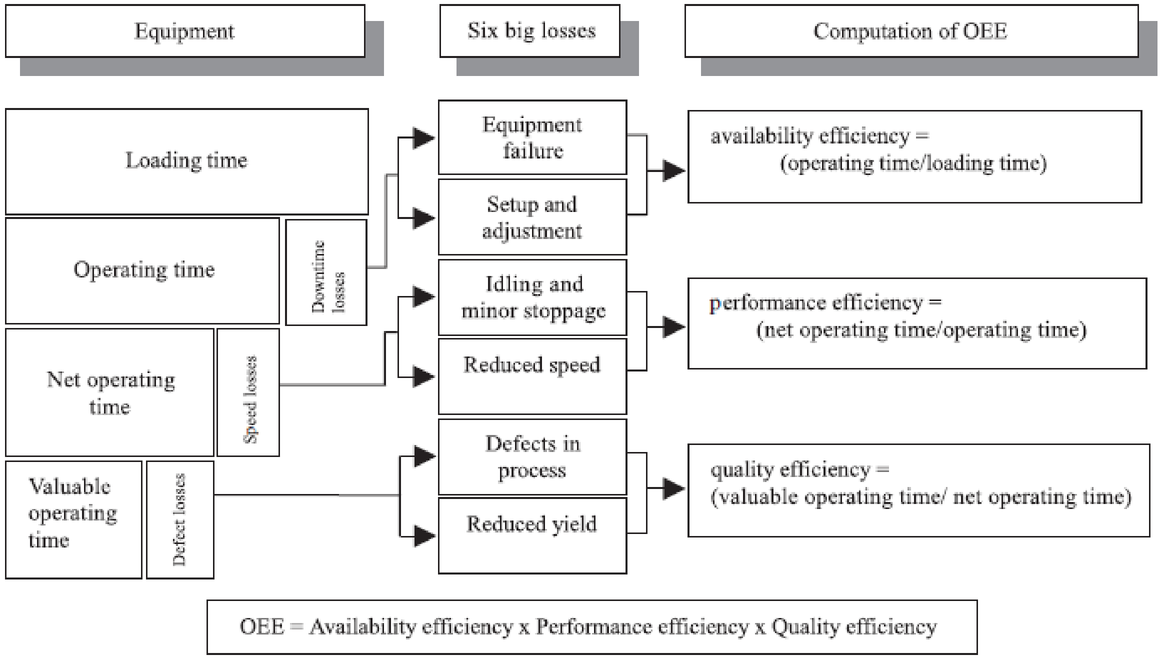
Six big losses of OEE

Based on TPM, Nakajima [8] introduced OEE as a measuring instrument, which is intended to achieve breakdown-free and defect-free equipment. In the end, this resulted in an increase in productivity, a decrease in expenses, and a drop in inventory levels. Muchiri and Pintelon [14] claim that TPM is primarily an effort to improve the quality, productivity, cost, inventory, safety and health, and manufacturing output of industrial equipment.

Overall Equipment Effectiveness	Recommended Six Big Losses	Traditional Six Big Losses
Availability Loss	Unplanned Stops	Equipment Failure
	Planned Stops	Setup and Adjustments
Performance Loss	Small Stops	Idling and Minor Stops
	Slow Cycles	Reduced Speed
Quality Loss	Production Rejects	Process Defects
	Startup Rejects	Reduced Yield
OEE	Fully Productive Time	Valuable Operating Time

[11]

As stated by Nakajima (1988), a bottom-up method is used to reduce the losses from manufacturing interruptions by removing six of the biggest losses. Based on his observations while living in Japan, Nakajima (1988) drew the following conclusions:



Overall equipment effectiveness and Computation procedure (Nakajima, 1988)

Unplanned downtime losses as a function of Availability

The losses from the first two significant losses listed below are used to determine how valuable a machine is in the business.

1. One of the most common causes of equipment failure is a breakdown, which is defined as a loss in terms of both time and quantity. According to Pintelon [14], a faulty material handling plant motor at a brewery resulted in production delays and losses.
2. Set-up and Adjustment: In the case of a shift in manufacturing from one item to another, these are known as "transitional losses". These set-up losses were mostly caused by product set-ups, testing during startup, and fine-tuning of machinery and equipment in the brewing process.

$$\text{Availability} = \frac{\text{Actual working time}}{\text{Scheduled working time}} = \frac{162.75\text{ hrs}}{252\text{ hrs}} = 0.646 = 64.6\%$$

[38]

Speed losses as a function of Performance

Subtracting speed losses from a machine's actual performance results in its true output. In the event of a breakdown, it is impossible to do the necessary calculations.

1. These losses occur when production is halted for a short period of time, such as when a machine is idle. In material handling machines, for example, dirty photocells create tiny interruptions even if they may be rapidly repaired, resulting in significant capacity loss.

Typical causes of micro stops are[2]:

- Equipment misalignment and poor positioning
- Incorrect settings
- Blocked sensors
- Material miss-feeds and jams
- Equipment design issues
- Periodic quick cleaning

2. Reduced speed: These inefficiencies are based on the difference between the speed limit and the real operating speed of the equipment. A study by Muchiri and Pintelon [14] found that using unadopted pallets resulted in higher processing times for the same number of bottles, which resulted in speed losses.

As suggested by Trattner, A., Hvam, L. and Haug, A. in their 16 December 2019 post, slow-speed reasons can be broken down into three categories [39].

1. Technology factors

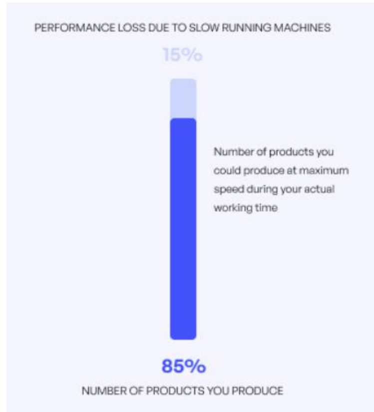
- Technological trustworthiness (equipment wear, machine reliability, improper maintenance, production stops).
- The existing technological limitations (equipment wear, incapable equipment, queue capacity for work in process).
- There are environmental constraints.

2. Human factors

- Incompetence of the operator (i.e., due to lack of training).
- Measurement error.
- Strategic planning is fraught with anxiety (ideal cycle time set too low or target too unambitious, capacity utilization issues, production scheduling).

3. Product factors

- Material availability
- The quality of the materials used
- Product variety
- Product quality (quality of finished goods)



$$\text{Performance} = \frac{\text{No. of products you produce}}{\text{Number of products you could produce at maximum speed during your actual working time}} = \frac{8\,300\text{ pcs}}{9\,765\text{ pcs}} = 0.85 = 85\%$$

[38]

Theoretical maximum speed

Assuming optimum operating circumstances, this is the maximum potential speed that the machine might theoretically accomplish. It's impossible to run at the theoretical maximum speed in real life since the conditions aren't right.

Nameplate capacity (NPC) or Design speed

This is the top speed that the device's maker specifies. As a rule, NPC is slower than the theoretically possible maximum. In order to meet or exceed client expectations, suppliers may propose a more realistic estimate. It's possible that your equipment runs quicker than the manufacturer's specifications and that your measured performance exceeds 100%.

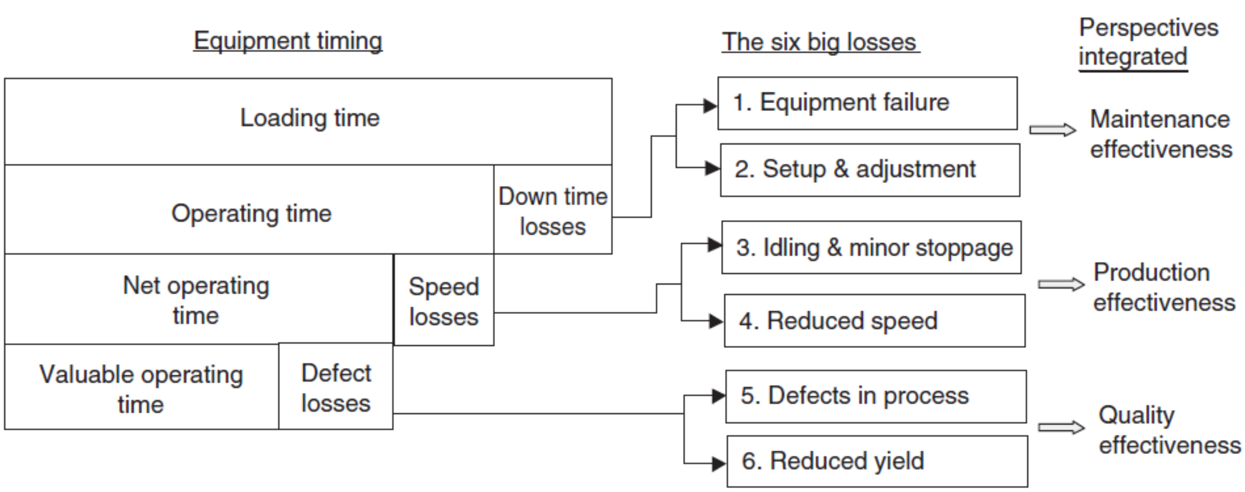
Quality losses as a function of Quality

Related to the quality losses, the output is impacted. This might have a negative impact on a company's bottom line because of the waste of resources or the expense of recycling. On the basis of:

1. Defects in process or rework: These losses are the result of equipment malfunctions. Palletizers and unpackers can damage pallets if they get caught in each other.
2. Reduced yield: From the time the machine is turned on until it has stabilized, there is a decrease in yield. As a result of issues with filling taps caused by the night shift, lower yields were achieved during the morning shift.

$$\text{Quality} = \frac{\text{Good products}}{\text{All products}} = \frac{8\,000 \text{ pcs}}{8\,300 \text{ pcs}} = 0.964 = 96.4\%$$

[38]



OEE measurement tool and the perspectives of performance integrated into the tool (Muchiri & Pintelon, [14]***)***

Evolution of OEE

Even though Nakajima (1988) was the first person to describe OEE, the definitions of other writers have developed through time, making it a fundamental performance metric today. OEE was proposed by Jonsson and Lesshammar [4]as a technique for detecting losses caused by production problems, whether they are persistent or occasional. According to Fleischer [6], any manufacturing sector's goal of preserving a competitive edge relies on the availability and productivity of its manufacturing facilities. According to Huang [7], the OEE tool is a common quantitative method for assessing productivity confined to specific equipment. According to Jeong and Phillips [40], other causes of OEE losses, including preventative maintenance, holidays, and off-shifts, were not regarded as suitable for the capital-intensive sector as initially characterized by Nakajima (1988).

It has been necessary to modify and broaden the scope of the OEE tool because of its inadequacy in industrial systems. New formulations have also emerged as a result of changes in theory and practice. It is possible that some modifications are confined to the effectiveness of individual pieces of equipment such as PEE and TEEP, whereas others, such as overall throughput effectiveness, overall plant effectiveness, and overall assembly effectiveness, have been extended to production line efficacy.

