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Master’s Thesis

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Measuring and Improving Production Efficiency of Paint Filling and Packing Line

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Tutkittu yritys on suomalainen maaleja ja lakkoja kansainvälisesti valmistava ja myyvä toimija. Yrityksessä otettiin vuonna 2010 käyttöön uudet tuotannon ja toimitusketjun tavoitteet ja suunnitelmat ja tämä tutkimus on osa tuota kokonaisvaltaista kehittämissuuntaa. Tutkimuksessa käsitellään tuotannon ja kunnossapidon tehokkuuden parantamis- ja mittaustyökalu OEE:tä ja tuotevaihtoaikojen pienentämiseen tarkoitettua SMED -työkalua.

Työn teoriaosuus perustuu lähinnä akateemisiin julkaisuihin, mutta myös haastatteluihin, kirjoihin, internet sivuihin ja yhteen vuosikertomukseen. Empiriaosuudessa OEE:n käyttöönoton ongelmia ja onnistumista tutkittiin toistettavalla käyttäjäkyselyllä. OEE:n potentiaalia ja käyttöönottoa tutkittiin myös tarkastelemalla tuotanto- ja käytettävyysdataa, jota oli kerätty tuotantolinjalta. SMED:iä tutkittiin siihen perustuvan tietokoneohjelman avulla. SMED:iä tutkittiin teoreettisella tasolla, eikä sitä implementoitu vielä käytäntöön.

Tutkimustuloksien mukaan OEE ja SMED sopivat hyvin esimerkkiyritykselle ja niissä on paljon potentiaalia. OEE ei ainoastaan paljasta käytettävyyshäviöiden määrää, mutta myös niiden rakenteen. OEE -tulosten avulla yritys voi suunnata rajalliset tuotannon ja kunnossapidon parantamisen resurssit oikeisiin paikkoihin.

Työssä käsiteltävä tuotantolinja ei tuottanut mitään 56 % kaikesta suunnitellusta tuotantoajasta huhtikuussa 2016. Linjan pysähdyksistä ajallisesti 44 % johtui vaihto-, aloitus- tai lopetustöistä. Tuloksista voidaan päätellä, että käytettävyyshäviöt ovat vakava ongelma yrityksen tuotannontehokkuudessa ja vaihtotöiden vähentäminen on tärkeä kehityskohde.

Vaihtoaikaa voitaisiin vähentää ~15 % yksinkertaisilla ja halvoilla SMED:illä löydetyillä muutoksilla työjärjestyksessä ja työkaluissa. Parannus olisi vielä suurempi kattavimmilla muutoksilla. SMED:in suurin potentiaali ei välttämättä ole vaihtoaikojen lyhentämisessä vaan niiden standardisoinnissa.

ABSTRACT

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The case company of this study is a Finnish paint and varnish manufacturing company acting on international markets. In year 2010 the company established new plans and targets for its production and manufacturing, and this study is a part of that holistic development process. The paper deals with production and maintenance measurement and improvement tool OEE's, and setup time reduction tool SMED's suitability and potential in the case company.

The theory part of the study is based mostly on academic journals, but also in interviews, books, internet pages and in an annual report. In the empirical part, the problems of OEE and its implementation success are studied by repeated user poll. The potential of OEE, as well as the success of implementation are studied also by reviewing the production and availability data collected from the production line. SMED was studied by using a software based on SMED. The SMED study was on theoretical level and no implementation was done.

The result of the study was that OEE and SMED are suitable for the case company and they hold big potential in them. OEE clears out not only the amount of downtime losses, but also the structure of the losses. With OEE results the company can target its limited production and maintenance improvement resources to the right places.

The studied production line was not producing anything 56 % of all the planned production time in April 2016 and 44 % of this off time was caused by setup work. This shows that downtime loss is a serious problem in the case company's production efficiency and setup work is truly important improvement target.

Setup time could be reduced ~15 % with simple and low cost changes in work order and tools. The improvement would be even bigger with more comprehensive changes. The biggest potential of SMED is not necessary in the setup time reduction, but in the standardization of changeovers.

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This master’s thesis ends six years lasted journey. During this journey I met amazing people, saw beautiful places and learned a lot, not only about industrial engineering but also about life and myself.

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Vantaa, 11th of August 2016

Lauri Riippa

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TERMS AND ABBREVATIONS

Arrow Machine Track	OEE software
AviX SMED	SMED software
Cycle time	Time period to complete a cycle of an operation
First OEE project/implementation	OEE project launched in the case company 2013
Lean	Management philosophy aiming to reduce waste
MC factory	Studied production site
OEE	Overall Equipment Efficiency
PDCA	Plan, Do, Check, Act
R&D	Research and Development
Reason tree	OEE reasons and subreasons
Second OEE project/implementation	OEE project launched in the case company 2016
SMED	Single Minute Exchange of Dies
TPM	Total Productive Maintenance
WIP	Work In Progress

1 Introduction

Introduction chapter deals with the background, objectives and restrictions, research questions, and the structure of the thesis. The chapter introduces also that part of the thesis project, which is not directly presented in the other parts of the research paper.

1.1 Background

Globalization increases competition on all fields of business around the world. Consumers have often more brand options than ever before, and they require high quality in low price. The value is not limited only to features of the product, but also to delivery time. Small batch sizes is growing trend on manufacturing industry, and a company who cannot adopt this trend will vanish.

Also economically unstable situation in Russia and in Europe shakes old business structures. Many manufacturing companies have had to reach to new markets or pursue growth on markets which used to be low-priority for them before. Because of this, many companies have to evaluate and adjust again their strengths and weaknesses in order to gain necessary profit from the new sources.

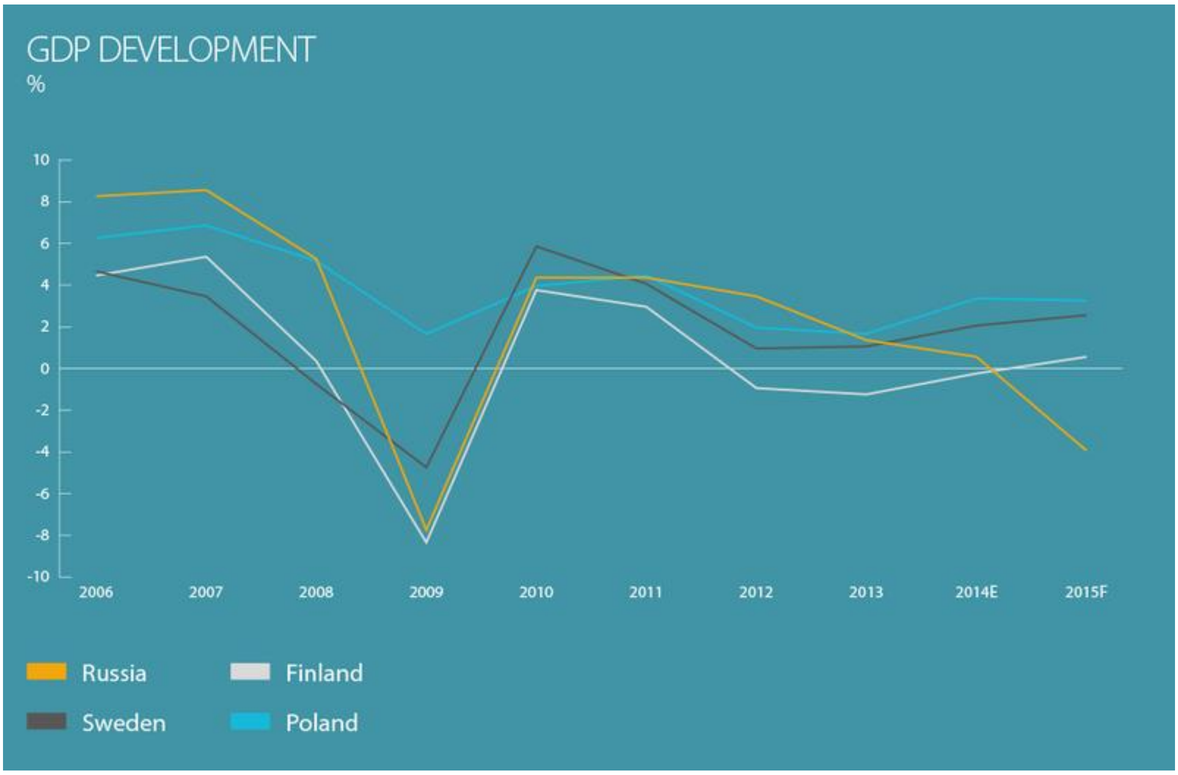


Figure 1 GDP development on TIkkurila's key markets (Tikkurila 2014, 55)

In order to readjust oneself to current situation, a company needs to improve production efficiency and reduce lead times and cycle times. This is especially important for the factories operating in countries of high business expenses. So that production efficiency could be improved and lead times reduced, those need to be measured.

Paints and varnishes manufacturing Finnish company Tikkurila aims to increase production efficiency. Tikkurila acts as a case company in this paper. Among the many ways to increase production efficiency, Tikkurila is interested of using OEE (Overall Equipment Efficiency) production and maintenance efficiency measure and SMED (Single Minute Exchange of Dies) setup time reduction method to reach this goal.

OEE is a production and maintenance efficiency measure, which is calculated by multiplying three OEE factors: Availability, Performance and Quality. All of these three factors are presented as percentages. Availability refers to the actual time an equipment is running compared to the planned running time, Performance describes the production speed and Quality is ratio between flawless and defect production.

SMED is a tool which aims to reduce setup time and simplify setup work. In SMED, setup work is divided in external and internal tasks. External tasks are tasks performed during the production (for example fetching tools) and internal tasks are tasks which can be done only when the production is stopped. In SMED internal and external tasks are recognized and then as many as possible internals are changed to externals.

1.2 Objectives and Restrictions

The aim of this paper is to define good practices of OEE implementation and identify issues of implementation in order to avoid those in possible upcoming OEE implementations in other production lines and factories. Another purpose of this paper is to study if SMED is suitable tool for batch change time reduction and standardization in Tikkurila's Monicolor factory. If these tools are found to be useful, the next question is, what kind of and how big potential those tools hold in them.

The research questions of this study are:

Q1 Is OEE suitable measurement and improvement tool for semi-automatic paint filling and packing line?

Q2 What should be taken in consideration, when implementing OEE on semi-automatic paint filling and packing line?

Q3 What kind of value OEE offers to the case company?

Q4 Is it possible to reduce and standardize batch change time in paint filling and packing with SMED?

Q5 What is the potential of SMED for the case company?

The company hopes that these tools first of all, increase planning accuracy and flexibility of production and decrease process time of filling and packing department. Increase of capacity and utilization rate are also wanted improvements. Nevertheless it is acceptable to produce a bit less, if the amount of production per hour is well known for each product.

The more specific, sub targets for the OEE is to help track bottle necks and general issues in production. It should also help to plan maintenance and help to address limited maintenance and development resources. With SMED Tikkurila wants to standardize and reduce product exchange times and make production planning more accurate.

Comprehensive cost-benefit calculations are left outside of the study. Also SMED implementation is not studied in this paper other than on theoretical level. The paper does not concentrate to solve problems of production or setup work, but to reveal them. Production amount information is hidden in the public version of the paper in order to protect company secrets.

1.3 Master's Thesis Project

This report is part of master's thesis project made on spring 2016 for Lappeenranta University of Technology. The master's thesis project started in the beginning of January and ended in the end of June. In order to find answers for the research questions, OEE pilot was started first. Even though the first OEE project was started already in 2013, the usage of the system was declined so much that new pilot project was necessary. In this paper the new launch of OEE is called the second OEE project or the second OEE implementation.

The first thing in the second OEE project was to define what is wrong with the system and why its usage has declined so much. This was studied by a user poll. When the problems were defined, those needed to be fixed. This happened by training and motivating the users, fixing possible technical errors in the system, changing some features and calculation principles of the system, and defining procedures and principles of the usage.

After fixing the problems, the fixing actions needed to be evaluated in order to see if the actions were right or should be developed for possible upcoming implementations. This happened by doing another user poll with the same questions and studying how well OEE measurement has taken place.

In order to see potential of OEE and its value, OEE measurement results were studied. This enabled evaluation of usefulness of the OEE system for the case company.

Another big part of the thesis project was reducing production line off-time caused by setup work. In this project SMED (Single Minute Exchange of Dies) was used as a setup time reduction tool. SMED was studied in theory and one example of batch change was processed with SMED tool. This enabled assumption of value, suitability and potential of SMED for the case company. Recommendations of the usage are based on the pilot test.

1.4 Structure of the Thesis

Thesis paper begins with presenting its topic by introducing the background of the study, the scope of the study, the research questions, the thesis project phases, research methodology and setting the objectives. The introduction gives the reader an overview on the study and defines the desired results.

Chapter 2 is the theory part of the thesis paper. This chapter presents the theoretical framework of the paper and explains the concepts of the research. The theory chapter introduces the background of the used models and gives comparison and target point to realized actions and results. Empirical findings are evaluated by the used theories. Theory sources are mostly academic articles but also internet pages, an annual report and books. The main discussed theories are related to lean. The basics of lean philosophy is explained in order to understand used theories which are included in wide term of lean. The main used theories are TPM (Total Productive Maintenance), OEE (Overall Equipment Efficiency), PDCA (Plan, Do, Check, Act) and SMED (Single Minute Exchange of Dies).

Chapters 3-6 deal with empirical part of the thesis. Chapter 3 presents the case company and the factory environment which was the platform for the studied systems. Chapter 4 concentrates to OEE implementation. The used OEE system and the attitudes of the line operators towards the system are presented in this chapter. Chapter 5 deals with the effects of visible measurement and the data gathered by the OEE system. Chapter 6 concentrates around SMED. It presents the used SMED system, its potential and an implementation proposal.

The results of the thesis are presented and summarized in chapters 7-8. Chapter 7 summarizes the results which are studied in the chapters 3-6 and chapter 8 is the summary of the whole paper. The structure of the thesis is summarized and presented in the table 1.

***Table 1** Input - output of the thesis*

CHAPTER	CHAPTER TYPE	INPUT	OUTPUT
1. Introduction	General	Task given by the company, scope and limitations	Overview and background of the topic and the thesis project
2. Theory	Theory	Literature	Key theories and concepts for the thesis paper
3. Case company and research background	Application	Data & information from the company	Presenting the company and the studied filling and packing department
4. OEE Implementation	Application	Arrow Machine Track, user poll, related theories presented in chapter 2	Presenting used OEE software, implementation problems and solutions for the future implementations
5. OEE measurement effect and results	Application/Results	Arrow Machine Track, palletizing robot data, related theories in chapter 2	Presenting production and OEE measurement numbers, Evaluating data reliability
6. Reducing setup time with SMED	Application/Results	AviX SMED, interview, related theories in chapter 2	Presenting SMED improvement possibilities and evaluating potential, Also presenting possible implementation model
7. Results	Results	Analysis done in chapters 3-6	Results, findings and actions needed, future study
8. Summary	General	Chapters 1-7	Summary of the thesis project

2 Theory

Theory chapter presents all the scientific theories which the master's thesis is based on. All the used theories are highly related to lean so the lean philosophy is the theory armature of the thesis. The used theory concepts are TPM, PDCA cycle, Performance measurement, OEE and SMED.

2.1 Lean

Lean manufacturing is a business strategy and management philosophy which originates in Toyota Motor Company. Lean aims to eliminate process waste and to improve operational efficiency (Salim, Ali, Musharavati 2015, 456). Since lean first established in the Toyota Motor Company, it has expanded and spread to other types of industries worldwide. During the years, many different principles, concepts and tools for lean implementations have been developed. Commonly used lean concepts and principles include usually elimination of waste, continuous improvement, zero defects, multifunctional teams, integration of functions, standardized work practices and doing it right the first time (Bhat & Shetty 2013, 117-118). (Al-Khalifa, Hamouda, Musharavati & Salem 2015, 1610)

In lean non-value-adding activities are seen as waste. Lean also identifies few common wastes in production processes which are called "the deadly wastes". The deadly wastes include overproduction, waiting, inventory, over processing, transportation, motion and defect. A great number of tools and techniques for implementing lean exists. Examples of these tools are Total Productive Maintenance (TPM), Just In Time (JIT), 5s, Kanban, Single Minute Exchange of Dies (SMED), standard work, visual control, cellular manufacturing and value stream mapping. (Al-Khalifa & Al. 2015, 1610)

There are five commonly used basic steps in implementing lean (Salim & Al. 2015, 456-457, Womack & Jones 1996, 16-26):

1. Specify value

Value is defined by the end customer. Value is specified in terms of satisfying customer's needs by providing goods or services with desired features at competitive price and lead time.

2. Identify the value stream

Value stream is a set of all actions needed to bring a product from raw material to the hands of the end customer through problem-solving, information management and physical transformation tasks.

3. Make the value Flow

This is done by reducing cycle times and batch sizes to minimum, ensuring that each operation is visible, defined and has a visible status to eliminate possible stoppages in the manufacturing process.

4. Let the customer pull

Processes and products should be produced and delivered on-demand to avoid overproduction and warehousing

5. Pursue perfection

Company should always strive to perfection, but it is never achieved. There is no end in the process of reducing effort, time, space, cost and mistakes while offering perfect value to the customer.

