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SMED streamlining applied to SMT production

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Resumo

Esta dissertação incidirá sobre os métodos de melhoria continua da área *SMED* (Single Minute Exchange of Die) da Bosch Security Systems.

Dois projetos de melhoria contínua foram efetuados, o objetivo é determinar desperdícios nos processos e analisar como é possível elimina-los. O primeiro consistiu em analisar a zona de (des)montagem dos carros que contêm os feeders necessários para as máquinas de *pick and place*. Para ser possível estudar corretamente os processos, foi inicialmente, necessário aprender os conceitos e metodologias do BPS (Bosch Production System) e, em seguida, analisar possíveis melhorias a serem implementadas. Posteriormente as ideias de melhoria foram testadas e implementadas, sempre respeitando a ideologia *lean* de melhoria contínua.

O segundo projeto envolve as áreas de SMED e produção. O objetivo foi determinar a quantidade necessária de componentes para a produção de um lote. O projeto aprensentou uma maior complexidade, envolvendo um maior número de departamentos, no entanto os procedimentos foram semelhantes aos descritos acima; Analisar, testar e implementar.

Para verificar se as implementações foram bem-sucedidas, uma revisão das capacidades foi realizada, os indicadores também foram revistos. Para calcular as horas de trabalho necessária para a produção mensal o cálculo de recursos mensais também foi calculado.

Trabalho futuro e ideias de melhoria contínua são apresentado em termo de conclusão de todos os estudos e implementações projetadas.

Abstract

This dissertation will focus on the improvement studies and methods of the SMED (Single Minute Exchange of Die) area at Bosch Security Systems.

Two continuous improvement projects were conducted, they both aimed to reduce the wastes in the production lines. The first one was an analysis to the SMED (dis)assembly of the cars, required for the pick and place machines. First this involved in getting to know the BPS (Bosch Production System) and then study where possible improvements could be implemented. After, these were tested and implemented, always respecting the lean ideology of continuous improvement.

The second project involved both the SMED area and the production. This was set to determine the required quantity of components for a certain batch. The project involved more departments, however the proceedings were similar to the previously described; analyze, test and implement.

To verify if the implementations were successful, a capacity revision was conducted to standardize them, and latter, a revision of the indicators was performed. To calculate the required amount of work for the processes, the monthly resource usage was also calculated.

Future work and continuous improvement ideas will be presented as a conclusion of all the studies and implementations designed.

Acknowledgments

I would first like to thank my thesis advisor Pedro João of Faculty of Engineering at University of Porto. The co-advisor, Cristina Brito, who's offices were always open whenever I ran into a trouble spot or had a question about my research or writing. They consistently allowed this paper to be my own work, but steered me in the right the direction whenever they thought I needed it.

I would also like to thank the MOE 6 team at Bosch Security System, without their passionate participation and input, the dissertation could not have been successfully conducted.

Finally, I must express my very profound gratitude to my parents and to my friends, especially João Águia de Moura, for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Author,

Francisco Caetano

"Success is not final, failure is not fatal: it is the courage to continue that counts."

— Winston S. Churchill

Index

Figure List

Table List

Acronyms and Symbols

List of acronyms (Presented Alphabetically)

SMT	Surface Mounted Technology
SMED	Single Minute Exchange of Die
IoT	Internet of Things
PCB	Printed Circuit Board
THT	Through Hole Technology
QCO	Quick Change Over
BPS	Bosch Production System
PQCDS	Product, Quality, Cost, Delivery, Safety
JIT	Just in Time
TC	Quality Control
TQC	Total Quality Control
IE	Industrial Engineering
TPS	Toyota Production System
TPM	Total Production Maintenance
TQM	Total Quality Maintenance
OEE	Overall Equipment Effectiveness
FOL	Flow Oriented Layout
IR	Infrared
SMC	Surface Mounted Components
PQI	Production Quality Instruction
MAE	Machinery And Equipment
PDCA	Plan-Do-Check-Act
DMAIC	Define, Measure, Analyse, Improve, Control
RFID	Radio-frequency Identification
ESD	Electrostatic Discharge
ROI	Return On Investment
PoUp	Person in charge of resupplying

Symbol List

Fx_n --→ Number of x Feeders in assembly n

T_{Fxn} --→ Feeder x time in assembly n

Fx_d --→ Number of x Feeders in assembly d

T_{Fxd} --→ Feeder x time in disassembly d

a ---→ Number of assemblies

d ---→ Number of disassemblies

z ---→ Total number of different feeders

n(i) ---→ Number of existing feeder in car

i ---→ car

x ---→ Auxiliary binary variable

y ---→ Auxiliary binary variable

Chapter 1

Introduction

This chapter will firstly present the Bosch GmbH, a boarder look of the company will be presented initially then focusing on the Security Systems business unit. A small introduction to the SMT, Surface Mounted Technology, production and SMED, Single Minute Exchange of Die, will follow. The motivation, objectives and the structure set by the author will be presented in the following subchapters.

The Bosch Group is a leading global supplier of technology and services. It employs roughly 390,000 associates worldwide (as of December 31, 2016). Its operations are divided into four business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology. As a leading IoT, Internet of Things, company, Bosch offers innovative solutions for smart homes, smart cities, connected mobility, and connected industry. It uses its expertise in sensor technology, software, and services, as well as its own IoT cloud, to offer its customers connected, cross-domain solutions from a single source. The Bosch Group's strategic objective is to create solutions for a connected life, and to improve quality of life worldwide with products and services that are innovative and spark enthusiasm. In short, Bosch creates technology that is "Invented for life." The Bosch Group comprises Robert Bosch GmbH and its roughly 450 subsidiaries and regional companies in some 60 countries. Including sales and service partners, Bosch's global manufacturing, engineering, and sales network covers nearly every country in the world. The basis for the company's future growth is its innovative strength. [1]

The Bosch division Security Systems is a leading global supplier of security, safety, and communications products and systems. In selected countries, Bosch offers solutions and services for building security, energy efficiency and building automation. About 9,000 associates generated sales of roughly 1.8 billion euros in 2016. Protecting lives, buildings and assets is the major aim. The product portfolio includes video surveillance, intrusion detection, fire detection and voice evacuation systems as well as access control and management systems. Professional audio and conference systems for communication of voice, sound and music complete the range. Bosch Security Systems develops and manufactures in its own plants in Europe, Americas and Asia. [2]

Bosch Security Systems in Portugal was introduced due to the acquisition of the Phillips manufacturing plant in Ovar. This takeover occurred in 2002 and the plant has been expanding and growing ever since. It now has sales of 51 million euros and counts with more than 300 employees.

The assembly process at Bosch consists on acquiring raw materials, *PCB's*, Printed Circuit Boards, and in order to transform them into a final product, the board has to go through a THT, Through Hole Technology, and/or SMT production line, followed by an assembly line for the casings. Occasionally, more sensitive products might require assembly processes provided by a cleanroom. In this project, we will focus on the SMT production line processes.

The SMT production process can be divided into 5 major steps, as shown in figure 1*:*

Figure 1 - *SMT* process Pipeline

Electronics manufacturing using surface-mount technology (*SMT*), simply put, means that electronic components are assembled with automated machines that place components on the surface of a board (PCB). This machines are required to change programs and feeding components every time that a new product is being assembled. As such there is a need for an auxiliary production procedure called SMED.

SMED is basically a methodology for systematic and radical reduction of setup times, with documented cases reductions from hours to less than ten minutes ("single [digit] minutes"). [3] Setup times define how long a line most stop in order to perform a QCO, Quick Changeover. It is intuitive then, that the faster a QCO is performed the more efficient and productive the line will be. This dissertation will focus on measurements, techniques and tools that could provide a streamlining effect on the existing processes. SMED procedures consist on performing all the external processes, these are performed while the line is in production and there is no need of stopping it.

All the procedures must be in compliance with the BPS, Bosch Production System, standards and ideals. Bosch Production Systems derives its ideals and prevailing optimization procedures from Lean manufacturing.

The SMT and SMED processes and the BPS values will be explored, explained and discussed in more detail in chapter 2, as these will provide the required concepts to then explore and analyze the projects posteriorly presented and discussed.

1.1 - Motivation

This dissertation was produced thanks to my interest in Industrial and Manufacturing Engineering. I firstly came in contact with the Bosch Company at the age of five and since then I have seen the company as the epitome of engineering. Combining my interest with such a large and multidisciplinary company was one of my objectives when looking for a curricular internship.

After receiving the project concept, I saw that I could contribute on the continuous improvement of the production lines at Bosch Ovar, by implementing a variety of waste reduction solutions. Adding to the challenge was the fact that the project also involves a lot of theoretical methodologies that provide the required academic fundaments.

1.2 - Objectives

The main goal of this dissertation is to provide continuous improvement ideas for the SMED processes. However, in order to get to this point there is the need to firstly identify wastes and then observe what type of improvements are possible. Following the analysis of the process and the potential solutions are determined the team can proceed with the testing and implementation methods. As with any BPS improvement the main goal is to eliminate waste with the implementations, thus reducing costs to the company.

The standardization of minimal quantities of components was then analyzed so that it could be assured that the lines would not require any immediate actions from the SMED operators, thus reducing the unplanned stoppages. This also allows for a better stock consumption and flow of materials analysis.