Total Effective Equipment Performance (TEEP)

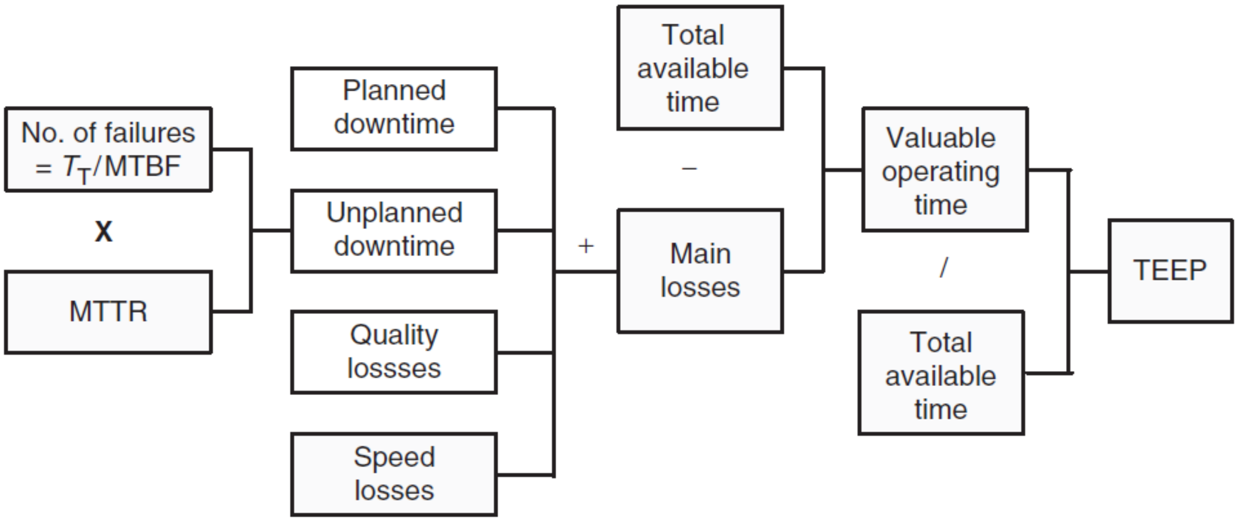
For a notion that is quite close to Nakajima's OEE, Ivancic [41] introduced the term "total effective equipment performance" (1988). The key distinction is that scheduled downtime is included in the entire planned time span, rather than being a separate item. A clear distinction is made between planned and unplanned downtime since maintenance increases the bottom-line performance of the facility. The purpose of maintenance is to minimize unexpected downtime, or technical downtime, which is frequently referred to as downtime. Pintelon [14] describes the relationship between downtime and different breakdowns over a certain period, such as the mean time between failures and the meantime to repair.

Both scheduled and unexpected downtime may be measured with the use of TEEP (Ivancic, [41]). The MTBF or MTTR of a piece of equipment might be increased or decreased based on the results of a comprehensive downtime investigation. TEEP losses are incorporated into the OEE model, which is based on speed and quality losses. Analysis and measurement of TEEP's basic elements are presented in this figure, which is derived from dividing available operating hours (AOH) by VOT (Valuable Operating Time, or VOT).

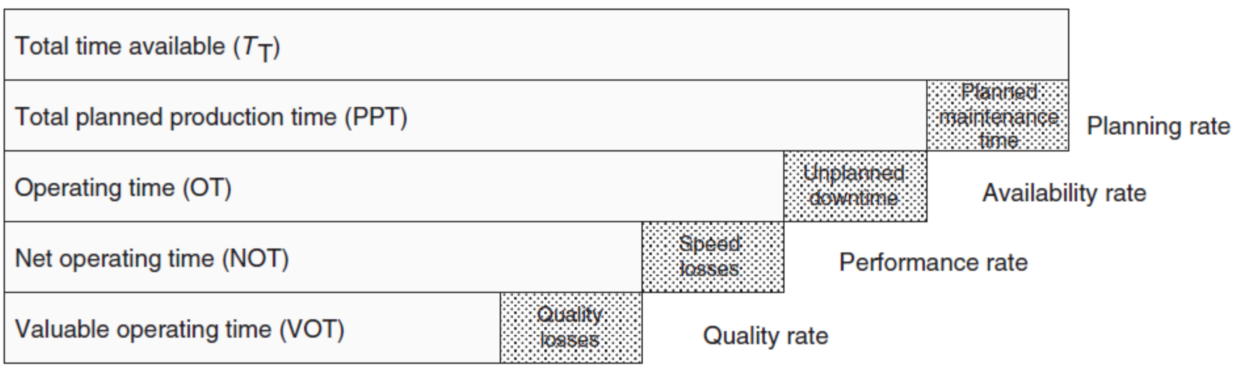
*TEEP = Valuable operating time/ Calendar Time = OEE * Loading time/ Calendar time*[27]

Machine performance may also be measured using TEEP, which is very similar to OEE and can be applied in production facilities where the entire production process is seen as one unit.

As a result, OEE and TEEP are closely connected metrics. On-site equipment is typically used, therefore, TEEP is a statistic that measures how well the equipment is being utilized in the workplace. Prior to investing in more capacity, it is critical to optimize the value of TEEP for data analysis.



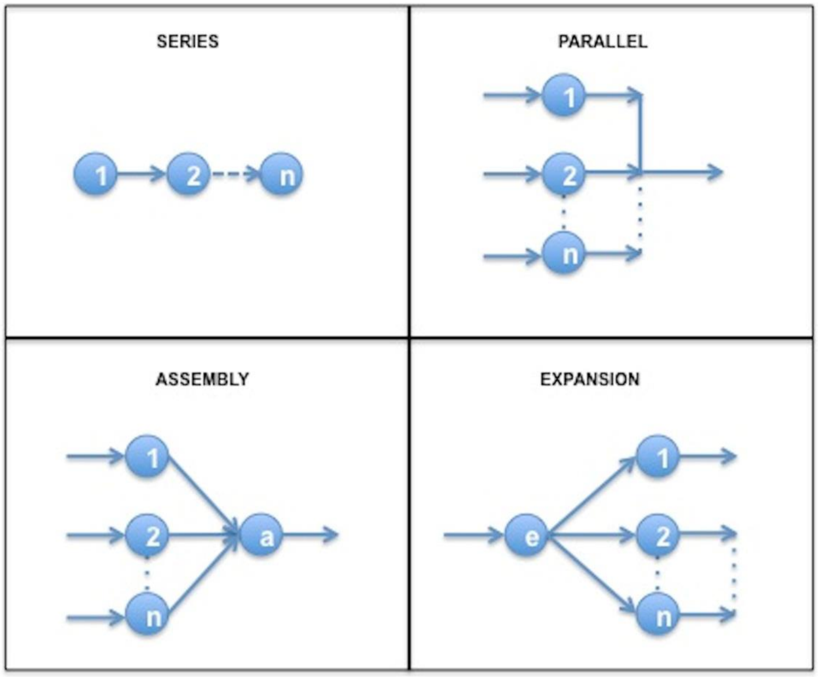
Constituent elements to calculate TEEP (Muchiri & Pintelon, [14]***)***



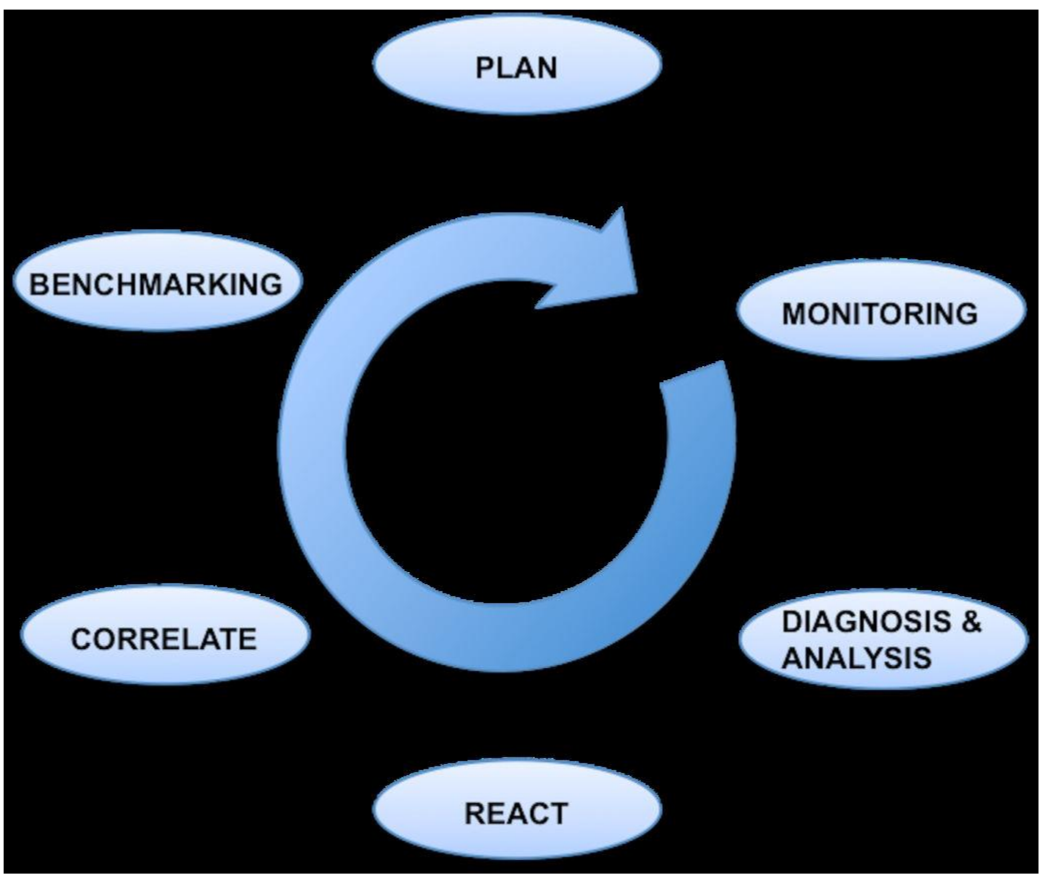
Constituent elements in TEEP (Muchiri and Pintelon, [14]***)***

PEE stands for Production Equipment Efficient, and it was first proposed by Raouf [27]. Weighted items are the key distinction in OEE. Because of this, OEE doesn't consider the three pillars of availability, performance, and quality in the same manner. We discovered methods for evaluating the overall efficiency, productiveness, and overall asset effectiveness on a large scale in the plant. Factory efficiency studies are the most popular and well-known type of research. An OEE tool's export effort is included in this fee. To get at a factory-level measure, it is necessary to apply some sort of algorithm to the OEE values of every piece of equipment [27]. OFE is not measured or analyzed using a defined set of metrics. According to Huang [7], it is possible to determine the factory level metric by synthesizing the observations of components.

A variety of formulations of OPE and OAE have been used in the business throughout the years. Their suitable methodology has been modified to satisfy the specific demands of numerous sectors.



Types of manufacturing subsystems.[42]



[43]

Improvement approach to increase the plant OEE.

Underlying metrics of OEE

Availability, quality, and performance are not dependent on each other. Six significant machine losses are broken out using OEE factors. OEE can be defined in the following way, based on the previous statement:

OEE = Valuable operating time/ Loading time

Valuable Operating Time measures the whole time that a piece of equipment is actually in use.