2.2 Plan, Do, Check, Act Cycle - PDCA

A central idea of Lean is continuous improvement. One technique to include continuous improvement in implementation process is PDCA (Plan, Do, Check, Act) cycle. In PDCA cycle, the actual results of an action are compared with the target. If the difference between results and target is large, corrective measures are adopted. (Pavletic, Pipan & Sokovic 2010, 477)

PDCA has been found to be more effective than adopting “the right first time” approach. Using PDCA cycle means continuously looking for better methods of improvement. Pavletic & al. argue that PDCA is effective tool for both, doing a job and managing a programme. The PDCA cycle enables two kind of corrective actions: temporary and permanent. The temporary action targets to practically tackling and fixing the problem. The permanent corrective action aims to investigate and eliminate the root causes and thus targets the sustainability of the improved process. (Pavletic et al. 2010, 477)

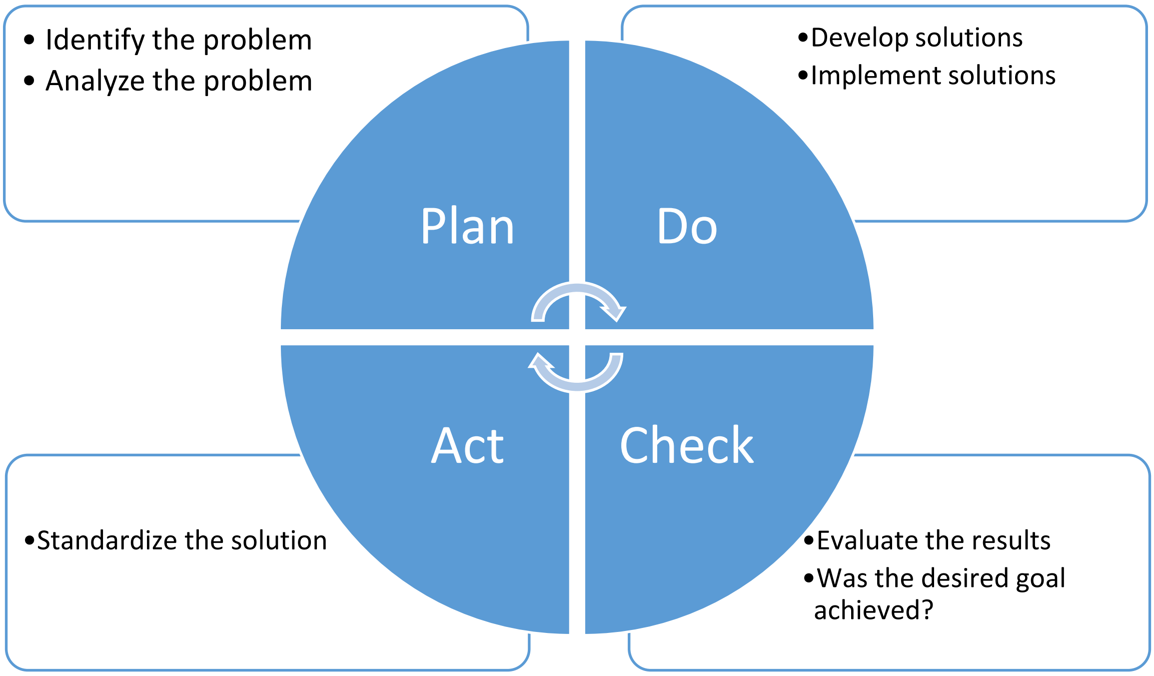


***Figure 2** PDCA (Johnson 2002, 120)*

Pellegrini, Manzione and Shetty argue that standardization is particularly important for setup time reduction because often reducing setup time is defining a new procedure for performing setup operations. Standardization is in the end of a well-defined process. By standardization, recurrence of fixed problems can be avoided. (Pellegrini et. al. 2012, 2356)

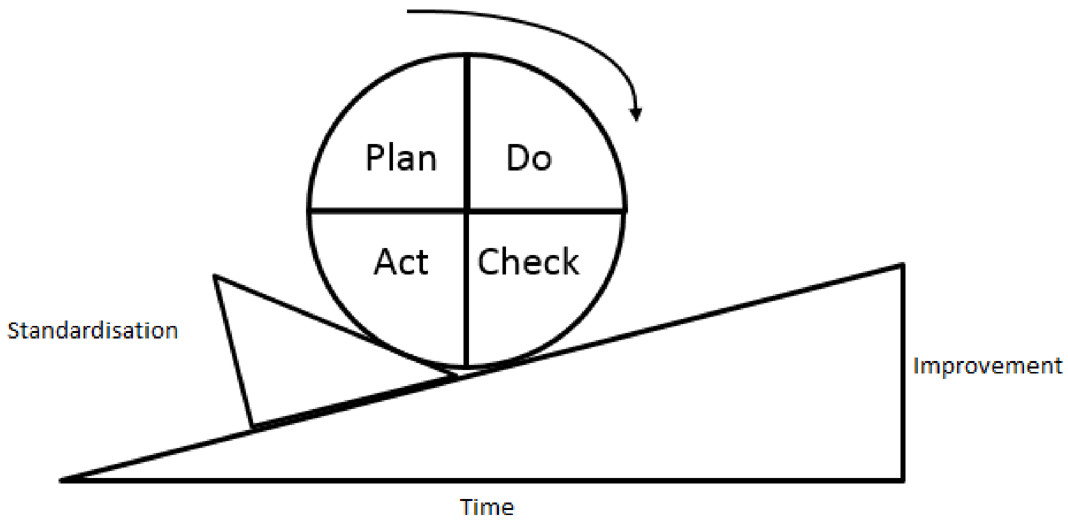


__Figure 3__ Standardization and PDCA (Pellegrini et. al. 2012, 2356)

2.3 Performance Measurement

Reliable performance measurement is important in order to motivate and sustain organization's competitiveness and profitability of their manufacturing operations (Wudhikarn 2016, 91). What has not been measured cannot be improved (Jonsson et al. 1999). There is not one, universal and the best way to measure manufacturing performance. Many different approaches, most of them on several hierarchical levels, exist. Common problem in performance measurement is that it includes too many different measures, which makes challenging to understand the big picture (Keegan et al., 1989).

Maskell presents in his book *Performance Measurement for World Class Manufacturing: A Model for American Companies* some common characteristics of world class manufacturers' performance measurement. Good performance measure should be directly related to the manufacturing strategy, use mostly non-financial measures, vary between locations, change over time if the needs are changed, be simple and easy to use, provide swift feedback to operators and managers and target to improve, rather than just monitor. (Maskell 1991, 19)

A company should have clearly defined manufacturing strategy. Strategies may vary between companies, but will center on such issues as quality, reliability, short lead times, flexibility or customer satisfaction. Performance measures should directly measure the success of the manufacturing strategy. This is because the company needs to know how well it is performing the strategy and people are concentrating on things that are measured. Manufacturing strategy should be shorter than one page and be simple enough to be understandable for every production employee. (Maskell 1991, 20-23)

According to Maskell other performance measures should be at least equal if not more important than financials. Financial measures are important for external reporting, and for high management, but in every-day control of manufacturing and distribution operations, non-financial measures are more important. The personnel measured, should be able to affect directly to the measurement results. That is, why financial measures can be irrelevant and confusing to production personnel. (Maskell 1991, 23-24)

Performance measures should be tailored by the location. Not all plants are identical even inside one company. Different plants have different challenges and priorities. (Maskell 1991, 24-27)

The basic idea of lean manufacturing is that nothing is ever perfect and continuous improvement is needed. Needs and priorities will change over time and so should the measures in order to follow them. (Maskell 1991, 28)

In order to be effective, the performance measurement should be easy to understand. It should be clear for the operators, how their actions affect to the measure. This does not only help them to concentrate to right things but it also motivates them. The measures are often used by wide range of people with different working and education background from shop floor to management. This is why measures should be simple and straightforward. (Maskell 1991, 30-33)

Good performance measure provides fast feedback. This enables to intervene almost immediately when the problem occurs. This is important so the real reason for the problem could be tracked and removed as soon as possible. The most used method of providing swift feedback is the use of visual signals like error, lights or real time monitors. (Maskell 1991, 33-36)

Performance measures need to show clearly where improvement has been made and where improvement is needed. That motivates people more than just monitoring their work. A good measure gives operators feeling that they are part of executing improvement process, not just bystanders. Operators should be able to see effects of their good or bad performance, so they could learn from that. (Maskell 1991, 37-39)

2.4 Data Quality of Performance Measurement

The measure is not only thing to consider when targeting to improve processes. Witt and Simson argue that even though data quality is only small part of the total efforts of system development, its impact to the quality of the final system is bigger than any other individual part of the system development. (Wang & Pan 2011, 5764 [Witt & Simsion, 2000])

US Census Bureau defines six dimensions of data quality which are relevance, accuracy, timeliness, accessibility, interpretability and Transparency. It explains the dimensions as following.

Relevance refers to the degree to which the data provides information that meets the needs.

Accuracy refers to the difference between an estimate of a parameter and its true value.

Timeliness refers to the length of time between the reference periods of the information.

Accessibility refers to the ease with which the information can be identified, obtained and used.

Interpretability refers to the availability of documentation to aid using and understanding the data.

Transparency refers to providing documentation about the assumptions, methods and limitations of a data to allow qualified third parties to reproduce the information.

(Tupek 2006, 1-2)

2.5 Total Productive Maintenance - TPM

Manufacturing systems operate often at a lower capacity which causes higher cost of the producing products. Low productivity is a consequence of imperfect function of the production lines. This can be result of the bad maintenance of the machines or workstations. The goal of the maintenance is to ensure the proper function of the system so it can do what it was designed to do. In other words, maintenance secures and improves availability, product quality, safety and plant cost effectiveness levels. According to Mobley, maintenance costs are a big part of the total operating costs of all manufacturing: depending on the industry, 15-60% of total production costs (Mobley 1990, 1). (Tsarouhas 2007, 6)

Total Productive Maintenance (TPM) is a concept developed in Japan early 1970s, in response to the maintenance and support issues faced in manufacturing environment (Tsarouhas 2007, 6). TPM describes a relationship between manufacturing and maintenance aiming to continuous improvement (Tsarouhas 2007, 6 [Nakajima, 1988]). The main idea of TPM is to maintain the equipment in optimum condition in order to prevent OEE losses. Autonomous and preventive maintenance is in the center of TPM and OEE is a tool to measure successfulness of maintenance. OEE is a crucial part of TPM, but not all of it. (Bhatti, Jain & Singh 2015, 505)

2.6 Overall Equipment Efficiency - OEE

The Overall Equipment Effectiveness is metric used to measure effectiveness of individual equipment or the whole production line. Even though OEE was originally part of TPM (Total Productive Maintenance), it has been widely used outside the boundaries of maintenance paradigm (Muthiah & Huang 2006, 473). OEE includes three measurable components which are Availability, Performance and Quality. These three components identify The six big losses which can be divided in three groups: downtime losses, speed losses and quality losses. Reduction in availability is caused by downtime losses, reduction in performance by speed losses and reduction in quality by quality losses. The six big losses and their super groups are explained with examples below.

Downtime losses

1. **Breakdown loss** occurs when the equipment is not running for example because of break down.
2. **Set-up and adjustment loss** occurs when equipment is down or doing defect during the adjustment for the new product.

Speed losses

3. **Idling and minor stoppage loss** occurs when production is interrupted by a temporary failure or when the equipment is idling.
4. **Reduced speed loss** occurs when the equipment is for some reason producing less than it should by the name plate speed.

Quality losses

5. **Quality defect and rework loss** occurs when the equipment produces defect.
6. **Start-up loss** occurs when the equipment is producing defect because of machine start-up to stabilization.

(Jonsson & Lesshammer 1999, 61 [Nakajima 1988])

The six big losses and their relation to OEE are visualized in figure 4.

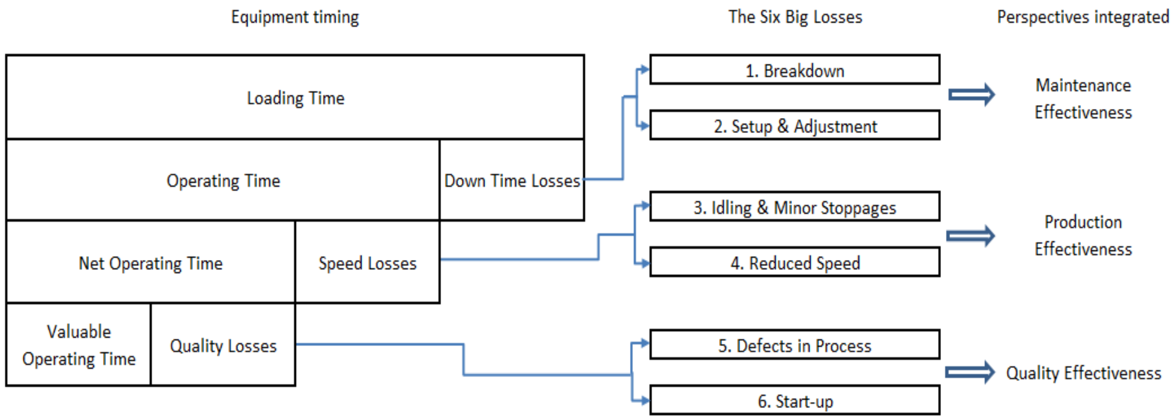


***Figure 4** The Six Big Losses For Computing OEE (Modified from Alok, Dangayach & Mittal 2011, 82)*

Another way to classify OEE losses is to divide them in chronic and sporadic disturbances. Chronic disturbances occur repeatedly and are usually small, hidden and complicated because they are result of several simultaneous causes. Chronic disturbances are difficult to notice, because they are often seen as the normal state and they are also build-in in the manufacturing process. Chronic disturbances cause high costs since their occurrence is large. (Eswaramurthi & Mohanram 2013, 132 [Tajiri & Gotoh 1992])

Unlike chronic disturbances, sporadic disturbances differ highly from the normal state and are, because of that, more obvious and easy to identify. Sporadic disturbances occur irregularly and the consequences are often dramatic. Understanding these two loss categories, helps to be aware of and identify the chronic disturbances. (Eswaramurthi & Mohanram 2013, 132 [Tajiri & Gotoh 1992])

2.7 OEE Calculation

OEE is calculated by multiplying the three components: OEE = Availability (A) x Performance (P) x Quality (Q) (Jonsson et al. 1999, 62 [Nakajima 1988]). There are several different ways to calculate availability, performance and quality of OEE. Two different methods are represented in table 2. One of the methods is original Nakajima's method and the other one is De Groote's method. Even though these two methods are highly similar, there are small differences in their point of view. For example in Nakajima's method Performance calculation is based on operating time and in De Groote's method it is based on planned amount of production.

Table 2 *Calculating OEE (Jonsson et al. 1999, 62 [Nakajima 1988], De Groote 1995, 17)*

	Nakajima (1988)	**De Groote (1995)**
Availability (A)	$\frac{\text{Loading time - Downtime}}{\text{Loading time}}$	$\frac{\text{Planned production time - Unplanned downtime}}{\text{Planned production time}}$
Performance (P)	$\frac{\text{Ideal cycle time x Output}}{\text{Operating time}}$	$\frac{\text{Actual amount of production}}{\text{Planned amount of production}}$
Quality (Q)	$\frac{\text{Input - Volume of quality defects}}{\text{Input}}$	$\frac{\text{Actual amount of production - non-accepted amount}}{\text{Actual amount of production}}$
OEE	A x P x Q	A x P x Q

It is difficult to determine universal OEE targets which would be reasonable for all firms in every industry, but some authors have tried that. For example Nakajima asserted that under ideal conditions firms should have have A > 0,90, P > 0,95 and Q > 0,99. With these figures OEE would be > 0,84. Kotze on the other hand argues that an OEE less than 0,50 is more realistic. (Jonsson et al. 1999, 63 [Nakajima 1988],[Kotze 1993])

OEE is not meant to be optimum measure for the manufacturing, but to be comprehensive and above all, simple measure. It tells to the production personnel where to spend their limited improvement resources, to get the best possible value. (Alok & Al. 2011, 82)

2.8 OEE Data Collection and Implementation Stumbling Blocks

Collecting data of the losses is an important part of continuous improvement and performance measurement. What has not been measured, cannot be improved. The data collection should be detailed enough to fulfill its objectives without being unnecessarily demanding of resources. Too detailed data collecting can result unmotivated personnel and raise reaction against the measurement. The data collection should focus on essentials. Variation built into the organization such as different shifts and weekdays, have to be considered. There are also variation in the market, such as seasonal demand. (Jonsson & al. 1999, 63)

The data collection should be done by personnel that can affect the measured parameters. Nearness is an important aspect in continuous improvement and therefore the result of data collection should be not only summarized to a key figure as a part of the measurement system, but also be used as input in small group activities. (Jonsson & al. 1999, 63)

The tracking of OEE losses can happen automatically when the machine records the reason for the loss without human work. Another way is to do tracking manually, when the whole responsible of recording the losses is on humans. The third way is semi-automatic system when an automatic system can recognize the loss, but not the reason for that. (Wang & Pan 2011, 5766)

There are some common stumbling blocks in OEE implementation, which need to be taken in serious consideration before and during the implementation. These stumbling blocks are highly dependent on the industry and the company itself. According to literature the stumbling blocks seem to be related to collecting data.

Some minor OEE loss events need to be recorded to make sure that the OEE number represents the reality. For example the time interval of an downtime loss can be small, but the frequency is still remarkable. The system requires the operator to input the status into the system frequently. This may cause the operator to resist the system strongly and the unscheduled downtime can arise because of time used to input the reasons. The data collection should be at such detailed level that it fulfils its objectives without demanding too much resources (Jonsson & al. 1999, 63). Another concern in the manual or semi-automatic OEE system is that data input is decided by the operator. It can cause the data to be inaccurate. (Wang & Al. 2011, 5766)

According to Olhager's, O'Neill's, Prajogo's and Sohal's study of issues and challenges in implementation of OEE, the most common stumbling blocks are resistive cultures. They argue that the management has key role in maintaining the shop floor engagement and commitment to the system. (Olhager et al 2010, 6-7)

2.9 Critical Evaluation of OEE and Its Limitations

As said in chapter 2.7, OEE is not an optimum measure. Even though OEE is widely considered to be an effective performance measure, several modifications of it have been published in order to improve its weaknesses. The modifications can be divided in two groups: scope expansion and calculation modification. An example of the limitations of OEE is that it assigns similar weights to its elements, even though, in most cases, the factors affecting OEE are not similar. (Raouf 1994, 50-51)

OEE is not suitable for manual manufacturing processes. It does not recognize the number of people working in a process and it assumes that there is a fixed ideal cycle time for each machine or line. In manual manufacturing process this is not obviously true, because working efficiency is depended on worker and often even the same worker may work with different efficiency. OEE is limited to automatic or semi-automatic production processes only. (Alok & Al. 2011, 83)

OEE is designed to measure the efficiency of individual equipment. In real life, machines are usually not isolated, but operate jointly in a production line. Also material handling, buffers, people and queues have a direct impact to efficiency of the line. When measuring traditional OEE for individual machine or equipment, can failure sometimes be caused by circumstances external to the equipment (De Ron and Rooda 2005, 193). On the other hand, when the line is highly automated and the material flow through the line is smooth and continuous, can one line be considered as one equipment or machine in the OEE. (Alok & Al. 2011, 83-85)

Jeong & Phillips (2001) argued that the original Nakajima's definition of OEE is not suitable for capital intensive industry because the loading time does not include scheduled maintenance time for preventive maintenance and nonscheduled time such as off-shift and holidays. These time losses are important in capital-intensive industries because those increase the investment payback period. Often equipment and machines need also long and costly warm-up time in capital-intensive industries, which is obvious inducement to reduce non-scheduled time. Jeong & Phillips enlarged the loss categories to ten:

1. ***Nonscheduled time****:* time duration for which equipment is not scheduled to operate. This time may include holiday and leave etc.
2. ***Scheduled maintenance time****:* time spent for preventive maintenance in the equipment.
3. ***Unscheduled maintenance time****:* time spent for breakdown.
4. ***R&D time****:* time spent for the purpose of research and development.
5. ***Engineering usage time****:* time spent for an engineering checkup.
6. ***Setup and adjustment time****:* time spent for setup and adjustment for operation.
7. ***WIP starvation time****:* time for which equipment is operating when there is no WIP to process.
8. ***Idle time without operator****:* time for which WIP is ready, however there is no operator available.
9. ***Speed loss****:* time loss due to the equipment that is operating under the standard speed.
10. ***Quality loss****:* time for which equipment is operating for the unqualified products.

