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Lean manufacturing in complex electronic assembly line

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LEAN MANUFACTURING IN COMPLEX ELECTRONIC ASSEMBLY LINE

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ISEP – School of Engineering
Mechanical Engineering

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KEYWORDS

Lean Production, Bosch Production System, Wastefulness's elimination, SMED, Lean Line Design Poka-Yoke, Quality tools.

ABSTRACT

The present work results from a curricular internship developed at Bosch Ovar, Security Systems.

Manual assembly lines are usually deeply studied before implementation, nevertheless, several problems upsurge when the product needs to be slightly changed. This is very common in complex electric and electronic devices usually produced in small batches, where the customers are demanding more and more features and the product needs to be continuously updated. However, these updates sometimes create huge difficulties for the previously installed assembly line, generating as well, line unbalancing and wastes of time regarding the initial situation. In this paper, a deep study of an adjusted assembly line of electronic devices was carried out using Value Stream Mapping (VSM) method to fully understand and document the different tasks and operations. The Lean Line Balancing (LLB) was also applied in order to reduce the line bottleneck by balancing the Task Time (TT) of each workstation so that there are no delays, and nobody is overburden with their task. Standardized processes and standardized work were also applied. During the line layout development stage, assembly fixtures, wastes reductions and visual management techniques were applied as well, different concepts were generated and, finally, the best solutions were selected. Throughout the study, many benefits for the studied manual assembly line were found, which can be considered as a strong motivation to apply Lean Manufacturing (LM) tools for better line efficiency and production rate.

LIST OF SYMBOLS AND ABBREVIATIONS

List of abbreviations

<Term>	<Designation>
CDQ	Central Directives for Quality
CT	Cycle Time
EPEI	Every Part Every Interval
LLD	Lean Line Design
OP	Operator
MA	Operator
MEK	MTM for job-order production and small batches
MTM	Methods Time Measurement
OEE	Overall Equipment Efficiency
PFEP	Plan for Every Part
PGL	Planning Guideline
POU	Point of Use
POUP	Point of Use Provider
SCAL	Scaling, element of BPS Planning Guideline
SOP	Start of Production
ST	Station
TCT	Target Cycle Time
TPZ	Technical forecast
TT	Takt Time
UAS	Universal Analysing System
STAB	
CIP	Continuous Improvement Process
FUP	
VSD	Value Stream Design
VSM	Value Stream Mapping
CO	Changeover
PLCP	Product life cycle planning
CTT	Customer takt time
PC/T	Planned cycle time
OBC	Operator balance chart
SW	Standardized work

List of units

<Term>	<Designation>
sdasdasd	dsadasadasdasd
dsdasdads	sdadsadsada

List of symbols

<Term>	<Designation>
sdasdasd	dsadasadasdasd
dsdasdads	sdadsadsada

GLOSSARY OF TERMS

<Term>	<Designation>
Term1	Designation1
Term2	Designation2

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INTRODUCTION

1 INTRODUCTION

This thesis describes the importance of lean manufacturing concept in modern industries. The competitive global markets, short product life cycles, and increased customer expectations have forced organizations to recognize the vital importance of investing and focusing in relentlessly work on eliminating waste from the manufacturing process.

1.1 Context

This document will reflect a project on the Lean ambit. It was a work made in one production line at Bosch Security Systems SA, in Ovar. The production line studied produce final assembling of one of most complex video units make in this plant, creating an additional demand in all manufacturing process to fulfil the design requirements of the product.

Figure 1 – The product studied.

Due to the reason of this product is a make to order production and classified as low manufacturing volume, the techniques used in the line to assembly this units are essentially manual process. A relevant aspect about this camera related with the robustness design is that the components used are in large quantity mechanical parts.

The operation of this final assembly line acquires a particular character, since each step assembly has a few numbers of operations and is produced in different workstations. There is a flow of materials between the workstations and the operators are switching from stand depending of the STAB defined for each product version they will produce on the line. This kind of product has many process sequences to guaranty the best result of assembling a product wish is failure proof and to assure this high-quality level the manufacturing conditions on the line are full of procedures as checklists, setups, process confirmations in different workstations. All these aspects require special attention in the work developed, since it differs from the scenario typically found in projects in this scope.

1.2 Dissertation Objectives

This thesis focused on the manufacturing improvement of one assembly production line for video units at Bosch security systems in Ovar. The manufacturing process in question is studied from the point of raw material mixing to the point where the products are in the finished goods inventory ready to be delivered. Due to a request from the target company, the batch sizes and financial benefits presented in this work are not the actual figures but modified numbers.

The goals for this research can be summarized in the following way:

- Contextualization of the present problem;
- Literature review on lean manufacturing, focusing on the importance and benefits of lean tools in the optimization of production processes;
- Identification of improvement opportunities and create a set of working solutions through which the target company can reduce its manufacturing lead time and process wastes.
- Illustrate how to base the solution creation on data analysis rather than intuition alone.
- Implementation strategy through the identification of difficulties to overcome and the following steps to take.
- Analysis of the lead time improvements and savings gained through the future implementation of improvements;

1.3 Methodology

The methodology that will be perform in the present dissertation consists of 8 stages, outlined in Figure 2.

Figure 2 - Methodology followed for the present work

The first topic of the methodology consists in expose the way of work by the company with emphasis on the process difficulties they currently face, and the limitations they are subjected to as a video manufacture.

The second topic consists of a literature review, in which the relevant philosophies, concepts and tools are studied, adding to a solid theoretical basis to support the problem approach.

The third topic defined is about collecting data from the production line studied. This data consists of the time study of the processes and the data on inventory levels.

In the fourth topic consist in identify the opportunities for improvement. For each main lean manufacturing method, will be presenting the actions to take in account to eliminate those wastes.

In fifth topic, the results are analysed to have a clear view of the current scenario.

The sixth topic correspond to the implementation strategy

The seventh and final stage concludes the study, and future work is proposed.

1.4 Structure

This dissertation is divided into 4 main chapters. Figure 3 presents the structure of this work in more detail.

CHAPTERS	DESCRIPTION
1	This chapter consists of an introduction into the subject of the dissertation, the presentation of the dissertation objectives, and the methodology to be followed;
2	In Chapter 2 the literature review is presented to support the lean tools used to study the present problem. Essential theoretical concepts and philosophies are introduced through the revision of prior studies on the subject improvement through applying lean methodologies;
3	This chapter focused on the project execution and the benefits the improvement project offered to the target company. Therefore, this chapter is followed by the results analysis and an implementation strategy proposal.
4	In chapter 4 the main conclusions of this study are presented, as for the managerial implications this study presents. Limitations throughout the study are also explained, and the proposed future work is presented.

Figure 3 – Dissertation structure.

1.5 Target company

Bosch is represented in Portugal by Bosch Terotechnology in Aveiro, Bosch Car Multimedia Portugal in Braga, and Bosch Security Systems – Sistemas de Segurança, in Ovar. At these locations, Bosch develops and manufactures hot water solutions, car multimedia and security and communication systems, over 85% of which are exported to international markets. The Bosch Group's Portuguese is one of the largest industrial employers in Portugal with total net sales of 1.1 billion euros in 2016 including internal deliveries to affiliated companies ("Our Company | Bosch Portugal," n.d.).

BIBLIOGRAPHIC WORK

2 BIBLIOGRAPHIC WORK

Exposed to the global competitive pressure of continuously changing market conditions, more and more enterprises face the challenge to lower the production costs (Dombrowski, Ebentreich, & Krenkel, 2016). Nowadays, production paradigm is distinguished by an increasing product variety and assembly to ordered paradigm determined by lean principles (R. J. S. Costa, Silva, & Campilho, 2017). Thus, assembly systems are today designed as manual assembly lines to produce several variants from a common product structure (Bortolini, Faccio, Gamberi, & Pilati, 2016). Several methods and approaches exist such as computer simulation, statistical analysis, and lean tools for improving the efficiency and productivity by determining the best combination of resources in production lines, construction process, energy, services and supply chains (Rohani & Zahraee, 2015).

A literature review on lean manufacturing is presented in this chapter and includes the description of the lean methodology, addressing the existent tools found in prior studies and a more detailed review of the tools which will be used to study the problem described beforehand.

2.1 Lean Manufacturing.

Lean manufacturing is a management philosophy in which the focus is on improving the work "flow" and its smoothness (Nagi, Chen, & Wan, 2017). Basically, is a long-term philosophy of growth by generating value for the customer, society, and the economy with the objectives of reducing costs, improving delivery times, and increasing quality through the total elimination of waste, so that all time spent on the product is through value-added activities (Wilson, 2010; Womack & Jones, 2003).

Lean has a direct effect on a company’s culture. Lean puts a big emphasis the role of employees. Without the help of employees, any change especially sustainable one seems to be out of reach. After a, thorough implementation of Lean, improvements can be observed in the fields of how employees perform their job, the relationship between employees and management, team-working ability, reactions to changes, etc.

At the heart of Lean is its philosophy, which is a long-term philosophy of growth by generating value for the customer, society, and the economy with the objectives of reducing costs, improving delivery times, and improving quality through the total elimination of waste (Wilson, 2010).

2.1.1 History of Lean Production

Lean Manufacturing (LM) was developed by Toyota Motor company to address their specific needs in a restricted market in times of economic trouble (Diego Fernando & Rivera Cadavid, 2007).

Initially, before being applied in Toyota, in 1913, Henry Ford has invented Flow Production system, which is an integration of consistently interchangeable parts with moving conveyor belt and standard work. It was a real revolution from traditional shop practices to a new one. Ford lined up the machines within the process wherever possible and used check on points in order to have fitting parts forwarded to the line side. The problem with the Ford system was that it was unable to provide variety when the market begun to demand more models. Every machine in the line was customized to produce special parts and there were no changeovers to make the machines able to produce different parts (Womack & Jones, 1990).

After World War II, Japanese manufacturers were faced with the dilemma of vast shortages of material, financial, and human resources. These conditions resulted in the birth of lean manufacturing concept. Toyota motor company, led by its president (Toyota), recognized that American auto-makers of the era were out-producing their Japanese counterparts; in the mid 1940's American companies were out performing their Japanese counterparts by a factor of ten. In order to make a move toward improvement early, Japanese leaders, such as, Shigeo Shingo and Taiichi Ohno, devised a new, disciplined, process-oriented system, which is known today as "Toyota Production System" or "Lean Manufacturing" (El-Namrouty, 2013).

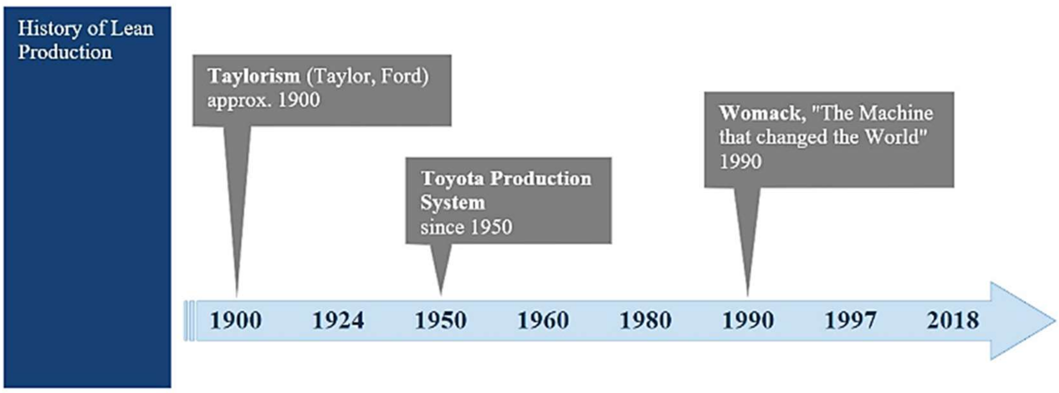


Figure 4 - Timeline of relevant milestones of Lean Production.

James P. Womack, Director of Research at the Massachusetts Institute of Technology (MIT), and author of the book "The machine that changed the world" (1991), set a milestone in the debate on "lean production" and the principles, methods and elements on the path to lean, waste-free production.

After initially being mainly applied in Asia, these principles, methods, and elements have also become increasingly prevalent in the West since 1997.

2.1.2 Definition

Lean Manufacturing is a term that has been around now for many years, originally spawned within the MIT study that led to the book “The Machine That Changed the World” by Womack and Jones in 1990. However, if you search through the many publications and web sites looking for a lean manufacturing definition you will find a myriad of differing definitions for Lean, partly because lean is a continuously developing philosophy and because it’s application is different for each and every company (Lean Manufacturing Tools, 2017).

The characteristics which define lean manufacturing in the industry are related to the socioeconomic context lived in Japan after the Second World War. The effort and the need to reconstruct a whole country which found itself completely destroyed allowed the industry to adopt new rules. The main objective of the lean philosophy is to decrease and, at its limit, eliminate all and any kind of waste in production processes so that all time spent on the product is through value added activities. Value can be defined as a capability provided to a customer at the right time and at an appropriate price, as defined in each case by the customer (Womack & Jones, 2003). Value added is when an activity unambiguously creates value. It can be explained as something that the customer is eager to pay for, whether it is a service or a product.

2.1.3 Lean Results

Experiences in the companies that have implemented Lean have shown that Lean has a comprehensive influence on a company due to positive changes in:

- Encouraging the commitment of the whole company toward continuous improvement;
- Focusing on customer requirements and expectations due to Pull point of view;
- Morale of the Employees;
- Value added activities;
- Identifying and eliminating wastes namely those actions that customer is not willing to pay for;
- Reducing lead times, costs and inventories;
- Work force empowerment;
- Quality of products and services;
- Management and employee’s relationship;
- Change over duration;
- Effective teamwork and productivity;

2.1.4 The 5 Key Lean Principles

Lean thinking may be termed as a five-step thought process proposed by James Womack and Daniel Jones in their book Lean Thinking to guide executives and managers through a lean transformation. Womack and Jones' five principles are:

The 5 Lean Principles Cycle is demonstrated in figure 5, and the description of each principle is presented below.

Figure 5 - 5 Lean Principles Cycle

1. Specify Value – Defining value for a specific product (a good or a service, and often both at once) from the end customer's perspective which meets the customer's needs at a specific price and at a specific time;

2. Map the Value Stream – Identify all the steps in the value stream across all parts of the organisation involved in jointly delivering the product or service to the customer. Identifying the value stream exposes waste in the form of unnecessary steps;

3. Establish Flow – Make the value-creating steps flow in a tight sequence so the product will flow smoothly towards the customer. Eliminating waste ensures the product or service flows to the customer without any interruption or waiting;

4. Implement Pull– Create level pull from the final customer through the value stream. Produce only what the customer wants when the customer wants it;

5. Work to Perfection – As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste. The world you live in is constantly changing and therefore your processes need to continue to meet the changing requirements and demands. Through building in proper review mechanisms, you ensure that you deliver what your customer needs not only now but in the future.

2.1.5 The 4P model concept

According to the book, The Toyota Way (Jeffrey K. Liker, 2004), it is a common phenomenon that companies view Lean as a toolbox. From this toolbox a company can pick and implement the tools and methods that seem most appropriate for a certain problem. However, Lean is rather a business philosophy that focuses on understanding and motivating people to build a "Lean culture". Jeffrey K. Liker uses the 4P model to characterize his 14 principles of Lean as well as a means for describing his view on Lean (Liker, 2004). Figure 6 illustrate the 4P model, below it, a description of each level, starting with Philosophy moving upwards in the pyramid, will follow.

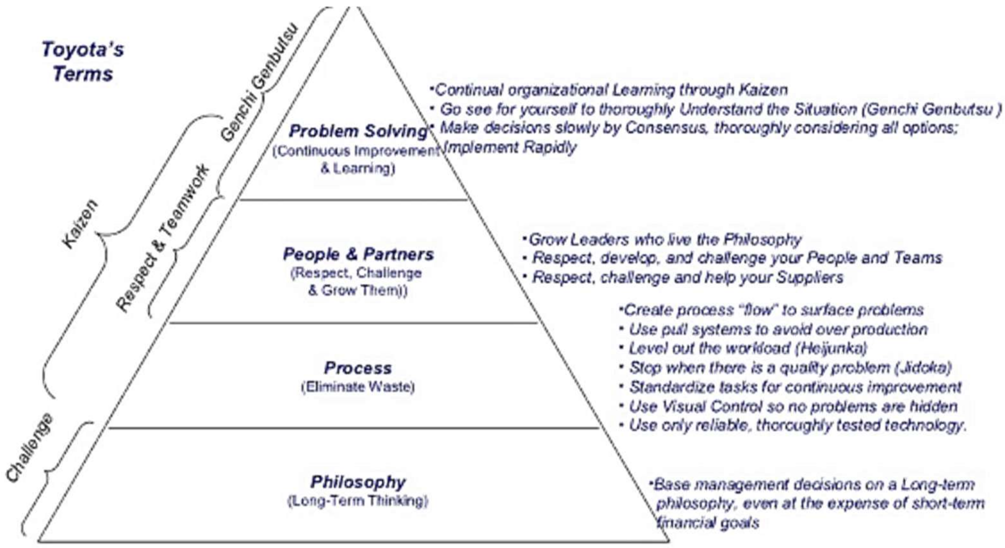


Figure 6 - The 4P model (Liker, 2004)

Philosophy: The fundamental level, of the 4P model, is Philosophy. This level could be contradictory to today's business mentality, where it is more important to do well on quarterly reports, than to ensure long-term sustainable profit. Basically what this level focuses on, is that management decisions should be based on a long-term philosophy in mind, even at the expense of short-term financial goals (Liker, 2004).

Process: The next level, which is Process, is probably the one that most companies think represent Lean. This level focuses on, what would be considered as, typical Lean tools and methods such as pull systems, 5S, etc. The mistake companies make is that they think they are "Lean", only because they are using a pull system, have 5S deployed, etc. The problem is that they have not understood the entirety of the Lean concept. They believe that this level is what represents Lean, hence not including the other levels (Liker, 2004).

People and Partners: The People and Partners level has a deeper focus on individuals, and how to motivate and develop them, both internally and externally (suppliers). Key words that can be found on this level is respect, to challenge and to grow People and Partners (Liker, 2004).

Problem Solving: The top level of the model focuses on the way problems are solved and involves methods for solving problems in a scientific way. Key words for this level is continuous improvement and learning (Liker, 2004).