During a specified timeframe, the actual length of time that a piece of equipment is supposed to be operational is known as loading time (year, month, week, or day).

Planning factor (Pf)

An additional element to take into account when considering the availability of a product is its loading time. Part of the TEEP statistic shows how much of the calendar year is set up for operational activities. After deducting any planned downtime[10], this is the duration of the shift, which involves aspects such as downtime:

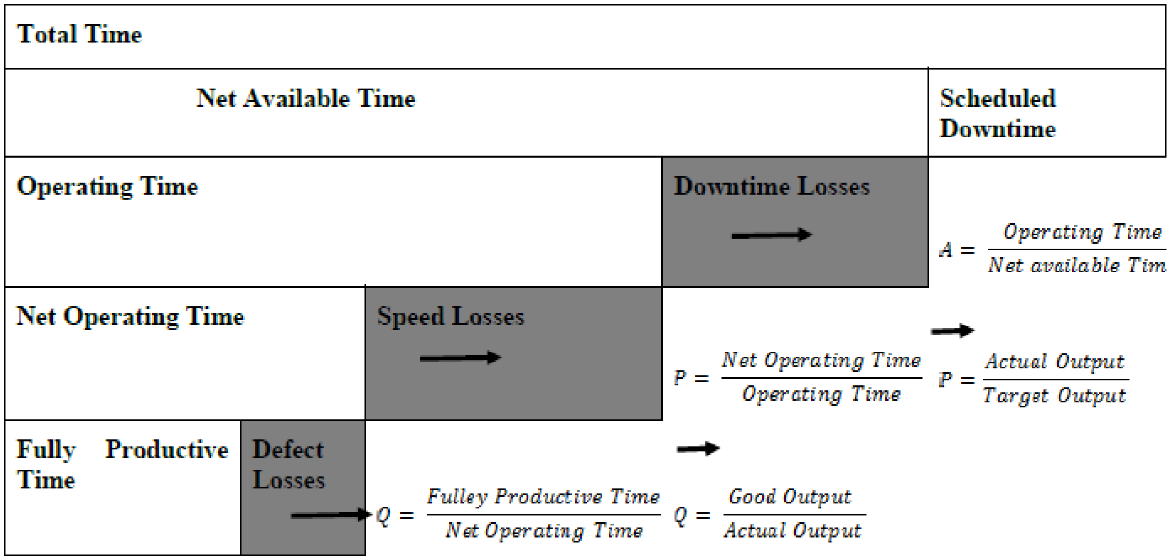
- Insufficient staffing owing to work shifts and breaks.
- Planned maintenance activities.
- Operator training.
- Equipment trials and process improvement activities.
- Machine cleaning and general operator maintenance.
- Waiting time due to completion of current orders.
- A shortage of personnel.
- Holiday.
- Line overhaul.
- Production modification.
- Inspections.
- Engineering activities.
- Security drilling.
- Problems with external or internal material.
- Personal time.

Time is lost owing to scheduled halts, although equipment efficiency is unaffected by the planning factor. The value of the planning factor will ultimately decline due to an increase in both planned and unforeseen losses:

Planning factor = (Planned time – Scheduled related stops)/Planned time

Total OEE can also be calculated as follows:

Total OEE = OEE x Planning factor



[1]

Availability factor (A)

This has to do with the amount of time the machine was operational, not merely the amount of time it was operational. When calculating OEE's availability, it takes unplanned downtime, setup, and changeovers into account. Instances of this include adjusting the actual output time to match the intended operating time and accounting for conceptual manufacturing time lost due to previously unrecognized stoppages.

Due to the potential for protracted activities or excessive process set-up times, availability calculations do not include scheduled preventive maintenance (Dal, [10]). Even if scheduled preventive maintenance is ignored, the OEE value still looks poor, which necessitates the use of TPM to reduce planned maintenance operations.

Availability activities include downtime activities, such as:

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

In terms of the availability factor, it may be represented as follows:

Availability = (Scheduled production time – Unplanned stop time)/ Scheduled production time

Performance factor (P)

Net operating rate and operating speed rate are added together to evaluate performance in the overall energy efficiency equation. Nakajima's (1988) output measurement shows actual output time variations from intended cycle timings. If you're looking for an example of how to measure deviations from a plan, go no further than De Groote [44].

The top five reasons why firms use performance metrics [45].

- Constructive criticism management has to be improved on every system.
- Clearly defined roles and duties are essential in order to establish accountability for certain outcomes or issues.
- Performance measurements have been shown to be a valuable tool in effectively communicating a company's strategy throughout the business.
- Grasp business functions, as information measurement involves an awareness of the production process.
- Determining the capacity of a process, since understanding a process also involves knowing its capacity is important.

The net operating rate (NOR) is a measure of the stability of the processing speed achieved over a period. For instance, an 8-hour production shift is not included in calculating whether the actual pace is faster or slower than the design standard speed[10]. It is possible to assess the losses arising from reported and unrecorded interruptions, such as minor flaws and modifications. A speed loss of 20% equates to a performance of 80%. The formula for calculating performance is shown below.

*Performance rate (%) = (Operating speed rate * Net operating rate) * 100*

Operating speed rate = Theoretical cycle time / Actual cycle time

*Net operating rate = (Actual cycle time * Number produced)/ Operating time*

Quality factor (Q)

When calculating the OEE as a quality rate, this is the final metric to consider. In this approach, the ratio of defective items in the total production is shown. Machine or manufacturing line malfunctions are the most common causes of these problems.

Quality rate = (Total quantity of produced product – Number Scrapped product)/ Total quantity of produced product

OEE formulation and ways to improve OEE

OEE Formulation

Machinery efficacy, according to Nakajima (1988), may be summarized as a % based on the following three factors. The formula is given below as:

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

It is proposed that OEE have a world-class value of 85.0%, which includes:

Availability 90.0 %

Performance 95.0 %

Quality 99.9 %

Overall equipment efficacy is defined as follows in terms of scheduled working hours:

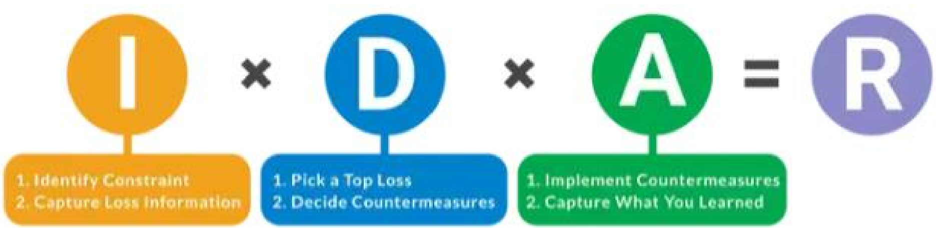
*Planning factor OEE = Planning factor * Availability rate * Performance rate * Quality rate*

Ways to Improve OEE

Six Sigma, Theory of Constraints, and Lean Manufacturing all fall under one broad definition. Over time, OEE has evolved into a powerful and comprehensive improvement process known as Total Productive Maintenance [46].

All these methods have a lot to offer in terms of improving production. These methods are not simple. A common question is: is there a way to get started while we're developing a thorough program? The answer is yes.

A FOURTH METHODOLOGY: IDA (Information, Decision, Action)



[11]

IDA highlights three factors:

Information: In the beginning, IDA was built on a solid foundation of information. In order to make informed decisions, you need information that is relevant, accurate, and simple to grasp.

Decision: Information and action are linked through decisions. During this stage, the data is analyzed and the final choice is made.

Action: The place where theoretical possibilities become real progress and decisions become outcomes is where the action takes place.

Information is the foundation for effective decision-making. The purpose is to provide all stakeholders with accurate and complete data. Determine where in the production process your data is being collected before moving on. Its throughput will always be limited by a single step or piece of equipment, regardless of whether you're filling bottles or packing boxes. This is the stumbling block.

Because the limitation is the weakest phase in the production process, its performance equals the whole manufacturing process's performance. Look for the phase with the lowest performance to find the limitation. Assuming that the line is rated for only one speed, the fundamental limitation is the principal equipment.

Decisions are the bridge between *Information* and *Action*. Analysis and decision-making take place during this period. We make decisions here, such as:

- What will we change?
- Over what period?
- Who will be responsible for the change?

The relentless emphasis on the worst defeats can be a rapid way to improve. Consider the lowest possible collection of improvement activities that are most likely to have a significant impact. Where is the biggest loss?

- Your team is ready to take action based on their suggestions.
- Minimal external resources are required.
- Action can be taken straight away.

Taking **action** is the key to turning prospects into reality and decisions into accomplishments. Quickly and consistently implement *Decisions* to make a real difference in the world. A good rule of thumb is to coordinate all of your assets prior to making any major alterations. For instance:

- Work with your team to provide education and information.
- Break the improvement cycle down into manageable chunks.
- Contact the team in charge of making appointments.
- Invest in any supplies required (such as replacement parts).
- Be an active participant in the project's management.

Benefits of OEE

When deployed correctly, an OEE system may provide instant benefits to industrial companies. Some of these benefits are outlined in more detail below.

1. Reduced Downtime Costs

Downstream processes are halted when a crucial machine fails. As a result, this might have a negative influence on the company's cash flow and revenue. An hour's downtime for a major piece of process equipment in a typical semiconductor application (based on data from the year 2000) is expected to cost the industry $100,000. On the other hand, a 1% reduction in downtime on the 50 most vital pieces of equipment can generate income possibilities and expense savings of more than $100,000,000 annually.

**International Technology Roadmap for Semiconductors 2002 Update*

2. Reduced Repair Costs

Predictive maintenance is possible because of OEE, which can cut repair costs significantly. In time, the maintenance team will be able to identify patterns in the downtime data and anticipate a breakdown.

Planned maintenance can also be performed by the maintenance department using a computerized maintenance management system.

3. Increased Labor Efficiency

Most industrial enterprises have slashed their workforces significantly due to the current economic climate. As a result, firms are looking for ways to increase the efficiency of their current personnel. An OEE system is helpful since it not only records downtime reasons but also productivity statistics for the operators. Management may now make more informed decisions about how to allocate resources depending on employee productivity thanks to this data. Managers might use an OEE system to find the additional capacity within their current staff rather than acquire new employees when the business situation improves.

4. Reduced Quality Costs

The Rate of Quality refers to the ratio of the total number of components manufactured to the number of high-quality parts. As a result, an OEE system must record the total number of parts produced, the number of scraps, as well as their causes, and the overall number of defective components. Since information is gathered at the machine or line level, this capability genuinely captures quality in the context of the component being produced. By collecting context-rich quality data, production managers may identify underlying causes and avoid additional costs related to rework and scrap. When quality is improved throughout all stages of manufacturing, warranty costs decrease. First pass yields of 97 percent (median value), scrap and rework of 2 percent (median value), and warranty costs of 1 percent (median value) were found in the Industry Week study.

5. Increased Personnel Productivity

Digitalized shop floors are possible with an OEE system. Time-consuming clerical work is typically required by facility operators and supervisors to gather the information needed to explain the source of unavailability to management. An OEE system automatically collects and reports downtime and efficiency. In the long run, this saves time and allows employees to focus on more important responsibilities. With OEE, everyone from the factory floor to the board is better informed, more frequently, and more simply.