(Jeong & Phillips 2001, 1402-1407)

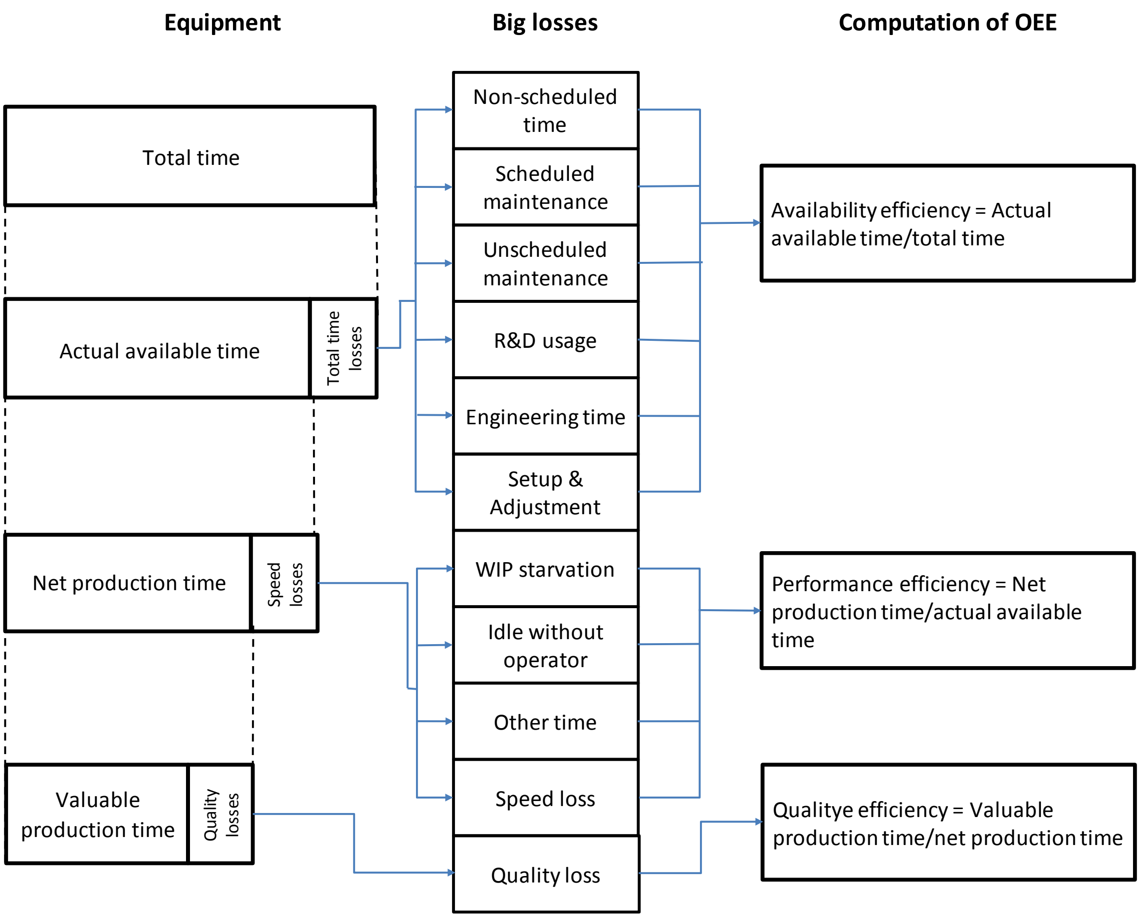


Figure 5 OEE computation with ten big losses (Jeong & al. 2001, 1410)

2.10 Setup Time Reduction

Providing multiple different products or product variations on common resources leads in to the need for changeover and setup activities. Setup activities cause costly disruption to the production process. Because of this setup time reduction is an important feature of the continuous improvement program of any manufacturing organization. Reducing setup time is even more critical if a firm expects to respond to changes like shortened lead times, smaller lot sizes and higher quality standards. (Allahverdi & Soroush 2008, 978)

Generally setup time can be defined as the time needed to prepare the necessary resources (people, machines etc.) to perform a task (job, operation etc.). Setup activities may include for instance obtaining tools, positioning work in process material, returning tools, cleaning up and similar activities needed to be done before starting to manufacture the new batch. (Allahverdi & al. 2008, 978)

Reduced setup time effects directly to the cycle time of batch production process. Reducing setup time does not necessarily affect to lead time of one produced unit, but lead time of one production batch. This is because batch size can be reduced if the setup time is reduced. Some benefits of reduced setup time are: reduced expenses, increased production speed, increased output, reduced lead times, faster changeovers, increased competitiveness, increased profitability and satisfaction, enabling lean manufacturing, smoother flows, broader range of lot sizes, lower total cost curve, fewer stockouts, lower inventory, lower minimum order sizes, higher margins on orders above minimum, faster deliveries and increased customer satisfaction (Allahverdi & al. 2008, 979). (Olhager 1989, 65)

Production planning targets; high efficiency, low tied-up capital and high utilization rate can be reached simultaneously by reducing the batch cycle time. Also other useful effects have been noticed to follow reduced batch cycle time. Quality of the process evolves remarkable when the batch cycletime is reduced. (Uusi-Rauva, Haverila, Kouri & Miettinen 2003, 350)

Short batch cycletime effects to productivity in two ways. It enables (Väänänen 1984, 6):

- Fast deliveries and good customer service
- Low inventories, especially in un-finished and finished goods

Fast delivery increases competition advantage of a firm and reduces need to store finished goods. Amount of unsold products will decrease and the production management will be facilitated. Reduced process lead time improves general management and coordination of material flows, which reduces failures and clarifies production and material flow overview. (Väänänen 1984, 6)

2.11 Single Minute Exchange of Die - SMED

Single minute exchange of die (SMED) is tool to reduce second of the six big losses (Setup and adjustment losses) presented in the figure 4. SMED is one among many lean methods aiming to reduce waste in a manufacturing process (Ulutas 2011, 1195 [Shingo 1985]). Japanese Industrial Engineer Shingo developed SMED in 1950s in order to enable smaller production lot sizes through reducing set-up and batch change time. Generally, SMED aims to standardize and simplify the operations. In other words, it provides a fast and efficient way to convert manufacturing process from running the current product to running the next product (Ulutas 2011, 1195 [Shingo 1985]). Need of special skilled workers is also minimized by SMED. The phrase “single minute” in SMED, does not mean that changeovers and set-ups should necessarily take only one minute, but that they should take single-digit number of minutes (in other words, less than 10 minutes). (Ulutas 2011, 1194)

Setup is defined as the preparation or post adjustment that is performed before and after each batch is processed. In SMED the setup operation is divided in two parts: internal setup and external setup. Internal setup includes tasks that can be done only when the machine is shut down and external setup includes tasks that can be done when the machine is still running. External setup can be performed either before or after the machine is shut down. Getting setup tools ready for the operation could be example of external setup. (Ulutas 2011, 1195 [Shingo 1985])

There are three main steps to implement SMED. The steps are listed and explained below.

Step 1: Separate internal and external setup

All setup activities are often done after the prior production. Setup activities should be divided into external and internal activities to reduce setup times. According to Shingo, this is the most important step in implementing SMED. External activities are the ones that can be done during the production of prior or next product. The internal activities are the ones that has to be done when the line is not running. (Shingo 1985, 29; Ulutas 2011, 1195)

Step 2: Convert internal setup to external setup

Step two starts when setup has been divided in internal and external setups or activities. On this step, as much internal activities should be changed to external, as possible. This is achieved mostly by executing technical modifications to setup processes. Sometimes setups can also be wrongly assumed to be internal. (Shingo 1985, 30; Ulutas 2011, 1195)

Step 3: Streamline all aspect of the setup operation

On the final step, internal and external activities are minimized. This requires a detailed analysis of each elemental operation. Some industrial engineering tools like method study, value stream mapping, cause and effect analysis or Pareto charts can be used in SMED, to simplify and standardize all the set-up activities (Khanduja 2009, 100 [Chao, 2001]). Step 3 does not necessarily need to be performed after step 2. Those can be almost simultaneous. (Shingo 1985, 30; Ulutas 2011, 1195)

Some authors present the steps as stages. They present that there are 4 stages, because they include stage 0 (Internal and external set-up conditions are not distinguished) also in implementing SMED stages (Culley, McIntosh, Mileham, Owen 2000, 2378 [Shingo 1985]). In this paper stage 0 is not included because it is actually preliminary stage.

The main steps of implementing SMED are visualized in figure 6. In King's Changeover window (figure 6), the last step is "perform internal tasks in parallel". This could be included in step 3, but in the figure it is highlighted by separating it to its own step. Performing internal tasks in parallel is naturally not possible always, for example in situation where tasks require continuous work or monitoring and there is only one person performing the tasks.

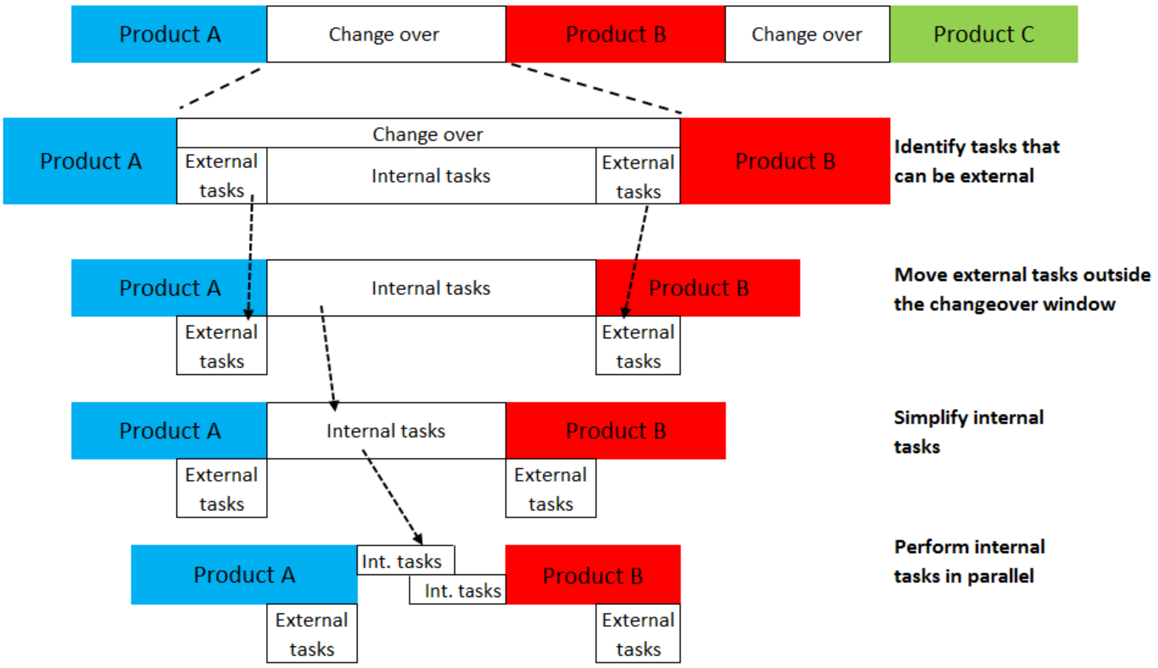


Figure 6 Changeover window (King 2009, 32)

3 Case Company and Research Background

This chapter deals with the basic information of the case company Tikkurila. The chapter presents the strategic targets behind the thesis project and important information about the business and production environment. The production environment is concentrated around filling and packing line 1, on which the study was carried out.

3.1 Backround of the Project

Tikkurila is strong regional player in paint industry. Its main markets are Nordic countries and east and middle Europe. Russia, Finland, Sweden and Poland cover 80% of Tikkurila's sales. Tikkurila has manufacturing in ten different countries (Tikkurila 2015). The company delivers its products for consumers, professionals and for industry use. (Tikkurila 2014, 48)

Tikkurila aims to grow on its current markets, especially on those where it has still low market share. Continuous improving in manufacturing is important part of Tikkurila's strategy. That aims to increase equipment utilization rate, improve planning and reduce manufacturing lead times. Harmonizing internal processes, raw materials, recipes, products and packaging is also one way to increase efficiency. Tikkurila is researching need to enlarge its product variety which sets requirements for manufacturing and its lead, cycle and setup times. (Tikkurila 2014, 30-31)

2010 Tikkurila set plans and targets to increase efficiency of procurement, logistics and manufacturing. Six years ago started holistic improvement process is still ongoing. This improvement process includes automatization, standardization and batch cycletime reduction. These actions increase flexibility and capacity, and decrease unwanted deviation and costs. During the year 2014 Tikkurila implemented thousands methods of continuous improvement. (Tikkurila 2014, 30-31)

Tikkurila established OEE measurement system pilot test period on its Monicolor Factory in year 2013. The use of the system was soon reduced and the system was bypassed on the production line, consequently reason codes were not properly recorded. The management did neither use the system in development and daily management decisions. Now Tikkurila wants resolve if OEE is suitable for it or should the whole system be buried. If the system is found to be useful, Tikkurila wants to avoid the same mistakes in the future which led to low usage of OEE in the first place.

Tikkurila has not previous experience of SMED, but the company wants to study if SMED could be used alongside the OEE to reach the strategic goals set for the production. Tikkurila targets to gain production efficiency through SMED and to be able to reduce batch change times and standardize them.

3.2 Tikkurila Filling and Packing Line

There are seven lines in Tikkurila MC Factory’s filling and packing department. Most of the machines and equipment are line specific, but some machines serve all of the lines and the whole material flow of the filling and packing department goes through those machines. These machines are pallet cart, wrapping & pallet tag machine and forklift.

OEE -pilot was launched on one line, which was filling and packing line 1. Most of the lines in MC factory are similar even though small differences occur. For example some lines are concentrated on bigger cans and there are not blind sticker machine on every line. Line 1 fills three different sizes of cans: 1/3 liter, 0,9 liter and 2,7 liters. The simplified material flow of line 1 can be seen in the figure 7. Material flow through the line vary a bit, depending the product. Blue arrows in the figure 7 mean material flows of the big cans (2,7 liters) and red ones refer to the small cans (1/3 and 0,9 liters). Purple arrows mean the material flow of the both big and small cans. The arrows represents mainly can flows, not other, separated material flows like paint or pallets. Through the line, paint, pallets and other materials are naturally added to can flow. Material flow of plastic and metal cans are not separated in the figure.

Some of the machines are represented combined to one unit, even though those could be considered as separated machines. This is to make figure more simple and understandable. The line includes several meters of conveyor belts, but those are not shown in the figure. Neither material flow congestion sensors are visible in the figure.

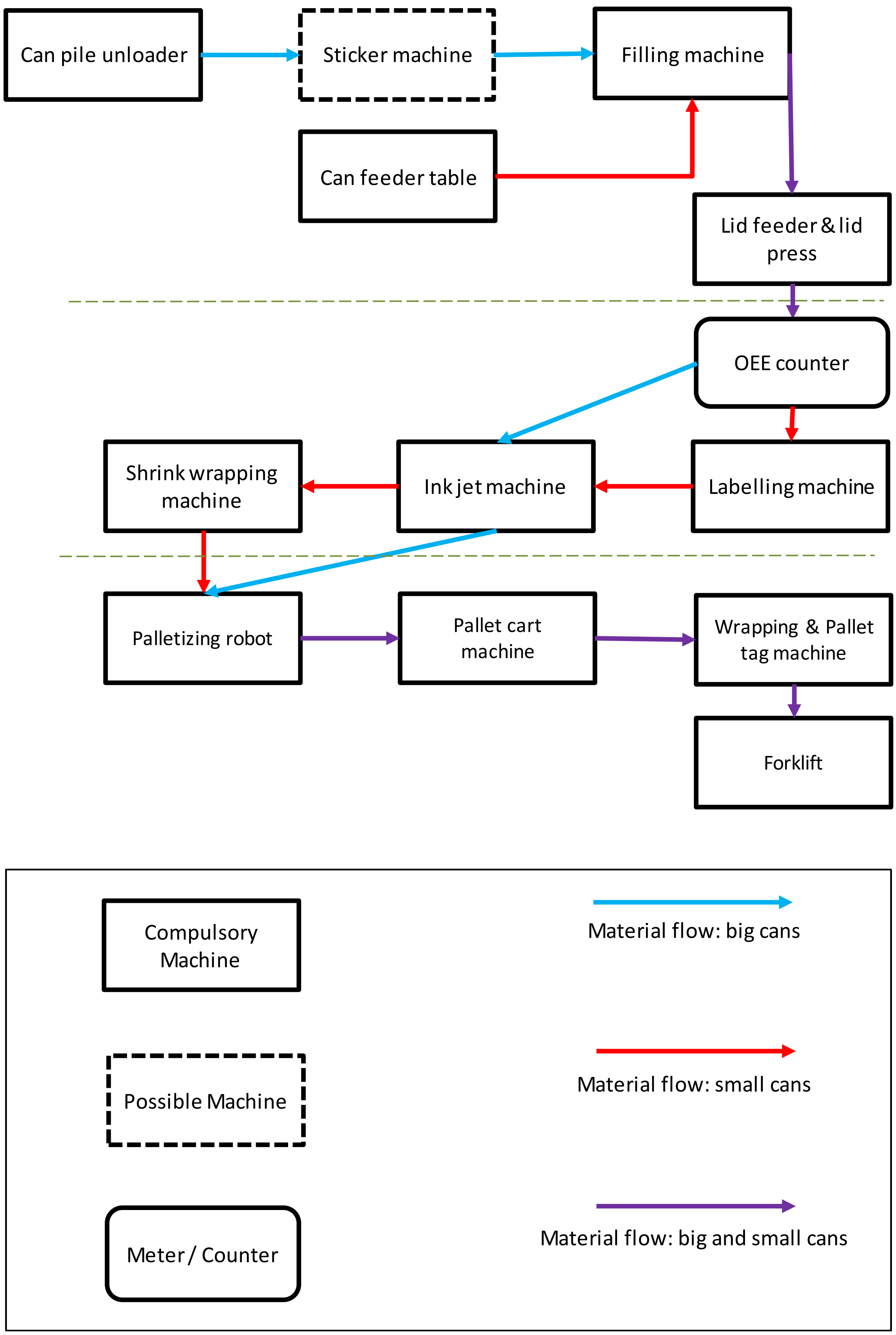


Figure 7 *Tikkurila filling and packing line 1 material flow*

The MC filling and packing department is usually divided in two sections which are filling and packing. These sections are physically separated by a wall. Nevertheless in following three chapters the department is divided in three sections: filling, packing and palletizing. This separations is because of the different operator policies and different nature of the machines on those sections.

3.3 Filling

The filling sections includes can pile unloader, sticker machine, filling machine, can feeder table, lid feeder & lid press and OEE counter. There is one worker per filling line, operating all the machines on that line.

Can pile unloader is used only for the big cans (2,7 l) and only certain batches need stickers on the sticker machine. If batch is filled into the small cans (1/3 l and 0,9 l), the cans are fed by the can feeder table instead of can pile unloader.

Every can goes through the filling machine. The machine can fill both big and small cans. After the filling machine, lid feeder sets the lid and the lid press closes it. Every can goes through this phase, but different presses are used depended on the lid size and the material. After the lid is placed, can goes through the OEE counter, which counts the cans. The OEE measurement is based on this sensor.

3.4 Packing

Packing section includes labelling machine, ink jet machine and shrink wrapping machine. One line operator is operating the packing section of lines 1, 3 and 7.

Big cans include already the product information and the final visual look, so those need only date stamp on ink jet machine before going to the palletizing robot. Small cans are plain, so those require label. Every small can is labelled and some batches are also stickered with color information sticker. After this, small cans get shrink wrap. Big cans go also through shrink wrapping machine, but the machine is then only conveyor.

3.5 Palletizing

Palletizing includes all the actions from placing cans on the pallet and removing the loaded and packed pallets to the warehouse. Machines in the palletizing section are palletizing robot, pallet cart machine, wrapping & pallet tag machine and forklift. Palletizing robot is the last line specific machine on the filling and packing line. Rest of the machines are common for every seven lines. The palletizing section is highly automated and monitored by the same operator than the packing section.

Palletizing robot places the cans on the pallets and after that pallet cart machine removes the full pallet forward. Pallet cart machine is also responsible for bringing the empty pallets to palletizing robot. Full pallet gets plastic wrap around it on wrapping machine and after that the pallet is marked with content tag on pallet tag machine. Forklift takes full, wrapped and tagged pallets to the warehouse. Forklift is the last machine of the OEE counting.

4 OEE Implementation

This chapter deals with the implementation of the OEE system. The basic information of the used system and its function principles are presented. The chapter also presents the results of the user polls made for the factory operators and discusses the implementing problems of the first OEE project and how those problems were overcame in the second project. The chapter also proposes advices for the future implementations of the OEE.

4.1 The Principles of Used OEE System

OEE based manufacturing measurement and improving system for Tikkurila is delivered by Arrow Engineering. The system is built around OEE, but it is not merely OEE counting system. The system enables tracking reasons for the OEE losses and running several different OEE related reports.

The software enables changing OEE counting principles. The pilot test of the software was carried out by the calculation represented in table 3.

Table 3 *Tikkurila OEE calculation*

Availability	$\frac{\text{Planned production time - Down time}}{\text{Planned production time}}$
Performance	$\frac{\text{Realized production per minute}}{\text{Desirable production per minute}}$
OEE	Availability x Performance

As can be seen from the table 3, quality factor of OEE is not taken in account in Tikkurila's OEE system. This is because the amount of defect is really low. Low amount of defect is result of accurate filling machines and quality control of the fill before it is released to filling. Line can produce defect, but it is usually noticed and corrected before the product runs through the whole production line or it is noticed by the customer which can happen months after the production. Tikkurila does not have yet systematic quality control system for the finished products, but need for it is evaluated currently. From the point of view of Tikkurila's

OEE system, finished product means filled and palletized can. If a defect is noticed during the production (for example in filling), it is corrected immediately, so the effect can be seen in availability or performance of OEE, not in quality. If the defect is noticed by the end customer, the information is received so late, that it is not expedient to count it in OEE. Tikkurila does record complaints, but it is not counted in OEE.