2.1.6 Five Primary Elements for implementation lean manufacturing

The Five Primary Elements for lean manufacturing are (1) Manufacturing, Flow, (2) Organization, (3) Process Control, (4) Metrics, and (5) Logistics (figure 7). These elements represent the various facets required to support a solid lean manufacturing program, and it is the full deployment of these elements that will propel a company on a path toward becoming a world-class manufacturer (Feld, 2001).

Following is a basic definition of each of the Five Primary Elements:

Manufacturing Flow: The aspect that addresses physical changes and design standards that are deployed as part of the cell.

Organization: The aspect focusing on identification of people's roles/functions, training in new ways of working, and communication.

Process Control: The aspect directed at monitoring, controlling, stabilizing, and pursuing ways to improve the process.

Metrics: The aspect addressing visible, results based on performance measures; targeted improvement; and team rewards/recognition.

Logistics: The aspect that provides definition for operating rules and mechanisms for planning and controlling the flow of material.

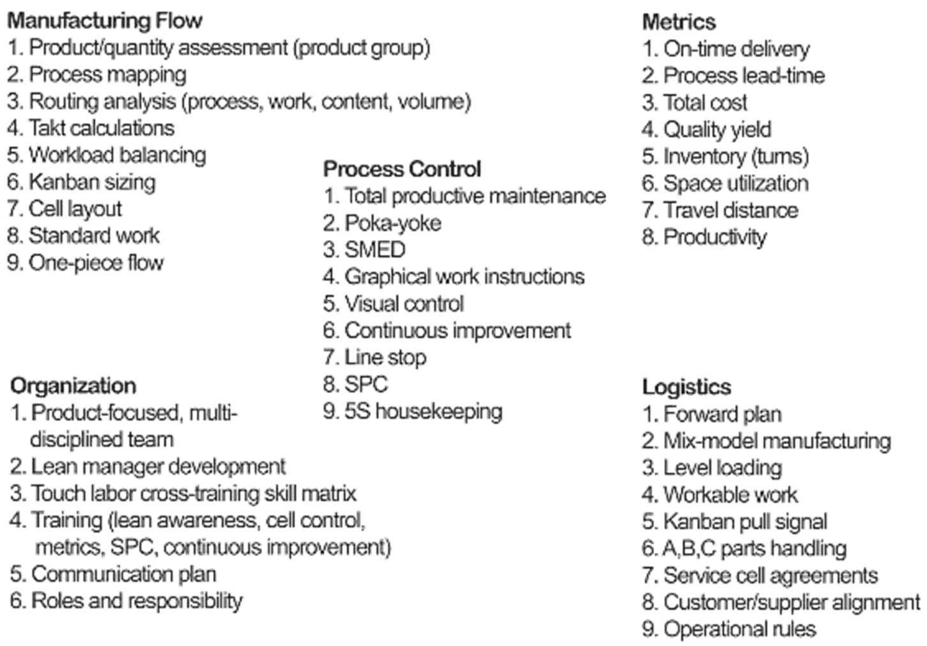


Figure 7 - Five Primary Elements of Lean Manufacturing (Feld, 2001).

2.1.7 Wastes

The seven wastes were initially identified almost 50 years ago by Taiichi Ohno during the development of the Toyota Production System. Waste exists at every level of the organization (Ortiz, 2006). There is one additional waste, which is one of the most destructive, and I will discuss it later in this chapter.

The order fulfilment process is composed of value-adding and non-value-adding activities.

- **Value-adding activities** increase the value of the product, and the customer is willing to pay for it. We want to optimize these activities.

- **Non-value-adding activities** do not lead to an increase in the value of the product. These include activities that are necessary and support value-adding activities. We want to minimize these activities. However, we want to completely eliminate activities that are unnecessary and have no supporting function.

The lean management makes it possible to obtain a product that adapts to actual demand using the minimum amount of resources and therefore minimizing the cost, with the appropriate quality and very high speed of response. For this purpose, all activities that do not add value, called wasteful, must be eliminated, including inappropriate processes, unnecessary carriage, unnecessary movement, stocks of all kinds which would result in increased costs (Arunagiri & Gnanavelbabu, 2014).

Overproduction: Overproduction is probably the most common form of waste in a manufacturing environment. Producing more than is needed, faster than necessary, and before it is needed, is a dangerous practice. Batch processing or building ahead can create problems for the assembly line (Ortiz, 2006).

Wait Time: Waiting occurs when all manufacturing processes are out of synchronization, causing an operator to be idle. Lack of parts, work content imbalances, inaccurate standards and methods, long setup times, bad equipment, poor communication, and rejects all create wait time (Ortiz, 2006).

Transportation: It includes any movement of materials that does not add any value to the product, such as moving materials between workstations. Transportation between processing stages results in prolonging production cycle times, the inefficient use of labour and space (El-Namrouty, 2013).

Overprocessing: Processes can be inefficient due to taking unnecessary steps in order to produce a piece or by having a poor product design. Also, providing a higher quality than necessary will create waste (Liker, 2004).

Inventory: It means having unnecessarily high levels of raw materials, works-in-process and finished products. Extra inventory leads to higher inventory financing costs, higher storage costs and higher defect rates. It tends to increase lead time, prevents rapid identification of problems and increase space requirements (El-Namrouty, 2013).

Motion: Wasted motion is any movement that does not add value to the product. Wasted motion does not only apply to the production line; moving equipment, unnecessary reaching, looking for parts and tools, confusing standards, walking to and from maintenance, poor visual management, floor layout, and improper work content order are all wasted motions (Ortiz, 2006).

Defects/Rejects: Producing defect parts is the purest form of waste, which leads to wasted time on repairing, reworking and producing replacement products (Liker, 2004).

The Eighth Waste: The eighth waste is wasted human potential or wasted skill sets (Ortiz, 2006). Underutilization of people and their ideas results in a loss of knowledge, skills and abilities which should be used to the fullest.

2.2 Bosch Production System (BPS)

2.2.1 The objective of BPS

The main objective of BPS is to eliminate as much waste as possible while looking for the highest quality products. In 2003 the Bosch Production System (BPS) was born. It is an initiative of the companies from the group BOSCH inspired by the Toyota Production System (TPS). Therefore, it is also the aim of the companies in the group BOSCH to deliver the right quantity of products or materials, with the perfect quality, in the place and at the time they are needed, reducing waste along the entire value chain (from suppliers to final customers, through production).

In addition to the main objective of the BPS that is to ensure customer satisfaction by the well-known triangle costs, quality, times, there are in fact two other objectives that are to achieve a sustained growth of value resulting from the contributions given by various employees and increase satisfaction of associated with the company.

2.2.2 BPS Principles

Our Bosch Production System is based on eight principles (figure 8). These BPS principles form the basis for action and cooperation among the various functions in the design of a sustainably waste-free and agile order fulfilment process.


Pull principle	We produce and supply only what the customer wants.
Fault prevention	We avoid errors by means of preventive measures in order to deliver flawless products to the customer.
Process orientation	We develop and optimize our processes holistically.
Flexibility	We adapt our products and services quickly and effectively to current customer requirements.
Standardization	We standardize our processes and implement best-in-class solutions.
Transparency	Our procedures are self-explanatory and straightforward; deviations from the target situation are immediately apparent.
Continuous improvement	We are developing continually and in a targeted way.
Personal responsibility	We know our tasks, competencies and responsibilities and carry them out actively and independently.

Figure 8 - The eight BPS Principles (Bosch Group, 2015)

Pull principle: In the value chain, we only initiate manufacturing and logistics if there is a current internal or external customer demand. Our goal is to be able to produce according to the customer takt and in line with customer orders. This means we can reduce lead times and stocks to a minimum. (Bosch Group, 2015).

Fault prevention: Our stated goal is "zero defects". The emphasis is on ensuring that errors do not occur in the first place – preventing faults is more important than detecting and correcting them.

Process orientation: Process orientation means viewing processes holistically and not only optimizing individual functions. In this sense, we design and control our processes more simply and quickly: The focus is on thinking in terms of value streams (Bosch Group, 2015).

Flexibility: We adjust to the current needs of our customers quickly and easily, in terms of the set-up of our machines as well as the organization of our work. We implement product variants in the value chain quickly and easily at the latest possible moment. Our production is organized in such a way that we can integrate new processes at any time and can refine all processes on an ongoing basis (Bosch Group, 2015).

Standardization: A standard defines the current best procedure for a process that takes place regularly in the same way. We always adopt such tried-and-tested solutions, both in terms of processes and methods as well as for machinery and equipment (MAE). We can only make standard deviations visible by setting a standard and thus forming the basis for improvements (Bosch Group, 2015).

Transparency: Transparent business processes and production sequences are designed and documented intelligibly, simply and comprehensibly. In this way, we create clarity and can quickly identify deviations from the target situation and rectify the causes. For us, transparency also means that every associate knows his tasks and goals, and that information is available, easily understandable and visualized clearly (Bosch Group, 2015).

Continuous improvement: Stagnation means a step backwards. We are therefore always striving to improve ourselves. We do not regard standards that we have already established as a final condition, rather as a basis and starting point for further targeted improvements and, in turn, new standards (Bosch Group, 2015).

Personal responsibility: We are all part of the global Bosch Production Network and are all called on to make an independent and competent contribution to the success of our production system as we want to utilize and promote the competence and creativity of our associates. Tasks, competencies and responsibilities are clearly assigned within defined processes. All associates are aware of their contribution to overall success and are motivated to get actively involved in the improvement process and to take advantage of the scope for development and qualification opportunities (Bosch Group, 2015).

2.3 Lean tools and techniques

Kaizen Assembly is unique because it focuses on the heart of the shop floor and where the product is made: the assembly line. This approach allows for greater detail in the subject matter and gives any engineer or engineering manager the tools needed to set up a lean assembly line (Ortiz, 2006). The Lean philosophy embraces methods and tools to support its implementation (T. Costa, Silva, & Pinto Ferreira, 2017).

Figure 9 describes some lean tools which exist in lean manufacturing, but not all of them will be addressed, in detail, in the literature review. The lean tools presented in the literature review are the tools most used in Bosch, which will be studied and developed in the following chapters.

Although lean manufacturing deeply utilizes lean tools, it is not by applying lean tools that a company will succeed to implement lean manufacturing. In the book "The Toyota Way" it is also explained that lean tools are just the tip of the iceberg of lean manufacturing (Liker, 2004).

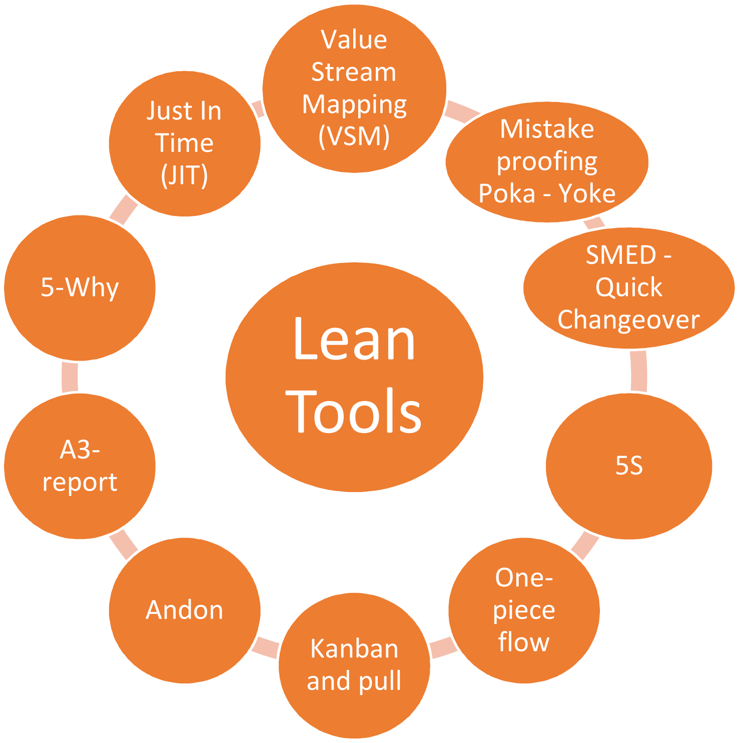


Figure 9 - Lean Tools

2.3.1 Value stream mapping (VSM)

Value steam mapping is a pencil and a paper tool that helps you to see and understand the flow of material and information as a product makes its way through the value stream (Rother & Shook, 2003).

Mike Rother and John Shook's landmark book, Learning to See (1998), was the first publication on the subject of value stream mapping. In Learning to See, the authors detailed value stream mapping's application to manufacturing.

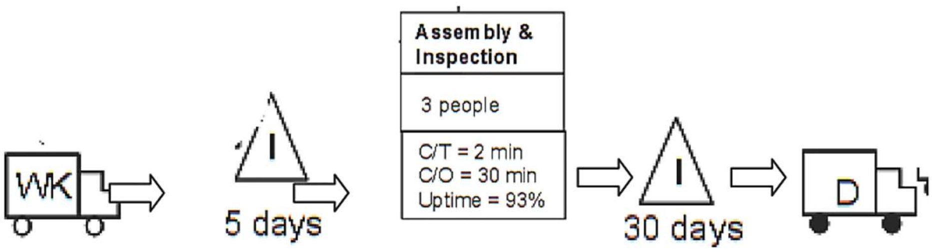


Figure 10 - Value stream mapping example (Rahani & Al-Ashraf, 2012).

Value stream mapping is a tool which enables a company to map the process flow that helps in identifying various factors like: value added time (time taken for producing the end product); Non-Value-added time (time taken which do not contribute to the production of end product); Cycle time (time required to perform a process) and Changeover time (time required to change tool and programming, etc.) (Venkataraman, Ramnath, Kumar, & Elanchezhian, 2014).

2.3.1.1 Objectives

Visualization and a clear presentation create transparency and a comprehensive overview of the interrelations between processes. The key elements of the value stream map are shown (Venkataraman et al., 2014):

- The Customer and his requirements.
- Process steps.
- Process Metrics.
- Inventory.
- Supplier with material flows.
- Information and Physical flows.
- Total lead time and Takt time

The visualization of the current situation that is created in this way provides an excellent basis for detecting weaknesses (i.e. bottlenecks) and identifying opportunities for improvement.

2.3.1.2 Implementation

As with all tools, there is a recommended process for using value stream mapping (figure 11).

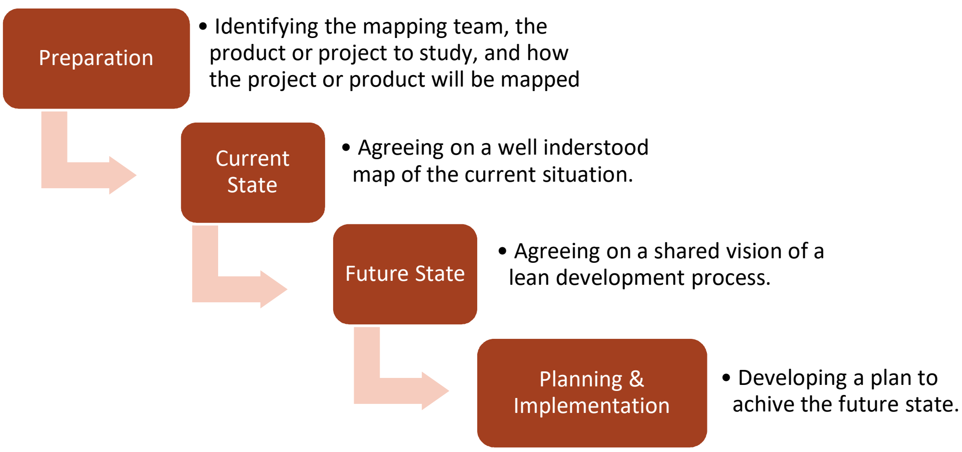


Figure 11 – The value stream mapping process

- **Preparation**

This step is critical to conducting an effective value stream mapping event, and to the successful implementation of the envisioned "future state"; the preparation step occurs before the mapping event itself. During the preparation step, the team tasked with the objective of improving the development process is assembled (Locher, 2008).

- **Current State**

At this point, the team will build a visual, agreed upon depiction of how things work today.

Understanding the current operating mode of the plant (Bosch-Norm, 2011):

- Go along the stream yourself from "ramp to ramp ".
- Always go against the material flow (e.g. from shipping to goods received => customer perspective).
- Draw material and information flow with standardized symbols.
- Assess the actual process data (no standard times!).
- With new products, it helps to analyse a similar value stream.

- **Future State**

This step is to the team then develops the future state, their shared vision of a new, Lean development process.

The goal is to build a chain of production where the individual processes are linked to their customer(s) either by continuous flow or pull, and each process gets as close as possible to producing only what its costumer(s) need when they need it (Rother & Shook, 2003).

Draft of an improved customer-oriented value stream (Bosch-Norm, 2011):

- Deducted from the system-CIP
- Keep customer cycle in mind
- Introduce continuous flow (FIFO)
- Introduce supermarket-pull systems where no flow possible
- Decoupling information flow from customer by levelling

- **Planning & Implementation**

Finally, there is the planning and implementation step. It's important at this stage to define a plan and describes how will be achieve the future state.

For implementation, it could be use tools like A3-sheet (figure 12).

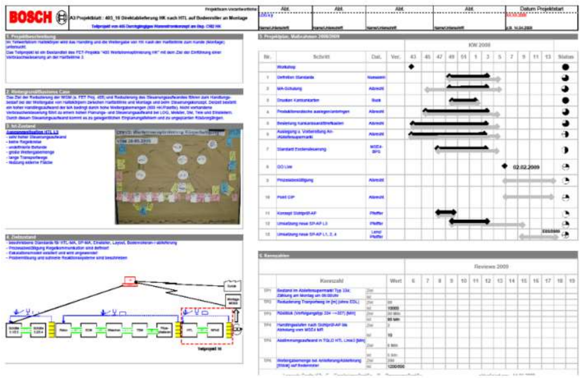


Figure 12 – A3-sheet an example of VSM implementation (Bosch-Norm, 2011).

2.3.1.3 Material and information symbols

Within the production flow, the movement of material through the factory is the flow that usually comes to mind. But there is another flow – of information – that tells each process what to make or do next. Material and information flow are two sides of the same coin (Rother & Shook, 2003).

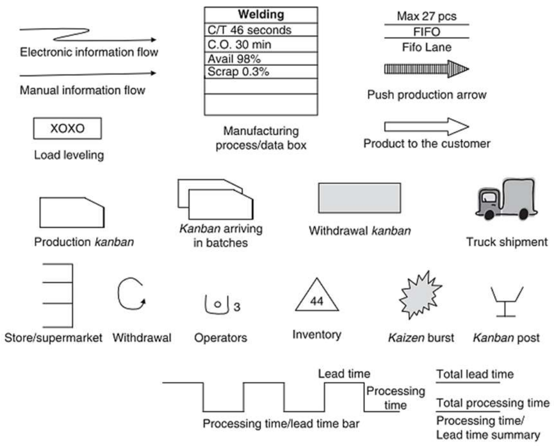


Figure 13 - Typical value stream mapping icons (Wilson, 2010).