After studying the effects of the proposed improvements, there is a need to revise the indicators, allowing the creation of new standards, capacities, to determine the new capacity of production and monthly resources required for SMED, to analyze the number of hours of occupation required for the operations.

Finally, it was also necessary to evaluate the effectiveness and efficiency of the streamlining ideas and revise what future improvements could be made.

1.3 - Dissertation structure

This dissertation will be divided into six chapters, first an introduction to all the topics that will be present in the development of the dissertation, after a literature review will be made regarding SMED streamlining techniques and methodologies. The third chapter will provide the information regarding all the observations and analysis made during the development of the project. The quantity standardization methods will be discussed and studied thoroughly in chapter four. The revision of the process indicators, capacities and required resources will be presented in chapter five. The final chapter will conclude the dissertation by proving ideas for continuous future improvements and summarizing all the work development and the objective fulfillment.

The author opted to the order information as presented, as it allows to firstly contextualize the BPS and the processes inherent to a SMT production line, then the project that required less departments is presented as its smaller impact in the overall production flow made advancing with the project easier. The second project is dependent on a bigger cooperation between departments, as it is a more complex and its impact more significant. Posterior to the implementations new capacities and monthly resources were calculated and new indicators created.

Chapter 2

Literature Review

This chapter will focus on the literature review of all the topics regarded throughout the dissertation and the different methods of improvement techniques used in manufacturing engineering, focusing more on the SMED process.

As presented in the previous chapter, the work will be focused on streamlining the SMED procedures in the SMT production. To understand how the improvements were made, there is a need to firstly study some concepts applied at Bosch, what is Surface Mounted Technology and its production and what the respective Single Minute Exchange of Die consists of. For that this chapter was subdivided into 3 sub chapters that will focus on set points.

However, the question poses: what is the production process?

The process of conversion of resources of production, in particular of raw materials into tangible goods or products, is called the production process. This usually consists of multiple production stages, on which multiple sets of operations are performed successively on workstations. [4]

The Security System production plant in Ovar, is designed to be service-oriented, this means that it relies on the PQCDS, Products, Quality, Costs, Delivery and Safety. This aims to attune to the current needs by providing the manufacturers with a diversified range of products (P), high quality (Q), at a low cost (C), with speedy delivery (D) and safety (S) from start to finish. [5] By using this methodology, in conjunction with other strategies, production plants can reduce their warehouse inventories and their lead times.

Lead-time is the time that a certain client's order takes to be manufactured, so by designing and planning production to attain the shortest lead-time possible is beneficiary for both parties, the different lead-times and its stages in the product production are presented in figure 2. The client can be sure that the desired good will be delivered promptly and the manufacturer reduces wastes in production and stock accumulation.

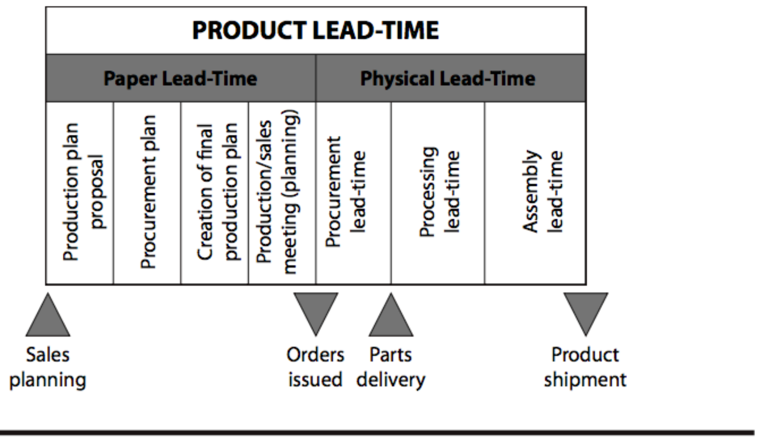


Figure 2: Product production lead-time [5]

As to understand as the principles described in this chapter there is a need to firstly define what production management is. This will endorse the reasons of why lean and TPS methodologies are so widely required and applied globally in most industries and companies.

Production management means building and commanding:

- a management system (organization framework, procedures, information, management techniques, and other information-based organizing factors) and
- a physical system (plant equipment, equipment layout, production methods, conveyance methods, and other equipment-based organizing factors)

While making effective use of the three M's (manpower, materials, and machines) to economically manufacture products of a certain value and quality, in certain volume and within a certain period of time. [5]

Today, factories are grappling with a common problem: how to combine the management system and physical system so that they function together in a level manner, serving current needs for wide product variety, high quality, low costs, and speedy delivery.

This is the focus point at Bosch, we strive to achieve perfection and as such continuous improvements is required to assure our clients that our service is not lagging in production technology nor in lean line designs. As it will be discuss in the later chapters, these methodologies are planned to assure that the plant is focused on "JIT, Just In Time, production management" and "JIT improvements".

2.1- TPS/BPS Improvement Methods

Bosch Production System is based on the Toyota Production System, being so, research and review to TPS was conducted. This will allow to establish the required groundwork to further illustrate the benefits and concepts laying under the Bosch Production System methodologies.

Just In Time manufacturing was firstly introduced by Eli Whitney in 1799, he created the concept of interchangeable parts in order to mass produce goods at lower prices. [6] The following century manufacturers were primarily concerned with the evolution of individual technologies. This ideology changed in the late 1890's with the endeavor of early industrial engineers. Frederick W. Taylor began to look at individual workers and work methods. The result was Time Study and standardized work. He called his ideas Scientific Management. The concept of applying science to management was sound but Taylor simply ignored the behavioral sciences. [7]

His work would be continued by Frank Gilbert, who contributed with the addition of motion study and with the invention of process charts, and Lillian Gilbert who brought the psychological motivations of workers into the manufacturing process. There were many more contributors, however these were the main people who created the idea of "waste elimination", a key tenet for the JIT and Lean manufacturing.

Henry Ford and his right-hand-man Charles E. Sorensen designed the first comprehensive manufacturing strategy. They managed to gather and intertwine all the elements associated with the manufacturing system, people, machines, tooling and products. By connecting them and arranging them in a continuous system he was able to create the world's first assembly lines, with the Model T. [8]

During world war II, Fords plants were retooled by the government in order to produce armament. They managed to do so on a fantastic scale as epitomized by the Willow Run Bomber plant that built "A bomber an hour" [9] , this caught the eye of Japanese industrialist post Allied victory. In August 15th 1945, Toyoda Kiichiro, president of the Toyota Motor Company at the time, communicate": "Catch up with America in three years. Otherwise, the automobile industry of Japan will not survive." In order to do so the company decided to import some of techniques used by Ford. The most important ones where the quality control (TC), total quality control (TQC) and industrial engineering (IE).

Ohno visited the USA to study Ford's production methods, but he was much more inspired by American supermarkets. He noticed how customers would take from the shelves only what they needed at that time, and how those stocks were quickly and precisely replenished. Ohno had the insight that a supermarket was essentially a well-run warehouse, with 'goods-in' closely matching 'goods-out', and no space for long-term storage. On his return to Japan, Ohno developed the same idea into the *kanban* concept. [10]

The basis of the Toyota production system is the absolute elimination of waste. The two pillars needed to support the system are:

• just-in-time

• automation, or automation with a human touch. [11]

JIT, or “Just-In-Time,” refers to the timing of production ow; goods are delivered to the manufacturing lines just in time to be used, just in the immediately needed quantities, and just to the production processes that need them. [11] `Just-in-t’me' is a philosophy and not a technique, to avoid inventory unbalance, surplus of equipment and workers, the use of a proper JIT production design, capable of adjusting to changes caused by troubles or demand fluctuation. [12]

The Toyota Production System and the scientific method that underpins it were not imposed on Toyota-they were not even chosen consciously. The system grew naturally out of the workings of the company over five decades. As a result, it has never been written down, and Toy’ta's workers often are not able to articulate it. That is why it is so hard for outsiders to grasp. [13] In redesigning the mass production system, they changed how production lines work, machine tools are used with built-in devices to check parts (poka-yokes). Between the machines are devices (decouplers) designed to assist workers perform the required changes, when a need to change production occurs. [14] This will allow for a greater flexibility in production and minimize change over times.

Steven Spear and H. Kent Bowen, in their publication “Decoding the DNA of the Toyota Production System”, argue that there are four rules that form the Toyota System, not the specific practices and tools used. Three rules of design, which show how Toyota sets up all its operations as experiments, and one rule of improvement, which describes how Toyota teaches the scientific method to workers at every level of the organization.

- Rule 1: All work shall be highly specified as to content, sequence, timing, and outcome.
- Rule 2: Every customer supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.
- Rule 3: The pathway for every product and service must be simple and direct.
- Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization. All the rules require that activities, connections, and flow paths have built-in tests to signal problems automatically. It is the continual response to problems that makes this seemingly rigid system so flexible and adaptable to changing circumstances. [15]

The main objective of the TPS is to increase profit by reducing the costs of production, this is achieved by eliminating several kinds of wastes. In this dissertation, mainly two of these will be analyzed, waste of time in hand in the QCO and the waste in process, the processes of the

SMED area. As will be shown further in this study all the principles applied in the BPS will regard these four rules.