4.2 Arrow Machine Track - Availability

In Tikkurila's OEE system availability is calculated as following: (planned production time - Downtime) / Planned production time. This means that off shift time is not included in calculation of Availability. Work shifts can be modified from the settings, but during the test period shifts were morning shift from 06:00 to 15:00 and evening shift from 15:00 to 24:00. Time from 24:00 to 06:00 was considered as off shift and the OEE system left that automatically out of the calculations. In the system it is additionally possible to mark some stops with reason "No resources" and "No planned time". By using those two reasons, individual stop is possible to leave outside of the OEE calculation, even though it would be during the work shift. Because of this, reasons external to production, like poor performance of sales department, do not effect on the OEE measurement. Maintenance breaks, like preventive maintenance, operator maintenance and test drive do effect on OEE availability.

Planned maintenance and operator maintenance are calculated in OEE availability, because increasing preventive maintenance time most likely decreases technical down time, but the overall uptime does not necessarily increase.

Machine Track requires entering a reason for the stop if it lasts 5 minutes or longer. Stops shorter than 5 minutes are considered as reduced speed. The shortest period of time that the system recognizes is 1 minute.

4.3 Arrow Machine Track - Performance

Machine Track is capable to calculate performance, but during the study the performance measuring feature was not fully implemented because of limited time for implementation and because availability is currently more crucial OEE factor for the case company.

In the second OEE implementation new desirable production speeds were defined, but there were only two speeds for the whole product portfolio: one for the small cans (1/3 liters and 0,9 liters) and one for the big cans (2,7 liters).

The production speed of the same fill of 1/3 and 0,9 cans is quite the same, but the fill effects to what is the realistic target speed. The desired production speed for the small cans was chosen to be 19 cans per minute, and for the big cans it was 24 cans per minute. These target speeds are suitable for the most of the products, but not for all.

Viscosity effects to realistic production speed. Filling with a high viscosity fill causes paint spatters if the line is running on set target speed. When filling the high viscosity products operators run the line as fast they can without spatters. They were guided not to aim to target speed with the high viscosity fills, in order to avoid spatters and therefore downtime caused by cleaning. Spatters could possibly be avoided with few different nozzles for different products, but currently only one type of nozzle is used on the filling line 1.

Machine Track tracks reduced speed automatically, but it does not require entering reasons for the reduced speed. There is no reason tree for the reduced speed, but it is possible to enter comments. Commenting reduced speeds was nevertheless required nor systematically done during the test period.

4.4 Previous Problems of OEE Implementation

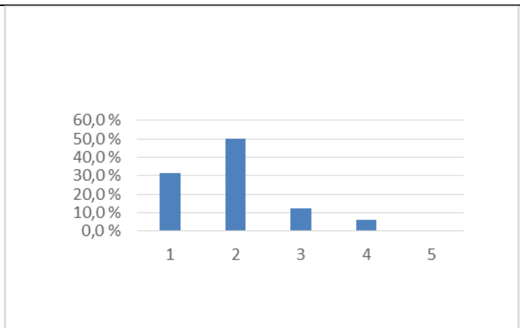
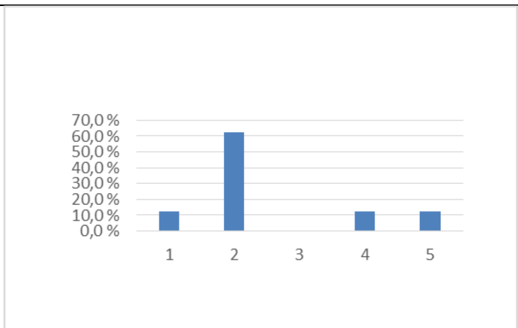
Tikkurila launched OEE pilot first time 2013 and since then Arrow Machine Track has been in passive use. At first, after the first implementation of the Machine track, the system was used daily, but soon after the first months the use of the system was reduced dramatically.

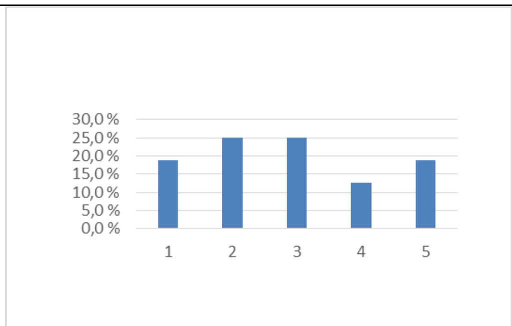
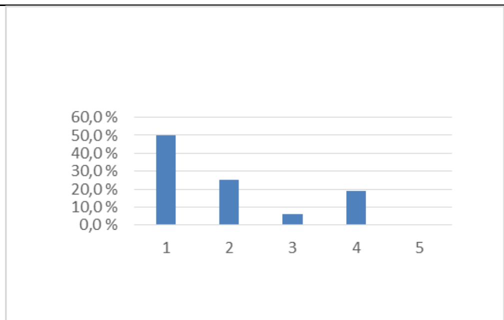
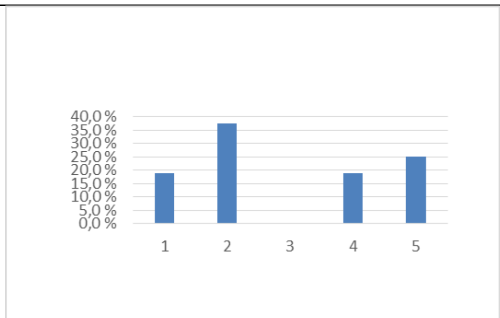
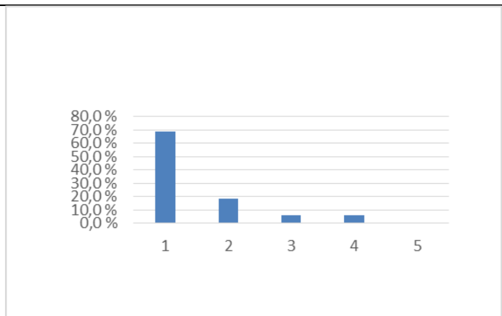
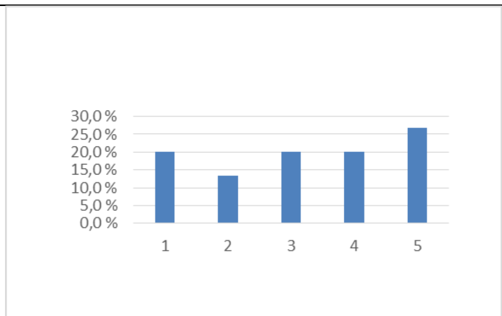
There have been several mainly managerial issues resulting the disuse of the OEE system. The main issue was that there was no owner for the system after the original owner transferred to other tasks. Lack of ownership led to situation where no one used the data of the system nor developed it after the implementation. Lack of managerial commitment also led to negative attitudes towards the system from the operators. Without management’s nor operators’ interest towards the system, bugs and errors started to occur in the system and that turned operators’ attitude towards the system even more negative.

The implementation was not made properly in the first OEE pilot. Informing and training of operators was neglected. Operators did not know properly how to use the system or why data was collected.

The operators and the foremen filled anonym user poll where they marked from 1 to 5, how well they identified with the statement. 18 operators and 2 MC factory foremen were asked to fill the poll. The response rate was good 89 percent. 16 polls were returned and statements 1-6 got 16 answers and statements 7 got 15. The polls were returned in sealed poll box. The polls were anonym, but every answerer were asked to sign the name list next to the poll box, after returning their poll sheet. The statements and the results can be seen in the table 4. The poll included also space for open text under every statement. On those spaces the answerers were able to tell more about their feelings and views related to every statement. The open texts nevertheless cannot be seen in the table 4.

Table 4 *1st Operator poll results*

<table>
<tr><td colspan="2">1. Fully agree
2. Somewhat agree
3. Not agree nor disagree
4. Somewhat disagree
5. Fully disagree</td></tr>
<tr><td>1. Using the software is difficult.</td><td>
</td></tr>
<tr><td>2. I do not know what is the reason for the stop/reduced speed.</td><td>
</td></tr>
</table>

3. I do not have time to enter the reason for the stop/reduced speed.	
4. I think that entering the reason is useless.	
5. I do not know who should enter the reason when stop/speed reduction occurs.	
6. There are technical errors in the software.	
7. I do not know how the data collected from the software is meant to use.	

The answers were scored in order to rank the statements. The scoring was executed following way:

- Fully agree = 0 points
- Somewhat agree = 1 points
- Not agree nor disagree = 2 points
- Somewhat disagree = 3 points
- Fully disagree = 4 points

Not all statements got same amount of answers so the points were scaled to 0-100 so the results could be comparable. 100 would mean that everyone fully disagreed with the statement and 0 points would mean that everyone fully agreed with the statement. The statements and their scores can be seen in the table 6.

The scaled points and their meaning in written form can be seen in the table 5.

Table 5 *User poll points and meanings*

Points	**Meaning**
$80 \leq$	Fully disagree
$60 \leq, < 80$	Somewhat disagree
$40 <, < 60$	Not agree nor disagree
$20 <, \leq 40$	Somewhat agree
≤ 20	Fully agree

Table 6 *Operator poll scores*

I do not know how the data collected from the software is meant to use.	55,0
I do not know who should enter the reason when stop/speed reduction occurs.	48,4
I do not have time to enter the reason for the stop/reduced speed.	46,9
I do not know what the reason for the stop/reduced speed is.	37,5
Using the software is difficult.	23,4
I think that entering the reason is useless.	23,4
There are technical errors in the software.	12,5

As can be seen in the table 6, only one of the statements got more than 50 points which means that people disagreed more than agreed with that statement. Two of the statements got only a bit less than 50 points and 3 got less than ¼ of the points. Generally answerers felt that the statements were quite true.

Because the OEE system was not systematically evaluated and improved after the first implementation, it included several flaws. One of the flaws was in performance calculation. The desirable production speed was not realistic. For some of the products it was too low which did not encourage to run the line as fast as it could have been possible. For the some products, the desirable production speed was too high which caused frustration; the operators felt that they were required unrealistic performance on the filling and packing line.

In the beginning of the second OEE project, which started in January 2016, Arrow OEE system included several technical flaws and errors. These flaws and errors inhibited creating OEE reports and collecting data. Arrow Machine track collected time data of availability automatically, but feeding reasons for stops was difficult because of technical errors.

After the first OEE project, the system was not developed nor properly used so the reasons for stoppages were in their original form. The original reason tree was seen as complicated and difficult to use. Some important reason codes were missing and some unnecessary ones were included.

It was confusing for the operators that there were OEE operating screens placed among the packing and filling line 1, but it seemed like those were not used for anything. Some of the operators continued entering the reasons in the system, some did not. Even the operators who kept entering the reasons, felt it frustrating because they really did not know how to use the system properly or that did, their time consumed to entering the reasons create any value.

In the first OEE project touch screen was chosen to be operating display for the Machine Track. This was later noticed to be difficult to use especially without adjustable stand.

4.5 Overcoming the Previous Problems of OEE Implementation

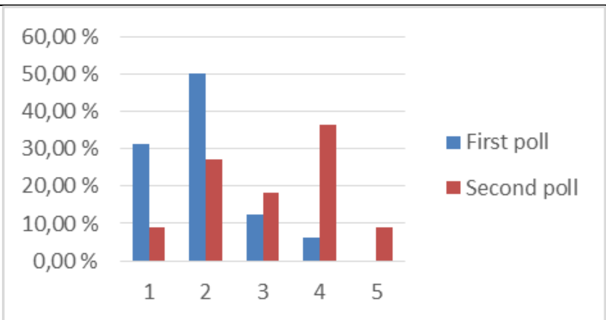
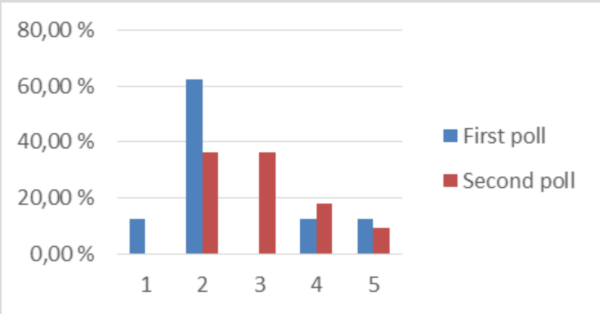
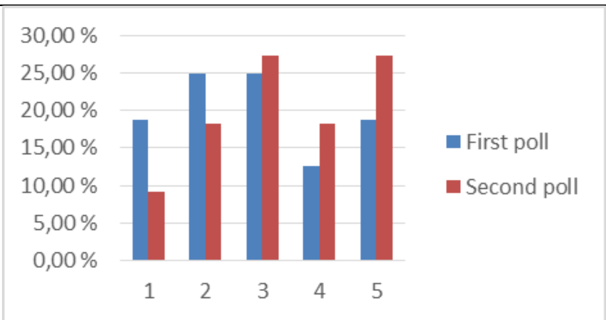
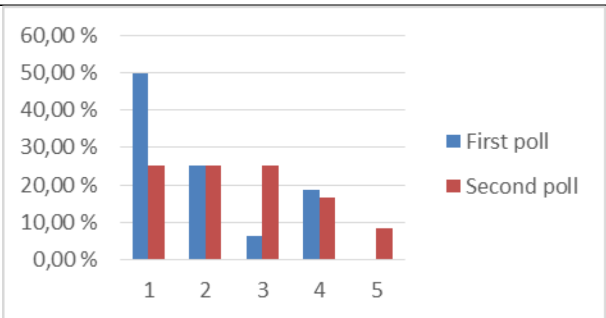
Lack of ownership and managerial commitment, neglecting training and informing the operators, technical errors and structural flaws were undoubtedly the reasons which led to disuse of Machine Track and negative attitudes towards it.

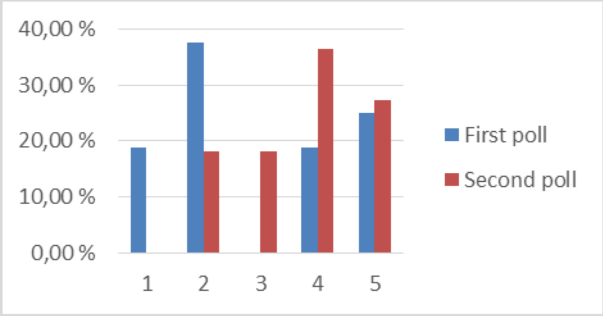
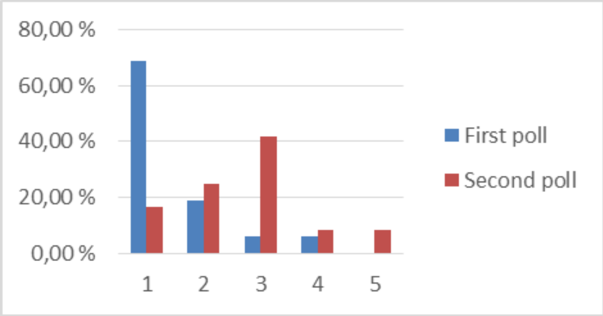
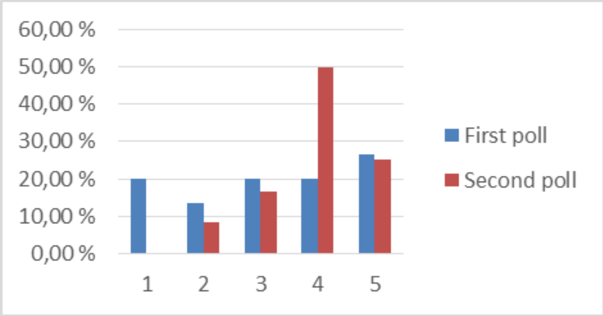
New operator poll was made three months after the first one and the results were clearly different. The poll was executed in the same way than the first one. The questions were exactly the same but one question added. The added question regarded the working experience on the filling and packing line 1 during the previous 3 months. The answering time was also extended with three working days because of low amount of answers on the planned answer time of one week.

Some changes on personnel occurred between the first and the second poll. Two operators and one foreman changed to another factory. Sick leaves also reduced the response rate of the second poll. 12 poll forms were returned out of 16, but one poll form had answers only to three statements (4, 6 and 7). The response rate was still quite good: 75% (response rate of the first poll was 89%).

The results of the first user poll and the second one are presented in the table 7. On every statement answers were more disagreeing in the second poll than in the first one. The statements are in negative form, so disagreeing means positive attitude or good knowledge.

Table 7 1st vs. 2nd user poll

<table>
<tr><td colspan="2">1. Fully agree
2. Somewhat agree
3. Not agree nor disagree
4. Somewhat disagree
5. Fully disagree</td></tr>
<tr><td>1. Using the software is difficult.</td><td>
</td></tr>
<tr><td>2. I do not know what is the reason for the stop/reduced speed.</td><td>
</td></tr>
<tr><td>3. I do not have time to enter the reason for the stop/reduced speed.</td><td>
</td></tr>
<tr><td>4. I think that entering the reason is useless.</td><td>
</td></tr>
</table>

5. I do not know who should enter the reason when stop/speed reduction occurs.	
6. There are technical errors in the software.	
7. I do not know how the data collected from the software is meant to use.	

In table 8, statements of the 1st and the 2nd poll are scored, scaled and combined the same way than in the table 6.

- Fully agree = 0 points
- Somewhat agree = 1 points
- Not agree nor disagree = 2 points
- Somewhat disagree = 3 points
- Fully disagree = 4 points

The more points means, the more disagreement. 100 points would mean that everyone fully disagreed and 0 points that everyone fully agreed with the statement. The difference between the 1st and the 2nd poll can be seen in the last column of the table 8. The bigger the difference, the more successful the implementation has been from point of view of that statement.

Table 8 1st and 2nd poll scored

Scores			
The statement	1st Poll	2nd Poll	Difference
I do not know how the data collected from the software is meant to use.	55,0	72,9	17,9
I do not know who should enter the reason when stop/speed reduction occurs.	48,4	68,2	19,8
I do not have time to enter the reason for the stop/reduced speed.	46,9	59,1	12,2
I do not know what the reason for the stop/reduced speed is.	37,5	50,0	12,5
Using the software is difficult.	23,4	52,3	28,9
I think that entering the reason is useless.	23,4	39,6	16,2
There are technical errors in the software.	12,5	41,7	29,2

In the first poll, only one statement got more than 50 points which means that it was more disagreed than agreed. In the second poll five out of seven got more than 50 points. The statement scores and assumptions of the causes are presented below.

I do not know how the data collected from the software is meant to use.

This statement got the highest scores in the both polls and the difference is quite close to average. In the beginning of the second OEE project, the line operators were informed in oral and written form, why the data is collected and how it is intended to use. It was also done unsystematically and occasionally during the project. During the second OEE project, planned reports for factory personnel were not taken in daily use, which can effect negatively on line operators knowledge of the usage intentions of the data. Nevertheless, 72,9 points means somewhat disagree, which is acceptable level. Relatively high scores in the first place might also be a reason for only average difference.

I do not know who should enter the reason when stop/speed reduction occurs.

The difference in this statement is on average level. In the beginning of the project, it was instructed that the one who repairs the cause of the stop, enters the reason in the Machine Track. This is difficult to some line operators because they do not see the value of the OEE measurement. They prioritize line running over OEE measurement and therefore frustrate if the line, because of entering the reason, does not start running immediately after the cause of the stop is repaired. Because of frustration they may sometimes enter the reason even though they do not know the cause of the stop. This happens often when the reason for the stoppage is in the packing or palletizing section. This leads to situation when entering the reasons in the packing or palletizing section is not trained.

I do not have time to enter the reason for the stop/reduced speed.

This statement has the lowest difference between the two polls. Tikkurila had employee co-operation negotiations on fall 2015, which may have resulted negative attitude to new personnel time consuming tasks on the production. This opinion came up several times during the project in shift start meetings, in bilateral conversations with line operators and once directly in the 2nd user poll. Some line operators also perceive entering reasons useless, which probably is one reason why they experience that they do not have time for it. When they do not see the value of the OEE measuring, other things and tasks are prioritized over entering the reasons.

I do not know what is the reason for the stop/reduced speed.

The difference was quite low on this statement. Machine Track has quite wide reason tree, which seemed to be pretty difficult to understand without more than one proper training meetings. The most common reasons are for the most of the operators clear, but rarer reasons and their equivalents in the software can be difficult to memorize. Also one reason for the low scores and low difference between the scores is that most of the operators do not work on the filling and packing line 1 regularly. If one uses Machine Track only occasionally, the reason tree and its logic is easy to forget. Solution for this might be, simpler, but less informative reason tree, more Machine Track training or more line concentrated personnel work shifts.