2.3.1.4 VSM Metrics

The principal indicator of value stream mapping is the lead-time. Therefore, other metrics are associated to the flow analyse, and will be mention in the following way:

- **Lead Time**

The time it takes one piece to move all the way through a process or a value stream, from start to finish. Envision timing a marked part as it moves from beginning to end (Rother & Shook, 2003).

- **Takt Time (TT)**

Takt time is how often you should produce one part or product, based on the rate of sales, to meet customer requirements (Rother & Shook, 2003).

$$Takt\ Time\ (TT) = \frac{Your\ available\ work\ time\ per\ shift}{Customer\ demand\ rate\ per\ shift}\ [sec./pcs]$$

- **Cycle time**

Cycle time is a time measured from the initial moment a work-piece delivered to the station, the required time to complete all the operation of the work-piece on that station.

- **Overall Equipment Effectiveness (OEE)**

OEE stands for Overall Equipment Effectiveness and is the primary measure of production effectiveness. It can be used for value stream or individual work station performance evaluation. Good value stream OEE is one of the key precursors to the implementation of Lean and is the product of three important operational parameters. These are (Wilson, 2010):

- Equipment availability
- Quality yield
- Cycle-time performance

$$OEE = \frac{Production\ quantity\ of\ goods\ parts\ \times\ Cycle\ Time}{Shift\ time - planned\ breaks - planned\ downtimes} \times\ 100\%\ [\%]$$

- **Target Cycle Time (TCT)**

Calculation of target cycle time TCT from the shift time and the availability, performance and quality losses (cf. OEE) to be considered. Changeover losses are scheduled losses and therefore considered separately (Bosch - LLD, 2015).

$$Target\ Cycle\ Time\ (TCT) = TT\ \times\ \frac{OEE\ (\%)}{100\%}\ [sec./pcs]$$

2.3.2 Lean Line Design (LLD)

LLD (Lean Line Design) is a method for implementing the BPS principles for the re-planning or the new planning of manual and partially automated work systems. The principles of process orientation, elimination of waste, standardization as well as personal responsibility of employees are the center.

The Lean Line Design (LLD) is a concept obtained from the lean manufacturing domain. In the lean line design concept, the manufacturing line is redesigned to form a lean line with an optimum layout which results primarily in the productivity improvement (Koppal & Arunkumar, 2013).

The Lean Line Design theory (LLD) helps to design sequential assembly envisaging waste elimination and ensuring flexibility. This theory can be applied both to an existing assembly line and to the design of a new one (António, 2009).

Figure 14 – Lean line design (Bosch Group, 2015).

As an associate, may perform several work steps in a lean line, these work steps can be distributed over different work stations within this line. A lean line therefore is usually U-shaped in order to ensure short routes in changing work stations (Bosch Group, 2015).

2.3.2.1 Objectives

- High and constant productivity with differing customer demand as well as a balanced workload for associates due to the flexible allocation of work content.
- A low level of investment and reduced space requirements due to a line concept that is as simple as possible with a low degree of automation.
- Short lead times due to the continuous flow (One-piece flow) and small lot sizes.

2.3.2.2 Implementation

Approaches to LLD- Designing the lean line means to rearrange the stations in the existing line which would be meeting the manufacturing industries standards. LLD which is used for rearranging is a step by step approach, the approaches flow is shown in figure 15 (Gowda, Kulkarni, & S, 2013).

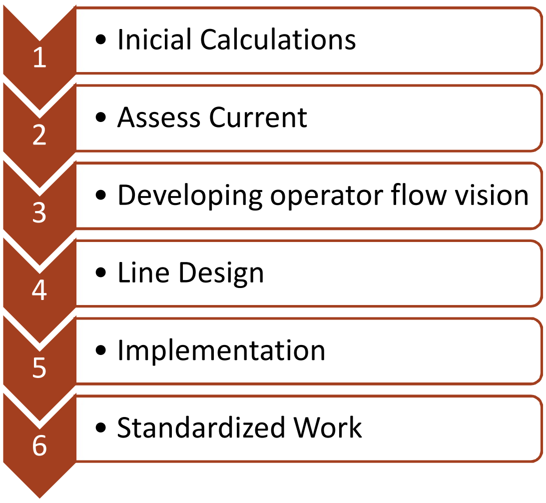


Figure 15 – Flow chart of LLD approach.

1. Initial Calculations

1.1 Product Data Determination

For the product data determination, it's relevant define requirement curves, expected product lifecycle and product families and variants.

1.2 Time Definitions

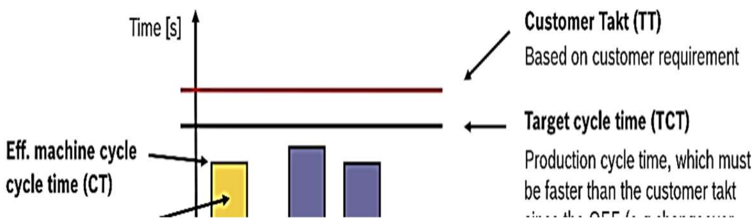


Figure 16 - Time Definitions.

- Customer Takt (TT)

The Customer Takt is based on the entire call-offs for one line/production unit. It forms the basis for the line design and the calculation of the target cycle time.

- Every Part Every Interval (EPEI)

Analysis of type spectrum (ABC analysis), specification of production frequency and thus changeover frequency (target values), determination of changeover losses to be considered.

- Target Cycle Time (TCT)

The target cycle time TCT for manual and semi-automated systems is ideally within the indicated range.

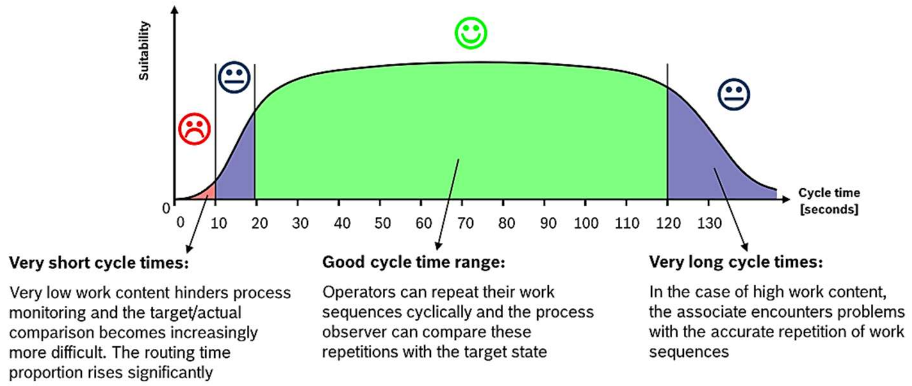


Figure 17 - Target Cycle Time (TCT)

2. Asses Current

2.1 Establishing the Actual State

In the case of rescheduling, the actual state is established by recording the current data and times for the line that is to be redesigned as a lean line in the next step. The actual state promotes a better understanding of the work steps and their interaction.

The following are required to determine the actual state (Gowda et al., 2013):

- Current line layout (possibly with photos or videos)
- Current time analyses (incl. resulting time components)
- Work distribution diagram (Operator Balance Chart)

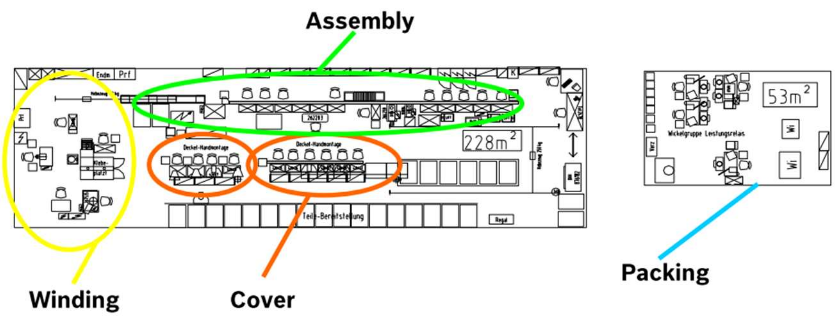


Figure 18 – Operator Flow Actual State

3. Development of Ideal Operator Flow

- Creation of a vision for "waste-free" workflows on the part of an individual operator.
- Listing of manual activities that are repeated in each cycle. Automated processes are not included.
- Start by configuring the Operator Flow and then the line. The supply and general conditions are based on the Operator Flow.

3.1 Checking Machine Capacity

The MAE configuration is defined in the scaling workshop. Advantages of single-purpose machines for the implementation of lean lines:

- Shorter procurement times (thus improving capacity planning).
- Simple changeovers; EPEI can be improved.
- Higher flexibility with regard to product modifications.

4. Line Design

- Development of a layout based on the vision for a single operator workflow.
- Before developing a detailed layout, the material flow must be defined to enable planning of the required space and the correct material provision.
- Detailed layout.

4.1 Rough Line Design based on Operator Flow specified in Step 3.

This sketch should be a straight line, and the layout should be drawn as if a single worker should perform all the operations to make the product. In this phase, there is no need to respect scale; it is enough that each simple box represents a different workstation. In a subsequent phase details of the machine are necessary to determine the optimal operator's flow, and the following indications should be made in the stations (António, 2009).

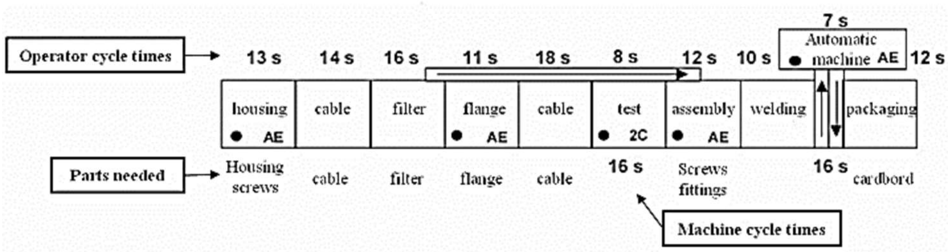


Figure 19 – Illustrative outline of the construction of a LLD.

4.2 Drawing a Detailed Layout (True to Scale)

After this phase, knowing the operator's flow, the materials needed, the reference times and a first line layout, the layout can be detailed drawn to the scale. A mock-up should be made, using paper contour models of the machines and the workstations drawn to the scale to propose and discuss layout solutions (António, 2009).

- Arrange the line in a U-shape, if appropriate:

- Benefits of U-line: simple line balancing and adjustment of headcount in response to tact time changes, short paths, generally compact.
- Benefits of straight line: clear overview, simpler layout.

When using a straight-line layout, operators perform one or more tasks on a continuous portion of the line. When using a U-shaped layout, operators are allowed to work across both legs of the line, while partially assembled units follow the U-shaped configuration. This is illustrated with the U-shaped layout in figure 20, where Operator 2 (i.e., O-2) performs Task 3 on the front side of the line, travels to the back side to complete Task 9 on a different unit, and then returns to the front side of the line to begin the next cycle (Lam, Toi, Tuyen, & Hien, 2016).

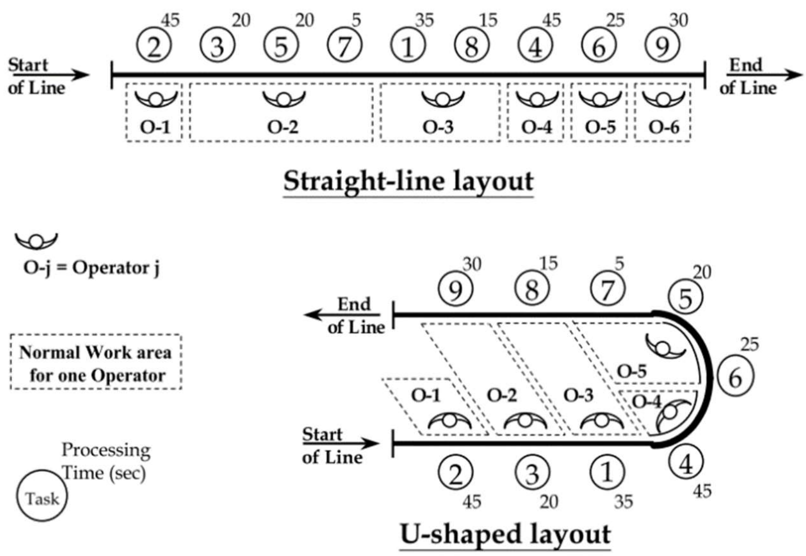


Figure 20 – Different layout options.

This is also an important step because layout affects dramatically to production performance. A well-designed layout can help to reduce transportation, easy to control and more convenience. The first activity is to define the number of tables needed, and then define criteria for evaluating new layout. In this case, the following criteria are considered (Nguyen & Do, 2016):

- Support material flow with linked working spaces
- Warehouse easy to replenish raw material and collect finished goods.
- Good visual management
- Be able to expand in the future
- Enough space for operator to handle
- Good space utilization

4.3 Specification of Work Distribution.

Time studies of manual times and process times for each station/operator will be copied into the operator balance chart. The time studies can be obtained by time study method or method time measurement/ universal analysis system (MTM/UAS) methods (Gowda et al., 2013).

- Headcount Calculation (Target).

- Calculation of the required headcount for the planned, maximum capacity.

$$No.of\ operators = \frac{Total\ manual\ activity\ time\ *}{TCT}$$

*Sum of work content from stack diagram

- Creation of Work Distribution Diagram (Target).

- Distribution of work content across operators (target number)
- Assignment of operator paths according work content and layout

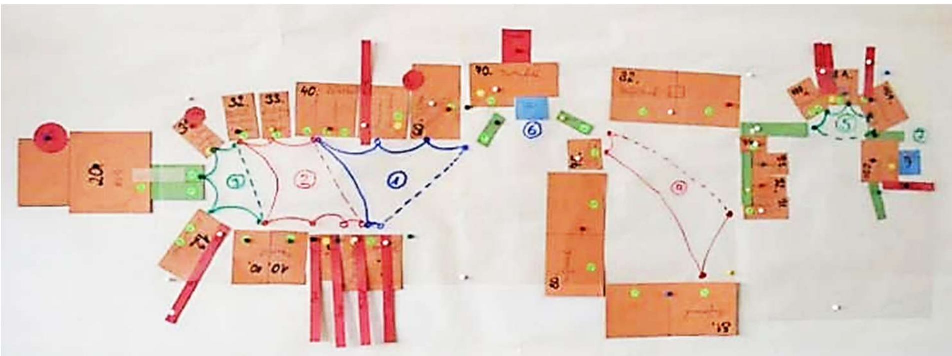
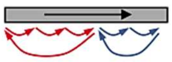
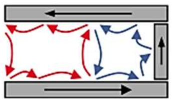
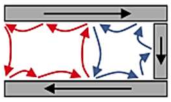


Figure 21 - Work Distribution Layout

Depending on the layout, work content and work distribution, there are different ways of arranging the Operator flow:

Table 1 – Methodologies for Operator Flow.

Methodology	Sketch	Explanation
Sequential distribution		Straight line; operator flow reflects process sequence; transfer point within station possible
Non-sequential distribution		U-shape; operator flow independent of process sequence; transfer point within station possible; start and end of line can be operated by one operator
Counterflow (against the flow direction)		Frequently better flow, if auto-eject not possible

Different line design layouts are all associated with an assembly line balancing (ALB) problem. Balancing distributes tasks to work stations and work content per station and variant. Line balancing is divided in areas depending on layout of the assembly line (Ignall, 1965).

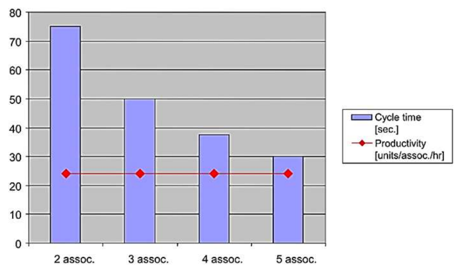


Figure 22 - Constant Operator Productivity

5. Implementation

Simulating the design by simple means helps to understand and visualize the flow.

Notes on the procedure:

- The simulation does not provide evidence of operator cycle times.
- Creation of a scaled, two or three-dimensional line. Rapid implementation through use of simple materials such as PVC pipes, cardboard or paper on tables etc. As well as use of original parts.
- Small details can be immediately adjusted and improved. If the workflow is changed, the operator flow, parts supply, construction of machines/stations and the overall layout can be adjusted accordingly at the same time.
- Before the mock-up, the iterations can lead to different alternatives.
- If multiple alternative concepts were developed, these are now compared.
- Determination of costs and risks involved in identified alternatives.
- Selection of alternative to be implemented.

Figure 23 - "Mock-Up" Simulation

- If the Lean Line Design was performed in the context of a planning guideline project, the selected alternative must be positioned in the production process as part of the "flow-oriented layout". Recursions may arise in this case.

6. Standardized Work

6.1 Cooperation with System Manufacturer

- Consider your system manufacturer as a special-purpose machine manufacturer and yourself as the line and flow designer. The flow is your responsibility.
- Include the system manufacturer in the planning of your process steps. This will not only give him a better understanding of your concept but also provide him with necessary training.

6.2 Implementation

- In the case of rescheduling, the new concept should be implemented as quickly as possible.
- To quench any problems that may arise during line ramp-up, appropriate safety stocks should be accumulated beforehand.
- In the case of complex lines, a "Layout Planner" simulation can complement the mock-up simulation.

6.3 Creation of documents:

- Work distribution diagram (per capacity level)
- Standardized work sheet (STAB) for each operator and capacity level as the basis for process confirmation and thus the continuous improvement process (Point CIP)
- Production and test instructions (FuP) for each station

2.3.3 Balancing line

Assembly line balancing includes assigning tasks to a set of workstations with consideration for constraints set of precedence relationships, processing time, and the cycle time. One major goal of line Balancing is to achieve a similar cycle time at each station, but this is nearly impossible in practice if lots of product variants which need different assembly operations have to be produced (ElMaraghy & ElMaraghy, 2016).

Line balancing is a technique to minimize imbalance between/among workers and workloads in order to achieve required run rate. Therefore, the line should be analysed in terms of assembly process, workstations layout, and workstation cycle time (Lam et al., 2016).