In the 1980's the term "lean" was coined by Jim Womack, PhD., at MIT's International Motor Program, to describe Toyota's business. This applied not only to the production lines but to all parts of the organization and its processes, as it is a way of thinking. In order to get a more detailed look at the evolution of the TPS and Lean concepts throughout history a timeline is presented in appendix 1.

While most organizations struggle with implementing a new system, fighting the general inertia that many employees experience when faced with yet another new initiative, the goal of lean is to open up the work process and abolish the usual hierarchies. [16]. This allows for a more adaptive system where improvements can be achieved continuously in order to achieve the ideal production system. However, an interesting quote is used in the book "The Machine that changed the world": Mass production is simply lean production run by the rule book, so that no one takes initiative and responsibility to continuously improve the system. [17]

The work will focus in the lean approach of TPM, Total Production Maintenance, as it is the most adequate tool to analyze wastes and possible improvements in autonomous production lines, as is the case with the Surface Mounted Technology production.

As of first, one must initially differentiate between TQM and TPM, as many of the Total Quality Management are used and implemented to optimize the TPM such as employee empowerment, benchmarking, documentation, among others. The differences between the methods are presented in table 1. In which we can observe that the Total Production Management aims to eliminate wastes, thus improving the processes and the profits.

Table 1: Comparison between TQM and TPM [18]

Category	**TQM**	**TPM**
Object	Quality (Output and effects)	Equipment (Input and cause)
Mains of attaining goal	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality for PPM	Elimination of losses and wastes.

TPM provides a comprehensive company-wide approach to maintenance management, which is usually divided into short-term and long-term elements. In the short-term, attention is focused on an autonomous maintenance program for the production department, a planned maintenance program for the maintenance department, and skill development for operations and maintenance personnel. In the long-term, efforts focus on new equipment design and elimination of sources of lost equipment time. [19]

The original TPM, developed in the 1960's, consists of a 5s foundation and eight supporting activities. The foundation defines 5 rules that intend to keep the work place well organized and clean. These are:

- Sort
- Set in Order
- Shine
- Standardize
- Sustain

Sorting seeks to eliminate all the non-work related items in the work area, thus creating a more work-focused ambience. Set in Order means that all the remaining items should be organized and have an appropriate fixed location, by doing so, the search time of set items is reduced and optimizes the usage of space. Shine, as the name implies, means that the work place should be kept clean and inspections should be made In order to observe if repairs are required, in the workspace. Standardize all the previous activities, consequently establishing guidelines for performing set tasks. Sustain refers to periodical audits that assure that the 5S's are up-to-date and applied accordingly. This foundation creates the groundworks for well-running equipment.

The pillars are focused on proactive and preventive methodologies for continuous improvement. These are:

- Autonomous Maintenance
- Planned Maintenance
- Quality Maintenance
- Focused Improvement
- Early Equipment Management
- Training and Education
- Safety, Health, Environment
- TPM in Administration

An in depth explanation of the purpose of all the pillars would be of little interest as not all are applied in the TPM-Bosch model, this model will be analyzed in great detail throughout the dissertation.

As with any improvement approach, there is a need to analyze the systems performance, for that, the TPM makes use of the OEE (Overall Equipment Effectiveness), this metric identifies, in percentage, the time that was truly productive from the planned production, this quantifies the losses that occur in production, making it possible to measure and track the improvement TPM initiatives. The OEE is composed of three components that take into account different types of productivity loss. Table 2 presents the different components, what their objective within the Total Production Maintenance is and the types of productivity losses associated with set component.

Table 2: TPM productivity loses [19]

Component	TPM Goal	Type of Productivity Loss
Availability	No Stops	Availability takes into account **Availability Loss**, which includes all events that stop planned production for an appreciable length of time (typically several minutes or longer). Examples include Unplanned Stops (such as breakdowns and other down events) and Planned Stops (such as changeovers).
Performance	No Small Stops or Slow Running	Performance takes into account **Performance Loss**, which includes all factors that cause production to operate at less than the maximum possible speed when running. Examples include both Slow Cycles, and Small Stops.
Quality	No Defects	Quality takes into account **Quality Loss**, which factors out manufactured pieces that do not meet quality standards, including pieces that require rework. Examples include Production Rejects and Reduced Yield on startup.
OEE	Perfect Production	OEE takes into account all losses (Availability Loss, Performance Loss, and Quality Loss), resulting in a measure of truly productive manufacturing time.

The OEE is given as:

$$\text{OEE} = \text{Availability x Performance Efficiency x Quality Rate}$$

Equation 1: OEE equation

where

$$\text{Availability} = \frac{\text{Loading time} - \text{Downtime}}{\text{Loading time}}$$

Equation 2: Avalability calculation

$$\text{Loading time} = \text{Available time} - \text{Planned downtime}$$

Equation 3: Loading time equation

Planned downtime refers to the scheduled maintenances and management activities.

$$\text{Performance efficiency} = \frac{\text{Theoretical cycle time x Amount processed}}{\text{Operating time}}$$

Equation 4: Performance efficiency

$$\text{Quality rate} = \frac{\text{Amount processed} - \text{Defective amount}}{\text{Amount processed}}$$

Equation 5: Quality rate calculus

Theoretical cycle time and loading time are constant per day. Therefore, OEE is directly related to the number of items of good quality. OEE can be improved by enhancing the availability, performance efficiency and, most importantly, the quality rate. Availability can be improved by reducing downtime and that performance efficiency can be improved by reducing the cycle time. [20]

The implementation of the TPS proved to be a challenge and inefficient for a great number of American and German companies, not managing to attain the desired improvement and cost reduction. As such, in 2002, Bosch decided to create its own system that was fit and adapted to the company's values and corporate structure. The Bosch Production System was thus created as a part of the Bosch Business System, already in practice at the time, it aims at continuously improve the core process order fulfillment.

The new mission statement – "We are Bosch" provides guidance for the Bosch Production System and influences the BPS vision. By creating sustainable waste-free and agile value streams, BPS helps safeguard the future of our company. [21]

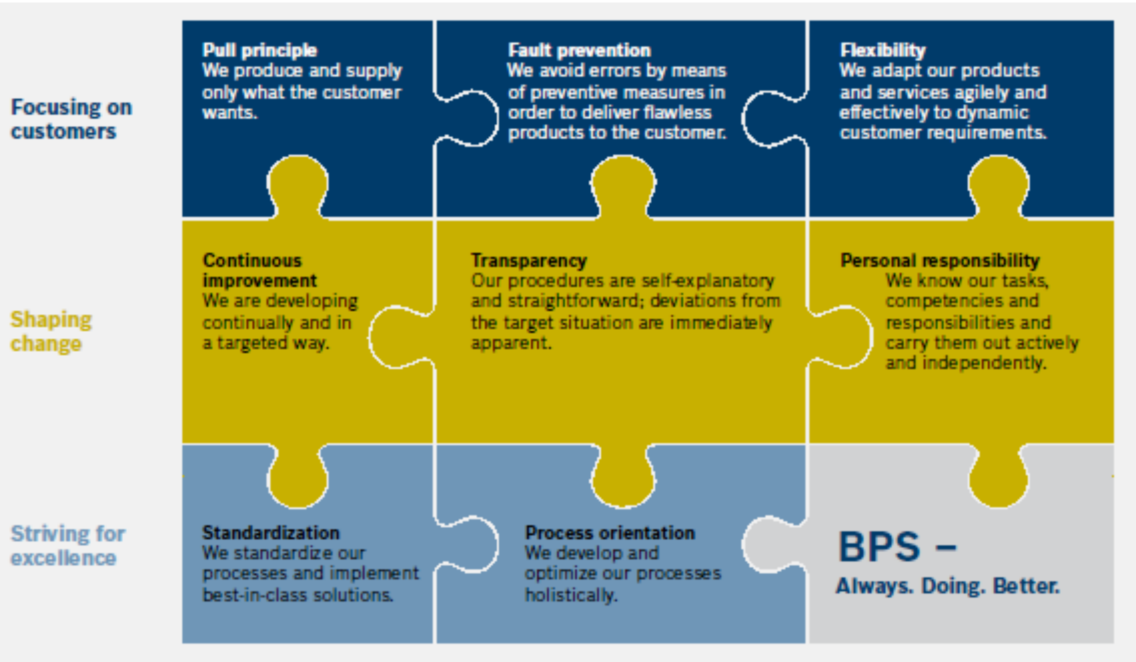


Figure 3: BPS Strategy and focal points [21]

The BPS is based on eight principles:

- Pull Principle (Produce and supply what the customers want);
- Fault Prevention (Use of preventive measures to assure flawless delivery);
- Process Orientation (Processes developed and optimized holistically);
- Flexibility;
- Standardization;
- Transparency;
- Continuous Improvement;
- Personal Responsibility.

These principles form the foundations for action and cooperation among the various functions in the design of a sustainably waste-free and agile order fulfillment process. To observe these interactions a Value Stream Design is always created. This tool allows to observe graphically all the flows of materials, procedures, interactions and possible waste generating areas.