In the second OEE project instructions to entering the reasons were placed on every OEE control panel, in both paper and electric form. That did not help a lot learning to enter reasons, because reasons were changed and updated few times during the project and because of that, instructions were not fully valid anymore. Most of the line operators neither looked for help from the instructions when problems occurred. Shortly it was noticed that effective way to train entering the reasons was putting short one page instructions of the most used reasons in visible place. That improved data quality a lot because the most common reasons (setups, breaks, meetings, sift changes) occur daily and consume easily the biggest part of downtime losses. It is also easier to train entering rarer reasons when everyday using of the software is not struggling.

Using the software is difficult.

This statement has the second highest difference. The score rise is probably result of training and education, which were on really low level before the second OEE project. Even though the rise was significant, the scores are not that high (52,3). This is the most likely for the same reasons than in previous statement: occasional work shifts on filling and packing line 1 and too little proper training meetings. Also technical errors and wide reason tree may cause line operators perception of difficult usage of the software.

I think that entering the reason is useless.

The difference is low and the total scores of the second poll are less than 40. This is clear sign of low motivation of the personnel towards the OEE -tracking. This is important part of the training, because unmotivated line operators make training challenging. At the time of writing, the regular report checks have not taken place yet. Example reports have been shown to operators, but those are not part of the daily routine. Showing OEE reports to personnel daily in the near future, will most likely make them disagree with this statement more. Also in the future, fixing the problems noticed with the OEE will concretize the value of the measurement to the line operators.

There are technical errors in the software.

In the beginning of the second OEE project there were several technical errors in the Machine Track. This was because the system was not in active use and therefore occurred errors were not fixed. A lot of work was done in order to fix the errors, because of this the difference in this statement is the highest. Nevertheless, the total scores of this statement in the second poll are the second lowest.

Operators have reported that sometimes when writing a long comment, it is suddenly deleted before saving. Similar error occurred also earlier, but then comment was deleted after writing a couple of words. Web based operator view in the Machine Track works often slowly and may freezes sometimes. This may have seen as a technical error of Machine Track even though it may be conclusion of not only Machine Track, but also weak internet connection and poor performance of the web browser. Machine Track sometimes splits stops in two without any known reason. This frustrates line operators because same reason has to be entered twice.

Machine Track requires entering the reason for stops of 5 minutes or longer. OEE sensor is not right after the filling machine in which Machine Track is connected, but few conveyor meters after that. Conveyor does not get information from the filling machine nor from the Machine Track. If a stop is caused by packing section, there are still cans on the conveyor between the filling machine and the OEE sensor. When the cause for the stop is repaired, starts conveyor run again and Machine Track registers moving cans and does not require entering the reason to start filling machine because the line is running already. Some operators also claim that Machine Track records stops which do not exist, but this claim has not been studied or proven to be fact.

In the second poll the answerers were asked to tell how much they have worked on the filling and packing line 1 during the year 2016. In the table 9 can be seen comparison between all answers, answers of the operators who have worked 2 or more shifts on the line 1 and the answers of the operators who have worked less than 2 shifts on the line 1. "*2 or more shifts*" got 6-7 answers on every statement and "*less than 2 shifts*" got 5 answers.

Table 9 *Comparison between poll answerer segments*

All, 2 or more shifts and less than 2 shifts			
The statement	All	2 or more shifts	Less than 2 shifts
I do not know how the data collected from the software is meant to use.	72,9	75	70
I do not know who should enter the reason when stop/speed reduction occurs.	68,2	62,5	75
I do not have time to enter the reason for the stop/reduced speed.	59,1	62,5	55
I do not know what the reason for the stop/reduced speed is.	50,0	62,5	35
Using the software is difficult.	52,3	62,5	40
I think that entering the reason is useless.	39,6	32,1	50
There are technical errors in the software.	41,7	46,4	35

A bit surprisingly some statements got more points from those operators who had worked less than two shifts on the line 1 in 2016. These statements are "*I think that entering the reason is useless.*" and "*I do not know who should enter the reason when stop/speed reduction occurs.*". The reason for this could be that for example logic of reason entering is quite clear in theory but might be confusing in practice. It is also possible that frustration in software have not occurred among those who have not used it a lot or at all. This could mean that in order to motivate users in using the system, the training might be useful to keep properly before the implementation, not in parallel with it. Regardless, the low amount of answerers affect to reliability of the poll result and too strong assumptions should not be done.

5 OEE Measurement Effect and the Results

The effects and the results of the OEE measurement are discussed in this chapter. The effect of visible performance measurement (OEE) is studied from the point of view of availability and production amounts. The measurement data and results of OEE are also presented.

5.1 Visible Measuring, Availability and Amount of Production

The second OEE project was launched 4th of January 2016. Line operators were informed about the project as soon as it started, but the project concretized to them slowly after the start-up. It was assumed that measuring line efficiency and making the measurement visible, would only by itself increase the efficiency. Reviewing production numbers does not support that assumption clearly. Production numbers are suitable measure for reviewing OEE's effect, because the filling and packing line 1 is priority line and it has not faced remarkable external requirements for off-time during the observed time period. In other words, it has been producing as much as possible. In figure 8 is presented weekly production of filling machine 1 in liters from week 37 2015 until week 16 2016. Small increase in production can be noticed, but the increase is not that remarkable that it could be assumed to be result of visible measurement of production efficiency.

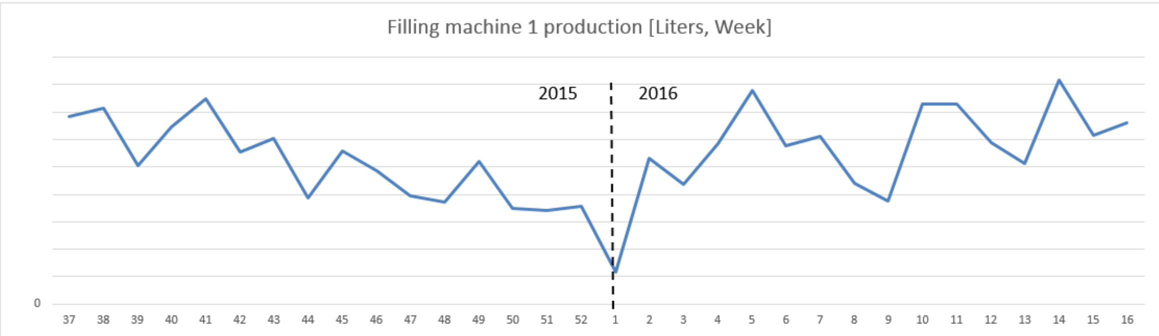


Figure 8 *Filling machine 1 production*

Figure 9 shows that the small production increase on line 1 can be caused by seasonal change. Orange line in figure represent the total production of filling machines 1, 2, 3, 4 and

6. Total production seems to be increased more than line 1's, where OEE pilot project was launched.

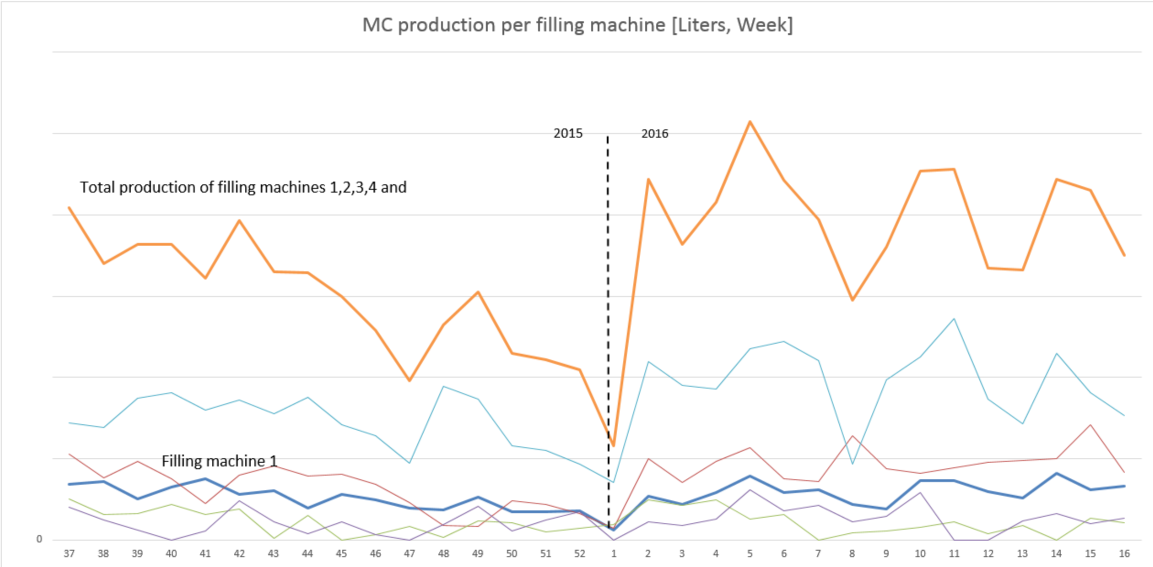


Figure 9 *MC production*

Figure 10 represents filling machine 1's production in daily basis. In order to avoid statistical error caused by unplanned production time, zero and close to zero days are removed. Figure 11 represents the total production of filling machines 1,2,3,4 and 6 in daily basis, without zero or close to zero days. Both figures 10 and 11 include also average line (the red one) of the observed time period.

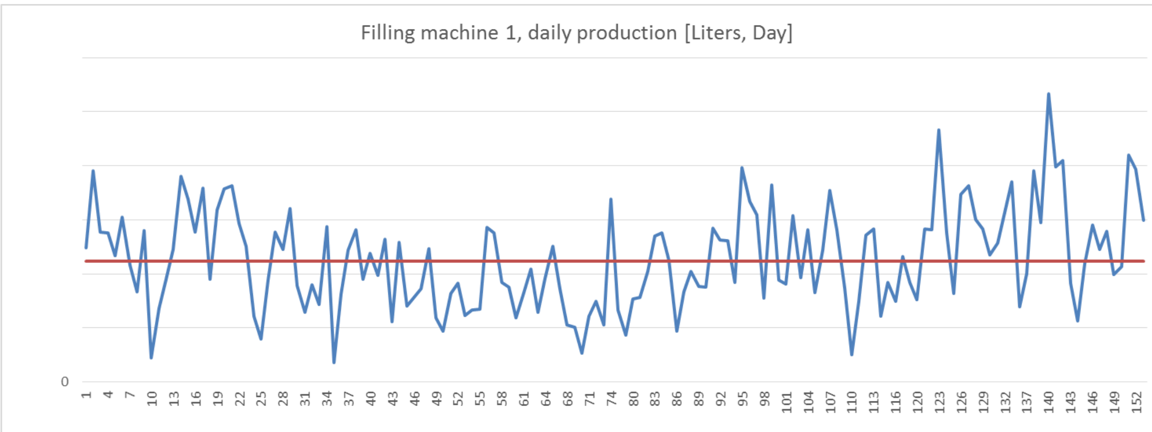


Figure 10 *Filling machine 1 daily production*

In both figures production has increased from the beginning of 2016, but because OEE was launched only on filling and packing line 1, the increase of total production cannot be assumed to be result of the project. It is possible that visible measurement increases production efficiency, but verifying that would require longer observation period so change of seasonal and random variation could be eliminated. It is also likely that not all the line operators have fully internalized OEE measurement and committed to it at the time of writing, so measurement visibility effect may not be fully seen yet.

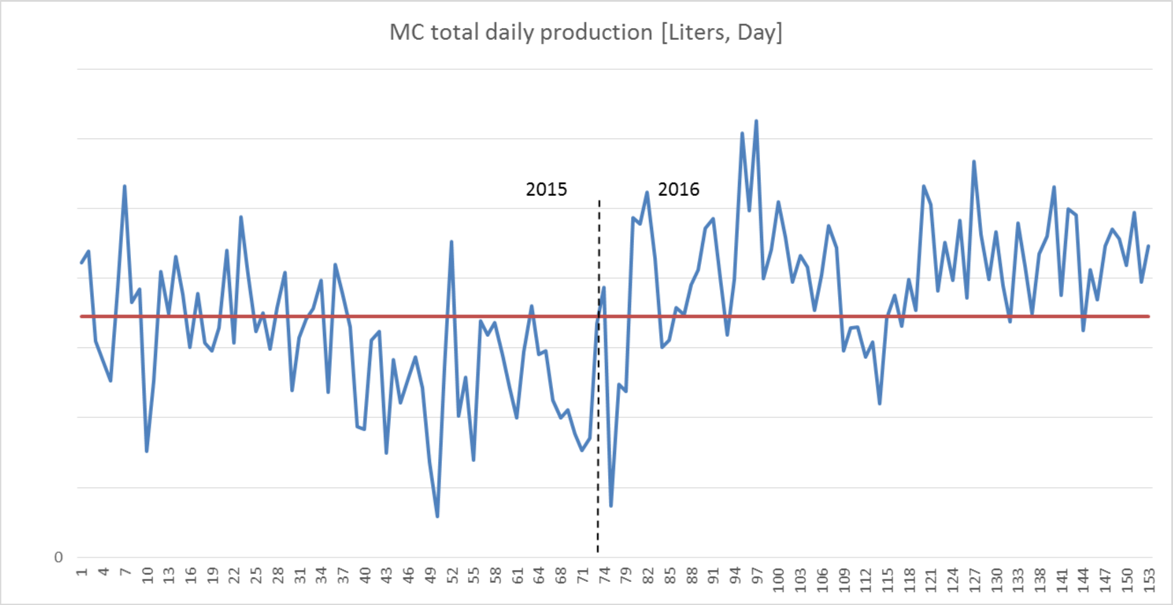


Figure 11 *MC total daily production*

Availability of filling and packing line 1 can be seen in the figure 12. The time period in the figure is the same as in in the production figures 8-11. When comparing the amount of production and availability during this time period, it is easy notice that even though production has arisen a bit in 2016, the availability has decreased since the second OEE project started.

In the observed time period, in 2015 the highest production of XXXX liters was achieved 8.9.2015 with availability of 74 % and in the 2016 the highest production of XXXX was achieved 10.3.2016 with availability of 54 %. The highest production of 2016 is 19,5 % higher than the highest production in 2015 even though the availability is 20 percentage points lower. The fill was the same in three different batches on 8.9., which explains the high availability. The low performance cannot be explained since the fill was not high viscosity fill and the cans were mostly the big ones. This shows that even though availability is 1st priority currently, the importance of performance should not be forgotten.

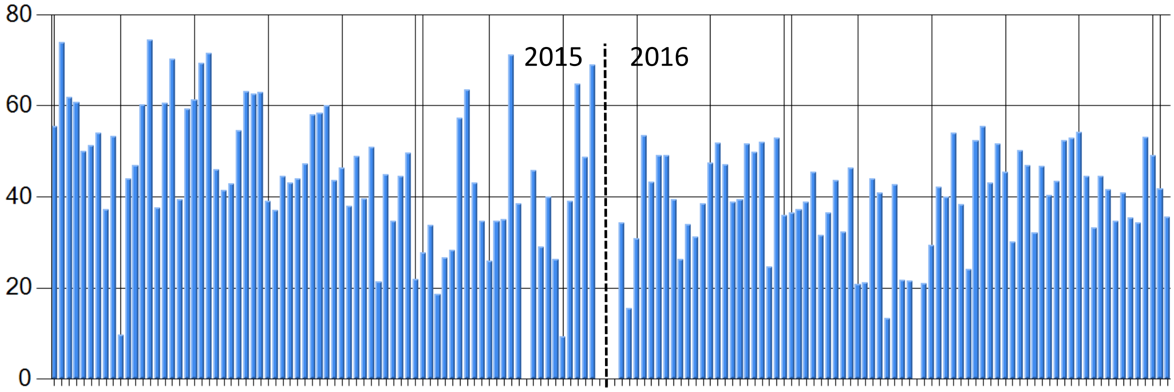


Figure 12 *Filling machine availability in daily basis: week 37 2015 - week 16 2016*

There is not any clear reason for this clash between the availability and production data. The availability data is not in line with the co-operation negotiations which took place in the fall 2015.

According to the line foreman, the production portfolio or production planning have not changed during the viewed time period. One reason could be the congestion sensors which were adjusted so that the time lag after a stop was removed. Micro stops do not affect to availability but to performance. Adjusting congestion sensors might have increased performance which lowered the availability, since the slower production speed is easier to handle for the line operators. It is also possible that for some unknown reason operators have started to run the filling machine with higher speed which lowered the availability. The target performance was changed during the second OEE project so there is no comparable data of performance before the change.

This phenomena should be studied more in order to see the cause of this clash. The company should be aware that high availability does not necessarily mean high amount of production.

5.2 OEE Number and the Factors

In this study, April was chosen to be reviewed time period of OEE downtime losses. This is because in April entering the reasons in the OEE system was on quite good level. The quality of the data before April is not accurate enough. One month is also period long enough to do some conclusions and it is easy time period to comprehend.

Filling and packing line 1's availability, performance and OEE number are presented in the figure 13. Performance was on the packing and filling line 1 81,49 % in April. Target levels of the performance are defined by measuring maximum production speed of few products and the target is set a bit lower than that. There are only two target speeds: one for the big cans and one for the small ones. Performance is not currently the biggest problem of the filling and packing line 1, and the target speeds should be defined more precisely before making too strict conclusions from the performance measurement results. The current performance is anyhow good comparison point and it should not drop below 80 in the long run. Since quality is not taken in account in Tikkurila's OEE calculation, OEE number 35,83 is result of multiplying availability by performance.

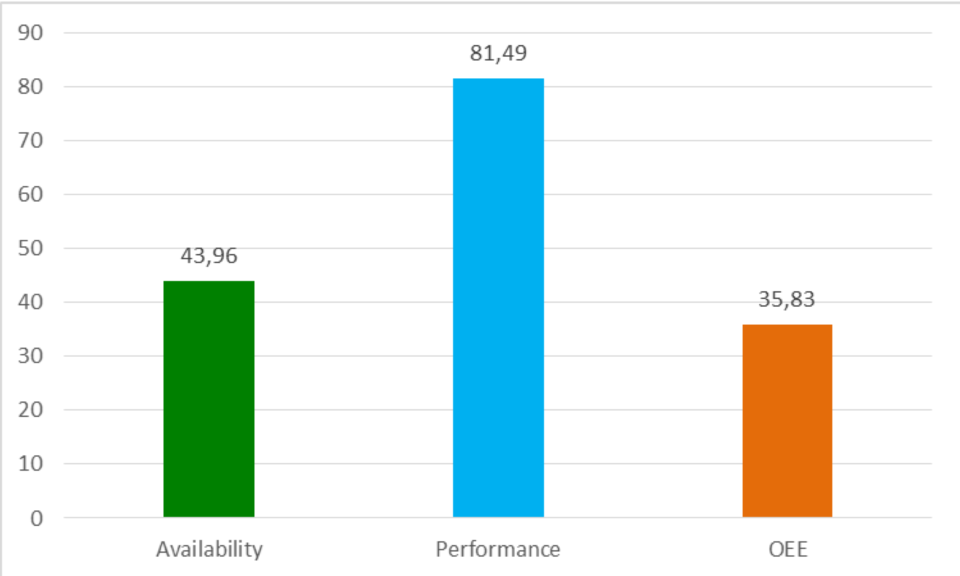


Figure 13 *Availability, performance and OEE*

The availability structure of the filling and packing line 1 is presented in the figure 14. As can be seen in the figure, maintenance is on quite good level; technical availability is more than 95 %. At the time of writing there are still some problems with entering the reasons. Probably technical availability is less than 95%, but the most likely not less than 90%. Operational reasons consume definitely the biggest part of the downtime losses.