The design of an assembly line requires assigning the tasks into stations considering the precedence relations among these tasks that have to be completed within the time interval between two successive outputs. This time interval is called as the cycle time. (Sabuncuoglu, Erel, & Alp, 2009). Remember that a process plan is defined by a set of operations, their sequence and corresponding tools necessary to execute these operations. Usually, there are a great number of possible process plans. Graph theory approach can help the manufacturers to analyse the possible plans and optimise a given criterion (Dolgui, 2007).

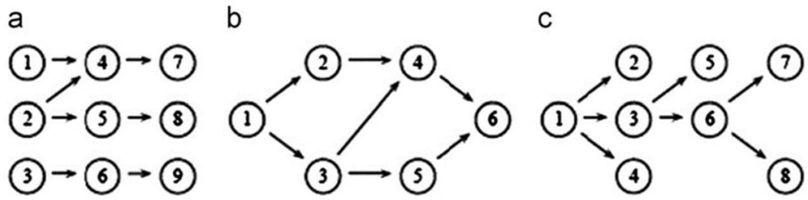


Figure 24 - Precedence graphs.

- Number of product models

According to this criterion, the following line types are commonly distinguished in the literature (Battaïa & Dolgui, 2013):

- **Single-model lines**: one homogeneous product is manufactured at the line. A set of all tasks to be performed for a product item is known. Each workstation performs a subset of these tasks. This subset is the same for all cycles.
- **Mixed-model lines:** several models from a basic product family are manufactured simultaneously. The main processes for the models are quite similar, since they differ from the basic product with respect only to some attributes and optional features.
- **Multi-model lines:** several products are manufactured in separate batches. In this case, the line can be rebalanced for each batch. Setup times need to be considered between the lots.

2.3.4 S.M.E.D (Quick Changeover)

The implementation of setup reduction is a cornerstone for any lean manufacturing program. The dependency on flexibility (especially in fabrication) is paramount to allowing level production schedules to flow. Following are benefits of the single-minute exchange of dies (SMED) (Feld, 2001):

1. Equipment changeover time measured in increments of less than 10 minutes
2. Minimal loss to throughput time on equipment
3. The ability to run a greater variety of product mix across a given resource
4. Building today only what is needed today

As Shingo states in The Sayings of Shigeo Shingo: Key Strategies for Plant Improvement:

“It’s the easiest thing in the world to argue logically that something is impossible. Much more difficult is to ask how something might be accomplished, to transcend its difficulties, and to imagine how it might be made possible.”

2.3.4.1 Objectives

Short changeover times make it possible to switch between product variants quickly and flexibly. We can thus respond quickly to changes and produce in small lot sizes, as is required for levelling.

The fewer facilities are standing idle, the higher their net production time and the shorter the lead times. This enables us to increase the added value and improve productivity. Quality is ensured by “subsequent approval following changeover”. This is part of the changeover standard.

The advantages for the employees include (Bosch - QCO, 2003):

- **Easier:**
  - easier and more transparent change over processes cause less problems.
  - consistent work load of all the employees.

- **Quicker:**
  - quicker change over time leaves more time for other work.

- **Safer:**
  - better organization means less physical strain during the changeover.
  - planning safety for production planning due to better standardization

2.3.4.2 Implementation

In order to speed up the changeover process, we consider three areas (Bosch Group, 2015):

- **Structuring of activities**.
  - We gather all activities required for a changeover and divide them into internal and external processes.
  - External changeover processes are those that also can be performed while the machine is running; internal changeover processes are only possible when the machine is stopped.
  - The aim is above all to reduce the internal changeover time.

- **Optimization of activities.**
  - For example, we can shorten routes, provide tools externally, standardize assembly procedures and reduce tool variants.

- **Optimization of organization.**
  - We can reorganize activities by deploying several associates simultaneously for one activity, for example.

<u>The Implementation comprises of 8 Steps (Bosch - QCO, 2002):</u>

1. Current status analysis

- Understanding and description of the changeover process.
- Identify the different CO processes (parameters) performed on the production line.
- Cluster CO families.
- Measure CO times for each family (focus on internal CO time) and generate CO matrix (figure 25).

Type (↓ from / to →)	A	B	C	D	E	F
A		20	10	20	10	20
B	30		30	30	30	30
C	5	30		30	5	30
D	30	5	30		30	30
E	5	30	5	30		30
F	30	30	30	30	45	

Figure 25 - C/O loss for C/O from Type to Type [min.] (Bosch - QCO, 2017)

- Describe the setup operation in a standard worksheet (task, time, walking distance, needed tools, internal/external).

- Identify bottleneck stations (should be main focus).

2. Segregation of internal and external activities

- Eliminate external CO while the machine is stopped
- Create and use checklists for each machine
- Perform function checks
- Improve transportation of CO parts and tools

3. Transferring internal activities to external activities

- Increase external preparation to minimize the internal CO time
- Preparation of needed parts and tools
- Standardize essential functions (clamps, centring devices ...)

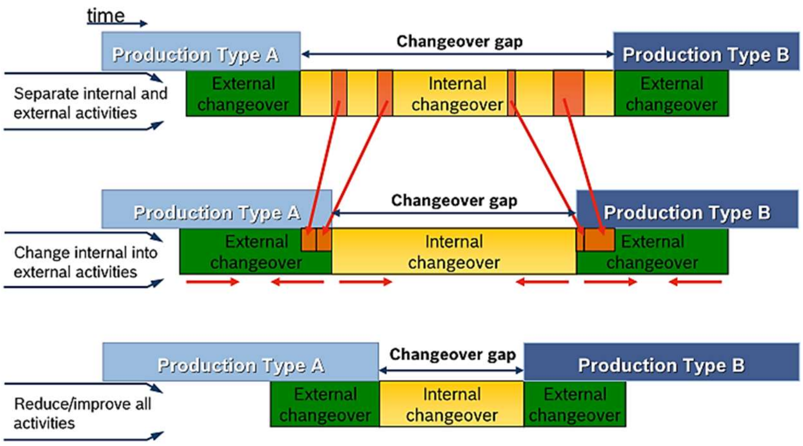


Figure 26 – Change internal activities to external activities (Bosch - QCO, 2006)

4. Localization of parallel activities

- Reduce CO time by improving manpower organization.
- Check if the longest setup action can be divided between operators.
- Visualize the walking way and waiting time for each operator.

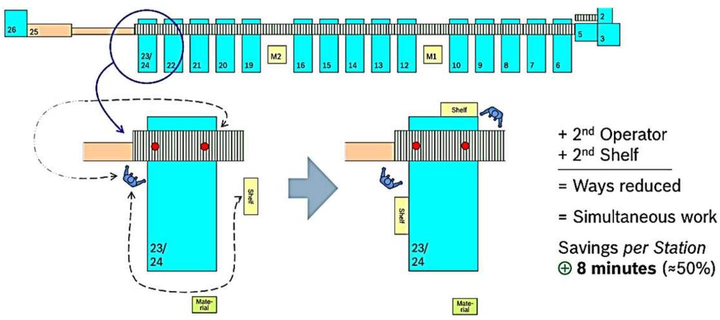


Figure 27 - Way walking (Bosch - QCO, 2017)

5. Rationalization of internal/external activities

- Reduce both external and internal CO times
- Implement parallel operations
- Use functional clamps
- Eliminate adjustments (i.e. teaching)

Figure 28 – Design improvement (Bosch - QCO, 2017)

6. Implementation of actions

- Implementation of actions from Step 1-5.
- Fixing of the future c/o process (script with considered change over steps) on printed form.
- Implementation of actions for entire change over matrix. Possibly define the required additional steps /data, determine and implement appropriate actions.

7. Verification of processes / Testing the results

- Analyse the status after the implementation

8. Standardization and target tracking

- Fixed, documented, standardized and trained process cycles
- Visualization of the improvements made and target tracking

2.3.5 Design modular and flexible fixtures.

Flexible fixture is being used with NC machine or machining center to clamp the different workpieces. Flexible fixture is divided into two categories: one is the traditional flexible fixture, and the other is the modern flexible fixture with the innovative principle and structure. The traditional flexible fixture is divided into the adjustable fixture and the modular fixture, and the modern flexible fixture mainly includes: phase change material fixture, adaptive fixture and modular program control fixture (Li, Chen, & Shi, 2016).

Traditionally, fixtures are applied for positioning and orientation of parts using basic elements (i.e. base plates, connectors, clamps, and locators) throughout manufacturing, assembly, or verification processes (Shirinzadeh, 2002). Applying dedicated fixtures may imply frequent and time consuming changeovers, if product variety is high compared to production volume, and every time a new part or product is introduced, it requires a development of a new fixture, which adds to the total number of fixtures to be stored and handled throughout the product lifetime (Bi, Lang, Verner, & Orban, 2008).

In the flexible fixturing concept, a single workholding system may be employed to hold workpieces of various shapes and sizes within a family and with similar manufacturing operations. Figure 29 shows the flexible fixturing strategies that have received significant attention in the past two decades (Shirinzadeh, 2002).

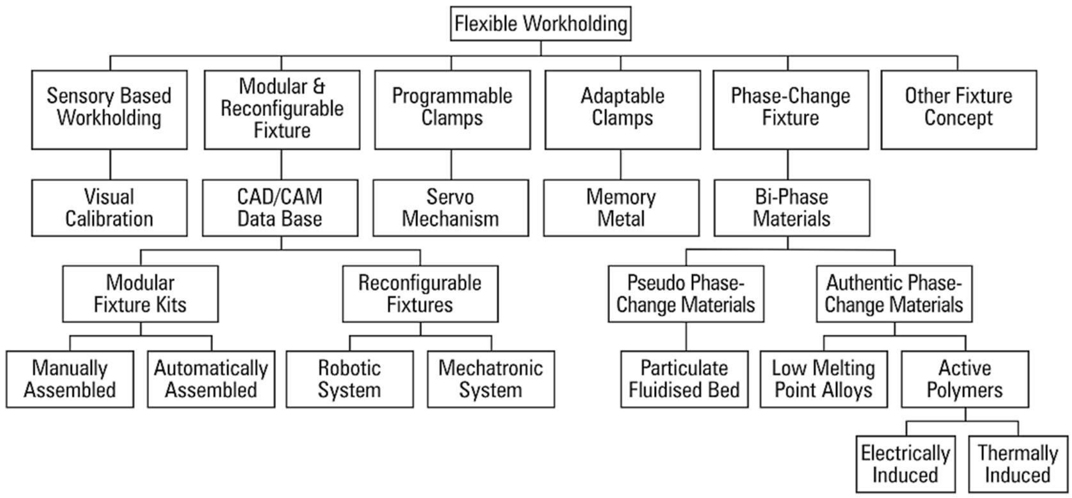


Figure 29 - Flexible workholding strategies (Shirinzadeh, 2002).

Modular fixture kits for machining, assembly and inspection operations have received the most research and commercial attention, and several solutions are available in the retail market (see Fig. 30). Machining solutions often consist of elements such as V-blocks, rectangular blocks and clamps bolted on a T-slotted plate or on a base plate with plain or tapped holes (Jonsson & Ossbahr, 2010).

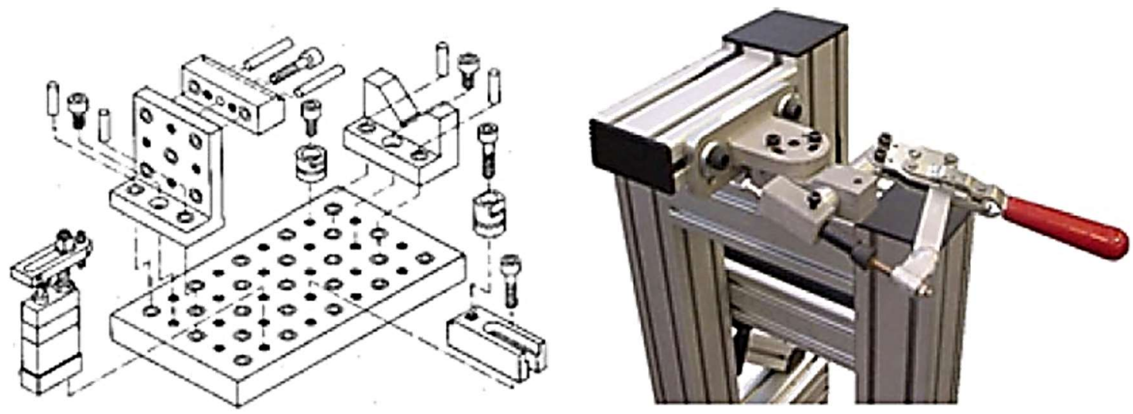


Figure 30 - Left A typical modular fixturing kit for machining. Right A modular kit for assembly.

2.3.6 Error and mistake proofing (Poka-Yoke)

In Japan, quality control experts coined the term "poka-yoke," which translates to "mistake-proofing." Poka-yoke refers to where the mistake is made—poka refers to the operation and yoke to the prevention of mistakes (HIRANO, 2009b).

Poka-yoke, another aspect developed by Shingo after World War II, in conjunction with source inspection, was designed to focus on the pursuit of quality at the source and capturing feedback on defects as close as possible to the root cause. In Zero Quality Control: Sources Inspection and the Poka-Yoke System, he states: "A Poka-yoke system possesses two functions: it can carry out 100 percent inspections and, if abnormalities occur, it can carry out immediate feedback and action." (Feld, 2001).

2.3.6.1 Objectives

- Understand definition of Poka-Yoke add its application in Lean management to identify & eliminate WASTE.
- Build Quality into process through early detection & prevention of Defects.
- Know the three basic functions of a Poka-Yoke device.
- Understand Approach of Poka-Yoke & its application in Defect Prevention.
- Learn to implement different Poka-Yoke approach.

2.3.6.2 Typical Errors

Processing errors	Wrong parts	Missing Operations
Damage materials	Inappropriate procedures	Tools or equipment improperly or setup
Missing part	Human errors	Missing information

2.3.6.3 Application

The process of Mistake Proofing is simply paying careful attention to every activity in the process and then placing appropriate checks at each step of the process. Mistake Proofing emphasises the detection and correction of mistakes at the Design stage before they become defects. This is then followed by checking. It is achieved by 100% inspection while the work is in progress by the operator and not by the quality inspectors. This inspection is an integral part of the work process (Basu, 2008).

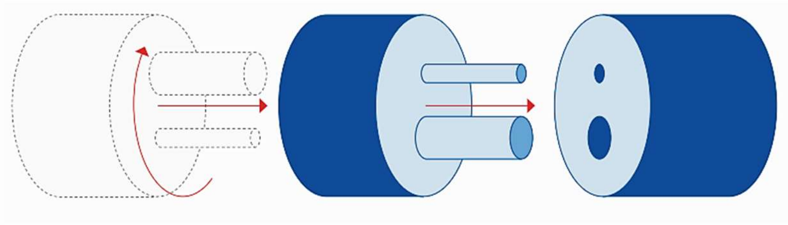


Figure 31 - An example for Poka-Yoke design.

Preventing errors in advance:

- In design: we design the geometry of all parts so that they can only be fitted in the correct position.
- In production planning: specially crafted devices prevent parts from being installed incorrectly.

Preventing errors during ongoing operation:

- Production planning and workshop managers: errors that occur are rectified immediately by implementing appropriate technical measures.

2.3.6.4 Basic steps

1. Perform Shingo's 'source inspection' at the Design stage. In other words, identify possible errors that might occur in spite of preventive actions. For example, there may be some limit switches that provide some degree of regulatory control to stop the machine automatically (Basu, 2008).

2. Ensure 100% inspection by the operator to detect that an error is either taking place or is imminent (Basu, 2008).

3. Provide immediate feedback for corrective action. There are three basic actions in order of preference (Basu, 2008)

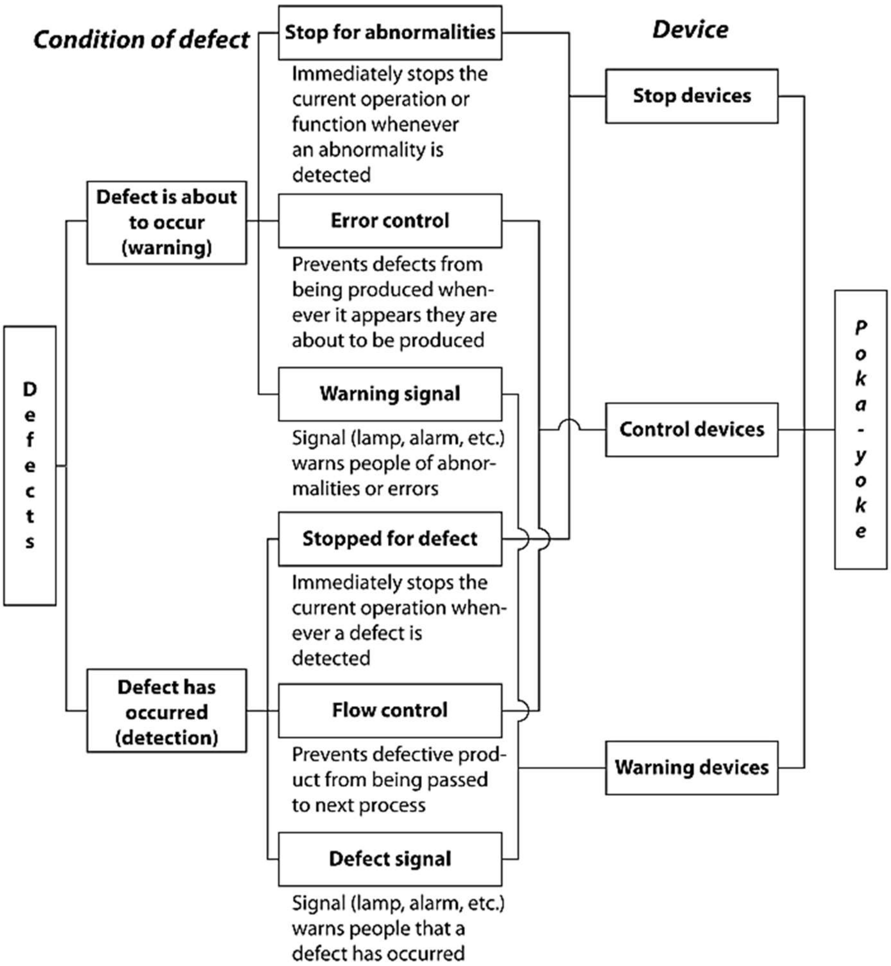


Figure 32 - The Relationship between Poka-Yoke Devices and Defects (HIRANO, 2009b).