6. Increased Production Capability

It is possible to increase production levels with the same number of resources by reducing machine downtime, increasing operator productivity, and decreasing faults.

Data collection

In the context of data collection, this means recording the values of one or more variables. What data must be recorded, how, and when must be determined. Depending on the situation, data might be entered manually or automatically. Ljungberg and Larsson [30] believe that, in the long run, automated data collection methods are likely to be useful.

OEE can't be calculated without knowing how the data was collected. Manual or automated data collection can be used for OEE calculations, which necessitate the accurate entry of variables from the production system (Ericsson, [35]). As a rule, manual data collection occurs in low-tech businesses, where personnel is expected to fill out a logbook with information regarding failures and performance losses. High-tech businesses utilize an OEE calculation system that automatically records the start time and duration of shutdowns while urging the operator to provide the system with accurate information regarding downtime reasons. Operators can put up lists of probable downtime reasons, plan runtime, and generate an automatic OEE estimate for any given period using the automatic technique. If the data entry is available in the system, not only can OEE results be delivered, but it also enables us to get a range of reports and visualizations of process performance from the system. However, if the system has too much information, the operators would have to seek out each outage reason, which is a waste of time. Many businesses have a huge difficulty due to operators' and foremen's reluctance to gather data. Ljungberg [30] believes that operators must be persuaded that some disruptions do not have a significant influence on efficiency, which subsequent measurements prove to be incorrect. Automated data collection is expensive, complicated, and time-consuming. Manual data gathering, on the other hand, maybe quite thorough since losses can be thoroughly investigated. As a performance metric, OEE requires both human and automated data gathering techniques, as well as training for OEE employees on a variety of aspects that impact OEE. There are two key reasons for this: to raise operator competency and to provide a more active role for operators in recognizing possible performance loss issues and delivering correct information to the system. OEE data was gathered over the course of three months from several types of equipment in a wide variety of sectors. In accordance with Ljungberg's advice [30], machine stops were recorded using a computer and the operators' assistance.

Set-up time

It was Taiichi Ohno, the previous president of Toyota in the 1950s, who was angry because Toyota was producing vehicles for stock. It was a waste of time for consumers to wait for their automobiles in the parking lot because the company manufactured components and finished items in big batches. Using lean manufacturing techniques, Van Goubergen and Van Landeghem [47] argue that lowering machine setup time has a major influence on production costs due to smaller series orders. Machines are dormant during this period because of the preparations required for the next manufacturing product to start. After a breakdown, losses might be referred to as such. When the machine is enabled for the next product to begin making, it may be necessary to remove and clean prior instruments, load additional tools and settings, examine and test them, and so on. This has a considerable impact on equipment downtime. Some industries do not include it in their OEE calculations since it is a scheduled activity that is necessary. Although it is considered a downtime loss that may be decreased, it is considered crucial in the computation of overall efficiency (OEE). There are long and short set-up timeframes for this task. The setup and changeover periods for each machine vary, so there is no standard amount of time allocated for each. In the majority of cases, OEE estimates must take into account unexpected shifts for unexplained reasons.

Here are a few more reasons why a machine may cease working:

- Program failure
- Tool change
- Waiting for the container (missing pallets)

- Missing tools (Searching or waiting)
- Machine failure
- Cleaning (Maintenance)
- Material loading
- Setup (tools)
- Inspections

According to Van Goubergen and Van Landeghem [47], allowing clients to purchase more items in smaller series and increasing throughput due to the lowering of installation periods of bottleneck units are two benefits of useful product setup time and increased machine efficiency, which results in an increase in company income. According to Suzaki (1987), industrial operations must be flexible enough to respond quickly to market changes. To better meet the demands of their customers, businesses always strive to provide a wider range of products. To reduce setup time and aid in the transfer of knowledge across products, use standardized components to operate several items on a machine at the same time (Pratsini, [48]). Setup time is reduced by using Single Minute Exchange of Dies, a set of standard approaches (Shingo, [49]).

Cycle time

Continual manufacturing cycle time refers to the time it takes to create a product. According to Ljungberg [30], the operating speed per hour is determined as the amount of time it takes to complete each task. Long and short cycle periods are also subdivided; however, it is typically deemed long if items are refused after manufacture and hence referred to as losses. cycles are impacted by design pace, initial ideal circumstance, and product modification (Nakajima,[8]).

Single Minute Exchange of Dies (SMED)

The single-minute exchange of dies was devised by Shigeo Shingo in the 1950s. Flexibility was necessary because of Japan's higher degree of smaller production batch sizes to fulfill consumer demand. As a way to cut down on manufacturing waste, it allows for a quick and easy switch to the following product (Shingo, [49]). “Single minute” refers to the time required for all changeovers and starting processes, which is less than 10 minutes.

The benefit of Setup reduction.

Below are the following benefits of applying SMED:

- Reduced waste and inventory, which results in cheaper costs.
- Improvement in quality after changeover (rapid change).
- Improvement in flexibility.

• Reduction of impact on equipment utilization.

• Improvement throughout.

• Reduction in batch sizes.

• Improvement in repeatability

• Improvement in changeover time.

Because each lot is processed twice, the act of setting up or changing over is referred to as "setup or changeover" (Shingo,[49]). It's broken up into two sections:

- When the system is shut down, it is possible to configure the internal settings.
- Setting up an external device while the computer is still operating.

Using the correct techniques, the SMED system may be implemented into any sort of setup (Shingo, [49]):

Step 1: Identifying and separating internal and external setups.

Setup time can be reduced by 30% to 50% using this method. When the system is operating, external settings are carried out to save time when setting it up in the future. A machine can only conduct internal setups when it is halted or on hold, and the preceding operation has been completed. Prior to the machine finishing processing a product, the operator must have completed all exterior preparations and be prepared to perform internal setups for the next product.

Step 2: Converting internal setups to external setups.

Improvements or a shift from internal to external operations may help both setups function more efficiently, but it's time-consuming on both. The majority of the exterior setup tasks, such as cleaning, material handling, and product, collecting equipment and fixtures, preheating, etc., take place within the internal setup period.

Step 3: Reorganize all aspects of the setup.

The working area must be well-organized, with tools placed close to where they are most likely to be used, and equipment and fixtures checked for proper operation. Quick fasteners and locator pins, which avoid alignment rework by using previously selected settings, should be used to help minimize internal setup tasks.

Step 4: Performing parallel setup activities.

By standardization of components, parts, and raw materials, set up activities can be minimized or removed. Workers and engineers must perform setup operations on a regular basis in order to reduce setup time. Ideas developed might be referred to as "principles" if they've been thoroughly examined and put into action. Practicing these ideas may then be used to make further advancements.

5 Why's analysis

This approach is used to investigate the fundamental cause-and-effect links of a specific issue. It is essential (Slack, [50]) to find the underlying cause of a problem or flaw. An investigation of one or more root causes is not a problem-solving approach, but rather a means of determining the genesis of an issue. In order to fix a problem, it is necessary to first identify what the problem is.

You may utilize this strategy if you have little expertise or experience and are dealing with minor difficulties, repeating problems, or social interaction issues caused by the operator's mistakes. It is a root cause analysis tool that is easy to use, effective, thorough, adaptable, entertaining, and economical. The following is an example:

Statement: The machine keeps failing.

1. Why did the machine fail? because the circuit board burned out.

2. Why did the circuit board burn out? because of overheating.

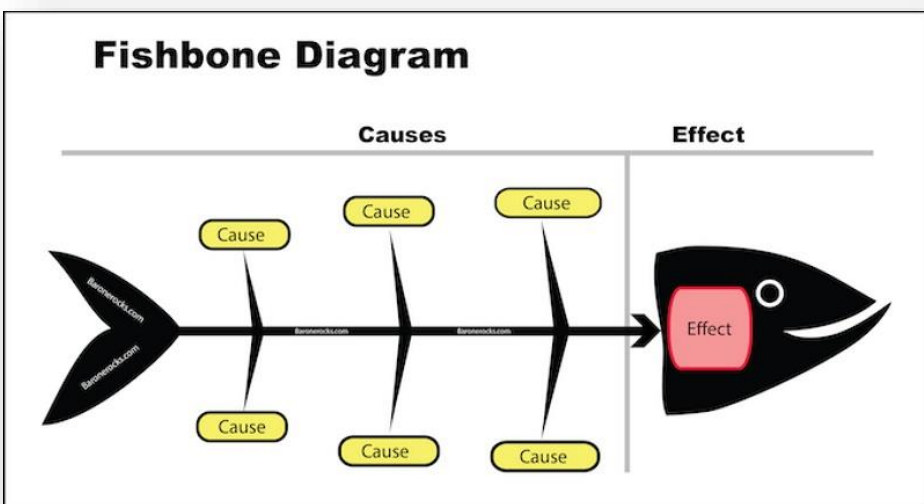
3. Why did it overheat? because it wasn't getting enough air.

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

5. Why was the filter not changed? Due to the lack of regular maintenance, the employee was not aware of it.

Fishbone (cause-effect) diagram

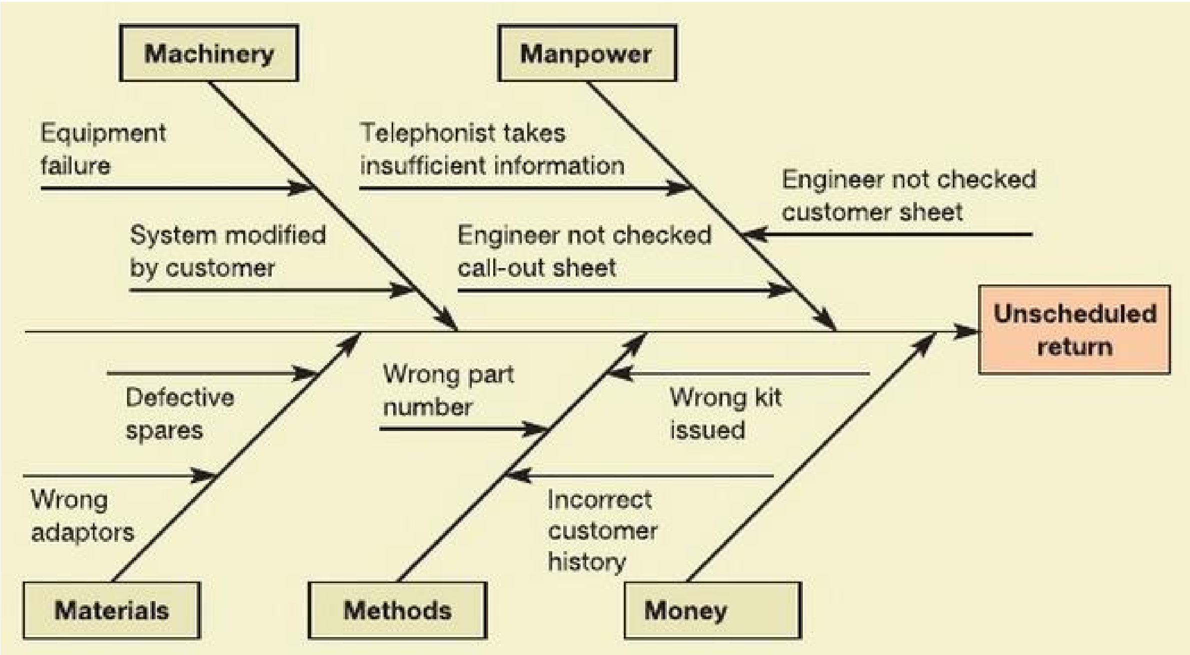
A fishbone diagram (also known as an Ishikawa diagram) may be used to discover the causative factors of quality problems. In the 1960s, Kaoru Ishikawa was credited with pioneering the usage of this chart (Juran, [51]).