The previously discussed methodology of the 5S's is also used by Bosch to assure that the work is trouble-free, making work more efficient. Lean Line Design is used when a need to create or change a manual or partially automated arises, even though this does not apply directly applied in the SMT production area, it is useful for designing the layouts, procedures and processes of the feeder car (dis)assembly area . As a change in layout will be presented posteriorly, examining the Flow-oriented Layout (FOL) is required. It consists on arranging all the machinery and equipment according to the sequence in manufacturing.

The Quick Changeover procedure is one of the most crucial for assuring that the facilities are not idled, thus achieving a higher net production, shortening lead times. Enabling the increase in added value and productivity. It consists on changing different parts, tools and components in the SMT lines so that production change can occur. Guaranteeing short QCO times allows the industrial engineers to optimize activities and organization.

The TPM-Bosch model consists of the 5S foundation and four pillars with training and forming standards encompassing all the TPM, the four main areas are as follows:

- Elimination of core problems:

Analyzing the root causes, implement appropriate corrective measures define a standard and monitor success.

- Autonomous maintenance:

Machine operators carry out maintenance work independently, including the continuous improvement of the machinery. Associates are actively involved and are jointly responsible for their production facilities.

- Planned maintenance:

Defining targeted maintenance activities, including the development of control and diagnostic systems, to further increase the reliability of facilities.

- TPM compliant design of machines and facilities:

Take future maintenance activities into account as early as the planning and procurement stage, with good accessibility and visualization of maintenance points, for example. [22]

2.2 - SMT Methodologies

The following chapter will discuss briefly the history of the SMT production and what type of machinery, tools and procedure are applied to assure reliability and efficiency. This serves merely as a contextualization for the readers as the study of the SMT production lines is not the focus of this dissertation.

Surface Mount Technology is the practice and method of attaching leaded and nonleaded electrical components to the surface of a conductive pattern that does not utilize leads in feed through holes. [23] In the 1960’s with the advances in automation techniques and increase of market for smaller, faster and better digital circuits, companies started studying and applying production lines capable of supplying the market. Adding to those factors, industrializing and automating the production reduces costs and human intervention, among others, increasing the potential profits and quality of the products. In figure 4 we can observe the “standard” process of SMT assembly lines, however depending on the needs of the company adjustments may be made.

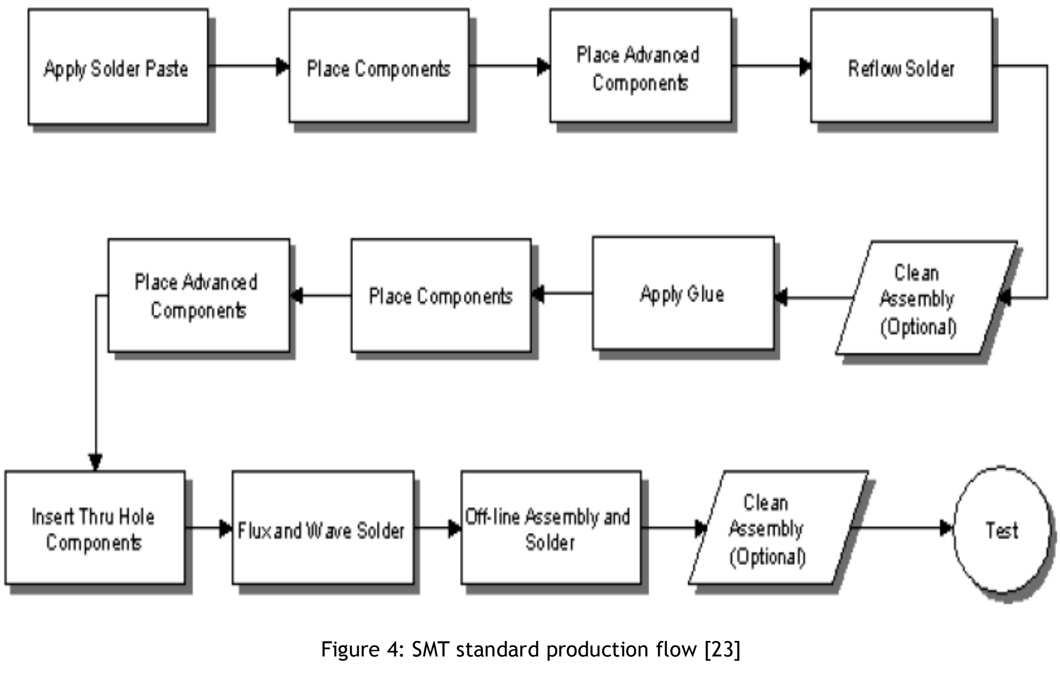


Figure 4: SMT standard production flow [23]

The principal surface mount attachment technologies used today are the adhesive/wave solder or the reflow soldering methods. The former attaches surface mount components (SMC) to the secondary side of the board using special adhesives. The reflow method derives its origins from traditional hybrid circuit techniques which place SMCs into solder bearing paste on the primary side of the board. The first step is to dispense a solder paste onto the bare board using either a silk screen or stencil (for prototypes and small volume production, the paste may be applied one dot at a time, either automatically or manually). Components are placed into the tacky paste, which is then dried or preheated. No additional adhesive is necessary since the paste holds the components in place. The solder is reflowed by one of several common methods, including infrared (IR), vapor phase or thermal convection using hot air. Many of todays reflow ovens contain nitrogen blankets to reduce oxidation and improve soldering-ability. The boards then go through a cleaning operation to remove residual flux and any solder balls. Finally, if leaded through-hole components are needed, they are inserted and the board is sent through a wave solder operation. Normally,

the primary side of the board does not get hot enough during the wave soldering to melt the previously reflowed solder holding the Surface Mount Components. [24]

All the production lines are fully automated, however in order to change to a different production order new components and programs have to be fed to the machines, these are the processes that the SMED operators will be required to do.

2.3 - SMED Methodologies

The SMED system was developed when Shigeo Shingo conducted improvement study for Toyo Industries in 1950. It took nineteen years to conclude and it started when he realized that there were two types of setup operations: internal setup, performed when a machine is shut down, and external setup, which can be done while the machine is running. [25]

This separation of setup allows for a more efficient work distribution and makes stoppage times smaller. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product. This rapid change over is key to reducing production lot sizes and thereby improving flow. The phrase "single minute" does not mean that all changeovers and startups should take only one minute, but that they should take less than 10 minutes. [26] By analyzing the process, SMED also focusses on making internal setup’s in external ones, doing so minimizes losses and costs. The validity of the method and procedures are verified by an application a Styrofoam manufacturing process where setup times are critical for time reduction. Significant time savings have been achieved with minimum investment. Further, the issues related with employer safety and ergonomics principles during die exchange are noted. [26]

Setup time, in general, can be defined as the time required to prepare the necessary resource (e.g, machines, people) to perform a task (e.g., job, operation). Setup cost is the cost to set up any resource used prior to the execution of a task. [27]

As with any Lean manufacturing approach the SMED process also has a defined procedure to assure the quality, efficiency and efficacy of the continuous improvements made to the Single Minute Exchange of Die. The process is as follows:

- Observe the current methodology: Current procedures generally recorded on video tape of all the changeover process. It covers the complete changeover from one model to another model.
- Separate the Internal and External activities: Internal activities are those that can only be performed when the process is stopped, while External activities can be done while the last batch is being produced, or once the next batch has started.
- Stream line the process of changeover: For each iteration of the above process, a substantial improvement in set-up times should be expected, so it may take several iterations to cross the ten minute line.
- Continuous Training: After the successful first iteration of SMED application the prime requirement becomes the training of all the operator of the cell. Training has been given by cell champion (Master of Changeover). [28]

Chapter 3

SMED Analysis

This chapter will focus on the observations done *in loco*. These observations provided the information and data of all the procedures and sub-processes inherent to the SMED process present at Bosch Security Systems in Ovar at the time. All the procedures described in the PQI, Production Quality Instruction, must be in accordance with the BPS standards, they allow the worker to read what tasks are standardized for set workstation. Wastes might occur due to suboptimal processes in the PQI tasks, when they are not respected or when they are not in line with the processes done by the worker.

As described previously, the SMED methodologies consist on performing all the external tasks of the production line, such as the change of K7's, stencils cleaning process, among others. The SMED tasks were already well defined before this project, in other words, all the external processes were already determined. The production lines were observed to analyze the possibility of an internal process becoming an external one, however the author concluded that the internal ones were already streamlined and there was no possible change from internal to external.

Provided with information, gathered through visual inspection, it was noticeable that the area that required a streamlining of processes was the car feeder (dis)assembly process. The process consists of assembling a car with feeders, these are then able to feed the machines with the required components for a determined production cycle. This pre-assembly allows for a faster QCO and thus improving the efficiency of the overall production. Even though no QCO was affected due to the lack of assembled cars, the process itself was wasteful and in need of optimization.

The SMED car assembly process is divided into three shifts, on the first one there is a collaborator assigned to (dis)assemble the feeder system, in the second there are three and in the third two. Due to shift restrictions the analysis was only conducted on the second one, other wastes may be present in the different shifts.

In figure 5 is presented an overall view of the required steps for the assembly and in figure 6 disassembly processes. This facilitates to determine if there are any repeated or unnecessary procedures.