The three types of poka-yoke devices shown in figure 32 are described below (HIRANO, 2009b):

- **Stop Devices**
  - Stop for abnormalities. This kind of device can detect certain abnormalities that can lead to defects. When it detects such an abnormality, the device stops the machine's current operation or function.
  - Stop for defects. This kind of device can detect when the machine has produced a defective product and immediately stops the machine's current operation or function so that it does not turn out more defective products.

- **Control Devices**
  - Error control. This kind of device prevents operators from straying from standard operations and making errors.
  - Flow control. This kind of device keeps defective goods from being passed to the next process.

- **Warning Devices**
  - Warning signal. This kind of device uses lamps and/or buzzers to warn people when an abnormality that may lead to a defect has occurred.
  - Defect signal. This kind of device uses lamps and/or buzzers to warn people when a defect has occurred.

2.3.6.5 Advantages

- Remove defect from root cause or source
- Faster defect detection and correction
- Less attention from worker/operators
- Improve safety of workers
- Improve equipment effectiveness and assures higher reliability

2.3.6.6 Limitations

- Requires special expertise in terms of instrumentation knowledge
- Requires work culture of 100% inspection and perfectionism, which is difficult to sustain
- Worker may sometimes fiddle with the instruments, especially settings on their machines, resulting in losses to the company

2.3.7 5S

5S is the basis for any lean implementation. It maintains stability and ground for the growth of lean in an organization. It is a tool to reduce waste. It separates what is needed from what is rarely used, leaving only what is strictly necessary to create value. In order to guarantee the continuous use of the 5S methodology regular audits should be implemented (Liker, 2004).

Figure 33 – 5S example (Bosch Group, 2015).

The 5S stand for:

- **Sort/Seiri**
  Sorting is the act of removing and discarding all unnecessary items from the work area (Ortiz, 2006).

- **Straighten/Seiton**
  Seiton deals with identifying and arranging items that belong in the area. These items should all be sorted and labelled as belonging in that area. This makes recognition of the proper tooling, resources, materials, etc. extremely visible (Feld, 2001).

- **Sweep/Seiso**
  Seiso has to do with maintaining order by sweeping and picking up on a regular basis (e.g., daily, bi-weekly). A production area should be neat and clean at the end of every shift (Feld, 2001).

- **Standardize/Seiketsu**
  Seiketsu is concerned with management discipline to enforce the standard activity. If the housekeeping activity does not become institutionalized within the operation, the area will not stay clean and employees will revert back to the old ways very quickly (Feld, 2001).

- **Self-discipline/Shitsuke**
  Shitsuke is management’s responsibility to reinforce the importance of housekeeping and to demonstrate leadership by follow-through and walking the talk.

2.3.7.1 Benefits of the 5S’s

It has gathered the essential benefits the 5S’s afford into a chart that shows their various interrelations. figure 34 shows this chart.

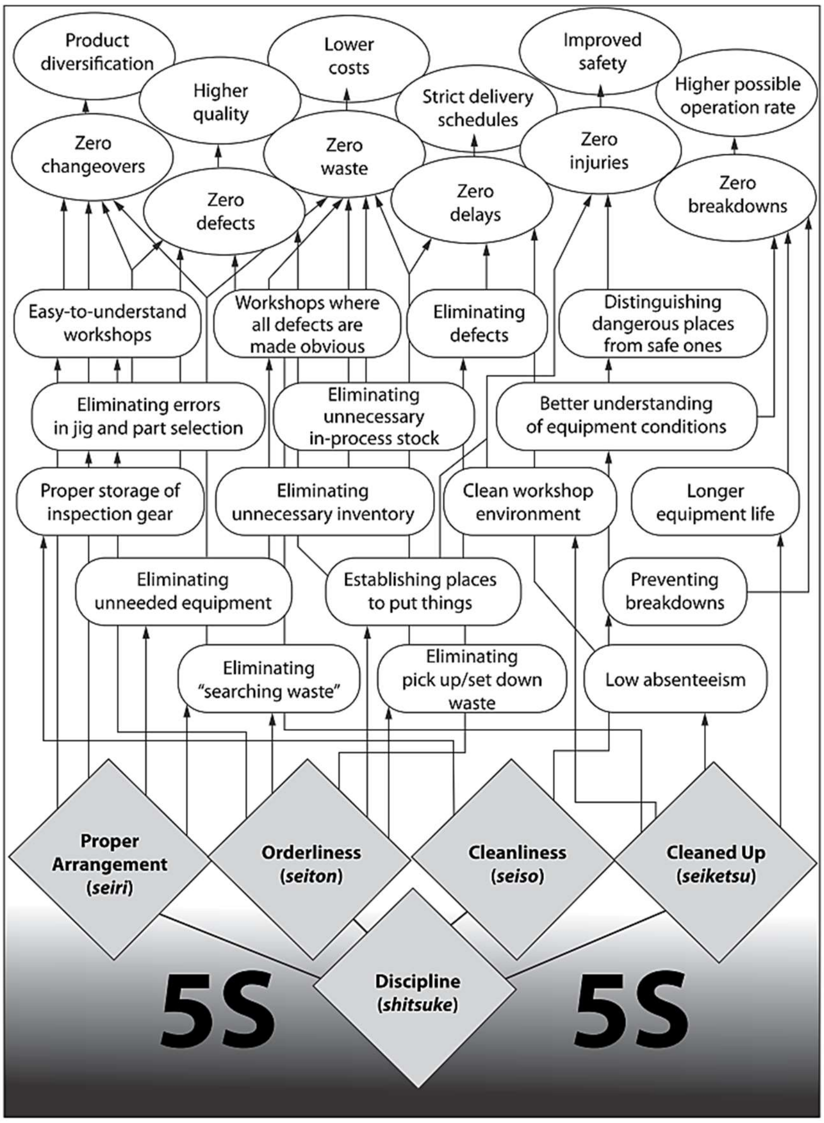


Figure 34 - The Eight Benefits of the 5S's (HIRANO, 2009a).

As Hirano states in JIT Implementation Manual (The Complete Guide to Just-In-Time Manufacturing: Volume 2) the eight benefits for 5S:

Benefit #1: Zero Waste Bringing Lower Costs and Higher Capacity

- Eliminate "stand-by waste" in in-process inventory and warehouse inventory.
- Eliminate actions that do not add value (such as picking up, putting down, counting, carrying).

Benefit #2: Zero Injuries—Bringing Improved Safety

- When the equipment is kept in spotless condition, you are able to discover mechanical failures and hazards immediately.

Benefit #3: Zero Breakdowns—Bringing Better Maintenance

- Trash, dirt, and dust can all lead to major equipment breakdowns and much shorter equipment life.
- Maintain and check the equipment daily to nip breakdowns in the bud.

Benefit #4: Zero Defects—Bringing Higher Quality

- Defects are harder to discover when the workplace is a mess.
- Pickup things from their proper places and put them back properly. This will help eliminate part- and tool selection errors.

Benefit #5: Zero Changeovers—Bringing Product Diversification

- Proper arrangement of dies, jigs, and tools eliminates a major form of waste: “searching waste.”
- Sparkling clean equipment and a neat and clean workplace help raise operational efficiency.

Benefit #6: Zero Delays—Bringing Reliable Deliveries

- When defects are gone, deliveries go out on time!
- Absenteeism is lower at 5S workshops.

Benefit #7: Zero Complaints—Bringing Greater Confidence and Trust

- Products that come from a neat and clean workshop have no defects.

Benefit #8: Zero Red Ink—Bringing Corporate Growth

- People who work in 5S workplaces earn more respect and trust in their community.

THESIS DEVELOPMENT

3 THESIS DEVELOPMENT

3.1 The Case Company – Bosch Security Systems

Founded in 1886 by Robert Bosch, Robert Bosch began as an electrotechnical and mechanics precision workshop, becoming one of the largest and most powerful international groups since 1964.

Currently, Bosch Group has activities in different business lines, which is reflected in the large number of products on the market with the Bosch brand, ranging from automotive components, power tools, hydraulic and pneumatic equipment, appliances, water heaters .

The Bosch Group is a world leader in the provision of technology and services and is divided into three main areas:

- Automotive Technology.
- Industrial Technology and Consumer Goods.
- Construction Technology.

Being the great success factor of the group, the Quality of the products supplied, "It has always been an unbearable thought for me, that someone can inspect some of my products and find them inferior at some point. For this reason, I have constantly produced products that support the most meticulous analysis - products that prove themselves "superior" in all respects. "(Robert Bosch, 1918).

Over the last years, the Organization has been committed to the process of continuous improvement, with an impact on its competitiveness.

The following successful goals are highlighted:

- 2005 Certification according to ISO 9001: 2000
- 2003 Introduction of the BPS program (Bosch Production Systems)
- 2004 Participation in the European Quality Award organized by EFQM
- 2005 Introduction to Six Sigma Methodology

3.1.1 Products Description

Bosch Security Systems - Security Systems, S.A. belongs to the Bosch Security Systems business unit, and is focused on the production of video cameras, monitors, digital recorders and accessories for security systems

Offering an unrivalled choice and an integrated approach, Bosch Security Systems offers a complete range of specialized state-of-the-art products and systems for standard or customized applications and projects.

Table 2 – Video products produced at Bosch Security systems.

Product	
	The DIVAR network and hybrid offer the ability to create video surveillance with professional security features that are easy to install and simple to use.
	With a selection of form factors including fixed dome (FLEXIDOME), bullet (DINION) and box (DINION) cameras, resolutions up to 5 megapixel, and low-light solutions like Bosch's starlight technology to choose from, this range offers a comprehensive portfolio to meet many different needs. From retail to industrial solutions, a smart combination of these cameras provides solutions for indoor or outdoor, day or night, discrete or visible video security.
	The security industry has been in a "pixel race" for several years. It's the level of detail that has driven the business. These cameras have the ability to locate a (moving) person fast and accurately - even when further away. They enable users to manually or automatically keep track of persons of interest as they move – even at speed, far beyond a fixed camera's field of view.
	The true potential of MIC IP cameras is the combination of their rugged design with built-in Intelligent Video Analytics that is specifically designed for the most demanding environments. MIC IP cameras are built to perform in practically any environment.
	The DINION IP thermal 8000 camera provides early detection by combining thermal imaging with Intelligent Video Analytics. The highest resolution and thermal capabilities of the camera offer excellent details of the scene, making the information easier for users to interpret.

3.1.2 Plant Overview

In Portugal since 1911, Bosch is one of the most recognizable companies in the country. With a strong presence, Bosch exports more than 95% of its production to international markets tend has expanded its research and development activities in hardware and software for different business sector.

Looking ahead and focusing on technological innovation, Bosch Termotecnologia, in Aveiro, Bosch Car Multimedia Portugal, in Braga, and Bosch Security Systems, in Ovar, develop and manufacture residential water solutions; car multimedia and sensors; and security and communication systems. The Bosch Group's Portuguese headquarters is located in Lisbon with central functions for sales, marketing, accounting and communication as well as a team which offers human resources related shared services for the Bosch Group. In addition, Bosch operates a subsidiary of BSH Hausgeräte GmbH in Lisbon.

The challenges of the market and the goal to become a leading company in IoT (Internet of Things) are also relevant for Portugal. With 3,967 associates (as per December 31, 2016), Bosch is one of the largest industrial employers in Portugal with total net sales of 1.1 billion euros in 2016 including internal deliveries to affiliated companies.

Figure 35 - Major location in Portugal.

3.2 The Work Context

This project focuses on a specific assembly line, where complex electronic products are produced. This assembly line is located in a distinct area of the factory where the production of video cameras is carried out or as it is commonly known in the organization by line 19 in an area of 159 m^2.

It is intended to intervene in this production line (L19) by studying the process in order to propose improvement actions, optimizing the assembly process of this type of products.

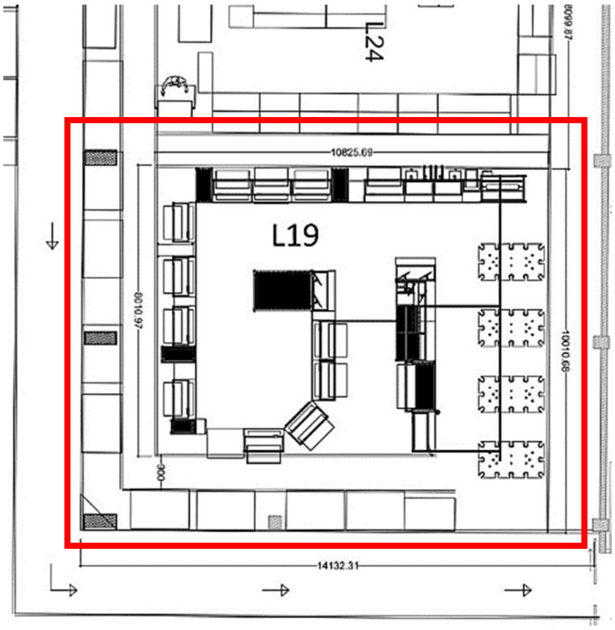


Figure 36 – Assembly line selected for improvement.

3.3 Methodology

Workers in the assembly line carry out a variety of tasks to produce the final products. There are many tasks in the different stages of the work process which includes tightening the components using fasteners, using mount fixtures, operating machines, testing the assembled product and build the package.

The procedure involves analyzing the process flow with the help of lean tools with the main goal of reducing wastes. Essentially, it was necessary: collect process data, as tasks and compile them; realize what are value and waste and getting the improvements opportunities.

A process line under an intensive lean environment in which workers can be rotated through all workstations within the cell to finish the product was considered for the study. The line will have to be monitored to observe the man flow, the process sequence, the fixtures used and the ergonomic aspects. Layout details including reach of tools and parts and distance between each workstation were considered. This industrial study was carried out in parallel with a new industrialization project for a new model that will be integrated into the same production line. Taking this project into account, it was necessary to evaluate the assembly sequence, specify the necessary tools and workstations. In order to have an efficient industrialization of this new model, it was important to consider how it will be possible to combine tools and probably the same workstations, in order to design the layout and the appropriate assembly process that contemplates this new reality.

The following table presents an adapted methodology known as DMAIC, which will be used in this project.

DMAIC is a data-driven quality strategy used to improve processes. It is an integral part of a Six Sigma initiative, but in general can be implemented as a standalone quality improvement procedure or as part of other process improvement initiatives such as lean.

Table 3 – DMAIC adapted methodology

PHASES	DESCRIPTION	TOOLS
Define the Problem	Identify and define the problems to characterize the initial situation of the working conditions and to identify new improvement opportunities	Pareto's chart.
Measure / Map the Process	• Collection of information from the process. • Creation of a process map in the initial situation. • Photographs.	Process Flow Map
Analyse the Process	• Identification of waste, value and activities without added value. • Identify, organize, and prioritize. • Select and verify the causes of the problems. • Define possible additional information.	Ishikawa Diagram.
Improve	• Enumeration of all possible solutions • Classification of solutions and selection of the best • Development of performance metrics • Communication and implementation of the solution • Measurement of results • Determination of the necessary follow-up time.	Brainstorming PDCA 5S A3 Sheet
Assess / Control the Process	• The purpose of this step is to sustain the gains. • Evaluation of the results of the modifications • Lessons learned • Monitor the improvements to ensure continued and sustainable success.	Plan. Pareto's chart. Standardization

3.4 Problem Description

This study deals with a complex manual electronic device's assembly line composed of 16 workstations and 5 test tables at the end of the line to assess and measure all products in a period of 12h. The product complexity requires a rigid schedule and a rigorous respect of the takt time. For these reasons, the line balancing, the fixtures used for assembly and process sequence properly architected are a core activity and needs to be efficient and effective. Although, the company where this study was implemented already has established a culture way of produce based in LM philosophy, in which the organization work methodologies are focused on a lean mindset environment, for these reasons it was a remarkable challenge and more difficult to find production wastes. However, after a thorough observation of this assembly line, some problems were detected to be analyzed, as the area occupied, the time needed to the operator change workstations, the production capacity and the flexibility of the line to get new products. In order to overcome this drawback and to eliminate wastes, a new ergonomic incorporated layout and a new approach to fixtures design needs to be developed. Change in work methodologies and redesign of the layout lead to tack time reduction and remove non-value-added activities.

3.4.1 Value Stream Mapping (VSM)

The VSM analysis permits identifying specific root causes bringing problems across value stream. The VSM method is only an analytical method and does not remove the manufacturing issues or root causes by itself. Therefore, it is a relevant tool to identify problems that others lean methods could fix. Take this in consideration, the aim of using VSM approach is to help a better visualization of what kind of problems need to be analyze, to work deeper on improvements solutions with the intend of eliminate wastes and increase productivity.

Another aspect relevant to notice, is the VSM present in this work has many information omitted, due to the restrict confidentiality rules from the company where this work is implemented.

3.4.1.1 Current situation

Due to the variety and complexity of electronic devices assembling the VSM chart illustrated in figure 37 represents the flow value stream chain of the product version with the high demand of the production line studied in this paper. The aimed of this technique is mainly focusing on the final assembling line of this kind of products, taking into account the identification of improvement opportunities related to reducing tack time outcome for a better line balancing and workspace optimization.

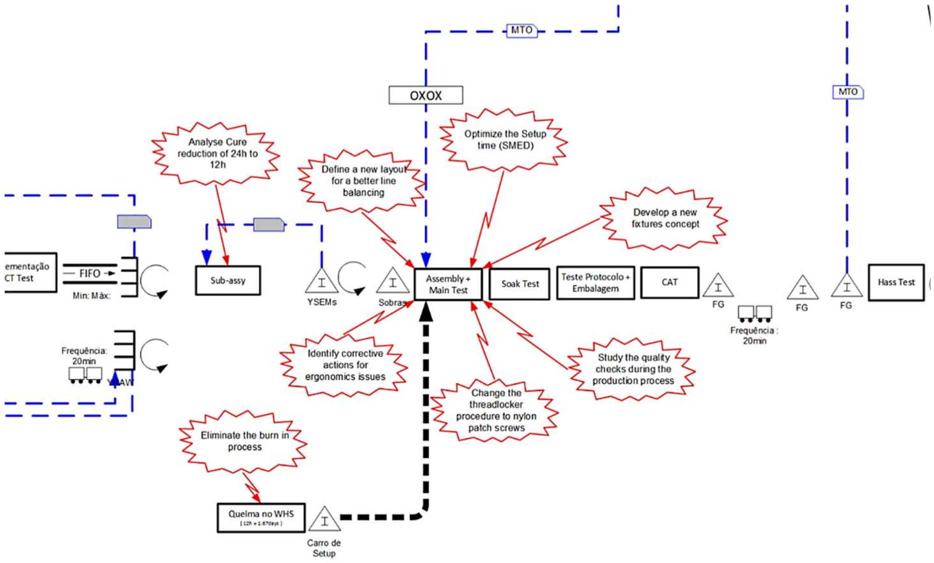


Figure 37 – Detail of the final assembly flow on the VSM.