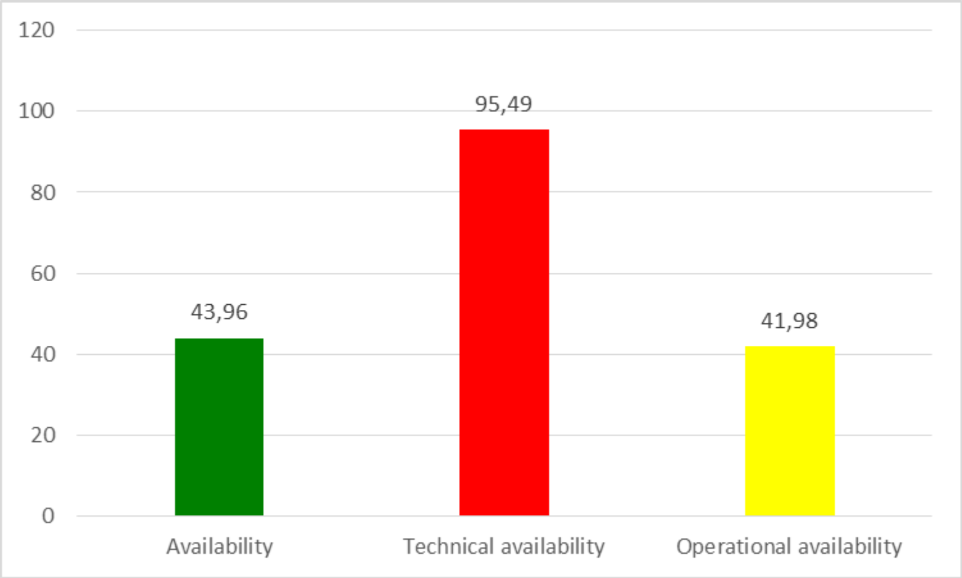


Figure 14 *OEE availability structure*

Since availability is currently the most important factor in the OEE number, it should be studied more specifically. In the figure 15 is presented OEE availability and technical availability of filling and packing line 1 in April, in daily basis. The figure views well the variation of these availabilities. Availability variates between 33 and 54 and technical availability between 85 and 100. The more important factor is availability since technical availability is even on its lowest quite high and when technical availability is low, also availability is low. The target level of the availability should be set at first around 45 which would be easily realistic target. Later the availability target should be raised.

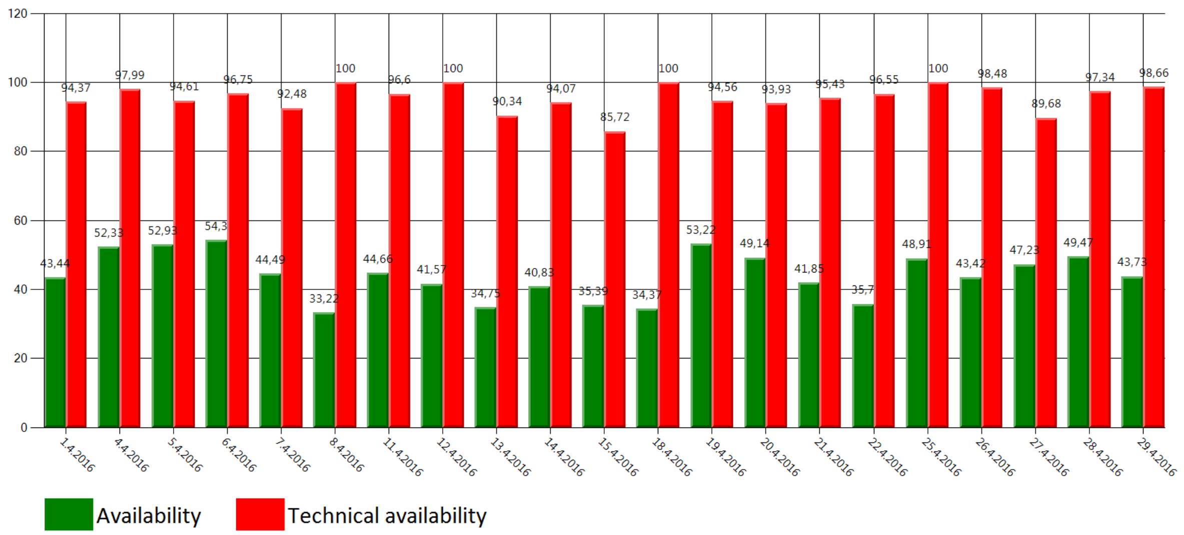
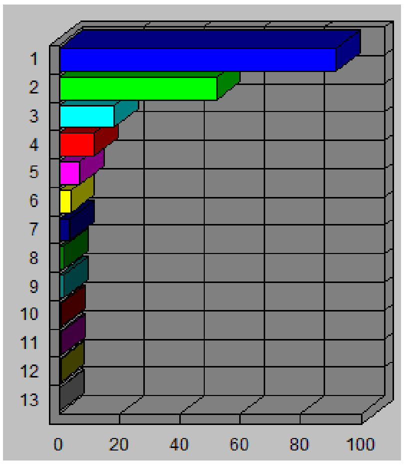


Figure 15 *April availability in daily basis*

5.3 Operational Reasons

Since availability is the lowest factor in OEE number and it creates the biggest loss of line efficiency, it is important to understand the structure of the downtime loss. This helps to target improvements to right places and to justify investments.

Operative downtime losses consume 91,88 per cent of all downtime losses and occur 51,5 per cent of all planned production time. Operative downtime losses of filling and packing line 1 can be seen in the figure 16. As can be seen from the table, Setup work consumes easily the biggest part of the operative downtime losses; more than 47 per cents. Also break is remarkable reason category of the downtime losses. Setup work and Breaks together consume almost 75 per cents of the all operational downtime losses.



	Reason	%	pcs.	h:min:sec	Cumulative %
1	Setup work	47,45	132	91:48:08	47,45
2	Break	27,01	93	52:14:55	74,46
3	No reason	9,41	36	18:12:18	83,87
4	Meeting	5,98	23	11:33:56	89,85
5	Other reason	3,56	23	06:53:33	93,41
6	Shift change	1,93	15	03:43:54	95,34
7	Ancillary work for other line	1,89	10	03:38:51	97,23
8	Roll/pallet change	0,90	10	01:44:07	98,13
9	Cleaning	0,84	4	01:37:21	98,97
10	Waiting	0,37	2	00:42:53	99,34
11	Filter change/cleaning	0,36	2	00:42:10	99,70
12	Nozzle change/cleaningn	0,20	3	00:23:40	99,90
13	Lack of material	0,10	1	00:11:44	100,00

Figure 16 *Downtime losses in April*

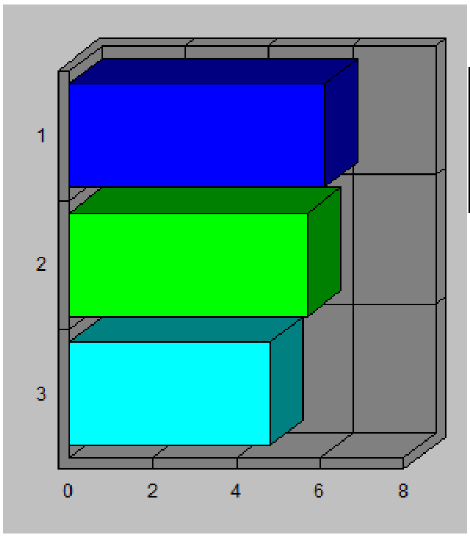
The reasons in figure 16 are upper reasons of the reason tree. Some of the upper reasons hold sub reasons under them. The Six biggest operational reasons are explained in the table 10.

Table 10 *The six biggest operational reasons*

Reason	**Sub reason(s)**	**Explanation**
Setup work	-	Setup work in the beginning of the batch/shift, ending batch/shift and batch change.
Break	-Lunch -Break	Lunch includes all eating breaks and Break includes all the other breaks like toilet break, cigarette break, coffee break etc.
No reason	-	This reason is fed by the Machine Track when no other reason is entered.
Meeting	-	Includes all the meetings, but mostly shift beginning meetings which are held daily.
Other reason	-	This reason should be entered when the stoppage is caused by event, so rare that it does not have reason in the reason tree. In reality this is often chosen when the line operator is not sure what to enter or does not enter the real reason for some other reason.
Shift change	-	The line is often idle for some time between the shift changes. This is caused by 15 minutes flexibility in line operator working times.

5.4 Technical Reasons

Technical reasons for downtime losses is quite small portion (7,91 %) of all downtime losses and 4,55 % of all planned production time. Tracking technical reasons is not yet on really good level, but current measurement data gives hint about the magnitudes and relationships between different technical reasons. Upper technical reasons and their percentages are presented in the figure 17.



	Reason	%	pcs.	h:min:sec	Cumulative %
1	Filling	36,76	18	06:06:43	36,76
2	Packing	34,27	15	05:41:50	71,03
3	Palletizing	28,98	14	04:49:04	100,01

Figure 17 *Technical downtime losses*

All the upper technical reasons hold under them several sub reasons. Upper technical reasons are divided by executing machines' physical places on the production line. All the filling section's machine errors are under filling reason, packing machines' errors under packing and so on. As can be seen, there are no big differences in percentages of technical reasons. Because of the inaccurate measuring, it is not worthwhile to examine sub reasons.

5.5 Machine Track Data Quality

There are still some problems in entering the reasons in the OEE system. Entering the most common reasons is on quite good level, but the rarer ones can be sometimes entered wrong. Excluding "No reason" and "Other reason", the six most common reasons are well understood and there is no reason to believe that those would be entered wrong that often, it would affect to reason statistics. The six most common reasons consume more than 95 % of all downtime losses.

“No reason and “Other reason” are more problematic reasons of the 6 most common ones. No reason is occurs when no reason is entered in the Machine Track. This happens when the machine is ran by manual control or the machine starts to run again before the stop is registered.

Some of the other reason feeds are reasons so rare, that those are not seen useful in the reason tree. But anyhow a part of “other reason” is surely wrong entered reasons. It is difficult to estimate how big part wrong entered is, but probably something between 1/3 and 1/2.

Likely no reason and other reason are in reality mostly some less common reasons, but it is possible that part of those should be entered as setup work, break, meeting or shift change. This does not create remarkable statistical error, because of magnitude of especially setup work and break.

Often two or more reasons occur at the same time or in a row. If the filling machine is not started between the reasons, the OEE system records only one stop. It is not possible to divide a stop in parts in the operation view of the Machine Track, but it can be done later from the factory view. Despite that, it was not always done. The operators were guided to enter the biggest or the fundamental reason to the Machine Track. For example, breaks were often held immediately after a meeting and only the meeting was entered to Machine Track. This distorts the reason data a bit.

6 Reducing Setup Time with SMED

This chapter deals with the setup time reduction with SMED. The chapter presents the basics of the used SMED software, test environment, outcome of the test, proposal for the continuous use and rough estimate of the potential of SMED. This chapter gives important information which should be used when using SMED is considered.

6.1 AviX SMED

AviX is Lean software tool developed by Solme AB. AviX includes several different modules aiming to improve and develop customer's productivity, production optimization and production efficiency. Tikkurila executed pilot test period of one of the AviX modules: AviX SMED. AviX SMED is simple tool aiming to facilitate implementing SMED and the steps presented in figure 6. (Solme AB 2015)

6.2 Preparation of Implementing SMED Steps

SMED test was executed by using Avix SMED software. Using AviX SMED starts by filming the whole batch changeover and all the tasks it includes. The filming was executed by using two portable cameras which were attached in the foreheads of the filling and packing sections' operators. One of the cameras filmed the changeover in the filling section and the other one the changeover in the packing section.

After the filming, factory, building, production line and working stations are created into AviX SMED software. The working stations are equivalent for the physical places where the setup work is done. Under every working station is created a resource or resources which execute the work. In case of Tikkurila, these resources are working personnel. Tasks are created under the resource which is executing them. These tasks include video clips, which present, how the work is done in practice.

It is also possible to create buffers in AviX SMED. Buffer is a time, which after, the work will start. For example in the studied case, the buffer between setup work in the filling section and packing section is around 4,5 minutes. It is the time that takes for the can to travel from the lid press to the shrink wrapping machine. An example of the factory, building, production line, working stations, resources, tasks and the buffer can be seen in the figure 18.

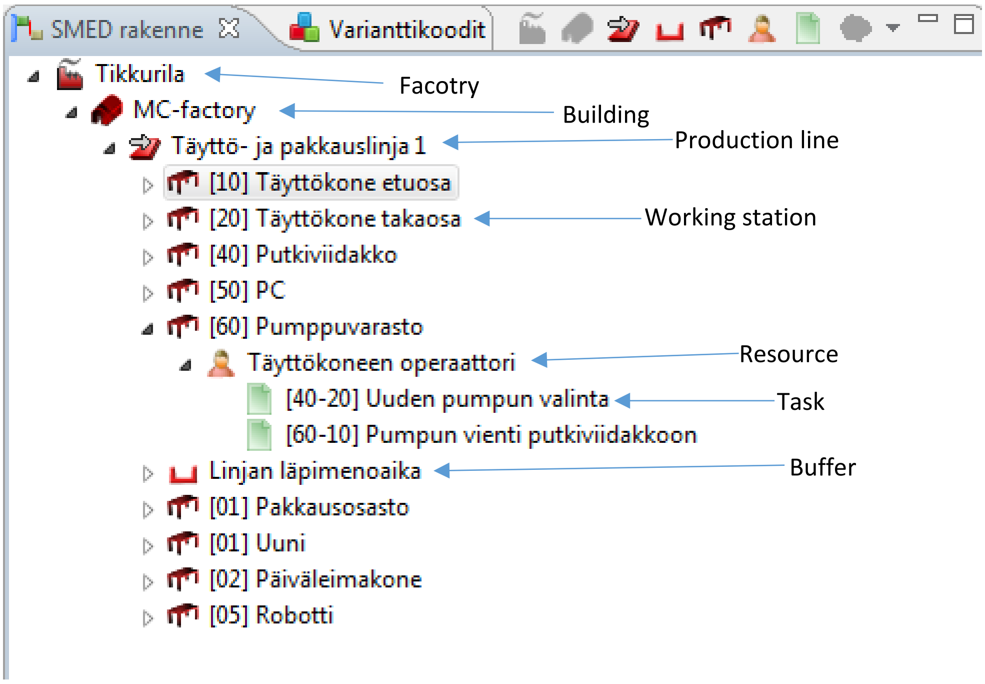


Figure 18 *AviX SMED working stations, resources and tasks*

The beginning of the setup timeline can be seen in the figure 19. The timeline is divided to working stations and resources. The tasks under the buffer line are executed in the packing section and the tasks above it, are executed in the filling section. Horizontal Axis in the figure is time. If two or more lines are alongside each other's, it means that those tasks are executed parallel.

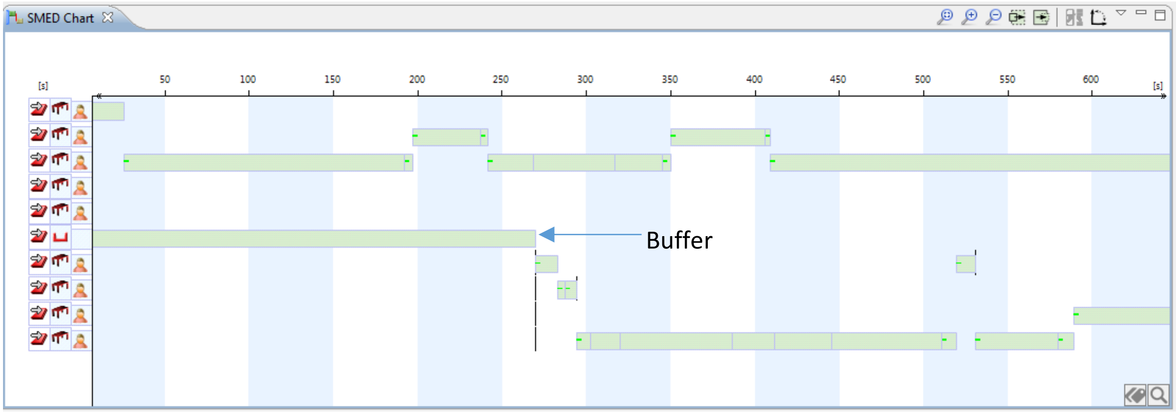


Figure 19 AviX SMED time line chart

6.3 Implementing SMED Steps

After filming the changeover and uploading it in the AviX SMED, it was divided in external and internal tasks. Also task orders were changed in order to simplify and shorten changeover time. This was done together with Automation Manager and Production Manager.

Afterwards the most questionable improvements and changes were also shown to the operator who executed the filmed change. The operator has the best knowledge of the changeover and he knew some limitations which did not come up in the first meeting.

6.4 The Packing Section Changeover

As can be seen in the figure 20, the packing section's changeover is remarkably shorter than filling section's (unnamed lines in the figure). The packing section operator is running packing section of the three lines: 1, 3 and 7. Because of this he/she cannot move helping in filling section's changeover even though he/she would have finished the packing section's changeover tasks. Because of this the packing section was left outside of the SMED analysis. Total changeover time is currently fully dependent on changeover time of the filling section.

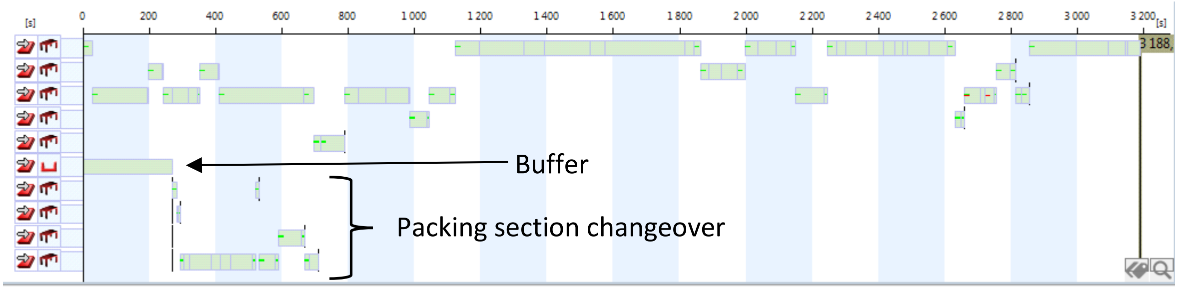


Figure 20 Packing section changeover vs. Filing section changeover

6.5 The Filling Section Changeover

After the task order improvement and changing some previously internal tasks to external, the change over time was reduced from ~3190 seconds to ~2710 seconds. The reduction in changeover time is 15%. The time reduction could be achieved with changes listed below the figure 21, which presents the layout of filling machine 1 and its surrounding area.