[52]

The ability to methodically investigate the causes and effects of a phenomenon using an analytical technique. It suggests a connection between the numerous sources of an impact and the effect itself.

Structural brainstorming sessions stimulate and improve group involvement in this framework because they use group understanding of the process (Slack, [50]). Bevel lines leaning horizontally show that various causes and sub-clauses have been distributed via both quantitative and qualitative methodologies (Ciocoiu, [53]). Machinery, personnel, materials, and processes may all be grouped into headings to help identify potential reasons. There is a wide range of probable causes that may be accounted for in every given category. Unscheduled returns are shown in the picture below, which displays the cause-effect diagram of spares shortages, identifying the reasons.



Fishbone diagram of unscheduled returns, (Slack, [50]***)***

COMPANY CASE STUDY

Introduction

Enhance production efficiency and environmental sustainability by utilizing equipment from the Commonwealth Handling Equipment Pool. When you collaborate with us, we will share our expertise, knowledge, and data collection so that we may develop creative solutions for the future. In order to make your distribution model more sustainable and circular, adopt CHEP. What about returns and repairs? Everything is taken care of by us. You no longer have to handle the exchange of pallets and repurchase them using CHEP!

Reliability and flexibility. Whether or not you succeed as a company relies on both. In the event that anything goes wrong, you can count on CHEP to provide the necessary equipment on time and where you need it. Our size is unmatched throughout Europe, with over 120 million pallets and 220 service locations [54]. You no longer have to be concerned about periodic highs or unexpectedly high demand.

When it comes to the consumer products industry, we have the breadth and depth of solutions and know-how to help you get more money out of every unit load you ship, because it's easier to get things done. As much as any company in the world, we've helped household product producers grow their businesses with more retailers.

Advantages of CHEP

Operating in this sector might be difficult. Increasingly, consumers are placing orders in tiny amounts, and they want them to arrive quickly. The customer's experience might be negatively impacted by any delays or damage that occur throughout the manufacturing process. Many international standards must be adhered to, and profit margins are limited and complex.

1. Compatibility

All CHEP pallets are accepted by the world's top online distribution networks, so you don't have to change pallets while shipping your items. We make sure that they are delivered on schedule to your clients.

2. Availability

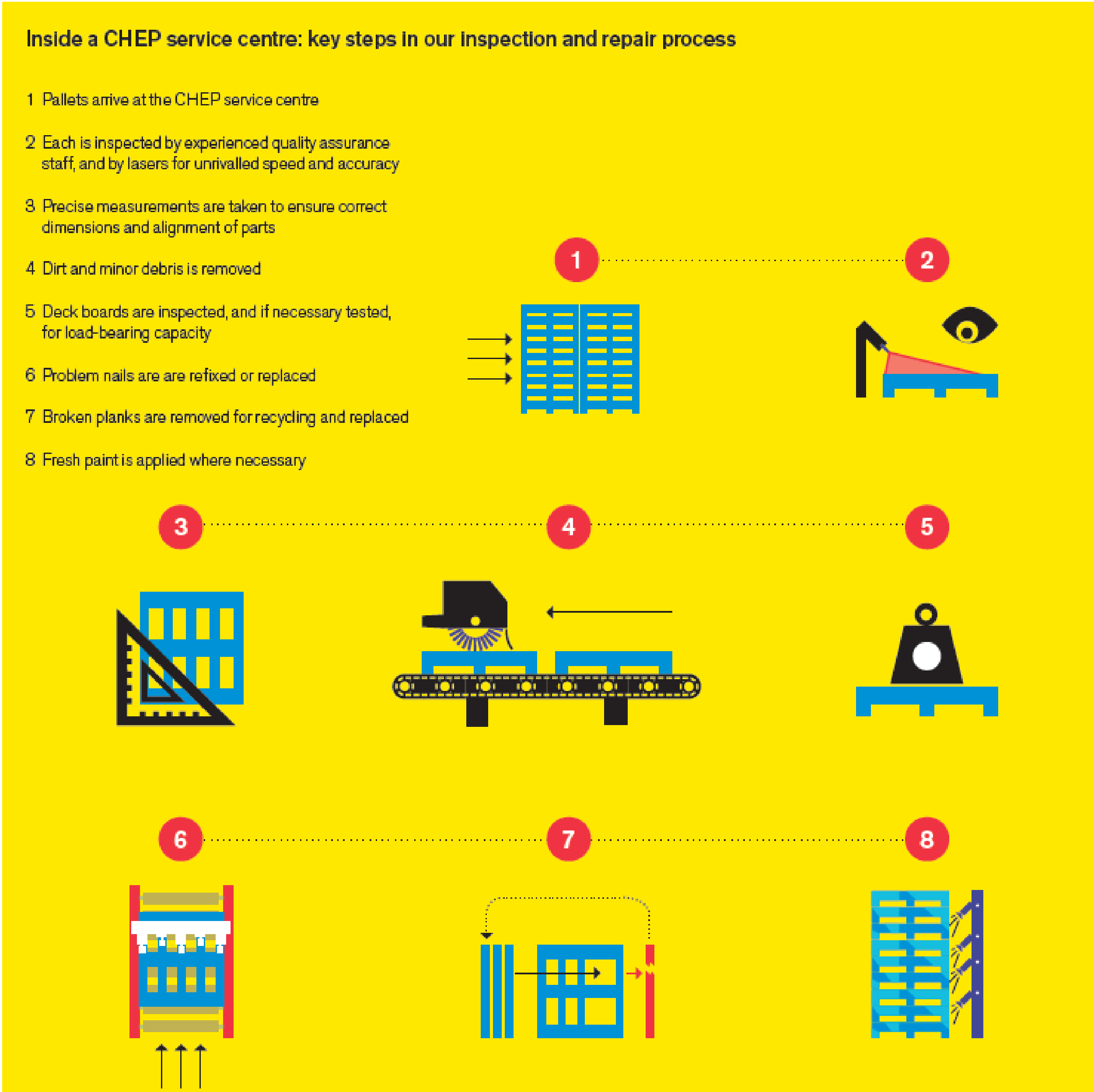
Online sales tend to rise at certain times of the year or in connection with unusual events. Our worldwide network, size, and expertise allow us to react swiftly to your requests and deliver them when necessary.

3. Quality

To prevent product damage and returns, we maintain rigorous quality standards in our service facilities for all CHEP rental pallets. Additionally, our pallets are well-suited for usage in warehouses and distribution centers that are completely computerized.

4. Sustainability

Keeping up with your company's sustainability needs is critical in the digital era since your consumers demand it, and your providers must support you in delivering a more environmentally friendly product or service. As a result, there are fewer vacant kilometers and reduced CO_2 emissions due to the use of the CHEP rental pallet [55].

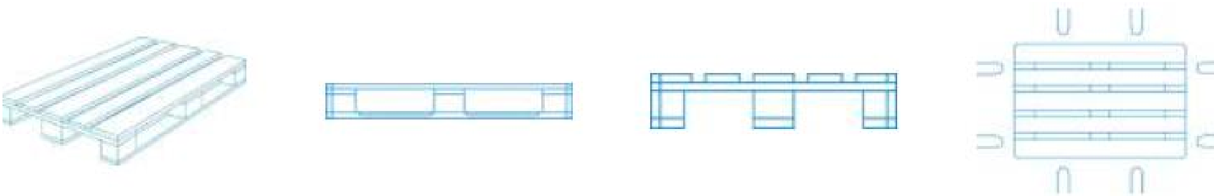


[56]

CHEP pallets

Approximately 120 million European pallets are put to use each year. With 220 service locations in 35 countries, we offer the widest support network. There is no need to worry about the fluctuating demand for our pallets since, no matter what, we can provide them on schedule and in the proper quantity.

[56]



		L	P	H
Dimensions - in millimeters	External dimensions	1200	800	144
Window / Pallet Entry - in millimeters	1200mm		383	100
	800mm		228	100
Nominal capacity and weight	Empty weight			25kg
Configuration and stacking	Load not exceeding 1000kg			
	Load not exceeding 4000kg when stacking loaded pallets			
	Up to 40 empty pallets can be stacked			

- Product damage and load stability are reduced due to its sturdy structure.
- To maximize operating efficiency in manufacturing facilities and automated warehouses, its technological requirements are ideal.
- The four-way design provides compatibility with all standard equipment, allowing for greater efficiency in storage and transportation.
- The health and welfare of the workplace may be ensured by using high-quality products.

[56]

- In transit, objects are less likely to be damaged due to the strong design of the steel blocks.
- Cost savings reduced picking times and easier cross-docking of consumer goods make it perfect for usage in distribution facilities.
- It saves time and decreases the risk of product damage by making it simpler and quicker to refill products on the shelf.
- To maximize operating efficiency in manufacturing facilities and automated warehouses, its technological requirements are ideal.
- The four-way design provides compatibility with all standard equipment, allowing for greater efficiency in storage and transportation.

		L	P	H
Dimensions - in millimeters	External dimensions	800	600	163
Window / Pallet Entry - in millimeters	800mm		250	120
	600mm		250	90
Configuration and stacking	Load not exceeding 500kg			
	Load not exceeding 2000kg when stacking loaded pallets			
	Up to 26 empty pallets can be stacked			

Helping to keep your supply chain moving

We understand non-standard, and variable quality pallets can hurt your reputation, and your bottom line.

That's why every CHEP pallet is independently verified to last up to ten times longer than other pallets.

All equipment issued to a customer from a CHEP Service Centre is inspected and, if necessary, reconditioned to ensure that it meets our quality standard.

Our high-quality pallets require less manual labour for repalletization and return handling and our quality pallets can be stacked higher when empty, and so take up less space in your trucks/yard.

Why quality matters

Product damage can hurt your profitability and your reputation. The inconsistent build quality of white-wood pallets can cause platform collapse, additional cost and delivery refusals, meaning more repairs and replacements. More sorting, too, as you try to decide whether the pallets are fit for purpose.

CHEP's improved design and construction can significantly decrease pallet related product damage. And our extensive network across Europe means that every single pallet is rigorously checked, repaired and certified before it goes to you, no matter how large your demand.

More standardization, less risk

CHEP pallets conform to industry standards, are designed for easier, safer and minimal handling. Our pallets are standardised to fit virtually all automated processes.

Higher quality means less disruption to production lines. During stoppages, energy is wasted rectifying problems rather than maintaining output.

A positive impact on the environment

At CHEP, we collaborate with customers worldwide to ensure our pallets are fully compatible with automated systems. 100% of CHEP timber is from sustainable forests and CHEP pallets are 100% recycled; nothing goes to landfill.