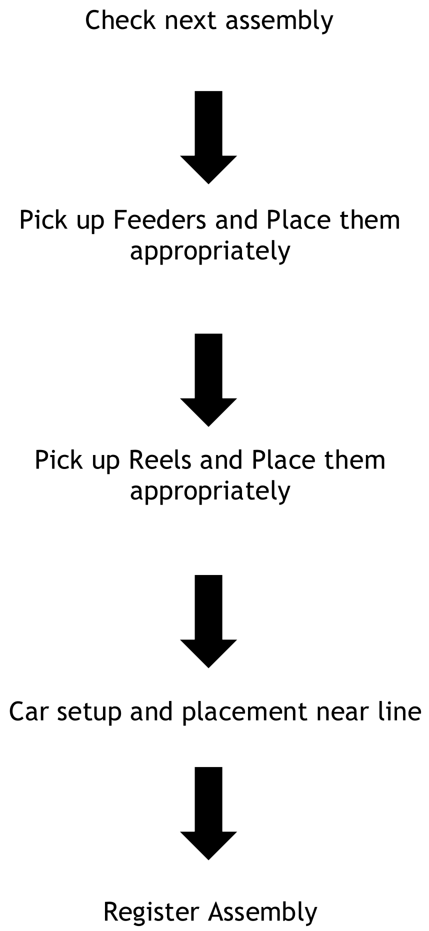


Figure 5 – Overall *SMED* car assembly processes steps

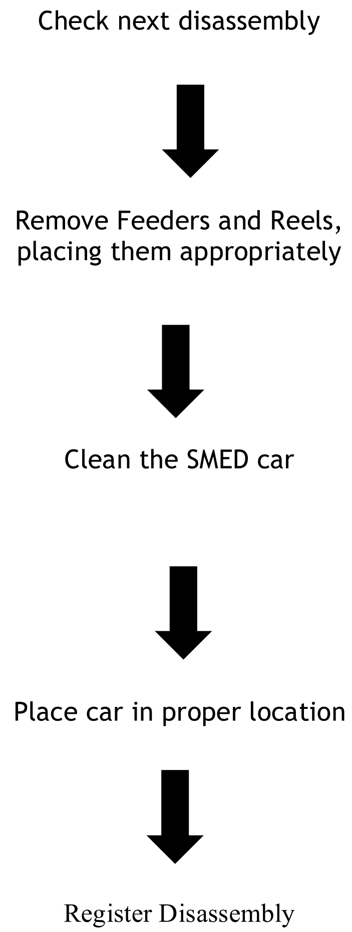


Figure 6 – Overall *SMED* car disassembly processes steps

It was established that all the steps were required in other to assure the efficiency and efficacy of the (dis)assembly. The following course of action was to analyze in detail all the sub processes, movements, placements of the required equipment, components and operators. In order to gather data, so that it could then be analyzed, it was necessary to acquire the times that each individual process took, so that conclusions could be drawn to where optimizations were needed and possible, verifying the initial hypothesis of the critical tasks. Posteriorly these ideas were tested to see if the improvements would be suitable and sustainable in a real-world scenario. If the observations, provided by the pilots, had a positive outcome, then these would be implemented, as part of the streamlining process. After one week of observations it was possible to determine what seemed to be the critical and non-critical parts of the assembly.

3-1 - BPS Improvement Methods

To analyze the required improvements there was a need to study and analyze the BPS methods of continuous improvement, these rely on the TPM, JIT production, consumption control and FOL. Being so, all the possible implementations and observations should be in line with these same principles that aim for a more flexible, standardized and transparent process.

TPM-Bosch is set on four main pillars, these emphasize in eliminating the main problems, autonomous maintenance, planned maintenance and TPM appropriate MAE, machinery and equipment design. All these are deeply rooted in the foundations of the 5S principles and continuous improvement methodologies and closely accompanied by training and coaching of the collaborators, thus achieving the agreed goals of the total productive maintenance. A visual representation can be found in appendix 2.

In this project, there was only a need to analyze the foundations and the first pillar, eliminating main problems. This pillar focuses on eliminating main problems through PDCA, Plan-Do-Check-Act, approach for sustainable results. In order to assure the intended result, the pillar consists in five steps:

- Identification of Losses & main problems;
- Cause Analysis;
- Action & implementation;
- Standards determination;
- Success control & determination.

Throughout the process, managers should review and provide proper training and coaching at the stages considered appropriate.

The first iteration consists on monitoring the process and analyze what problems arise, through the OEE (Table 2) and direct observations of the work flow. The OEE tool indicates the productivity of a certain unit (machine or production line) and combined with a verification of the operations it was possible to draw the appropriate conclusion.

3.1.1 – Results and conclusions

After the OEE calculations, the values of 0000 for the availability and 1111 for the performance and a value of 2222 for the direct method of calculation were obtained. This showed that most of the deviations were availability losses. The values presented are not the real values, as these are subjected to an agreement of non-disclosure. There was also a concern regarding the performance losses, this however would require a separate in-depth analysis, thus creating the second project presented and described by the author in this document. The losses observed were: personal unproductive use of time, production preparation and technical malfunctions.

Posterior to the loss factor identification, there was the need to proceed to a root cause analysis through the 5 why analysis, this being the second step in the TPM-Bosch model. The 5 Whys is a technique used in the Analyze phase of the Six Sigma DMAIC, Define, Measure, Analyze, Improve, Control, methodology. It is a great Six Sigma tool that does not involve data segmentation, hypothesis testing, regression or other advanced statistical tools, and in many cases, can be completed without a data collection plan. By repeatedly asking the question "Why" (five is a good rule of thumb), you can peel away the layers of symptoms which can lead to the root cause of a problem. Very often the ostensible reason for a problem will lead you to another question. Although this technique is called "5 Whys," you may find that you will need to ask the question fewer or more times than five before you find the issue related to a problem. [29] Quoting Edward Hodnett "If you don't ask the right questions, you don't get the right answers. A question asked in the right way often points to its own answer. Asking questions is the ABC of diagnosis. Only the inquiring mind solves problems."

With all the required data gathered, via the BPS methodologies, it was now possible to draw a fair conclusion that the SMED process was in need of streamlining as part of the continuous improvement model implemented by Bosch Security System. At the same time, it was also required that the problem was contained, that is, controlled until the solution could be found. As previously shown this managed to present the main losses and main problems in the process, thus concluding the first step of the eliminating main problems pillar of TPM-Bosch.

3.2 - Improvement points

This chapter will focus on the process steps that show inefficiencies, all the points discussed regard the SMED processes, as discussed previously. Table 3 shows the measurable wastes and the time that set operation occupies. In the TPM-Bosch, this is the second step when it comes to eliminating the major problems, as it seeks to determine the causes underlying the inefficiencies.

Table 3 – Inefficiencies analysis

Waste	Measurements	Number of measurements
Duct tape	Assembly : 20 s Disassembly : 27,2 s	Assembly: 12 Disassembly: 29
Component search	4:02 (per Component)	Measurements: 17
Registrations	Assembly : 1:55 Disassembly : 1:14 Printing Time: 51 s	Assembly : 12 Disassembly : 12 Printing: 13
Feeder conversion	37 s	3
Waiting lines	1:04 Frequency : Occasional	3
Assembly list verification	No data	--------------------------
Problems with feeders	No data Frequency: Frequent	--------------------------

Duct tape refers to the method and positioning the duct tape to avoid component rejection. Feeder conversion is the process by which the operators modify the feeder from one size to another. These relate to the feeders of 12/16mm and 24/32mm, there are additional feeders but these are the must commonly used. The waiting lines relates to the time that an employee must wait due to occupation of the computer.

Posterior to the determination of were waste might exist in the procedures, possible solution had to be hypothesized and studied, so that tests could then be done in the most viable ones.

3.2.1 – Solutions studied

Numerous ideas of optimization were studied, ranging from Industry 4.0 implementations to collaborators training. This study represents the action study, as it aims to determine potential solution that could improve the overall efficiency. Table 4 presents the solutions studied and what procedures they aim to improve.

Table 4 – Proposed solutions

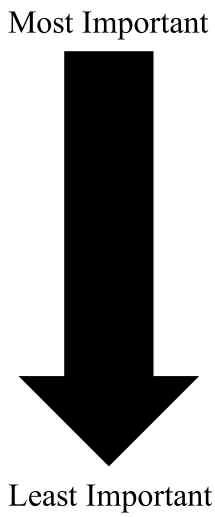
Solution	Goal
RFID tagging components	Reduce component search time and start implementing Industry 4.0
New SMED warehouse layout	Reduce component search time
New duct tape application method	Reduce duct tape application time
Preventive feeder maintenance	Reduce frequency of feeder related problems
Reduction of required registries	Reduce time spent registering (dis)assemblies and waiting lines
Previous orderings of component reels	Reduce time spent verifying assembly list while assembling
Previous search of missing component reels	Reduce component search time
Buy new feeders or creation of new tool	Eliminate feeder conversion

All the potential improvements presented above are compliant with the Bosch Production System standards, being so this does not mean that no restriction exists as projects goals and criteria had to be met.

3.2.2 – Solutions selected

To obtain the most favorable outcome, a criteria selection for the possible solutions had to be conducted. Table 5 shows the selection criteria, ordered by priority.

Table 5 – Selection criteria



Criteria
Cost
Adaptability
Added value
Time
Feasibility

The selection process occurred throughout several meetings with the different coworkers. This was not only to get approval for the proposals but also allowed me to adapt the solutions, so that they could be tested in a real-world scenario.