The table 4 presents all identified problems, their initial causes identified by method 5 whys and possible solutions identified by brainstorming discussions with the associates of the company.

Table 4 – Identified issues, it's causes and potential solutions.

Identified Issue	Proposals to improve	Classification
Cure time of sub-assemblies with a duration of 24 h	Reduce the cure time for 12h, to be possible a cure supermarket optimization, generate an increase of the store capacity.	Process
Inappropriate line Layout	Design a new layout for a better balancing and ergonomic aspects	Balancing Line layout
Setup times too long	Optimize the setup times	SMED
Low Line capacity, due to the cycle's times been too high	Develop a new fixtures concept; Eliminate unnecessary assembly operations wish don't add value to the product;	5S Design JIG's
Ergonomic issues	Identify all the critical ergonomic issues, to be possibly create solutions to avoid operator fatigue.	Ergonomic
Inadequate quality confirmation during the mount process	Quality checklist revision, to assure the adequate evaluation take in consideration what is real need to be check by the operators.	Quality

3.4.2 Lean Line Design (LLD)

Lean line design is one of the best systematic approaches to streamline processes and eliminate waste. The goal is to redesign production and logistics to improve overall efficiency and flexibility, as well as reduce the proportion of investment, the required space and shorten the output time. This method can be used to combine two assembly lines to reduce the area occupied or just to optimize a complex assembly line to achieve better overall performance. In this case, the LLD method was applied to an optimization of the production line, improving the time of output of the different versions of a product family, but all the work carried out took into account that the desired version has the highest forecast for this line, not considering versions already defined as end of life (EOL), that is, product variants whose quantities planned to produce in this line are very low and a deadline is already established to stop the production of these models.

The Lean Line Design method as shown in figure 38, is complemented by different techniques such as line balancing, layout design, 5S and others that can be applied to achieve the expected results. Therefore, it is necessary to have the proper knowledge of each tool to have a clear vision of what will be necessary to redesign a new assembly line. So, the reason for applying this tool was to eliminate some ergonomic problems that were identified as critical, decrease target cycle time, reduce the area occupied, improve walking flow, match all workstations and equipment in the same space.

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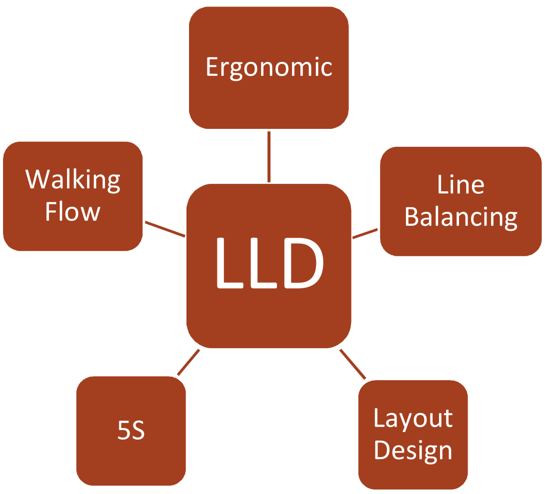


Figure 38 – Lean techniques used on the LLD method.

3.4.2.1 Current State

The actual state was established by recording the current data and times for the line that needs to be redesigned as a Lean line in the future step. The actual state promotes a better understanding of the work steps and their interaction. In order to have a complete understanding of the productive organic of an assembly line, it is important to design several options in terms of the number of associates available to work on the line, because this information will give us a better functional notion about the decisions that will have to be taken to redesign the line in the future. Thus, the data collection was based on an assembly line scenario with a flow operation contemplating the number of associates of 6 and 8, as these are the most common realities in this assembly line, otherwise it would be an exhaustive data collection if we had to look at all the options.

1. **Line Layout**

The studied assembly line is categorized as a line that produces each model in batches, being the different models of the same product family, having thus, a very similar architecture. Basically, whenever there is a need to produce a different model it is necessary to setup the line, which consists of replacing the raw material in each workstation and changing the assembly fixtures needed. It is more economical to use one assembly line to produce multiple products versions in batches than to create a separate line for each model.

The current layout is designed in a U-shaped configuration, where the occupied space is divided into two areas, the main area that has the dimensions of 143 m^2 and a second secondary area with the dimensions of 16 m^2. Therefore, we are facing a large assembly line, take in account the building of video cameras. The location of this assembly line at the factory only allows having material supermarkets on two sides, that are close to the corridor side, which allows simple and easy delivery operation. In the figure 39 show 3d model of the main assembly area.

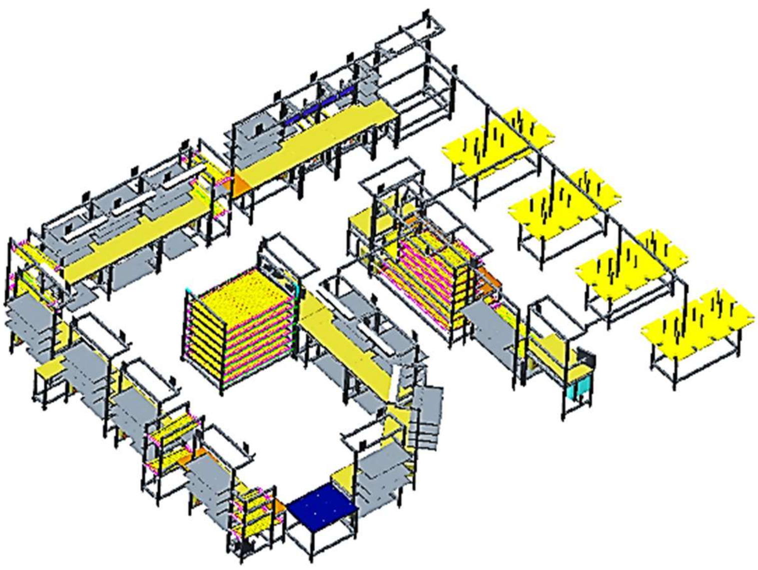
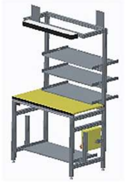
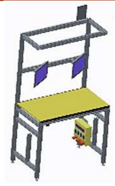
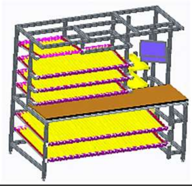
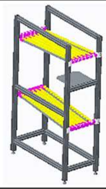
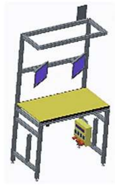


Figure 39 – Assembly line 3D model

In table 5, are referenced all the workstations, support structures and equipment that influence the occupied space of the designated main assembly area.

Table 5 – Detailed workstations that belongs to the main assembly area.

Station Picture	Description	Qt	Station Picture	Description	Qt
	Assembly Workstation	**12**		Man test workstation	**4**
	Package Workstation	**1**	-	Leak Test	**1**
	Support ramps to rework units	**4**		Supermarket of all sub-assemblies that need to have 24h curing	**1**
	Soak test table	**4**		Quality inspection station	**1**
	manual hand press machine	**4**	-	Pneumatic press machine	**1**

In table 6, are referenced all the workstations, support structures and equipment that influence the occupied space of the designated secondary assembly area. This second has a new process that appears with the necessity of having the production competence of gluing windows

Table 6 - Detailed workstations that belongs to the secondary assembly area.

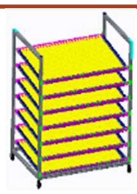
Station Picture	Description	Qt	Station Picture	Description	Qt
	Assembly Workstation	**1**		Supermarket of all windows that need to have 48h curing	**1**
	Soak test table	**1**		Gluing machine	**1**

Figure 40 shows an overview of the entire area occupied by the studied assembly line, so that the distance between the main and the secondary area is visible, as well as the existence of another assembly line in the middle of both. Different sections of the layout were highlighted and respectively identified with captions.

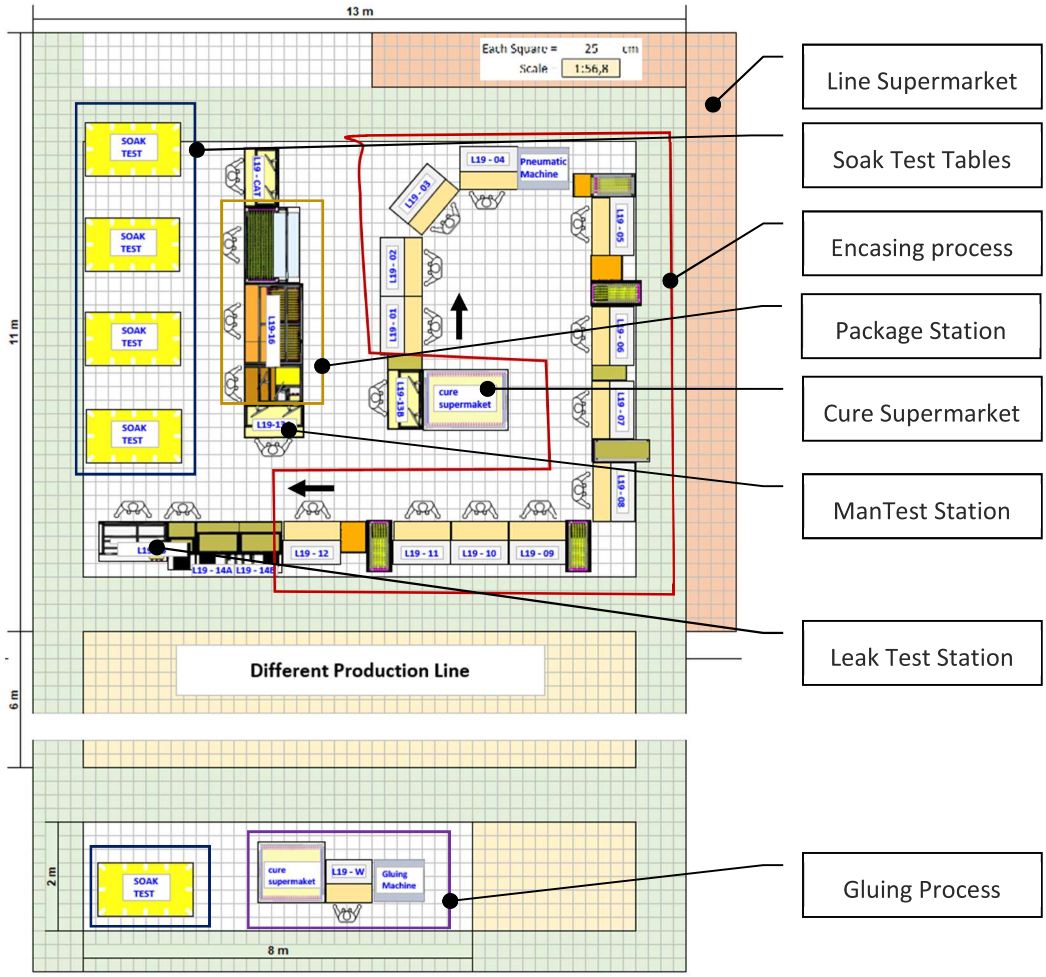


Figure 40 – Current line layout

2. Line Balancing Process

The line balancing process is performed first by plotting the operator line balancing chart. To plot the operator line balancing, Customer Takt Time, Planned Cycle Time and Operator Cycle Time is calculated.

The Customer Takt Time (CTT) is based on the entire call-offs for one line/production unit. It forms the basis for the line design and the calculation of the target cycle time.

For calculate CTT it was considered one shift of 8 hours and the parameter customer demand was defined take in account the maximum line capacity simulating a reality of 6 and 8 associates on the assembly line. The reason for this approach is because the version of the product being studied is a production make to stock. So, the CTT value is:

$$Costumer\ Takt\ Time\ (CTT) = \frac{Your\ available\ work\ time\ per\ shift}{Customer\ demand\ rate\ per\ shift}\ [sec./pcs]$$

Table 7 – Costumer Takt Time for 6 and 8 associates.

Simulation	Your available work time per shift [s]	Customer demand [pcs]	CTT [s/pcs]
6 Associates	29100	24	**1212,5**
8 Associates		32	**909,4**

With CTT result obtained from the previous equation, it’s time to calculate the Target Cycle Time (TCT). It’s necessary considering the performance and quality losses (OEE) of the line. Changeover losses are scheduled losses and therefore considered separately. Equation to calculate CTT is as below:

$$Target\ Cycle\ Time\ (TCT) = CTT \times \frac{OEE\ (\%)}{100\%}\ [sec./pcs]$$

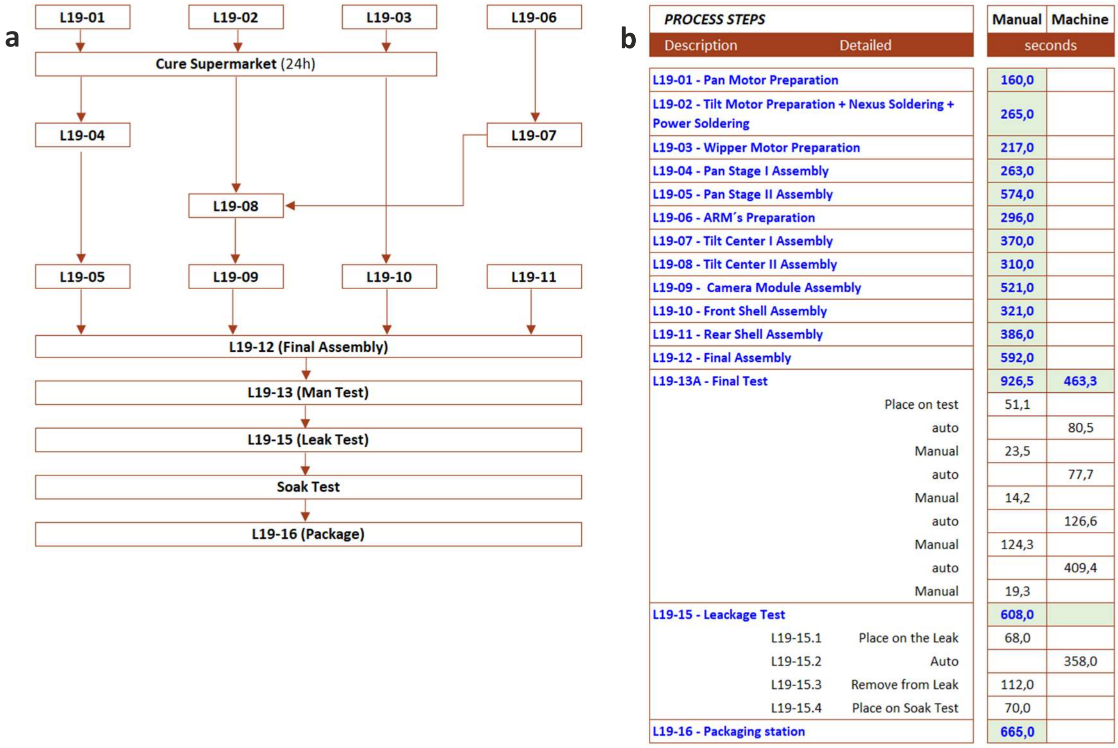
Table 8– Target Cycle Time for 6 and 8 associates.

Simulation	OEE [%]	CTT [s/pcs]	TCT [s/pcs]
6 Associates	94,24	1212,5	**1143**
8 Associates		909,4	**857**

The starting point for the design of a lean line is to plan the flow of associates. To do this we gather all repeating manual tasks/work steps, as well as the time required for them, and arrange them into a sensible order. This creates a “waste-free” sequence of manual, cyclically recurring activities. Then we gather all non-manual, automated process steps and determine the machine capacity. We calibrate manual and automated steps so that they lie within the target cycle time.

Process flow would help us to know the mount sequence carried out in the assembly line. The below figure 41a shows us the process flow currently carried out in the most produced unit on this assembly line.

A stack diagram is prepared for all manual operations in the assembly line, which are put in a stack in a scaled manner completely independent from the physical workstation as show in figure 41a, the time study of each station is carried out and arranged in stack diagram as shown in figure 41b.



PROCESS STEPS		Manual	Machine
Description	Detailed	seconds	
L19-01 - Pan Motor Preparation		160,0	
L19-02 - Tilt Motor Preparation + Nexus Soldering + Power Soldering		265,0	
L19-03 - Wipper Motor Preparation		217,0	
L19-04 - Pan Stage I Assembly		263,0	
L19-05 - Pan Stage II Assembly		574,0	
L19-06 - ARM´s Preparation		296,0	
L19-07 - Tilt Center I Assembly		370,0	
L19-08 - Tilt Center II Assembly		310,0	
L19-09 - Camera Module Assembly		521,0	
L19-10 - Front Shell Assembly		321,0	
L19-11 - Rear Shell Assembly		386,0	
L19-12 - Final Assembly		592,0	
L19-13A - Final Test		926,5	463,3
	Place on test	51,1	
	auto		80,5
	Manual	23,5	
	auto		77,7
	Manual	14,2	
	auto		126,6
	Manual	124,3	
	auto		409,4
	Manual	19,3	
L19-15 - Leackage Test		608,0	
L19-15.1	Place on the Leak	68,0	
L19-15.2	Auto		358,0
L19-15.3	Remove from Leak	112,0	
L19-15.4	Place on Soak Test	70,0	
L19-16 - Packaging station		665,0	

Figure 41 - a) Process flow diagram; b) Cycle time for each workstation.

After the information obtained through process flow diagram to build a unit and know the cycle time for each station as shown in figure 41, it is time to start showing the stack workflow for each operator, considered the scenarios of 6 and 8 associated.

In the table 9 is shown the actual state flow assembly sequence with the condition of being working 8 operators in the line.

Table 9 – Flow assembly sequence for 8 associates

Operator	Flow Assembly Sequence			Walking [s]	Operator Time [s]
Operator 1	L19-01	L19-05		58	**792,0**
Operator 2	L19-02	L19-03	L19-04	26	**771,0**
Operator 3	L19-07	L19-08		9	**689,0**
Operator 4	L19-06	L19-09		28	**845,0**
Operator 5	L19-10	L19-11		7	**714,0**
Operator 6	L19-12	L19-15.1		14	**674,0**
Operator 7	L19-13	L19-15.3	L19-15.4	10	**655,3**
Operator 8	L19-16			33	**698,0**
			Total =	**185**	

The current condition of the layout with the cycle times of all the operations is plotted in the Operator balance chart as shown in the figure below.