All this means less damage, less contamination and less CO_2

CHEP wooden pallets last up to **10x** longer than white-wood pallets

260 CHEP Service Centres: inspecting & repairing pallets every day

We operate in **31** countries across Europe: where you need us, when you need us

100% of CHEP timber is from sustainable forests

> **Before CHEP, we never got back many of the pallets we put into the exchange system, plus the quality of the returned pallets was often too poor for us to use again. The savings realized by using CHEP vs. white exhange pallets is as much as 30%.**
>
> Bernd Berghofer, CEO, Austria Pet Food

AUSTRIA PET FOOD

ONLY CHEP: No one has helped more companies move more goods to more places for more people than CHEP. Our engineers and supply chain experts have been at the heart of thousands of supply chains – collaborating with customers to streamline operations and take their products to new markets.

Find out more at **CHEP.com**

CHEP's greatest asset (chep.com)

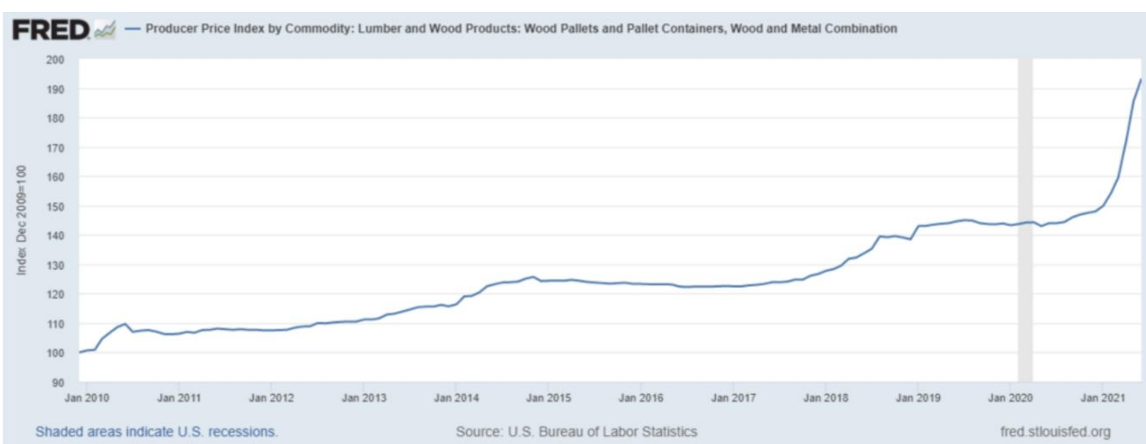
To improve the efficiency and convenience of your delivery, make use of our experience and relationships developed through working with more than 20,000 firms worldwide. Our supply-logistics professionals are always ready to assist clients, and this is part of the service we provide.

Our service is relied upon by several major companies, including Henkel, Ferrero, and Coca-Cola. That's why our pallets are used to deliver products like washing powder, chocolate, and lemonade to retailers. CHEP ensures that everything is where and when it should be.

[58]

Existing problems

During the pandemic, the demand for pallets is increased significantly. In addition, the pallets market is estimated to achieve a CAGR of 5.2 percent during the forecast period (2021 - 2026)[59]. As supply networks become gradually global customers expect greater transparency as to how products and commodities travel through them.



[60]

In order to meet with rising demand, the sector has to enhance its supply. The greatest strategy to expand the supply is to implement OEE. While investigating difficulties that exist in CHEP, discovered that concerns were long setup/changeover time, lack of highly skilled employees, and time spent on quality issues/rework.

FRAMEWORK APPLICATION AND DATA ANALYSIS

At the CHEP factory in Turin, Italy, this research was carried out. All machines' data is gathered in a methodical manner. Every day, measurements, observations, and interviews were carried out in order to gather and analyze the data. There were 64 working days, each with two shifts and two times each shift included in the data collection.

The transfer of framework in an application is considered to be a crucial part of any research. As mentioned above, many theories were described, however, few of them were applied during the research. One of these technics is the quantitative method since any company has an internal database to gather data related to the production process. CHEP's internal system is not an exception, numerical data were gathered, analyzed using mathematically based methodologies, and updated on daily basis. According to the method, all related data was under our eyes, as periodically control was carried out, we could insert around 2500 pallets per day. Furthermore, qualitative approach, it was clear to identify some issues making random sampling. During the daily investigation, we sorted around 2-3% of the total number of pallets to check their duration to repair and quality from the technical point of view.

Total productive maintenance is a comprehensive approach to equipment maintenance that attempts to ensure optimum productivity. During the investigation, it was determined that productive maintenance in the plant was a little bit less than the typical producer's TPM, having electric and mechanical concerns. As electric and mechanical engineers had to arrive in order to examine and research the functionality of the complete system and figure out flaws caused to stop of the operation. Due to these performance and availability metrics started falling steadily. The significant difficulty resulting in these breakdowns is relatively old elements of the system, and it was important to replace them with new ones despite the expense of the parts.

As a consequence of the additional maintenance management, it was found out the probable methods of the equipment failure, for example, overheating of the complete system, resulting in protracted set-up and change over time. Which influenced a big effect on OEE. Moreover, there was another breakdown resulting in a connection failure which were the control center and compressor. Both had connection difficulties between distinct sections, producing a short circuit. In addition, the low performance not connected to the system was a shortage of workers, since during the pandemic it was difficult to operate with a complete workforce. Due to this issue, the speed performance was lowered, as occasionally two persons had to labor for either three or four. On the other hand, it was not discovered any loss connected to quality. Since each product was examined more than two times, that enhanced OEE.

One of the important performance metrics is total effective equipment performance (TEEP), which measures the percentage of All Time that is truly productive.

TEEP = OEE * Utilization

Utilization = Planned Production Time / All Time

Utilization during the research is around 46%, which means that more than half of the time machinery is not being utilized which represents a huge, wasted opportunity.

All time => 92 days (October, November, December) * 24 (hours per day) = 2208 (hours)

Planned Production Time => 64 (working days) * 16 (2 shifts having 8 hours each) = 1024

Utilization = 1024 / 2208= 46.38%

The total scheduled production time is 1024.

Change-over time: 201 h.

Electric maintenance takes 3.5 h.

Mechanical maintenance = 12.8 h.

The pause time of the system is 48 h.

Other planned stops total 30.5 hours.

The absence of personnel is 80 hours.

Micro stoppages = 37 h.

Quality check = 58.5 h.

The total operation time is 552.7 hours.

Total downtime is the difference between total scheduled production time and total operation time, which is 471.3.

Types of Cycle times	Time
Short cycle time	30-60 seconds
Medium cycle time	1-2 minutes
Long cycle time	2-3.5 minutes

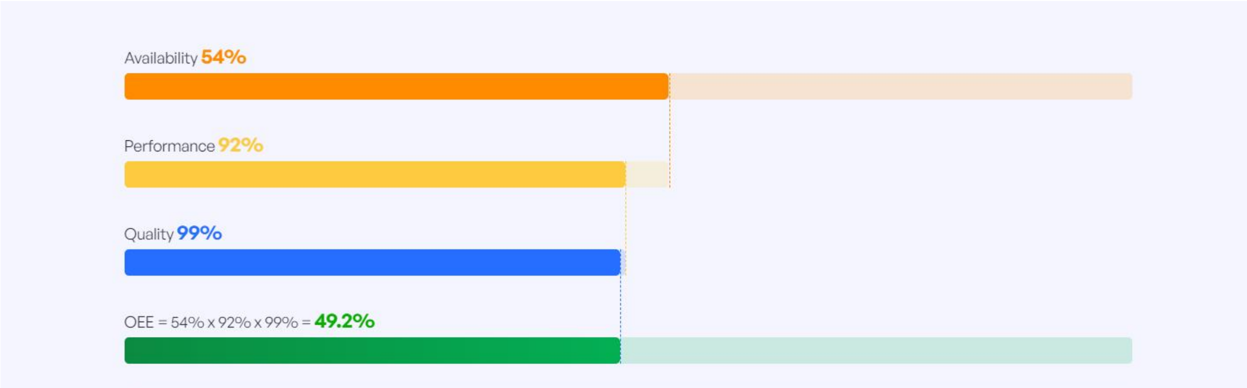
The total availability is 53,9%.

Downtime losses (Aggregate Stoppage Reasons)	Time	Percentage of Losses
Setup/Changeovers	201	42,65%
Planned service/Maintenance	16,3	3,46%
Shift changes and breaks	48	10,18%
Other planned stops	30,5	6,47%
Lack of personals	80	16,97%
Micro stoppages	37	7,85%
Quality issues /reworks	58,5	12,41%
Total	471,3	100%

***Results of downtime losses and their stoppage reasons were done according to the gathered data*.**

The average quality is considered to be the highest parameter as a whole, with 98,99%.

Average Availability	Average Performance	Average Quality
53,9%	91,6%	98,99%

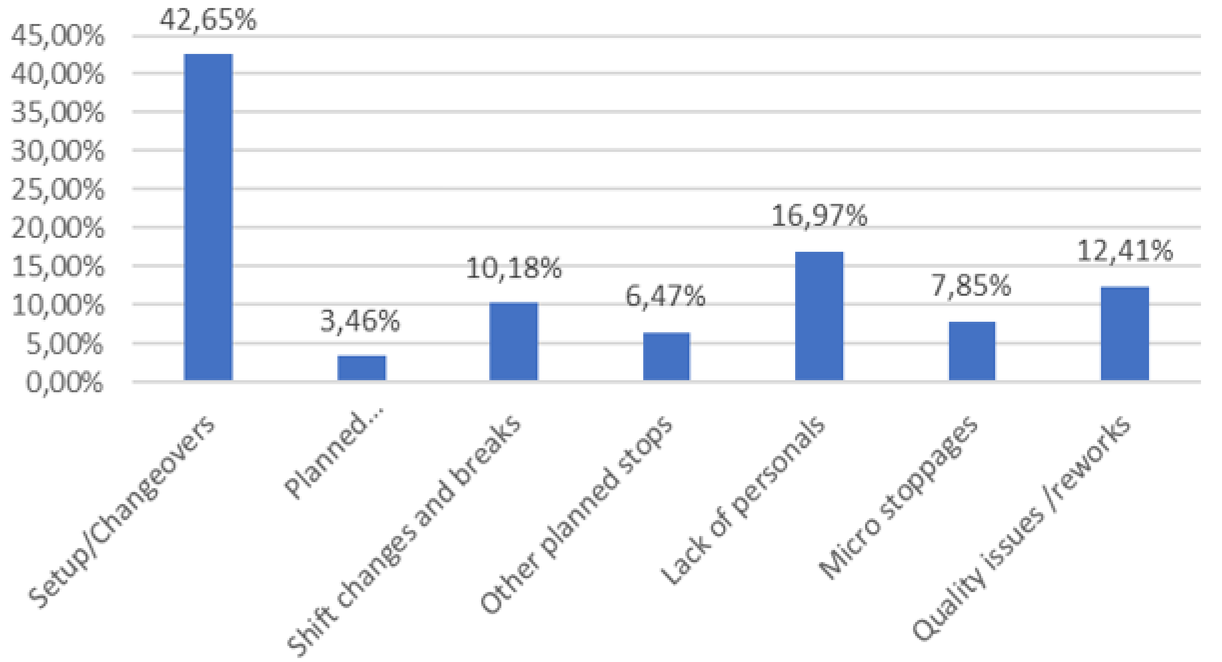


Results of OEE in CHEP

Results

This chapter includes discussions on what has been done and how it has been done. What might have been done better, as well as the probable causes that may have influenced the task, are evaluated.