Implementation costs would have to be minimal, inexistent if possible as it is not one the main priority projects. Adaptability was crucial as the production plant is expanding and maintaining the flexibility of the processes is crucial. Added value refers to the fact that the improvements should have a considerable impact reducing wastes in the processes. Time was of the essence as the project had to be concluded previous to the conclusion of the six-month internship. Feasibility aims at determining if a solution would be fit in a real-world scenario. The solutions were all reviewed, now that the approval criteria had been defined.

To determine the best possible solution, these were discarded following the criteria importance. When analyzing the costs involved in the improvements, both the RFID, Radiofrequency Identification, tagging and the acquisition of new feeders involved a considerable investment, adding to the fact that it would occupy a longer time span when implementing, due to the involvement of third party elements.

The previous ordering of component reels was briefly studied, however it proved to be incompatible with the existing system. Not only did it require a new operator as it proved to be a time-consuming process, thus not adding the needed value for the continuous improvement project.

The preventive maintenance would not add value to the SMED process, because another department is responsible for maintaining the conditions of the equipment and machinery required for the production. Being so, it was not fitting as a process that the SMED operators could add to their workflow.

The four-selected solutions were: the new SMED warehouse layout, previous search of the component reels, new duct tape application and the reduction of registrations. As the

previous gathered all the conditions imposed by the criteria, there was no need to test it posteriorly. After a brief reunion with the responsible members, the number of registrations was then set to one, thus implementing it. This showed an improvement of 2,1% in the overall assembly process and 0,9% in the disassembly, this was concluded after gathering new data to attain the impact of the implementation.

3.2.3 – Solutions tested

Posterior to the selection there was a need to evaluate the improvement potential. In order to attain a realistic expectations of the potential improvements, a real-world test of the concepts was conducted.

Three solutions were tested: New SMED warehouse layout, Previous search of component reels and New duct tape application methods. The goal of the tests was to gather data; this would then be compared with the expected results thus providing the required conclusion regarding the impact and improvement potential of the measures. The test conducted for each solution is presented in table 6.

Table 6 – Solution tests

Solution	Test
New SMED warehouse layout	A random Setup was chosen and organized by component reel, alphanumerically.
Previous search of component reels	One of the skilled workers was asked to gather all the reels required for an assembly.
New duct tape application method	New components and methods were studied to determine a better method.

3.2.3.1 - Solutions results

To verify the impacts of the implementation of the new methodology testing was required. This allowed us to analyze possible flaws, problems and benefits of the improvements. The test results are as follows:

- The new warehouse layout presented an improvement of 70% on the overall assembly procedures. Even though it increased slightly the disassembly time. It was also combined with the Quantity optimization process to attain a more lean and standard workflow.

- The component search, before the assembly process showed an improvement of 28.9% in time spent performing set task.

- The tape placement procedure was also tested in ideal situations, the results presented a decrease of 74.6% on the time spent on set task. However, the operators and the line leader saw that in practice, due to the ESD, Electrostatic Discharge, specification, it would be hard to implement

After obtaining and analyzing all the data it was possible to decide which solutions should be implemented. The implementation procedures will be discussed in the following chapter. This results cannot be taken as conclusive though, due to the large standard deviation in the number of search components.

3.2.4 – Solutions implemented

To be able to implement these improvements, all the responsible parts must agree to this, from the skilled workers to the process engineer. After a brief meeting with the collaborators actions and deadlines were defined, responsibilities were set and standards were determined. This is the fourth step of the focused improvement pillar.

Regarding the registration, the improvement implementation was made with no need of testing. This decision was easily reached because a process repetition was verified, hence adding no value to the workflow. Analyzing the PQI, we can see that there were two registration procedures, one on the computer and one in the work diary. Posterior to *in loco* observations, the conclusion was simple, most operators do not make use of the diary book, being so, the team unanimously decided to make the diary registry obsolete. With this change the registration procedure duration was reduced by half, as verified by posterior observations. Another registration was discussed, regarding the assembly, where the workers must print a file saying that the verification of the car were made and note any significant information. However, some workers found it useful in order to backtrack who had mounted the feeders, so no action to eliminate it was taken.

New methodologies and products to minimize component waste were studied, however it proved to be too costly, for the expected return. This is due to the ESD standards, the smaller useful life of the products and that other applications techniques proved hard to assure the fixation of the reel tape to the reel.

The preceding search of the reels required a new operator, however it was fitting that a decision regarding this solution should be on hold and only agreed upon after the implementation on the new layout, to the SMED area. This will change the workflow and will require new data acquisition to verify if the search still occurs and what waste it leads to.

The new layout of the warehouse of the area proved to be very efficient at reducing the overall assembly time, while managing to have a small impact in the disassembly procedures. This was implemented after a team was assembled and it gathered all the components reels and sorted them alphanumerically, while the lines were not producing, so that it would not disturb the production cycles. Has expected all the participants of the process were informed about the change beforehand. After a brief period of adaptation, significant improvements were made and a more lean and efficient workflow was verified.

After implementation follows the fifth and final step for focused improvement, success control and determination. This step is intended to check the effectiveness of actions and visualize Trends in PDCA form Horizontal deployment. This allows for the continuation of continuous improvement by the plant and for future optimizations to be done to the process.

Chapter 4

Quantity Optimization

Before this work, it was identified that the production lines had unplanned stoppages due to the lack of components in the feeders, as shown in the OEE performance values presented in the previous chapter. This proved to be especially hard to handle as the root cause was unclear. As such, a project was created to discuss and analyze streamline ideas that would be able to mitigate or even eliminate stoppages due to the lack of components in the feeder car.

Having defined the problem, it was then necessary to study possible solutions that could be implemented and assure that these kind of component shortages would not happen. All this analysis was made by observations, not data gathering, of the process, hence there is no accurate data of the stoppage times and the frequency of set stoppages.

This chapter is then dedicated to the study of a new procedure capable of assuring no more occurrences, of the phenomena described above. The main goal is to minimize the small stoppages and get the real production time closer to the theoretical one, thus improving the OEE indicator and overall efficiency of the production. This is what lean manufacturing and the BPS strive to do, continuously improve manufacturing, making it less wasteful, more reliable and safe.

4.1 – Process analysis

To understand the underlying problems that generate the shortage of components in the SMT lines, it was necessary to observe what kind of existing procedures are related to the batch quantities.

In the beginning of each assembly the operator grabs a sheet of paper where the set-up is defined. This sheet contains information regarding the assembly of the set up. Throughout the process, defined previously in chapter 3 (figure 5), there is no other information regarding the assembly, as so, there was a need to either create a new method to analyze the quantities or to take advantage of the information already provided and enhance it. In figure 7 we can see all the fields contained in the sheet.

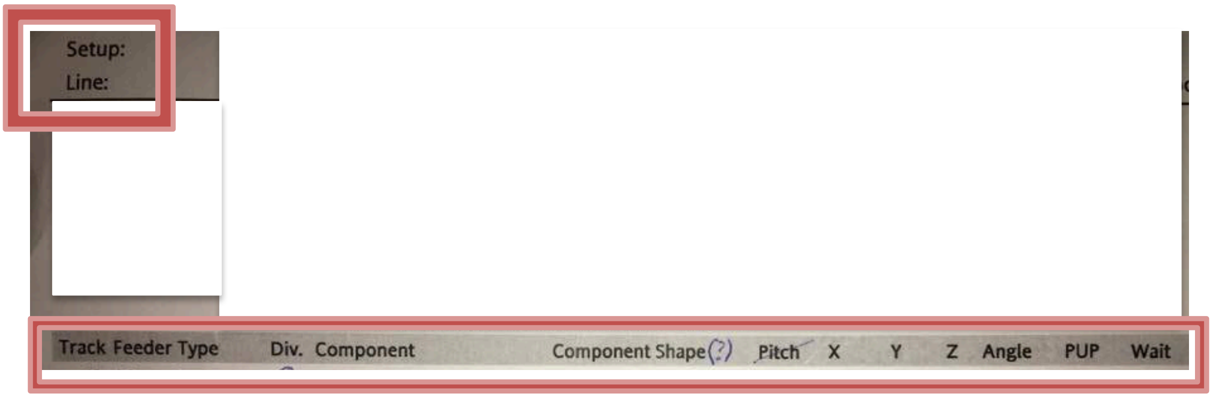


Figure 7 – Information sheet

Adding to the lack of the relevant information, the inexistence of a tool or machine capable of accurately counting the total number of components in a reel influences these types of inefficiency. Another problem was that the operator might only have one reel available at the time, this scenario makes it difficult for the worker to manage the lack of components. Furthermore, the components and reels sizes and weights are highly variable, thus complicating the analysis of when a splicing is required.

Through the observations made and meetings with the Line Leader and the employees a conclusion was drawn. It was identified that the matter requiring most attention and analysis, was the lack of information that the workers had in the process and the fact that component had to be searched, thus augmenting the stoppage time. Having identified the causes, potential solutions had to be analyzed. These will introduce new procedures that after could be streamlined as new improvements. As in the previous chapter improvements, an identical work breakdown structure was used for the problem.