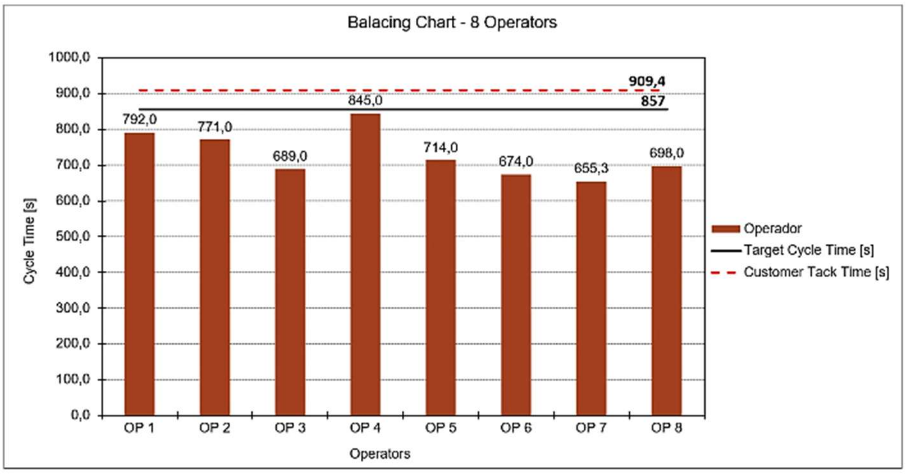


Figure 42 – Current Line Balance chart for 8 operators.

The operator line balancing chart plotted for the current condition has a bottleneck loop whose cycle time is close to the Customer Takt Time, which is the loop made by the operator 4. The cycle times of all operations are less than the Cycle Time Target. This line is unbalanced by 7% and the production capacity is 32 pcs/wd, the calculation of these values can be verified in the balance sheet in Annex 5.

In the figure 43 is demonstrated in the actual state layout the work flow for each operator. The walking time for each operator gives a total of 185 seconds moving across stations.

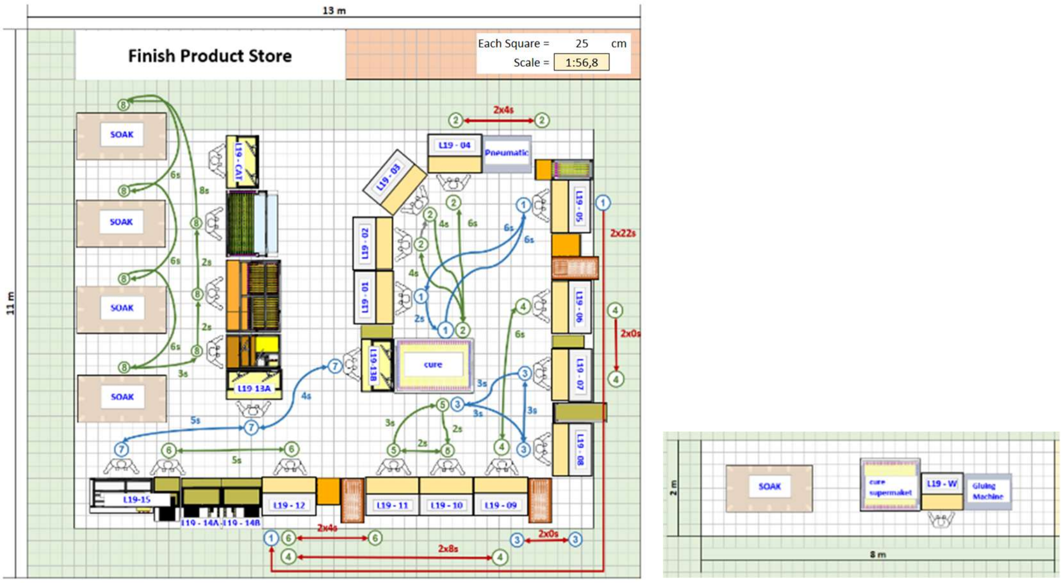


Figure 43 – Current flow diagram Layout for 8 associates.

In the table 10 is showed the actual state flow assembly sequence with the condition of being working 6 operators in the line.

Table 10 - Flow assembly sequence for 6 associates

Operator	Flow Assembly Sequence				Walking [s]	Operator Time [s]
Operator 1	L19-03	L19-04	L19-05		61	**1115,0**
Operator 2	L19-02	L19-06	L19-07		19	**950,0**
Operator 3	L19-01	L19-08	L19-09		31	**1022,0**
Operator 4	L19-10	L19-12			15	**928,0**
Operator 5	L19-11	L19-13			13	**862,3**
Operator 6	L19-15.1	L19-15.3	L19-15.4	L19-16	39	**954,0**
			Total =		**178**	

The Current condition of the layout with the cycle times of all the operations is plotted in the Operator balance chart as shown in the figure below.

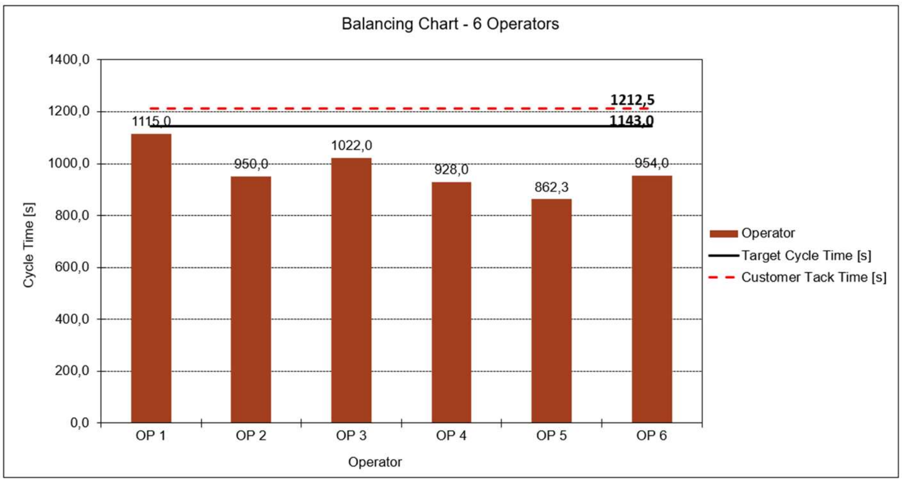


Figure 44 - Current Line Balance chart for 6 operators.

The operator line balancing chart plotted for the current condition has a bottleneck loop whose cycle time is close to the Customer Takt Time, which is the loop made by the operator 1. The cycle times of all operations are less than the Cycle Time Target. This line is unbalanced by 7% and the production capacity is 24 pcs/wd, the calculation of these values can be verified in the balance sheet in Annex 6.

Figure 45 shows the workflow for each operator of the current state layout. In this scenario it is possible to see a huge cross over between loops of different operators and the distance to walk between stations is longer compared to the current scenario of 8 associates. The walking time of each operator gives a total of 178 seconds passing through the stations.

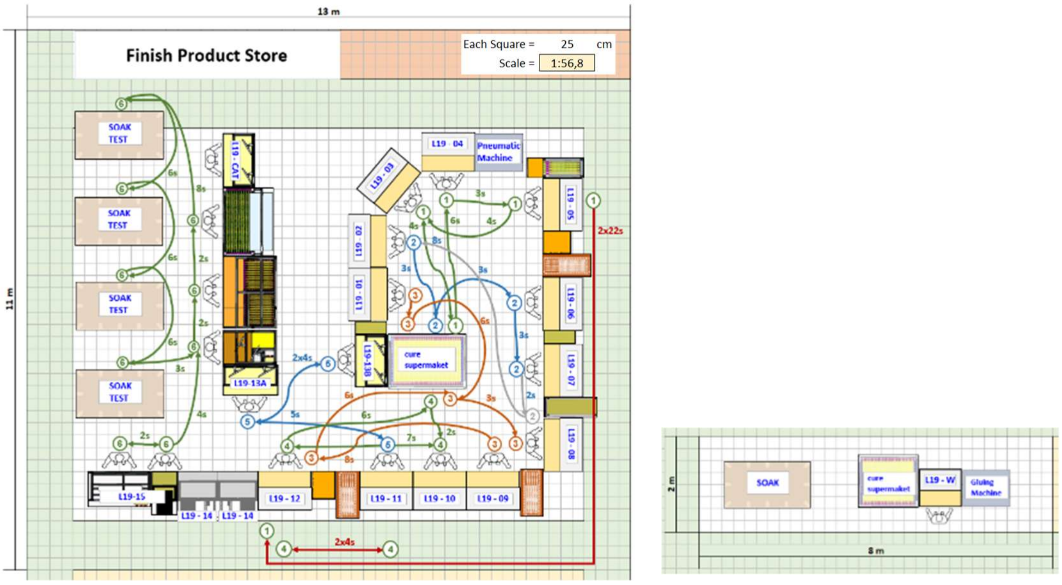


Figure 45 - Current flow diagram for 6 associates.

3.4.3 Production Process Optimization

In order to improve productivity and efficiency in each workstation on this complex manual assembly line, a deep knowledge of the product design is mandatory, in a way to understand where the production wastes are and how could be possible optimize this assembly line. After the operation process has been analyzed, the operator value-added and/or non-value-added activities were identified for every workstation. At each workstation, all operations processing cycle time were collected. The following topics are summarizing some wastes reductions.

The optimization of the production process is intended to adjust a manufacturing process to optimize some specified parameter sets without violating any constraints associated with what is specified in the product. The objectives of the optimization of the production process are:

- Create an ideal workspace on the assembly line that allows workers to perform their duties without obstruction or delays;
- Minimize the cost of production;
- Maximize yield and / or efficiency.
- Improve ergonomics aspects;

The production process optimization topic as showed in figure 46, is complemented by different approach’s such as SMED, 5S, TPM, assembly fixtures and others that can be used to get a leanness line.

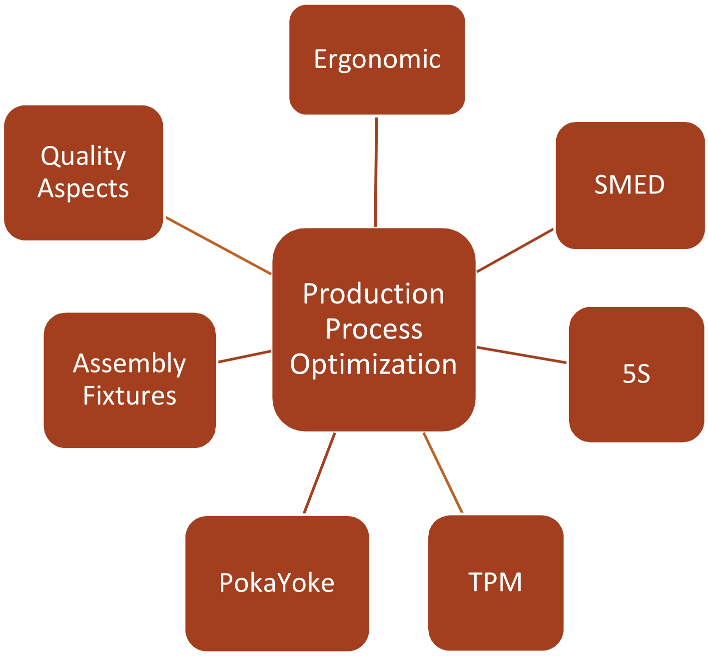


Figure 46 - Techniques used on the Production Process Optimizations.

3.4.3.1 Current State

Regarding the process optimization in this assembly line, the actual state was established by observing and recording the current production scenario. The current state promotes a better understanding of manufacturing processes and the interaction between them. In order to have a better understanding of the production process it is important to detail all the assembly tools used in this line in all the workstations and to understand their functionality to perform a quality assembly. Another relevant observation in the presentation of the current scenario is to identify processes that do not add value to the product, thus allowing the possibility of reducing or eliminating the current need, such as completing a quality checklist and placing threadlocker adhesive in all the screws.

1. **Assembly fixtures**

After the observation, registration and analysis of all fixtures used for assembly two models of one product in a complex manual production line, it was possible to deepen knowledge about the process and the improvement needed it to develop a new approach concept to redesign the mounting fixtures. The complexity criteria are intended to be used by engineers in manufacturing engineering for identification of potential quality issues in the development of assembly solutions.

1.1 Workstation 01 – Pan Motor Preparation.

In this station in necessary to consider the follow aspects:

- The position of the pinion and the position the tilt motor related to the mount plate. This is fulfilled with the fixture on the figure 47a.
- Press fit two bearing into pan motor plate. This operation is done by one adaptor used on a manual press equipment, check figure 47c;

a

c

Figure 47 - a) The assembly fixture; c) the manual Arbor.

1.2 Workstation 02 – Tilt Motor Preparation.

In this station in necessary to consider the follow aspects:

- The position of the pinion the tilt motor related to the mount plate. This is fulfilled with the fixture verified on the figure 48a.
- Press fit one bearing into tilt motor plate. This operation is done by one adaptor used on a manual press equipment, check figure 48b and c;

a

b

c

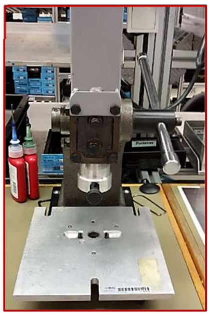


Figure 48 - a) The assembly fixture; b) The adaptor for press fit the bearing; c) the manual Arbor.

1.3 Workstation 03 – Wiper Motor Preparation

In this station in necessary to consider the follow aspects:

- Assure is proper mounted. The design only permits attach the parts in one way. The fixture is illustrated on the figure 49.

- Plug in the motor to check if works and set up a correct orientation.

Figure 49 - Fixture for mount wiper assy.

1.4 Workstation 04 – Pan Stage I Assembly

In this station in necessary to consider the follow aspects:

- Press fit one gear into a shaft, a bearing into Pan body and at last press fit a leap seal into the Pan body. For each task of press fit is necessary to set up of the equipment. The manual press and the adaptors used are illustrated on the figure 50.
- Another relevant factor in this task is the enormous force required to perform the mechanical interference between the gear and the shaft. Due to the use of a hand press, the force applied is made by an operator.

a b

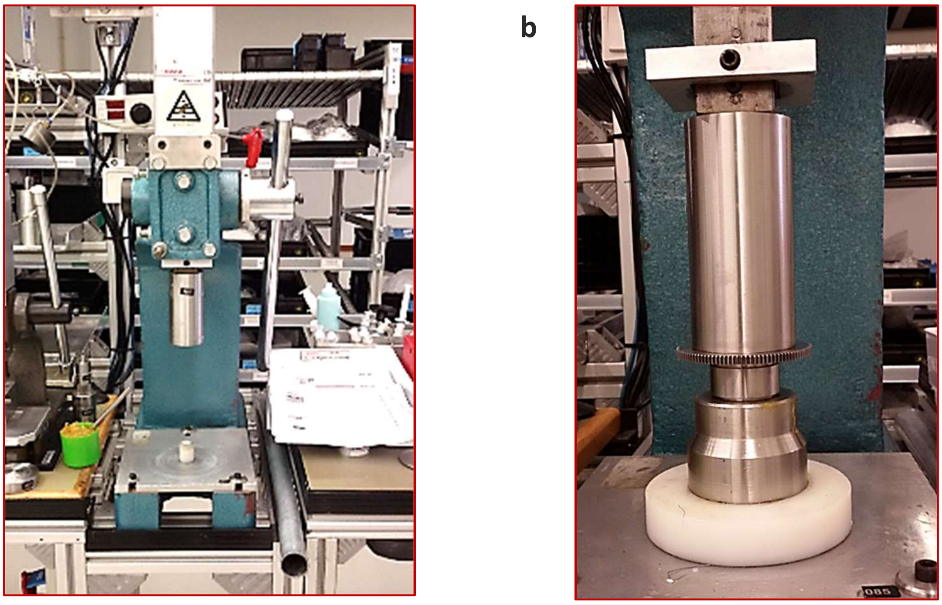


Figure 50 - a) Manual press equipment; b) The adaptors used to press fit.

- After making the press fits it is time to fix the Pan body to the fixture in figure 51a and tight the pan base with the help of a special tool as is showed on figure 51b.

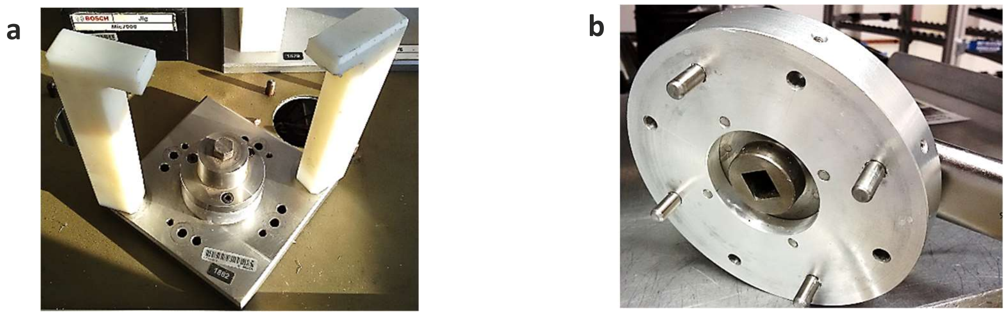


Figure 51 - a) Fixture to mount Pan assy stage 1; b) Special tool to tight Pan base.

1.5 Workstation 05 – Pan Stage II Assembly

In this station in necessary to consider the follow aspects:

- Quality confirmation by a fixture of the previous assembly.
- Press fit one ferrite into a plastic part. This operation is done by hand.
- The rest of the assembly process performed on this workstation only requires an accessory with the intention of ensuring some stability during assembly.

1.6 Workstation 07 – Tilt Center I Assembly

In this station in necessary to consider the follow aspects:

- Press fit one gear into a shaft, two bearings into Tilt center holes and at last press fit two leap seals into the same place of the bearings. For each task of press fit is necessary to set up of the equipment. The manual press and the adaptors used are illustrated on the figure 52.