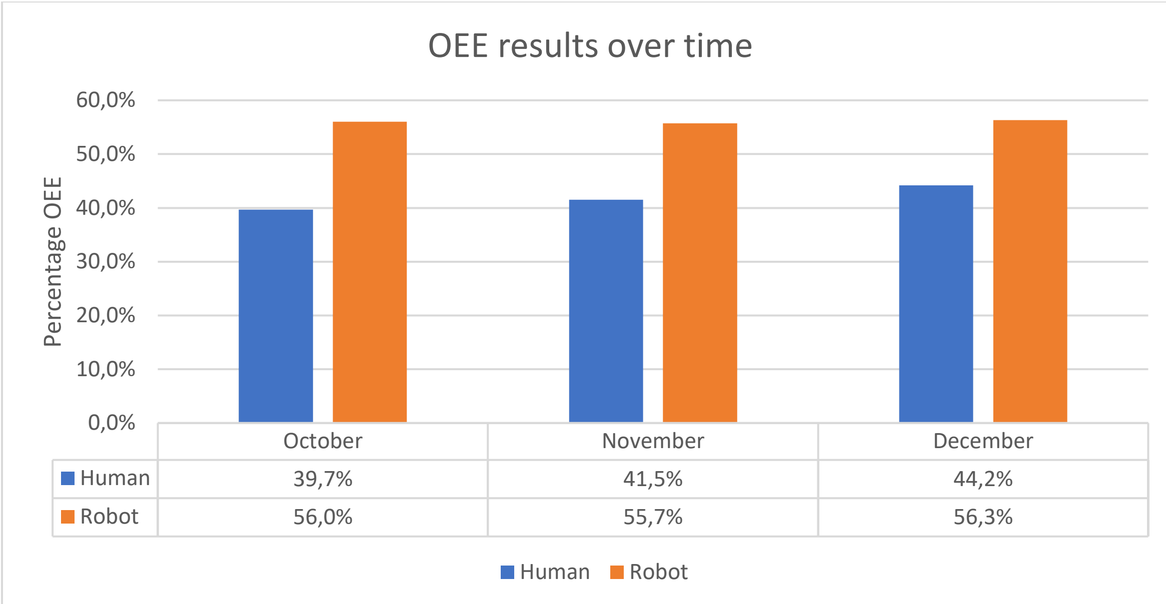
Detailed OEE measurements are reported in this section of the report. That approach was previously discussed when flaws were uncovered and highlighted in this section.



Research-based data (Excel)

Below is a breakdown of the many reasons for a CHEP-based loss related to the aforementioned methods. Setup and changeover losses accounted for 42,65 percent of overall losses, with a scarcity of employees accounting for 16,97 percent. First came quality concerns (12.41 percent), shift changes and breaks (10,18 percent), and micro-stoppages (7,85 percent).

Maintenance-related losses were 3.46 percent, while other scheduled stoppages amounted to 6.47 percent of total losses.



There was a rise in OEE values for human factor-related devices, while the values of entirely autonomous machines remained stable. In October, human beings' OEE value was 39.7 percent; in December, it was 44.2%.

These OEE levels are less than 100% for each month. The shift changes and breaks, maintenance, and other scheduled stoppages resulted in 20% of the losses. Due to a lack of personnel and set-up/changeover time, the availability-related pauses were unanticipated losses.

There were 8% of performance-related losses due to micro stoppages, whereas 12% were quality-related losses due to quality issues/reworks.

Factor	Losses	Stoppage reasons	Percentage(s)
Availability	Planned Losses	Shift changes and breaks	10%
		Planned service/Maintenance	3%
		Other planned stops	7%
		Shortage of personnel	17%
Total Availability	Unplanned Losses	Setup/Changeover	43%
Total Performance	Minor idling losses	Micro stoppage	8%
Quality	Defect and rework	Quality issues/Reworks	12%

Analysis and scope of improvement

OEE outcomes can be improved by focusing on big losses and finding strategies to remove them rather than lesser losses, which are often overlooked. In an empirical investigation, Schmenner and Vollmann [5] found that they typically included too many diverse measurements, which may be difficult to grasp or doubtful of utilizing the proper measures in the correct manner.

The typical OEE rate is 48.9%. In addition to its 98.99% average quality, its average availability and performance rates of 53.9% and 91.60% each impact this. A total of 20% of OEE outcomes were impacted by anticipated losses. Some of the anticipated losses can be reduced by taking the appropriate steps:

• Changes in shifts and rest periods can be reduced with forethought and preparation.

• The 3 percent of planned service/maintenance that can be scheduled outside of work hours.

• With a 17% staff shortage, it's clear there hasn't been enough forethought.

"Setup and changeover" accounted for 43% of the total losses incurred. Applying for the SMED program will allow you to drastically minimize setup and changeover times. Twenty percent of the overall losses were attributable to poor planning at CHEP. Five whys helped us figure out why we had these setbacks. To optimize the planning factor, shifts and breaks might be cut, or additional operators might be added to the facility. The cause-effect diagram can be used to reduce unplanned losses (e.g., equipment breakdowns).

CONCLUSIONS AND RECOMMENDATIONS

This thesis investigates the overall efficiency of CHEP's equipment by identifying and quantifying all of the equipment's losses. OEE offered a comprehensive picture of the plant's various processes in terms of efficiency.

A manufacturing industry's competitiveness may be improved by increasing productivity and achieving a higher return on investment (ROI) through OEE. An OEE rating of 85 percent indicates world-class performance, with availability, performance, and quality all at or above 99.9 percent. The discrepancy between ideal and actual states has a significant impact on this value, which is determined by possible losses. Based on the plant's empirical analysis, Williamson [61] claims that there is no distinct world-class value, which is also the case. In the manufacturing sector, setup and adjustment times increase when the product mix changes. This, of course, has a negative impact on OEE. The average quality factor is the only OEE metric that fits this number. The average performance and availability rates of each component have an impact on the mean overall efficiency values. As a rule, accessibility is the poorest OEE criteria in business. This is a direct result of their massive losses or the specific losses they have suffered.

OEE's projected world-class quality value OEE resulted in the lowest quality losses; nevertheless, availability suffered the most losses. There must be a greater understanding, and perhaps even a training program for everyone in the industry, about the value of knowledge. Because it aids in decision-making and establishes a standard against which future improvements can be measured, understanding why something is being measured is critical. Because stoppage reasons were not mentioned, this research should continue to investigate this issue.

The CHEP's average OEE has been below average. In this case, it is clear that they are not adhering to the OEE ideas and applying the theory's essential principles. Reasons for this might include:

- That they believe their equipment is more efficient than it is and don’t see the need to measure their operations.
- Untrained operators don't know how to operate the system that has been put in place.
- Due to the diversity of the technology and the difficulties in understanding it.
- Procrastination is a major factor.
- As a result, they fear it could evaluate their own performance.
- The fact that the service isn't functioning properly.
- When it comes to the system, such operators have no interest in it or its advantages.
- There was no use for the earlier data by the management, and it's irrelevant.
- In light of several management and system shifts.
- Inappropriately used and misunderstood
- Accounting, not future progress, is the sole purpose of this system.

It is possible to overcome the reluctance of employees to change by putting a lot of time and effort into internal communication and making sure that everyone understands the message. Improvements in current performance could be necessary to sustain long-term competitiveness.

If you're looking for probable causes of loss-related events, you may utilize the 5 Whys or Fishbone Diagram for Complex Systems, which is a basic technique for determining possible causes. Because OEE values are so reliant on accurate data, this poses a problem for data quality as well. Therefore, it is essential to invest in an automated monitoring system that can often increase the credibility and trustworthiness of the data that is generated.

A growing number of businesses are investing in expensive new technology and equipment. Using new technologies and equipment has resulted in a higher risk of a crucial system failing, as this is essential to the operation. Because of these unplanned losses, the capacity of operators to operate might be significantly impacted. OEE's advantages include:

- Accuracy of information through automatic data collection.
- Proper utilization of their current infrastructure and tools.
- Making decisions based on well-presented and understandable data.
- Energy efficiency and quality monitoring facilities.

Availability-related losses were the primary cause of poor OEE in CHEP. Setup and changeover were the most significant drawbacks of any other process that required SMED. With the implementation of SMED, inventory costs will be reduced, and customers' needs will be met.

Before implementing any of these approaches, future advice would be to notify all the controllers and people. The requirement to inspire and explain the rationale for these adjustments should be pushed to the forefront because people are often reluctant to change. When individuals are educated and given authority, they become more self-aware. Additionally, a system must be created to meet every industry's distinct procedures. Qualitative research includes interviews (over the phone or in-person), questionnaires sent to employees, and other means of acquiring data, all examples of qualitative research. A cross-functional team's data might lead to more accurate and important information.

Preventive maintenance or vibration analysis may be necessary in the case of additional unforeseen actions due to machine malfunctions. Some of the following issues might well be examined in the long term:

• Operation and production design.

• How to calculate the cost-effectiveness of various pieces of equipment.

• Machine design or mechanical design.

• Frequency studies on man-hours (Human OEE).

REFERENCES

[1] F. Aldo Zammori, M. Braglia, and M. Frosolini, "Stochastic Overall Equipment Effectiveness," *International Journal of Production Research*, p. 1, 2011, doi: 10.1080/00207543.2010.519358ï.

[2] S. J. Benjamin, M. S. Marathamuthu, and U. Murugaiah, "The use of 5-WHYs technique to eliminate OEE's speed loss in a manufacturing firm," *Journal of Quality in Maintenance Engineering*, vol. 21, no. 4, pp. 419–435, Oct. 2015, doi: 10.1108/JQME-09-2013-0062.

[3] "Lord Kelvin Quotes: If you can not measure it, you can not improve it. ..." https://www.wisefamousquotes.com/lord-kelvin-quotes/if-you-can-not-measure-it-you-can-2050917/ (accessed Jan. 29, 2022).

[4] P. Jonsson and M. Lesshammar, "Evaluation and improvement of manufacturing performance measurement systems - The role of OEE," *International Journal of Operations and Production Management*, vol. 19, no. 1, pp. 55–78, 1999, doi: 10.1108/01443579910244223.

[5] R. W. Schmenner and T. E. Vollmann, "Performance Measures: Gaps, False Alarms, and the 'Usual Suspects,'" *International Journal of Operations & Production Management*, vol. 14, no. 12, pp. 58–69, Dec. 1994, doi: 10.1108/01443579410072391.

[6] T. C. Fleischer, C. M. Weaver, K. J. McAfee, J. L. Jennings, and A. J. Link, "Systematic identification and functional screens of uncharacterized proteins associated with eukaryotic ribosomal complexes," *Genes and Development*, vol. 20, no. 10, pp. 1294–1307, May 2006, doi: 10.1101/gad.1422006.