4.2 - Optimization solutions

After pondering several solutions, a compilation of the five most viable and precise processes that could possibly be implemented, was made. All the solution aim to add no significant time in the overall assembly of the cars, while reducing wastes posterior to the QCO.

4.2.1 - Solutions studied

The solutions presented are aligned with the Bosh Production System standards in order to assure the linearity, efficiency and cohesiveness. Due to the high cost of some proposed solutions an economical study of ROI, Return on Investment, and investment need would be required, however due to time constraints and the deviation from this dissertation focus, these were not conducted.

As in the previous chapter, table 7 shows the solutions proposed and what is intended to achieve with set solution.

Table 7 – Proposed solutions

Solution	Goal
Creation of new procedures	Give the component quantity requirements so that operators can verify quantities
Precision scale	Accurately measure the number of components
Acrylic with perimeter markings	Estimate the number of components
Component counting machinery	Approximate number of components
Minimum reel length standard	Provide a safe zone to assure no stoppages right after the QCO

All the presented solutions were individual thoughts and ideas of the author. The next step was to discuss their viability and selection criteria with colleagues, to ensure that the most efficient optimization would be set as standard.

4.2.2 – Solution selection

More methods of optimization selection were discussed and agreed upon when discussing the criteria required for the improvements, changing the PoUp workflow in order to supply the SMED with the reel amount required, creation of a Kanban system that references the lot size and creating mobile racks for the spare components and removing the fixed ones.

Following several meetings and weighing in all the factors we concluded that the best implementation at the time would be the one that was readily available and without any costs involved, a summary of the requirements is presented in table 8.

Table 8 – Solution criteria

Most Important

Least Important

Criteria
Cost
Flexibility
Complexity
Added value
Feasibility

These criteria were set in attempt to create a simpler implementation process and to assure that all the possible improvements maintained the process flexible.

4.2.3 – Solution analysis

Following the decision, it was then necessary to ponder on what the best implementation would be. As these new methodologies imply changes in several workflows it is crucial to assure that the optimization maintains its lean design.

The Kanban implementation was designed to make the system a pull system, where production can be planned, to certify that there is enough components for a certain production lot, by only creating the card after releasing the order, checking if all the components are available, and give the worker the information required to print an assembly sheet with the component quantity needed.

There were two viable options, regarding the printing of new assembly sheet, use a sheet of paper for each assembled setup every day or use a tablet in the work stations that can provide the same information. As setting up new tablets would represent a more immediate expense to the project the team decided that printing the paper sheets would be the most adequate solution. However it was concluded that the tablets would be the best option, also considering that the production lines are going to be placed at a new area that provides the ideal opportunity to install the devices required.

The worker would then do a visual estimation of the amount present in a reel and if more reels are required the worker would then fill a request. This request would then be given to the PoUp, which in turn would supply the SMED. As the PoUp would no longer have to supply the intermediate racks containing the most used reels, the time added on this new task would be neutral as the flow would be similar.

All the improvements discussed above are in line with the criteria set, they require no investment, maintain and augment the flexibility of production, their implementation and would be simple, would add a lot of value by not increasing process times and reducing the unplanned stoppages and do maintain the expected results in a real-world scenario.

These tests elapsed during a week and proved to significantly reduced unplanned stoppage times due to the lack of components in a reel. It resulted in a decrease of 54.6% of stoppages.

4.2.3.1 – Solution results

The implementation process proved to be time consuming, requiring new deadlines, as aligning ideas of how these improvements should be made proved more complex than expected. As the project was still being implemented at Bosch Security Systems at the time of the author left, there was not enough time to gather data to conclude how effective the improvements were.

The BPS standards define a continuous improvement, that require set analysis that will assuredly be done posterior to the conclusion of this project.

Chapter 5

Process Revision

Most of the process targets and measurements were outdated. This was concluded after observing that the earliest measurements were from the year two thousand and fifteen. Adding to the fact that new improvements were implement it was fitting to recalculate the capacity, indicators and resources. This meant that all the steps required to assemble a SMED car had to be timed.

This is part of the continuous improvement ideology that intends to verify the implemented techniques and standards. Note that all the data gathered in this chapter refers to the operators from the second shift, as that was the most critical one and it coincided with the work schedule.

5.1 – Capacity Revision

Capacity is defined as being the maximum possible output of any process. To determine the SMED capacity, new time measurements were made for every phase of the (dis)assembly, this information is vital for planning the production. The capacity was calculated by type of feeder; this allows for a better estimation of the ideal assembly times. Furthermore, it is projected for the worst-case scenario, where slight problems might occur, this means a five percent margin was added to the values. This is intended to eliminate error associated to the measurements and consider the normal deviations that occur while performing the tasks.

The calculation formula is as follows:

$$\text{Capacity (i(k))} = \frac{3600}{sum\ of\ all\ tasks\ i(k)\ (s)} * 0.95 \text{ (feeders p/ hour)}$$

Equation 6 – Feeder Capacity

The tasks vary from feeder type and depends if the process is an assembly or disassembly, i represents the feeder type and k represents if it is an assembly or not. The multiplication for the constant of 0.95 represents the five percent margin previously discussed. The capacities obtained for the different feeders, these values were then updated in the database, to assure that future calculations are more accurate than the pre-existing ones. This allows for a more accurate prediction of the setup time of different cars, this calculation is explained in equation 7. Where z represents the total number of different feeders, n(i) represents the number of existing i feeders in the car and x and y are binary, when x=1, y=0 and vice versa. The variable x is one if it is an assembly and y is one if it is a disassembly.

$$\text{Car capacity} = \sum_{0}^{z} n(i) * \frac{Capacity(i(k))}{3600} + x * 276 + y * 245$$

Equation 7 – Car capacity

This revision allows the process engineers to extract data related to the efficiency that was designed in the adoption of these proceedings. By comparing the expected values with the obtained ones, it is possible to observe if the steps achieved the desired results. It was concluded that the process had gained small inefficiencies due to sub-optimal habits that the operators gained through time.

A discrepancy was found between the capacity values calculated through the individual tasks and the total assembly time. This can be explained through the existence of wastes that are not observable when the process is divided into small subtasks.

5.2 – Indicators Revision

To obtain an idea of the performance of the operators, an indicator is used. However, it proved ineffective, prompting a revision of set indicator. The major fault with the indicator was that the responsible for evaluating it was the operator, one car per hour for the SMED area. This led to amazing results of 100%, 100% of the times. This scenario seemed too unrealistic and implausible. Being so, a new indicator had to be conceptualized, that could assure quality data.

The focus for a new indicator would be to have a third party analyze if the targets were accomplished or not. This would probably assure more reliable data however it would also add to an employee work load.

To better understand the requirements of the indicator, there was a need to meet with the line leader responsible and attain his opinion regarding which data set indicator should aim to provide. It was concluded that the most useful was to verify if there were no inefficient time usage from the operators.

After some pondering a plausible solution was presented. It consisted on calculating how long a certain (dis)assembly of a car should take and compare with the time it took for the operator. This would take advantage of an existing platform that already provides this analysis but is not used as an indicator for the efficiency of the SMED process. Another possible implementation methodology would be to add a process in the workflow of the

POUP. This person would be responsible for gathering the required reel for a certain assembly and deliver it to the operator responsible for the car assembly with an expected assembly time, based on the car capacity, previously calculated.

5.3 – Monthly Resources

A monthly production plan is designed at the end of the preceding month. Subsequently the occupation of all resources must be calculated, including the SMED operators, even though they might provide some help when performing a QCO the main tasks is to prepare the feeder cars. As it is a secondary, non-priority, procedure it was not considered when conceiving an equation that would give the total amount of resources, in hours, occupied in the SMED area for a month's production.

Equation 8 presents the calculation methodology that allows any user to analyze the minimum required resources for set month. Due to the variation of the number of set ups required for each month it is not possible to determine accurately an estimation of resources for a desired month. Thus, it is required that the calculation is performed after the planning of each month is obtained.

$$\text{Resources} = \sum_0^n Fx_n T_{Fxn} + \sum_0^d Fx_d T_{Fxd} + 276 * a + 245 * d$$

- Fx_n --→ Number of x Feeders in assembly n
- T_{Fxn} --→ Feeder x time in assembly n
- Fx_d --→ Number of x Feeders in assembly d
- T_{Fxd} --→ Feeder x time in disassembly d
- a ---→ Number of assemblies
- d ---→ Number of disassemblies

Equation 8 – Monthly resources

The constant 276, that multiplies by a, the number of assembled cars, represents the tasks that are not accounted for in the feeder capacity. These are the registration,

movements of the cars from the and to appropriate locations and component assembly verification.

The variable d, is being multiplied by the fixed value of 245, this represents the additional steps required when disassembling. These processes are not included in the feeder process capacity; however, they add a significant amount of time to the operation. The cleaning of the feeders, registration and dislocation of the car are the actions that complete the overall SMED proceedings.

This calculus determines if there is a need to add extra personnel or if the existing one is enough for the planned production, the main problem is determining the number of cars that will require (dis)assembly. This is because some setups are fixed, the existence of micro setups and the need for research and development of new products.