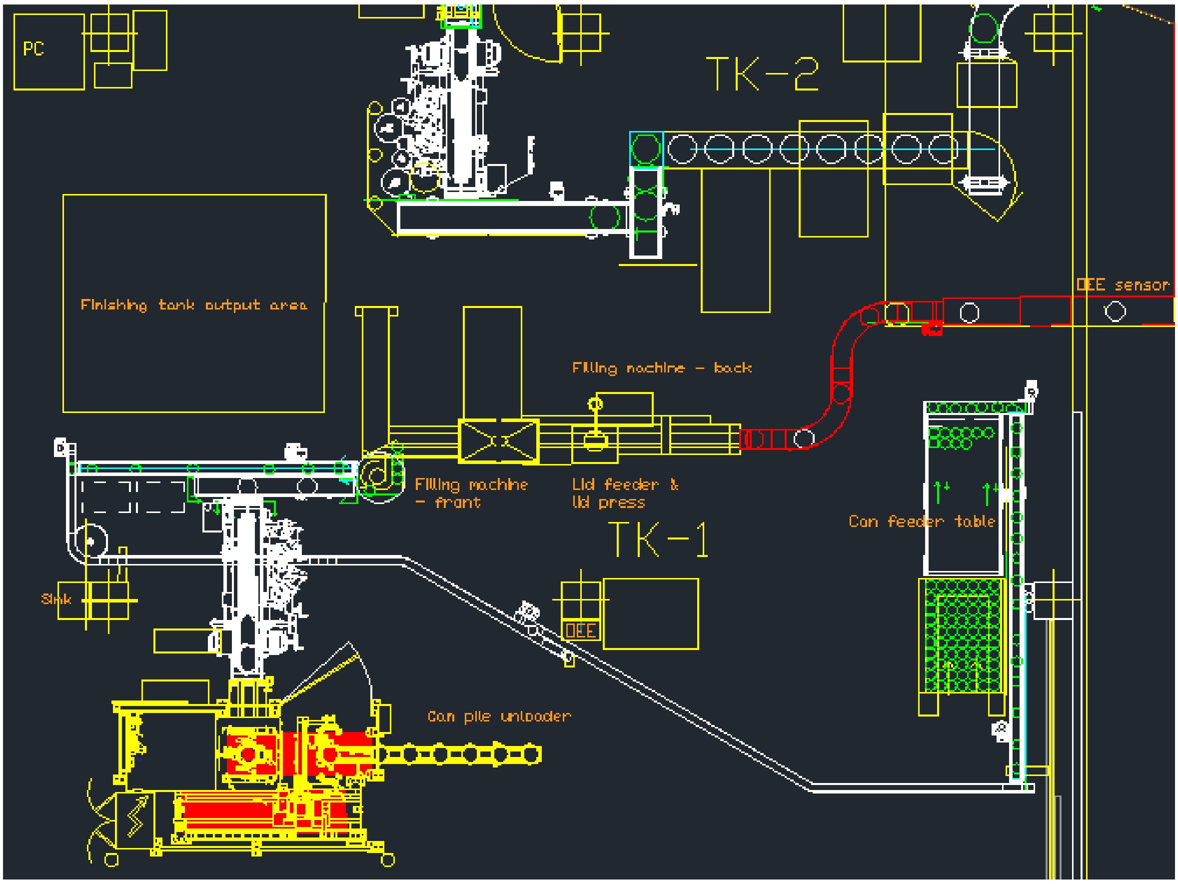


Figure 21 The layout of filling machine 1 and its surrounding area

1. **Personal knife**

Every operator should have his/her personal knife or one common knife should be behind the filling machine. Time is spared when the operator does not have to fetch knife to remove blocking from the filling machine feed pipe's drain tube.

Figure 22 *Removing blockage from the drain tube*

2. **Two wrenches**

There should be two wrenches in the front side of the filling machine. Time could be spared on two phases. The first time two wrenches is needed is when the nozzle is removed from the filling machine. The second time is when the sewage tube is removed from the filling machine's output.

Figure 23 Removing the sewage tube

3. **Two nozzles**

Every time when the product type changes the filling machine nozzle has to be washed. Washing would not consume changeover time if there were two nozzles on the filling machine. Then washing could be changed from internal task to external. This requires can or bowl containing water or some other suitable liquid which prevents paint to dry before the washing.

4. **Taking trashes**

In the studied changeover, time was consumed in taking trash into a trash can. Small trashes could be easily put in a pocket and take those to the trash can after the changeover or when the operator is executing some other task next to the trash can.

5. **Unplugging pump from the sewage pipe**

When the pump filter is emptied from the dirty water after washing the pump, the operator is waiting the filter to be empty. After this he/she unplugs the pump from the sewage pipe. The unplugging could be done while the filter is emptied automatically through the bottom valve. Theoretically all the sewage water left in the pump and its parts should drain out through the bottom valve of the filter, but this has not been tested in practice. If pumps pressure tube's valve is not closed, it may cause small amount of sewage water draining on the floor. If the valve is closed, some water may stay in the pressure tube. This work order improvement is questionable and it should be investigated more. The time reduction effect (67 seconds) is nevertheless calculated in the improved changeover.

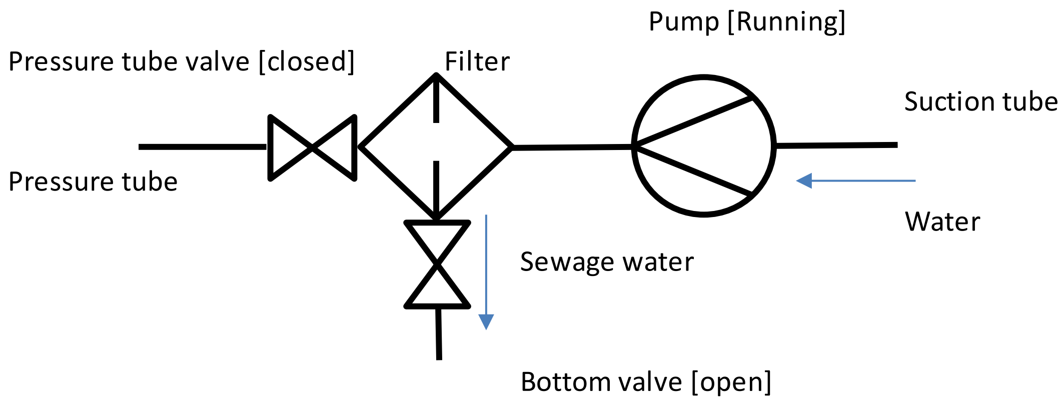


Figure 24 *Pump system flow sheet*

6. Trough washing

In the studied changeover, trough washing was done in following order: Hand washing, cylinder washing, input pipe washing, hand washing, input pipe washing and hand washing. The washing operation could be done with less phases: input pipe washing, cylinder washing and hand washing.

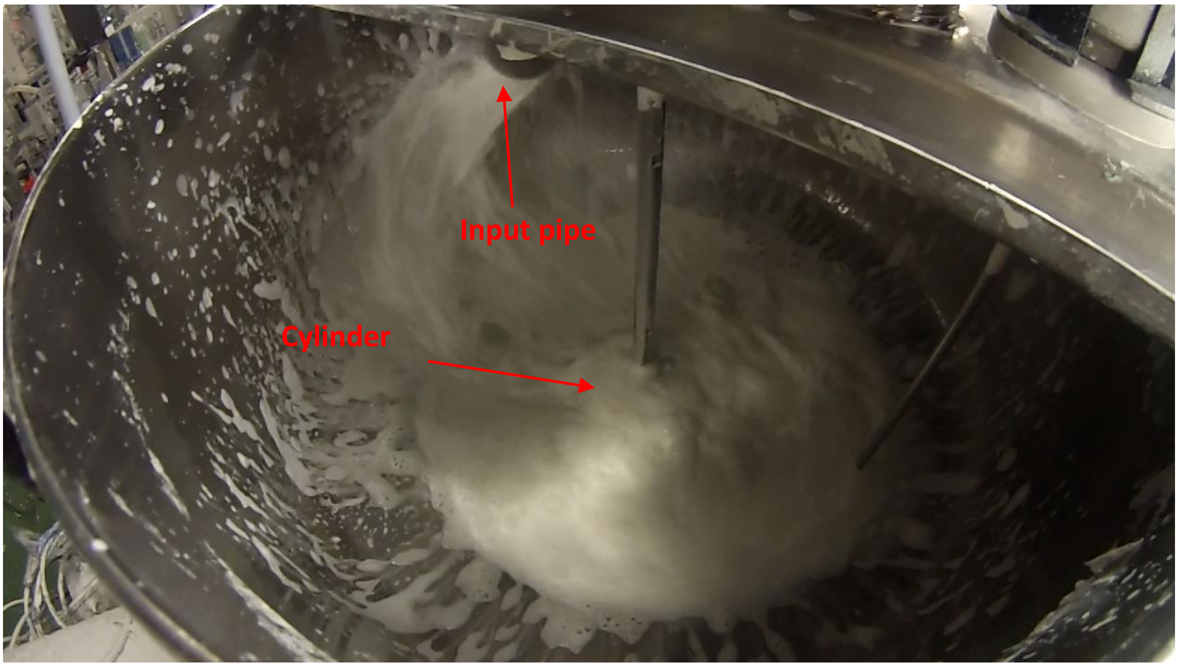


Figure 25 Input pipe washing

7. Rags

There are several possible situations when cleaning can be needed. There should be rags on several different work stations to minimize time consumed to fetching rags. In studied changeover rags were needed in finishing tank output area, but the closest rags were on other line's filling machine.

8. Fetching new can pallet

The can pallet for new batch is fetched during the changeover, just before loading the can pile unloader. It could be changed from internal to external task in order to spare changeover time. It could be done for example in the end of prior batch production.

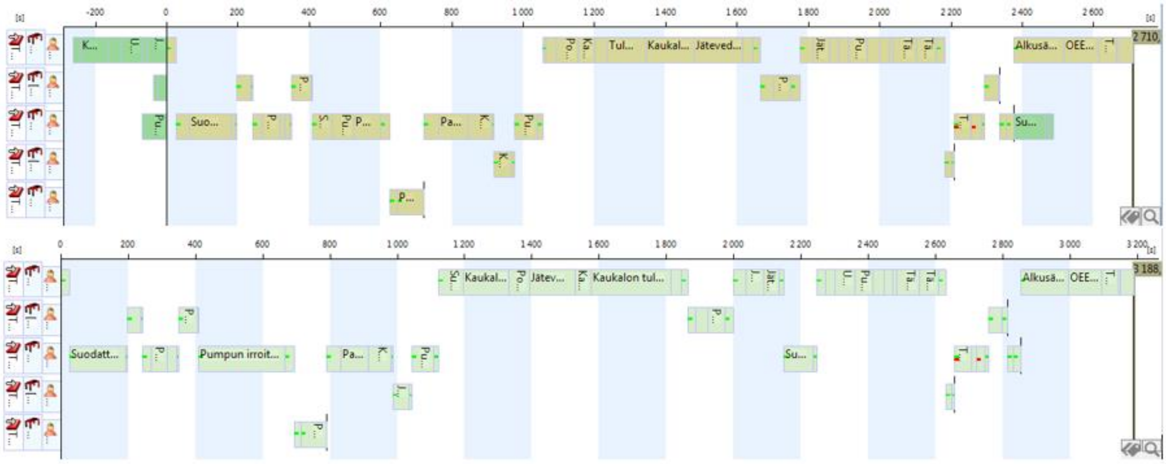


__Figure 26__ Changeover improvement

These 8 changes which led to 15% time reduction in changeover, are easy to implement and do not require big investments. In figure 26 can be seen visualized reduction in changeover length. In upper segment of the figure is the draft of the changeover with these 8 improvement ideas. Dark green tasks are external and brownish tasks are internal. Some of the tasks could be removed by changing the changeover process. This does not mean that tasks are changed from internal to external but removed totally. In figure 26 these removed tasks are visualized as externals, but this does not affect the result of total internal changeover length. In the lower segment with light green tasks, the changeover can be seen as it was filmed.

During the changeover film analysis, several other development ideas came up. These other development ideas could reduce changeover time even more and simplify and ease the changeover tasks. The other development ideas are presented below.

1. **Ensuring pipe/tube joints with tape**

When tube is plugged in pipe, it is often ensured with tape. Taping, removing tape and fetching tape roll consumes time. Removing tape also creates trash and if the trash are taken into the trash can during the changeover, time is wasted again. Need of taping should be considered again. If it is seen as necessary action, different kind of fasteners in the end of pump tubes should be considered. Time consumed in taping and other resulting tasks was 103 - 120 seconds in studied changeover.

2. Plugging tubes in pipes

In the studied changeover there were not big problems in plugging tubes in pipes, but this is known to be problem for many operators. There are often dried paint in the tube nozzles. Because of this, plugging requires a lot of force or sometimes the dried paint need to be removed before plugging. Nozzle material could be changed or removing dried paint could be done as external changeover task. Dissolving dried paint from the nozzles when the pump is not in use is also one possible solutions.

3. Finishing tank output area

When the pump is moved in, out or inside the finishing tank output area, pump's filter hits often paint tank output pipes. This could be minimized by lowering the pump height. This could be done by changing how the pump is attached to the cart. Other possible solution is to remove old, unused tanks' output pipes. Finishing tank output area includes several tank output pipes which are not used anymore. Finishing tank output area and a mobile pump can be seen in the figure 27.

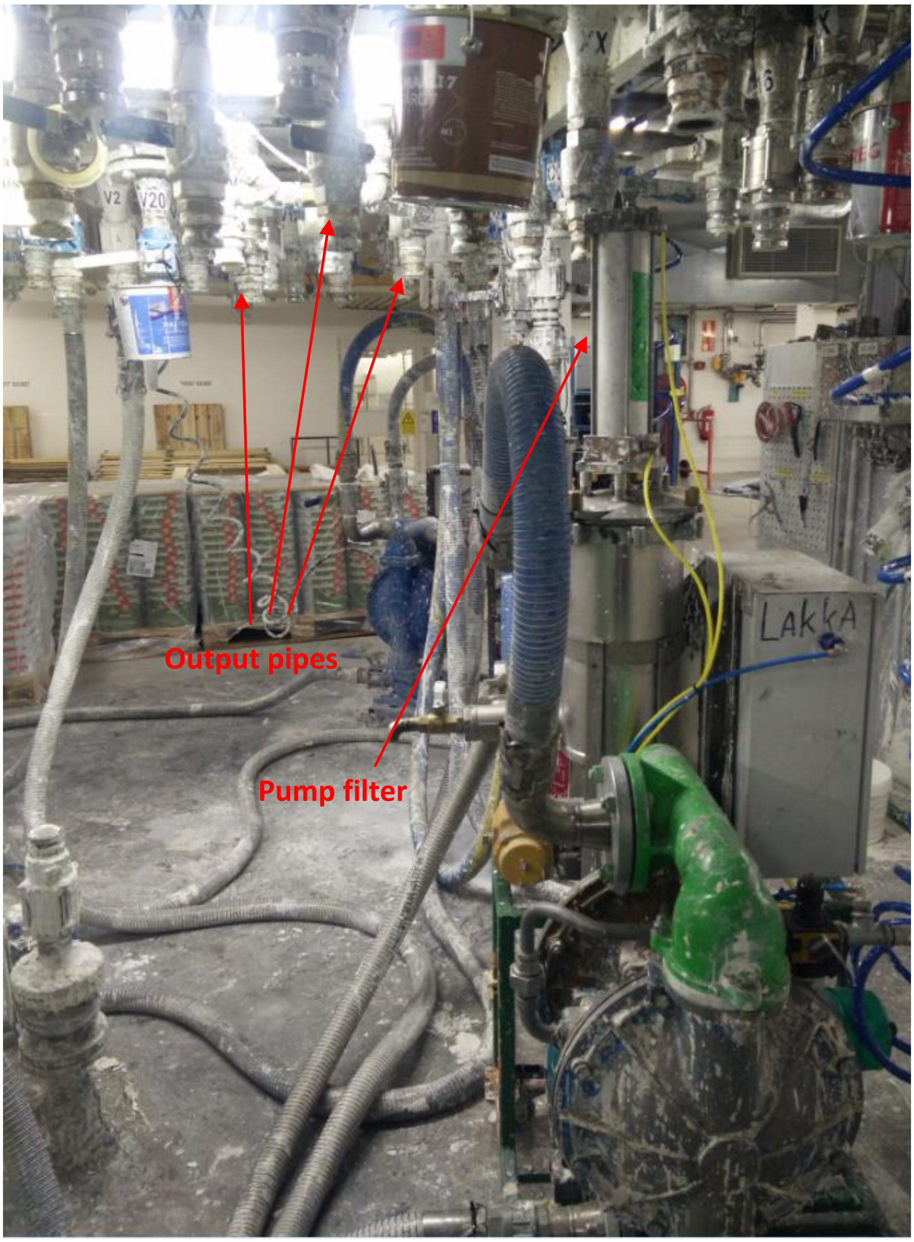


Figure 27 Finishing tank output area and a pump

4. Personnel

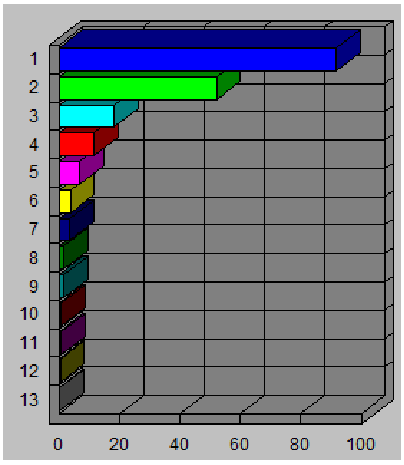
One possible, but expensive solution to reduce changeover time is to add personnel resources in the MC factory. With two operators, several changeover task could be done parallel.

5. Moving pumps

Old pump is taken into the pump storage and the new pump is fetched during the changeover. Those tasks could be changed to externals, but there are some limitations which question this idea. First of all, usually there are no room in the finishing tank output area for the pumps which are not in use. New pump could be brought next to the finishing tank output area before the changeover and the old could be removed to the pump storage after the changeover, but there are limitedly space next to finishing tank output area. Changing old pump to the new one takes 60 seconds, excluding the work and moving done in the finishing tank output area. Another possible solution could be changing location of the pump storage next to the finishing tank output area, but once again, space could be a problem.

6.6 Potential of SMED

According to the OEE measurement, setup work caused 47 % of the all operative downtime losses on filling and packing line 1 from April 1st to April 30th. During this time period entering the reason codes in Machine Track has been on good level. The data gathered before this is quite inaccurate and that is why it is not regarded. 47 % of the all operative downtime losses in hours is 92.



	Reason	%	pcs.	h:min:sec	Cumulative %
1	Setup work	47,45	132	91:48:08	47,45
2	Break	27,01	93	52:14:55	74,46
3	No reason	9,41	36	18:12:18	83,87
4	Meeting	5,98	23	11:33:56	89,85
5	Other reason	3,56	23	06:53:33	93,41
6	Shift change	1,93	15	03:43:54	95,34
7	Ancillary work for other line	1,89	10	03:38:51	97,23
8	Roll/pallet change	0,90	10	01:44:07	98,13
9	Cleaning	0,84	4	01:37:21	98,97
10	Waiting	0,37	2	00:42:53	99,34
11	Filter change/cleaning	0,36	2	00:42:10	99,70
12	Nozzle change/cleaningn	0,20	3	00:23:40	99,90
13	Lack of material	0,10	1	00:11:44	100,00

__Figure 28__ Filling and packing line 1 operational off-time

If total changeover time including all the changeovers, setups and set-downs on the line 1 could be reduced 15,0 % by SMED as in the Avix test was estimated, would it reduce line's total off-time by 7,1 % which would be around ~14 hours per month. For small cans this would mean XXXX cans and for the big cans XXXX cans production increase per month. These numbers are estimations for line 1 only, but represent the right magnitude. Possible downtime losses of the added 14 hours are not regarded in the production estimations. Using the SMED in all lines would most likely multiple the positive effects.

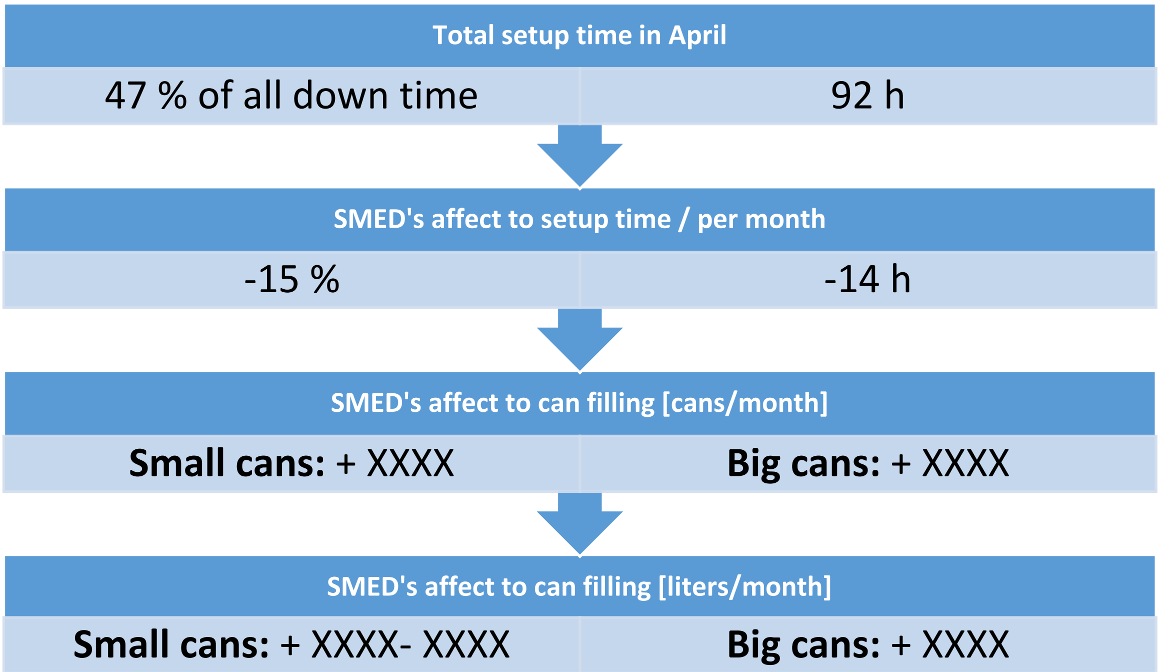


***Figure 29** SMED effect in numbers*

The biggest potential of SMED is not necessarily in changeover time reduction, but in changeover standardization. Currently changeover tasks include several uncertainty factors which cause variation inside one type of changeover. These uncertainty factors can be for example dried paint in nozzles, taping couplings, moving pumps and physical strength of the operator. By removing these uncertainty factors, variation could be minimized or eliminated. Reducing changeover time variation would make production planning easier and more accurate. Standardized changeovers are also easier to improve when the time consumption of the changeover is always the same, no matter of luck nor executing operator.