[7] J. Huang, H. Shimizu, and S. Shioya, "Clustering Gene Expression Pattern and Extracting Relationship in Gene Network Based on Artificial Neural Networks," *Journal of Bioscience and Bioengineering*, vol. 96, no. 5, pp. 421–428, 2003, doi: 10.1016/S1389-1723(03)70126-1.

[8] Seiichi Nakajima, *Introduction to tpm: Total Productive Maintenance*. 1988.

[9] O. S. Ohunakin and R. O. Leramo, "Total productive maintenance implementation in a beverage industry: A case study," *Journal of Engineering and Applied Sciences*, vol. 7, no. 2, pp. 128–133, 2012, doi: 10.3923/JEASCI.2012.128.133.

[10] B. Dal, P. Tugwell, and R. Greatbanks, "Overall equipment effectiveness as a measure of operational improvement - A practical analysis," *International Journal of Operations and Production Management*, vol. 20, no. 12, pp. 1488–1502, 2000, doi: 10.1108/01443570010355750.

[11] "What Is OEE (Overall Equipment Effectiveness)? | OEE." https://www.oee.com/ (accessed Jan. 29, 2022).

[12] P. Arunagiri and A. Gnanavelbabu, "Identification of Major Lean Production Waste in Automobile Industries using Weighted Average Method," *Procedia Engineering*, vol. 97, pp. 2167–2175, Jan. 2014, doi: 10.1016/J.PROENG.2014.12.460.

[13] "Redefining OEE for the Modern Era." https://www.reliableplant.com/Read/31479/modern-era-oee (accessed Jan. 29, 2022).

[14] P. Muchiri, L. Pintelon, L. Gelders, and H. Martin, "Development of maintenance function performance measurement framework and indicators," *International Journal of Production Economics*, vol. 131, no. 1, pp. 295–302, May 2011, doi: 10.1016/j.ijpe.2010.04.039.

[15] E. Bell and A. Bryman, "The ethics of management research: An exploratory content analysis," *British Journal of Management*, vol. 18, no. 1, pp. 63–77, Mar. 2007, doi: 10.1111/J.1467-8551.2006.00487.X.

[16] Martha. Aliaga and Brenda. Gunderson, "Interactive statistics," p. 676, 1999.

[17] "Qualitative research Images, Stock Photos & Vectors | Shutterstock." https://www.shutterstock.com/search/qualitative+research (accessed Jan. 29, 2022).

[18] "Qualitative Research Methods in Management Research | Request PDF." https://www.researchgate.net/publication/215915855_Qualitative_Research_Methods_in_Management_Research (accessed Dec. 21, 2021).

[19] J. W. Creswell, W. E. Hanson, V. L. Clark Plano, and A. Morales, "Qualitative Research Designs: Selection and Implementation," *The Counseling Psychologist*, vol. 35, no. 2, pp. 236–264, 2007, doi: 10.1177/0011000006287390.

[20] "(PDF) Research Methods for Business Studies." https://www.researchgate.net/publication/201382148_Research_Methods_for_Business_Studies (accessed Dec. 24, 2021).

[21] "The Concepts of Reliability and Validity Explained With Examples - Psychologenie." https://psychologenie.com/concepts-of-reliability-validity-explained-with-examples (accessed Jan. 29, 2022).

[22] "Reliability vs Validity in Research | Differences, Types and Examples." https://www.scribbr.com/methodology/reliability-vs-validity/ (accessed Dec. 27, 2021).

[23] "(PDF) Decoding the DNA of the Toyota Production System." https://www.researchgate.net/publication/200552318_Decoding_the_DNA_of_the_Toyota_Production_System (accessed Dec. 24, 2021).

[24] Andris. Freivalds and B. W. Niebel, "Niebel's Methods, standards, and work design," 2009, Accessed: Dec. 24, 2021. [Online]. Available: https://books.google.com/books/about/Niebel_s_Methods_Standards_and_Work_Desi.html?hl=ru&id=Bn1nPgAACAAJ

[25] "Types of Validity in Research with Examples & Steps." https://www.irelandassignmenthelp.com/blogs/types-of-validity-in-research/ (accessed Jan. 29, 2022).

[26] "Types of Reliability in Research | How to Measure it." https://www.irelandassignmenthelp.com/blogs/types-of-reliability-in-research/ (accessed Jan. 29, 2022).

[27] R. Iannone and M. Elena, "Managing OEE to Optimize Factory Performance," in *Operations Management*, InTech, 2013. doi: 10.5772/55322.

[28] "Difference between efficiency, effectiveness and productivity - Business-Building Information." http://smartmanagement.info/lean-manufacturing/oee/difference-between-efficiency-effectiveness-and-productivity/ (accessed Jan. 29, 2022).

[29] K. Amasaka, "The foundation for advancing the Toyota Production System utilizing New JIT," *Journal of Advanced Manufacturing Systems*, vol. 8, no. 1, pp. 5–26, Jun. 2009, doi: 10.1142/S0219686709001614.

[30] A. , L. E. , Ljungberg, *Processbaserad verksamhetsutveckling, Studentlitteratur, Lund.* 2001.

[31] D. J. Bamber, I. M. Cockerill, S. Rodgers, and D. Carroll, "Diagnostic criteria for exercise dependence in women," *British Journal of Sports Medicine*, vol. 37, no. 5, pp. 393–400, Oct. 2003, doi: 10.1136/BJSM.37.5.393.

[32] S. A. Brah and W. K. Chong, "Relationship between total productive maintenance and performance," *International Journal of Production Research*, vol. 42, no. 12, pp. 2383–2401, Jun. 2004, doi: 10.1080/00207540410001661418.

[33] G. Ahuja, C. M. Lampert, and V. Tandon, "1 Moving Beyond Schumpeter: Management Research on the Determinants of Technological Innovation," *The Academy of Management Annals*, vol. 2, no. 1, pp. 1–98, Jan. 2008, doi: 10.1080/19416520802211446.

[34] M. E. Kotze, "Die verband tussen loopbaanvolwassenheid, rolbelangrikheid en akademiese prestasie: 'n Verkennende studie," *SA Journal of Industrial Psychology*, vol. 19, no. 3, pp. 13–17, Jun. 1993, doi: 10.4102/SAJIP.V19I3.561.

[35] J. Ericsson, "Disruption Analysis - An Important Tool in Lean Production," *undefined*, 1997.

[36] M. Tajiri and Fumio. Gotō, *TPM implementation, a Japanese approach*. New York: McGraw-Hill, 1992.

[37] A. J. de Ron and J. E. Rooda, "Equipment effectiveness: OEE revisited," *IEEE Transactions on Semiconductor Manufacturing*, vol. 18, no. 1, pp. 190–196, Feb. 2005, doi: 10.1109/TSM.2004.836657.

[38] "How to Calculate OEE – Formulas & Examples | Evocon." https://evocon.com/articles/how-to-calculate-oee-formulas-examples/ (accessed Dec. 10, 2021).

[39] A. Trattner, L. Hvam, and A. Haug, "Why slow down? Factors affecting speed loss in process manufacturing," *The International Journal of Advanced Manufacturing Technology 2019 106:5*, vol. 106, no. 5, pp. 2021–2034, Dec. 2019, doi: 10.1007/S00170-019-04559-4.

[40] K. Y. Jeong and D. T. Phillips, "Operational efficiency and effectiveness measurement," *International Journal of Operations and Production Management*, vol. 21, no. 11, pp. 1404–1416, 2001, doi: 10.1108/EUM0000000006223.

[41] I. Ivancic, *Development of maintenance in modern production*. 1998.

[42] "Types of manufacturing subsystems. | Download Scientific Diagram." https://www.researchgate.net/figure/Types-of-manufacturing-subsystems_fig2_259289574 (accessed Jan. 29, 2022).

[43] "Improvement approach to increase the plant OEE. | Download Scientific Diagram." https://www.researchgate.net/figure/Improvement-approach-to-increase-the-plant-OEE_fig3_259289574 (accessed Jan. 29, 2022).

[44] P. (1995) de Groote, "Maintenance performance analysis: a practical approach," *Journal of Quality in Maintenance Engineering*, vol. 1, no. 2, pp. 4–24, 1995.

[45] S. Ojha *et al.*, "OEE as an indicator for Performance Measurement in Coal Handling Plant," 2015. [Online]. Available: www.ijiset.com

[46] "How to Improve OEE | OEE." https://www.oee.com/improve-oee/ (accessed Dec. 25, 2021).

[47] D. van Goubergen and H. van Landeghem, "Rules for integrating fast changeover capabilities into new equipment design," *Robotics and Computer-Integrated Manufacturing*, vol. 18, no. 3–4, pp. 205–214, Jun. 2002, doi: 10.1016/S0736-5845(02)00011-X.

[48] S. E. Pratsinis, "Flame aerosol synthesis of ceramic powders," *Progress in Energy and Combustion Science*, vol. 24, no. 3, pp. 197–219, Jan. 1998, doi: 10.1016/S0360-1285(97)00028-2.

[49] S. Shingō, "A revolution in manufacturing : the SMED system," p. 361, 1985.

[50] N. Slack and M. Lewis, “Operations Strategy”, Accessed: Dec. 26, 2021. [Online]. Available: www.pearsoned.co.uk/slack.

[51] J. F. Riley and J. M. (Joseph M.) Juran, “The quality improvement process,” 1999.

[52] “Is there a tool that helps creating fishbone diagrams? - Quora.” https://www.quora.com/Is-there-a-tool-that-helps-creating-fishbone-diagrams (accessed Jan. 29, 2022).

[53] “(PDF) Application Of Fishbone Diagram To Determine The Risk Of An Event With Multiple Causes.” https://www.researchgate.net/publication/46567642_Application_Of_Fishbone_Diagram_To_Determine_The_Risk_Of_An_Event_With_Multiple_Causes (accessed Dec. 26, 2021).

[54] “Pallets in Consumer Goods | CHEP UK.” https://www.chep.com/uk/en/why-chep (accessed Dec. 27, 2021).

[55] “Manufacturers CHEP Italy.” https://www.chep.com/it/it/perche-chep (accessed Dec. 24, 2021).

[56] “Soluzioni per piattaforme | CHEP Italia.” https://www.chep.com/it/it/I-nostri-prodotti (accessed Jan. 29, 2022).

[57] “Pallet in legno - 1200 x 800 mm | CHEP.” https://www.chep.com/it/it/product/wooden-pallet-1200-x-800-mm-03 (accessed Jan. 29, 2022).

[58] “Sostenibilità | CHEP Italia.” https://www.chep.com/it/it/sostenibilita (accessed Jan. 29, 2022).

[59] “Global Pallets Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021 - 2026).” https://www.reportlinker.com/p06192782/Global-Pallets-Market-Growth-Trends-COVID-19-Impact-and-Forecasts.html?utm_source=GNW (accessed Jan. 30, 2022).

[60] “Federal Reserve Economic Data | FRED | St. Louis Fed.” https://fred.stlouisfed.org/ (accessed Jan. 30, 2022).

[61] R. M. Williamson, “Total Productive Maintenance: What It Is and What It Is Not,” *Strategic Work Systems, Inc. Columbus, NC 28722* , 2006.