Chapter 6

Conclusion

As the work presented above shows, a lot of effort is required to achieve the best production possible at the lowest cost. This is one of the reasons the Bosch Productions System was created, to adapt the TPS and Lean Methodologies to the company's ideals and production needs. This provides Bosch with the required techniques to adapt to the markets shifts and innovate.

The continuous improvement is always in practice at Bosch and all the projects of improvement aim to create a more efficient, safe, robust and flexible production. All these

6.1 – Work developed and objective fulfillment

The scope of this project was to study and implement possible improvements for the SMED area of the SMT production line. This lead to other two projects, one consisted on determining the required amounts that had to be sent to the production lines and the revision of all the indicators and the production capacity.

The (dis)assembly SMED area improvements were tested, implemented and revised. Thus, it is possible to conclude that all the requirements set by the project team and the company were completed in due time and an improvement of 12% to the process was calculated, through the removal of registration procedures and the layout changes. This value represents the total time saved in the overall SMED processes. However, it was also possible to conclude that the improvements would have been more significant if not for the cultural nuances observed, when changing certain workflows.

The second project aimed at determining the required amounts to avoid unplanned stoppages in the production lines, requiring the cooperation of four departments of the plant adding that it was also time-consuming process. The author referred in chapter 4 that due to the need of the inter department cooperation and the required schedule availability from all ends led to the project's delay. Being so it was only possible to conduct certain studies and tests, no implementation method was applied by the time this dissertation was written. The tests confirmed a stoppage reduction due to insufficient components in a reel of nearly 55%.

This was calculated by calculating the difference between the initial total amount of stoppages and the stoppages verified during testing, divided by the initial total amount of stoppages. This was achieved due to the proximity of the reels to the line operator and the verification of reels when assembling a feeder car.

The final development in the work was the capacity and indicator revision. This was fully concluded by the time the SMED implementations were done.

6.2 – Future work and continuous improvement

The quantity requirement project will be continued by the company, as all the departments are aligned are certain actions were already defined to improve the production of the PCBA's.

The BPS is an ideology based on the continuous improvement mentality, being so these projects can diminish the existing wastes in the SMT production lines. However, it is continuous, so new projects will arise to determine new possible improvements and one of the possible future improvements is the implementation of Industry 4.0 and IoT. This would allow for a better JIT system, where both the producer and client can observe in what stage of production the product is and the stock and waste are more easily determined.

In conclusion, the project goals that were set out were fully carried out. However, no Just In Time production is perfect and new situations and new improvements will arise, while assuring that all the standards defined by the BPS are fulfilled.

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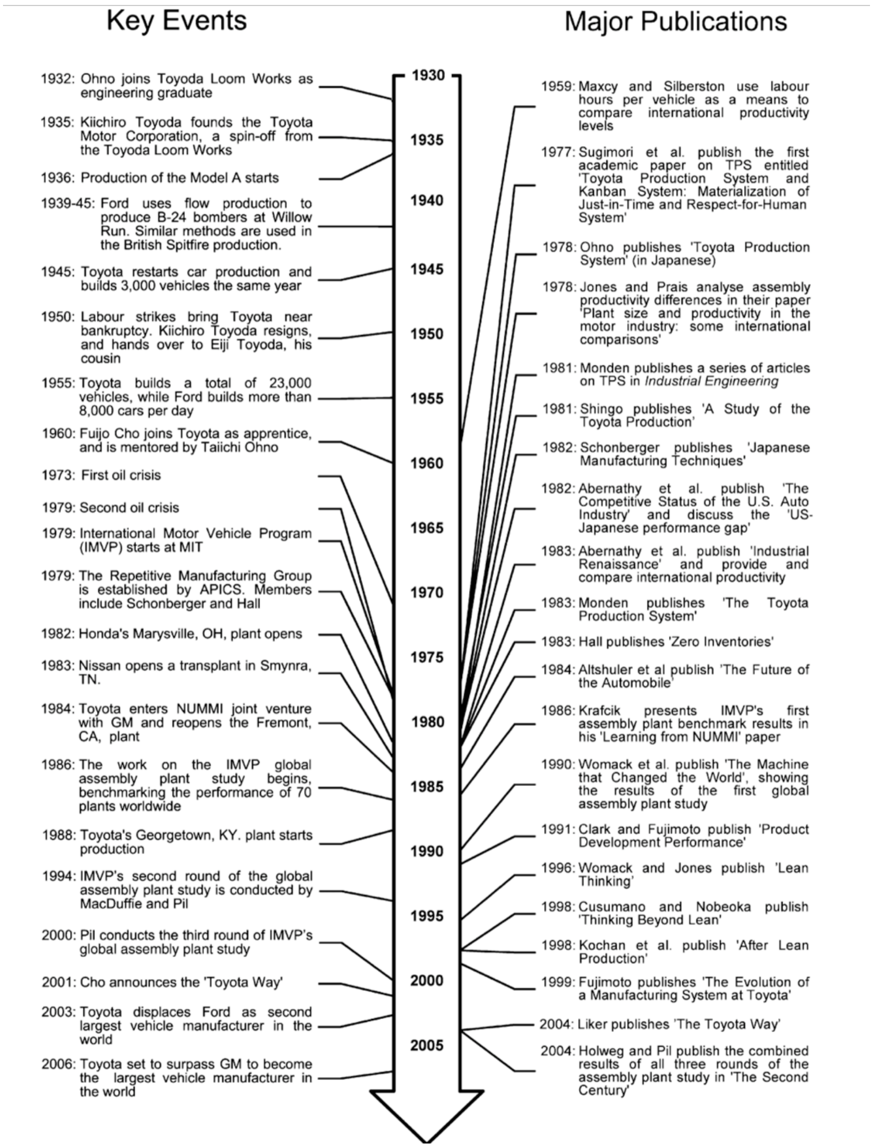
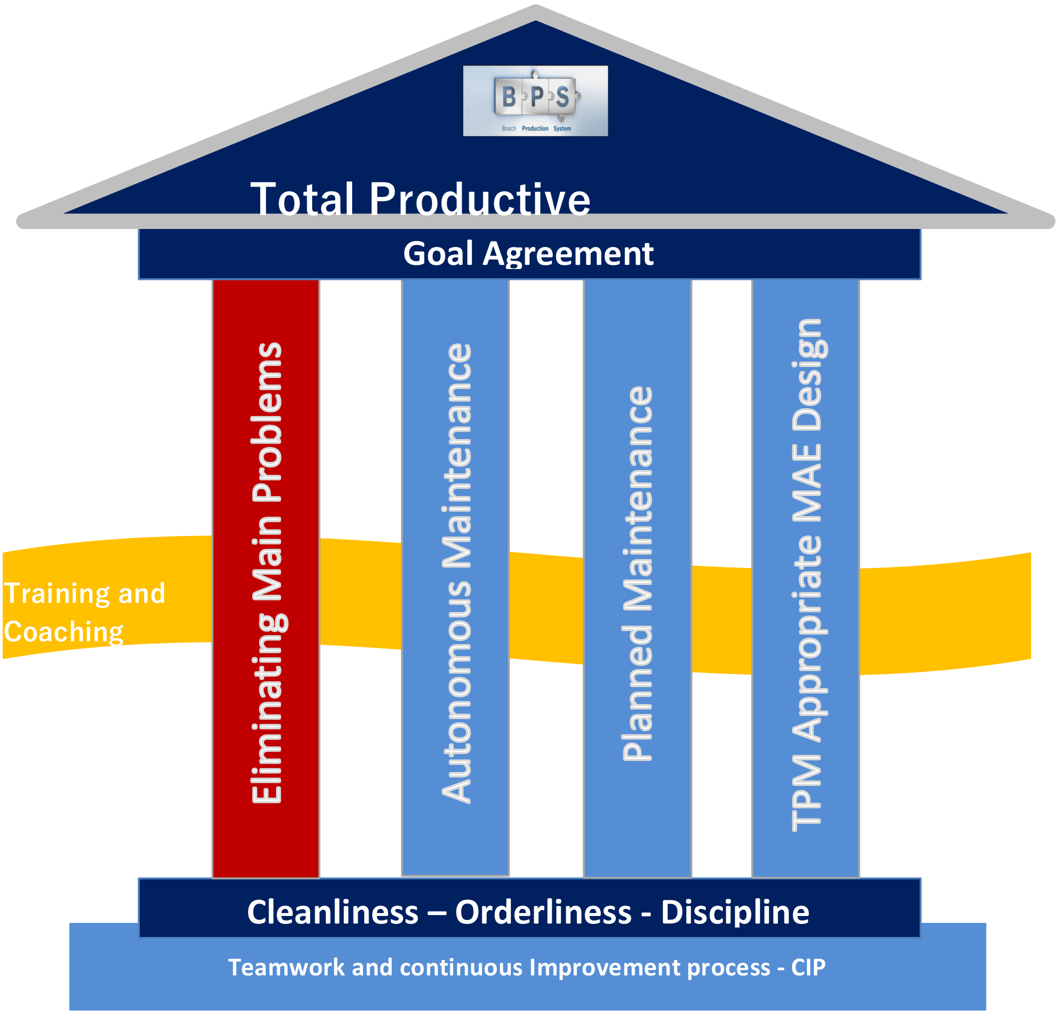
Appendix



Appendix 1: Historical development of the TPS Methodology



Appendix 2: TPM-Bosch Four Pillar Model