Changeover standardization would require studying the same changeover made on different days and by different operators. Studying only one individual changeover does not necessarily and most likely reveal all the uncertainty factors in the changeover.

6.7 Implementing SMED

Implementing SMED does not necessarily require big investments nor lot of work. It is relatively easy to do on low level, but more standardization and improvements requires naturally more recourses.

In order to discover possible future challenges of SMED implementation, Jukka Lintilä Development Coordinator in Valio Seinäjoki was interviewed. Jukka Lintilä has strong experience of reducing and standardizing changeover times with SMED.

According to Lintilä, it is important that setup improvement signal comes from someone working with production line in daily basis. This person could be for example the line supervisor or factory foreman. This is because he/she is the one who observes the performance of the line daily and line performance is tightly related to his/her responsibilities. Signal to improvement should be based on setup time measurement, instead of Foreman's/line supervisors' intuition. (Lintilä, interview, 19.4.2016)

Lintilä argues that line operator should be taken in setup improvement planning process. This motivates operators to implement intended changes and commits them to improvement process. The line operators have also often comprehensive knowledge of limitations that production line holds in. Even though, line operator is well aware of setup work, he or she may have become blind to waste that setup holds in. This is why there should be someone who is not working on the line and has knowhow regarding SMED and AviX, challenging existing manners and practices in SMED brainstorming. This person can also see SMED improvements objectively, because those are not effecting to his/her daily work. (Lintilä, interview, 19.4.2016)

Changeover performance should be measured in order to notice if it should be improved. In case of Valio, there are always daily predetermined changeover times and if the realized changeover repeatedly exceeds the predetermined changeover time, the causes are investigated. The predetermined timeline including setup time, could be integrated in OEE system. If the changeover time never or rarely exceeds the predetermined, it means that the changeover is well standardized and improvement resources could be concentrated to reducing the changeover time. (Lintilä, interview, 19.4.2016)

SMED improvement process can be seen in the figure 30. It shows the actions needed in the circling SMED improvement process and the responsible people for the actions. In this process, a lot of responsibility is given to line operator. It is not necessary to train SMED and AviX to every line operator but to one or two capable and willing (Lintilä, interview, 19.4.2016). This/these operator(s) represents all line operators in SMED improvement.

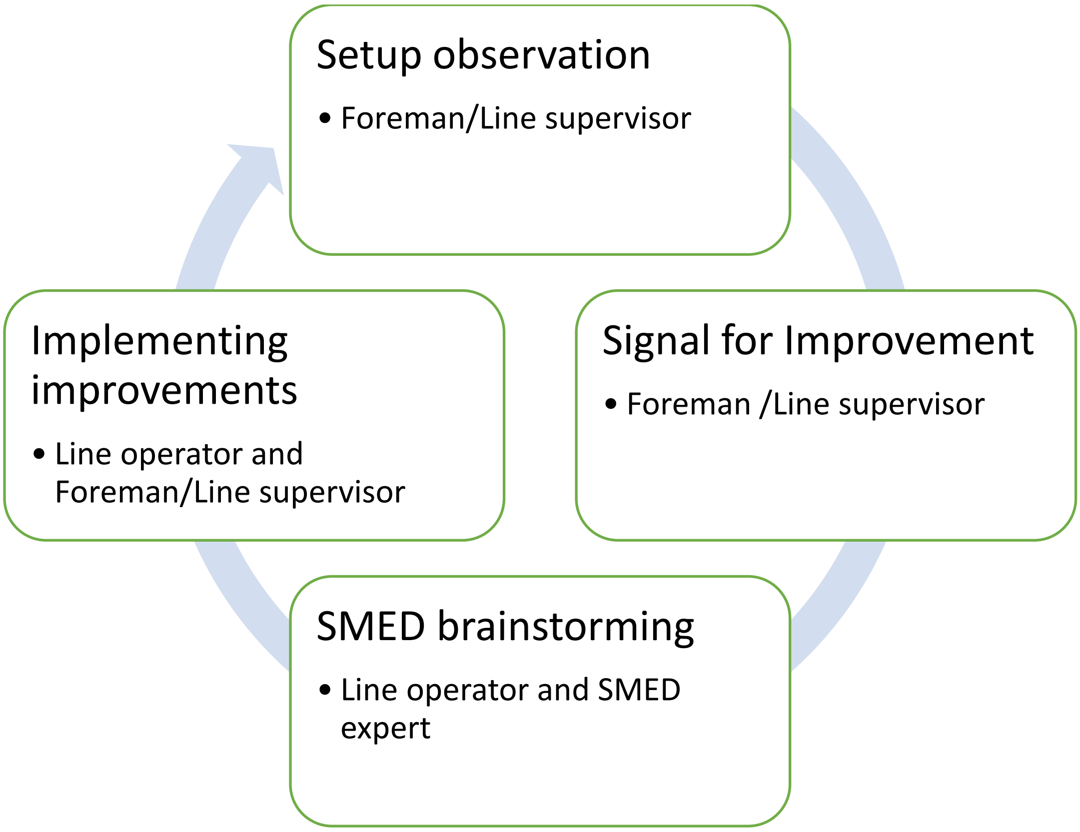


Figure 30 *SMED process*

SMED process can be presented also in terms of PDCA cycle (Plan, Do, Check and Act). PDCA cycle highlights continuity of SMED process and standardization followed by it. Figure 31 illustrates the connection between the PDCA cycle and the SMED process.

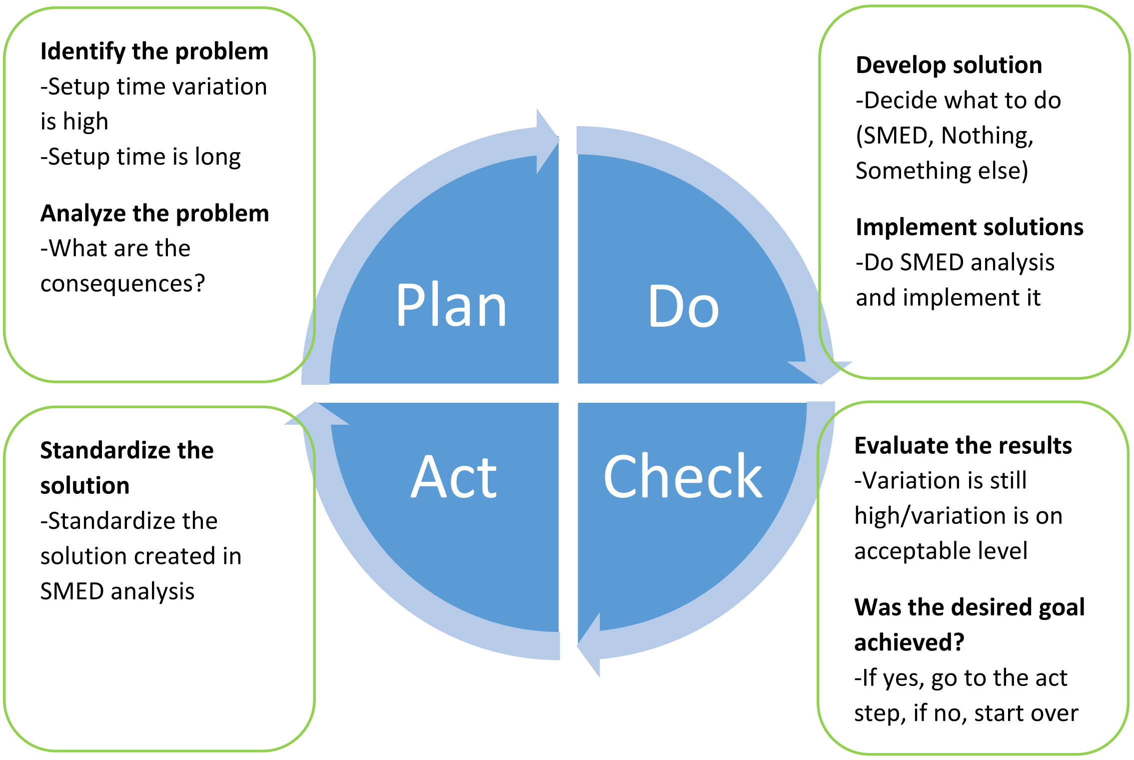


Figure 31 SMED by PDCA

6.8 Avix as a SMED Tool

SMED could be implemented by just studying the changeovers in real time, but using portable video cameras makes it more convenient. SMED could be implemented also with a basic video editing software, but Avix has some advantages. It enables comments, dividing work in work stations, changing work orders and moving tasks from internal to external is easy.

7 Results

In the beginning of the project the case company Tikkurila wanted to study if OEE would be suitable tool for it and if setup times could be reduced with SMED. OEE had been in passive use for a three years so Tikkurila wanted to study if the usage should be expanded or the whole system should be buried. At the same time the company had holistic programme on, which aimed to reduce production cycle time. Setup times were known to be big part of the all downtime losses measured by OEE and affected to cycle time.

7.1 OEE results - Implementing

The case company saw a big potential in OEE, even though the measurement system faced some problems after the first implementation. In the beginning of the thesis project, five research questions were defined for the study. First three of the research questions regarded OEE and these questions were:

Q1 What should be taken in consideration, when implementing OEE on semi-automatic paint filling and packing line?

Q2 Is OEE suitable measurement and improvement tool for semi-automatic paint filling and packing line?

Q3 What kind of value OEE offers to the case company?

The project showed that the most difficult part of the implementing OEE is motivating the line operators. An important part of the motivation is training and education and need of those should not be underestimated. Motivated operators is a crucial factor in order to collect high quality reason data. Five important notices of motivating and training production personnel are presented below.

1. **Training/briefing meeting in the beginning of the implementation project**

Before starting the implementation, line operators and factory foremen should be informed and trained properly. The attitudes towards the measurement should be turned as positive as possible, already before the implementation so the project could get a good start. The meeting might be useful to repeat shortly after the start of the implementation project. During the thesis project it was noticed that one short info meeting, written notification and one ~2h training meeting, in the beginning of the project was not enough.

2. **Observation and conversations in daily basis**

The software will most likely require some changes during the implementation and training work needs to continue also after the prior implementation training meeting(s). The improvement requirements will clarify when discussing with the users. It also helps to track and understand problems of the usage.

3. **Weekly education meetings**

Short training meetings should be held in weekly basis. In these meeting all the changes made in the system and the occurred problems should be informed and educated for all of the operators at the same time. These meeting also show to line operators that management is interested to observe and develop the OEE system.

4. **Written instructions**

It was noticed during the project that long comprehensive guidebook of the OEE reasons tree was rarely used for problem solving by the operators. More useful instruction was short quick guide which presented the most common reasons for the stoppages. Nevertheless, comprehensive guidebook should be done, because a few operators did use it. The advantage of the quick guide is also that then basic daily reason entering is improved which is crucial for getting right reason feed also in the rarer occasions.

Management has important role in implementing the OEE system. Lack of ownership leads easily to disuse of the system like happened in the first OEE project. It is yet to be seen if the same issue will be repeated in the second OEE project. Managements role do not end in implementing, but the benefit should also be taken out from the system. As was seen in this study, the measurement itself does not increase efficiency, but reveals the problems. The value of OEE concretizes only as well as the revealed problems are fixed. OEE should be kept on the table by taking it in regular meetings on few hierarchical levels.

One of the big advantages of OEE is that it is simple measurement. Also OEE data collecting should be kept simple at least in the beginning. The reason tree expands easily and includes a lot of reasons that are so rare and small that those should not be recorded separately. It is better to have a few wider reasons which hold several different kind of, but related reasons in them, than separate reason for every part of the same machine or equipment. The reason tree can be expanded later if it is seen necessary.

There are few practical things that should be considered when implementing OEE system. It is important that OEE sensor is as close as possible to the measured machine. That minimize the measurement errors which occur between the machine and the sensor. When one OEE sensor measures the whole production line, there should be clear sign which informs the operators that OEE requires a reason. With the sign, unnecessary waiting of reason entering and checking the need of entering could be minimized. In studied case the only way to notice that OEE requires a reason was to check it from the OEE screen.

7.2 OEE Results - Suitability and Potential

As implicated in theory part of this paper, there is no reason to claim that OEE would not be suitable measure for semi-automatic paint filling and packing line.

A bit surprisingly, OEE measurement seemed not to have steep and clear effect on line efficiency without other actions than measuring. It was assumed that operators would perform better when the measurement was made visible for them by OEE.

OEE measurement results give important information of structure of the down time losses. As can be seen in the table 11 the downtime losses concentrate strongly to few most common reasons. Setup work alone consumes almost 44 % of all downtime losses. This helps to concentrate improvement resources to the biggest reasons and estimate the financial effects of the improvements.

OEE does not only help to make structure of the downtime losses visible, but it also concretizes the magnitude of the downtime losses, which may be trigger to improvements. Yellow rows in table 11 are operational reasons and red ones are technical reasons.

Table 11 Structure of the downtime losses

	Reason	%	pcs.	h:min:sec	Cumulative %
1	Setup work	43,7 %	132	91:48:08	43,7 %
2	Break	24,9 %	93	52:14:55	68,6 %
3	No reason	8,7 %	36	18:12:18	77,2 %
4	Meeting	5,5 %	23	11:33:56	82,7 %
5	Other reason	3,3 %	23	06:53:33	86,0 %
6	Filling	2,9 %	18	06:06:43	88,9 %
7	Packing	2,7 %	15	05:41:50	91,6 %
8	Palletizing	2,3 %	14	04:49:04	93,9 %
9	Shift change	1,8 %	15	03:43:54	95,7 %
10	Ancillary work for other line	1,7 %	10	03:38:51	97,4 %
11	Roll/pallet change	0,8 %	10	01:44:07	98,3 %
12	Cleaning	0,8 %	4	01:37:21	99,0 %
13	Waiting	0,3 %	2	00:42:53	99,4 %
14	Filter change/cleaning	0,3 %	2	00:42:10	99,7 %
15	Nozzle change/cleaningn	0,2 %	3	00:23:40	99,9 %
16	Lack of material	0,1 %	1	00:11:44	100,0 %

7.3 SMED Results

Two of the 5 research questions regard SMED. These two questions are:

Q4 Is it possible to reduce and standardize batch change time in paint filling and packing with SMED?

Q5 What is the potential of SMED for the case company?

In April, more than 56 % of the planned production time the line 1 was not running and 43,7 % of this time it was because of setup work. This means that there are setup work going on almost 25 % of the planned production time. The setup time could be quite easily reduced by ~15 % by using SMED. This 15 % would require quite easy to implement and low cost changes in the tools and work orders. The setup time could be reduced even more with more comprehensive improvements.

It is also important to notice that improvements triggered by OEE affect to possibility to change previously internal tasks of setup to external. When the line requires less operator's presence, the operator can be longer away doing the external tasks during the production.

Another way to benefit from the parallel use of both, OEE and SMED is daily target timeline of OEE. The target timeline would present the estimated daily production of the line including planned stops. The target timeline could be compared to realized, and for example prolonged setup could be noticed immediately. This would require well standardized planned stops.

Nevertheless, the biggest potential of SMED is not yet in setup time reduction, but in standardization. The 15 % reduction estimation includes also time which follows poor level of standardization (for example taking trashes, removing tube blockage etc.). With higher level of standardization production planning could be improved, line operator requirements lowered and the line operator work could be made less consuming.

7.4 Future Study

The thesis project did not only answer to research questions but also raised new ones and enables interesting future studies. The data collected with OEE enables alone and combined with other data sources several different studies like which factors effect to production performance and how downtime losses could be reduced. Also measuring effect to production efficiency, personnel motivation and work wellbeing could be studied.

In this paper SMED is evaluated as a tool to reduce and standardize production setup time. Setup times are a huge downtime loss cause in the case company and reducing setup time should not be tried to do only with SMED. There are several other methods to reduce setup time and potential and suitability of those should be studied. Also setup time variation would be interested topic for the future studies.

8 Summary

The trigger for this project was a belief that the OEE (Overall Equipment Efficiency) system, when used right, would support the development direction of Tikkurila. Tikkurila wanted to get full benefit out of it or stop using the measurement for good.

The idea of using SMED (Single Minute Exchange of Dies) in reducing and standardizing production setup times rose in discussions at the same time. It was known that setup time would be an important improvement target in reducing production cycle time, even though setup times were not recorded nor measured. It was decided that SMED together with OEE would be evaluated in the same project of measuring and improving production efficiency.

It was clear from the beginning that clarifying the potential and suitability of both of the tools and implementing them would be too big task for one thesis project. It was decided to implement OEE and unravel its potential and suitability in practice, but to leave SMED study on more theoretical level without implementing, just clarifying the potential and suitability.

The main theories in this paper are OEE and SMED, but also some related theories are presented, like lean philosophy and TPM (Total Productive Maintenance) which are super theories for OEE and SMED. Also PDCA cycle (Plan, Do, Check, Act) is introduced because it is a tool to implement continuous improvement. In this paper PDCA cycle is highly related to SMED but can be also used in other improvements triggered by OEE.

The project was started by carrying out a user poll for the line operators and for the foremen. This poll revealed the attitudes towards the OEE system and the knowledge of it. The second implementation was based on this user poll because it helped to focus resources in right places. Later the user poll acted also as a measurement of success of the implementation project, when the poll was repeated and the results compared.

The second user poll showed that there is still work to do in informing the users about the benefits of the system. It seems that the line operators do not trust to OEE as a measurement tool or management’s ability to fix noticed problems. According to the second poll, they do know how the measurement results are meant to be used, but they do not think that entering the reasons is useful. This is probably because at the time of writing, any problem fixing actions have not been executed yet. Also technical errors seemed to be an issue for the users.

A bit surprisingly, visible measurement itself did not increase line efficiency. No remarkable correlation can be seen between the start of the second OEE project and production efficiency. Nevertheless, OEE revealed the downtime loss amount and structure of the studied production line. Three out of five biggest downtime loss reasons are not actually errors, but built-in in the production process. These reasons are setup work, breaks and meetings and together they consume almost 75 % of all downtime losses. OEE has an important task of revealing these kind of downtime losses which would be easily left outside of improvements because of their nature of normality.

OEE measurement shows that setup work is the biggest individual reason for the downtime losses. This is a proof that there is need in the case company for SMED or a similar improvement tool. In SMED test several uncertainty factors were noticed. Uncertainty factors cause variation in setup times which impairs production planning and efficiency. In SMED test, setup time was theoretically reduced by 15 %. This reduction was achieved with simple and low cost improvements. With more comprehensive changes the setup time reduction would most likely be even more. Nevertheless the biggest potential of SMED is not yet in setup time reduction, but in the standardization of it.

This study does not solve problems of production efficiency nor reduce the setup times, but it shows where the problems are and gives a few improvement propositions. In order to get full benefit out of this study and the project, more work needs to be done and improvements need to be implemented.

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INTERVIEWS

Lintilä Jukka, Development Coordinator, Valio, Seinäjoki, Interview 19.4.2016, Interviewer Lauri Riippa.