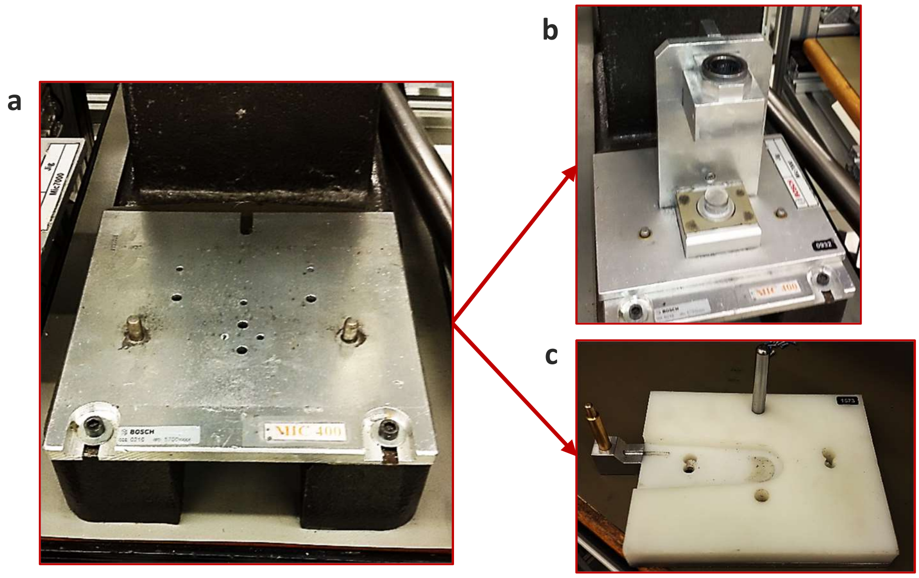


Figure 52 - a) Manual press equipment; b) The fixture to press fit bearings and leap seals; c) Press fit tilt gear.

- After performing the operations of press fitting is necessary do a quality inspection related to the position of tilt gear, and per last is need to tight the arms into the tilt center. On the figure 53 are showed the fixtures.

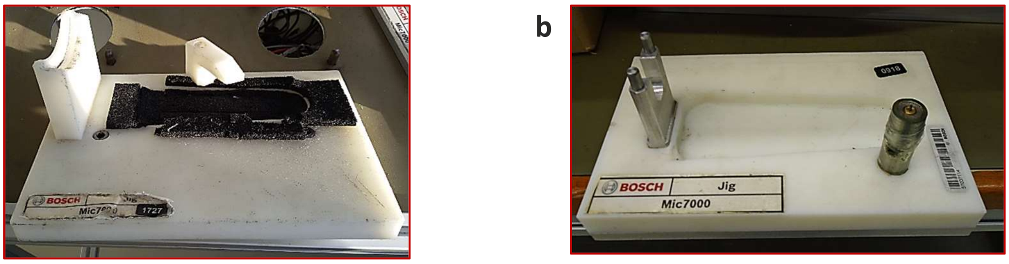


Figure 53 - a) Fixture used to tight the arms; b) Quality fixture to check the tilt gear position.

1.7 Workstation 08 – Tilt Center II Assembly

In this station in necessary to consider the follow aspects:

- In the workstation 08 is only needed one fixture to maintain the previous assembly in vertical position.

Figure 54 – Fixture to maintain the previous assembly in vertical position.

1.8 Workstation 09 – Camera Module Assembly

In this station in necessary to consider the follow aspects:

- To mount the camera modulo is needed a fixture able to guaranty a proper orientation of the different parts. In the figure 55 is showed the fixture used.

Figure 55 - Fixture to mount camera modulo.

1.9 Workstation 10 – Front Shell Assembly

In this station in necessary to consider the follow aspects:

- Is critical the position and the way which the optical window is tightened.
- Is necessary to press fit one bushing I a proper position and this operation is showed in the figure 56a.

a b

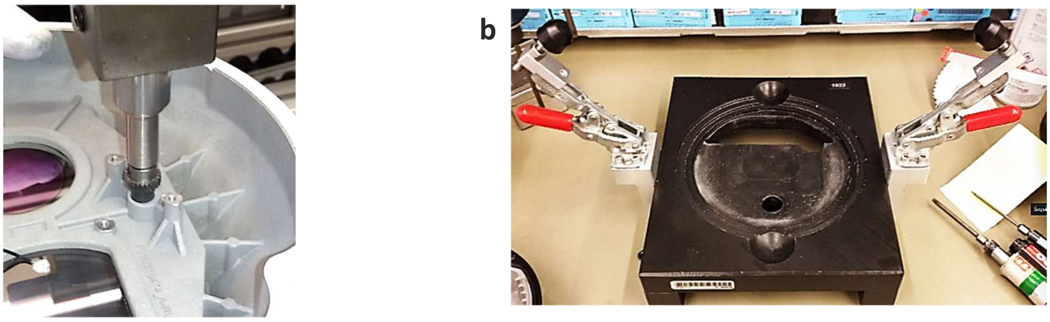


Figure 56 - a) Manual press fit of one bushing; b) Fixture to assembly front shell.

1.10 Workstation 11 – Rear Shell Assembly

In this station in necessary to consider the follow aspects:

- To get this assembly well done is necessary to place the rear shell in three different positions. In the figure 57 is showed two fixtures used on this station.

a b

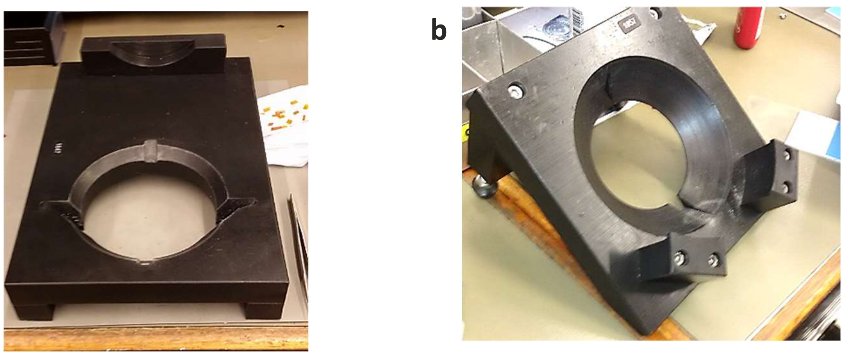


Figure 57 - a) Principal fixture for rear shell; b) Fixture use to add inclination.

1.11 Workstation 12 – Final Assembly

In this station in necessary to consider the follow aspects:

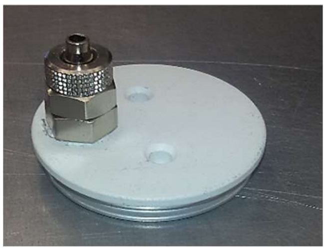
- The fixture used needs to support all the previous assembly to be easier for the operator handle them.
- Before start to close the unit is necessary the perform a torque confirmation in one type of screws.

1.12 Workstation 15 – Leak Test

In this station in necessary to consider the follow aspects:

- Necessary a special cap which would need to be tight on the unit for attach the air tube. This adaptor is a spare due to wearing. The adaptor is showed in the figure 58a.
- After the leak test, place the unit in the fixture showed in figure 58b for tight the yoke caps parts.

a



b

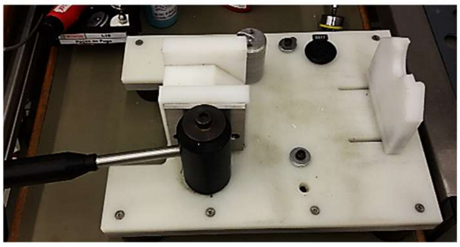


Figure 58 - a) Special cap to plug the air tube; b) Fixture use to fix the unit to tight yoke caps.

Table 11 and figure 59 show the classification of the mounting accessories used on the assembly line, with the time values resulting from the use of the assembly tools. Through the analysis of the graph shown in figure 59, it is evident that the most consuming time activity is the need to make fixations adjustments and the second one is the time required to perform the assembly operations. For more details, it is possible to consult in annex 9 the table where the critical time and the classification defined for each tools handling is verified for each workstation.

Table 11 - Fixtures classification percentage.

Classification	Time [min]	[%]
Fixtures Adjustments	3,7	65%
Operation	1,6	28%
Quality Checking	0,4	7%

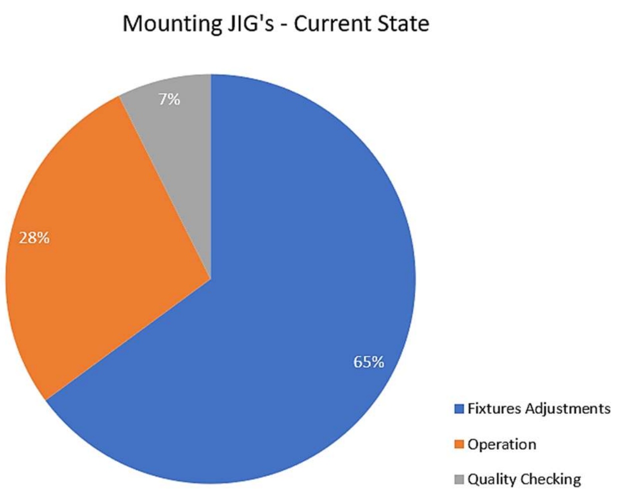


Figure 59 – Mounting JIG’s, current state.

2. Process activities

The main target of this step is to optimize the workplace regarding all manual tasks that imply quality verification or process steps. It is intended to identify unnecessary activities which do not generate value-added to the products, as well as remove unnecessary items.

On the follow topics will be describe some of the subjects that are a standard in the assembly process, which are:

2.1 Quality checklist

The quality checklist is a standard procedure with the purpose of conducting a quality control process for monitoring and recording product quality.

This document corresponds to signing and recording the date of the operation performed at each workstation by the operator in order to verify a set of necessary steps that have already been performed. Therefore, each product build is followed by a quality checklist, and all of these documents are stored in a specific location at the factory.

The time required to fill this document during the entire assembly process is approximately 30 seconds.

2.2 Liquid threadlocker task

Liquid threadlocker is a procedure applied in this case on screws, to prevent self-loosening and prevent loss of clamp load due to vibration and shock loads. The reason for using this type of adhesive is due to the characteristics of the product being able to be used in extreme applications such as the military industry, where it may be subjected to vibrations, and therefore, it is necessary that the torque applied to each screw is guaranteed and there are no gaps jeopardizing the robustness and reliability of the product.

This type of approach requires attention in the preparation of the screws, such as cleaning the screw with a solvent to eliminate dust and any oil present, derived from the process of manufacturing and transporting of them.

The amount of screws in this product that need to apply the liquid threadlocker is about 71 screws, used in different workstations. In the figure 60 is one example of the application of this type of adhesive in a screw. It should also be noted that whole process is manual, which causes variations in the application time and the quantity of liquid required.

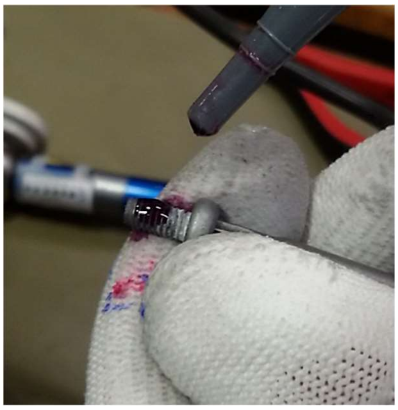


Figure 60 – Liquid threadlocker application.

Table 12 shows the average time required to apply the liquid threadlocker. This procedure is consuming time and does not add value to the product, because the reason for this is not to be considered an assembly operation of the parts that make up the product, but an additional task of putting glue on the screws to ensure a characteristic of the product that is the robustness to environments subject to vibrations. Therefore, the time required to perform this operation was measured on all workstations. As can be seen in table 12, the time for performing this activity is:

- Clean the screws with a kind of solvent the time spent is about 27 seconds.
- To put just one drop of glue on each screw, the time required is about 117 seconds.
- Finally, another task in this procedure is to make a pen mark on the screw with the aim of the operator constantly remembering that do not forget to put the glue. The time for this is about 31 seconds.

Table 12 – Average of times corresponding to the liquid threadlocker task.

Workstation	ECSP	Loctite	Marking
	Average ECSP [s]	Average time per station [s]	
P5	5,32	6,78	2,58
P6	3,19	9,19	6,52
P7	2,53	10,08	3,21
P8	5,21	25,10	2,79
P9	3,50	15,72	4,55
P10	2,46	16,70	2,59
P11	1,91	18,64	7,19
P12	2,80	14,49	1,55
Sum =	**26,915**	**116,69**	**30,975**

3.5 Problem analysed

In this chapter, the current state of the line layout, its associated unbalance, and the efficiency of the assembly process will be analyzed.

In terms of lean line design, what matters is having a clear view of the actual constraints of the current layout and what impact it has on line balancing.

Another important point will be to understand the assemblies and other activities of the process, in order to identify the residues and then the opportunities for improvement to obtain leanness in the assembly process.

3.5.1 Lean Line Design (LLD)

3.5.1.1 Current state analysis

Before going any further into the study of identifying possible improvement solutions, it’s time to analyze the production tasks, their integral movements, and the layout configuration. To assist in the process of analyzing this problem, we use a very useful quality tool in order to analyze all possible causes that may influence line balancing and efficient layout. Thus, in figure 61 below is the analysis of the actual state using the Ishikawa Diagram.

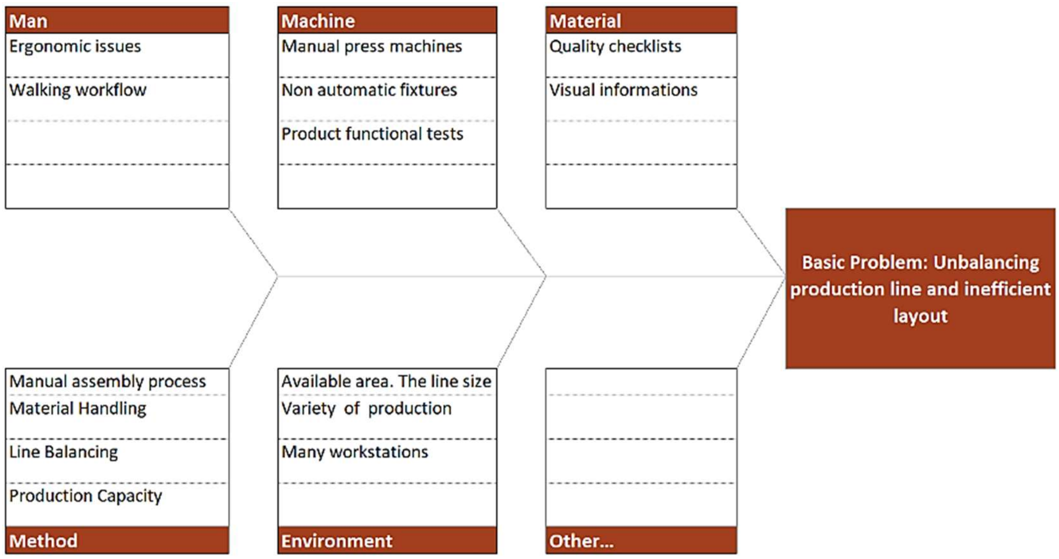


Figure 61 – Ishikawa Diagram showing issues for unbalancing line

All these possible causes are closely related with one another and have a considerable impact on the assembly line performance as well as production cost. The possible causes detected for the problem can be from different types and the most critical will be analyzed and mention on further.

1. **Man**

In terms of causes related to the associates, we identified some ergonomic issues present in the line as the necessary time and human physical effort to handle and assemble some parts.

We also detected the walking workflow, which in both current situations of 6 or 8 operators in the production line, there is a lot of time walking through the stations and some cross paths between each operator.

2. **Machine**

In this production line 4 manual press machines are identified, which have a certain impact in relation to the occupied area and for some assembly operations these equipment's are not so close to the workstation where they are needed

Because it is a low volume production assembly line, most of the tools and fixtures used in the process are fully manual utilization, increasing the time required to perform the operations.

Another factor that has a strong impact on line output is the functional tests needed to verify product performance. The reason for this is because, for example, testing one unit in the final test (Soak test) takes 12 hours, and although each test table is capable of have 12 units, but it is only possible to test one unit at a time.

3. **Method**

The sequence of the assembly process is too manual, this type of approach origins having a high cycle time per workstation and, as can be seen in figure 41, workstations 5, 9 and 12 have the longest established time for build one part of the assembly.

The assembly line balancing standard is not determining to have an ideal distributing of the total manufacturing workload uniformly among all the workstations present along the assembly line. Therefore, in both cases register on the current state the line is 7% unbalancing. The overall performance of the production system is greatly affected by this distribution of work.

4. **Environment**

Regarding the area available for this assembly line, it is visible in figure 43 that we are facing a large assembly line, being the largest line in the plant. The reason for this is due to the complexity of the product produced. The layout is divided into two areas, one that is the main one and the other as a secondary one.

In summary, after analyzing the current state of the assembly line studied, we understand that it is necessary to redesign the layout to ensure a better production performance of the line, in this way we must:

- Combine the two assembly areas in just one, this will relieve the space for other production lines, if necessary.
- Decrease the time it takes for operators to move through the workstations to have more time in value-added activities.
- Improve workload distribution across workstations uniformly and achieve a better balancing line.
- Arrange the assembly tasks ideally to achieve greater productivity capacity on the assembly line.

3.5.1.2 Improvements solutions

To achieve a well-balanced assembly line, it is important to eliminate factors that cause losses, the wastes. Thus, in order to implement the improvements identified through the analysis of the current state describe in LLD, it is important to the organization have the same understanding of the improvement objectives and where these improvements will lead to.

It is therefore structure how will be the implementation. One of the managing techniques for continuous improvement is the PDCA cycle, which stands for Plan, Do, Check, and Act. Each step is explained below:

- **Plan**: In this step, the targets to achieve are defined and quantified, to measure the effectiveness of the improvements.
- **Do**: Implement the action plan. In this step, all the changes are made, and the new data is collected.
- **Check**: It is time to check the data got in the previous step. Therefore, it will be necessary to analyze data trends and other deviations occurrences happen.
- **Act**: Apply any needed corrective measures to the new implementation. If something in the new process is not running according to plan and can be easily fixed, it should be done in this step.

One way to apply the PDCA concept is the technique A3 sheet, that is an excellent visual method, which will be useful to help a group of people with a collaborative engage to solve the issue of production capacity, the occupied area and ergonomics problems. This kind of approach drives the group to address the wastes and identify all the activities which may be eliminated or modified, with the intend to improve the assembly line.

In figure 62 the details regarding the implementation of this process A3 are structured. It is important to have in this document an explicit description of the project, the current situation and the target the group needs to achieve, with a clear understanding, of what performance indicators the project will influence. The next step in this method is to determine all the activities that must be done with an appropriate schedule. Finally, it is necessary to specify what the metrics will be in the different areas to work, in order to quantify what the gains and benefits of implementing this project. A clear overview can be verified in the A3 sheet in Annex 4.

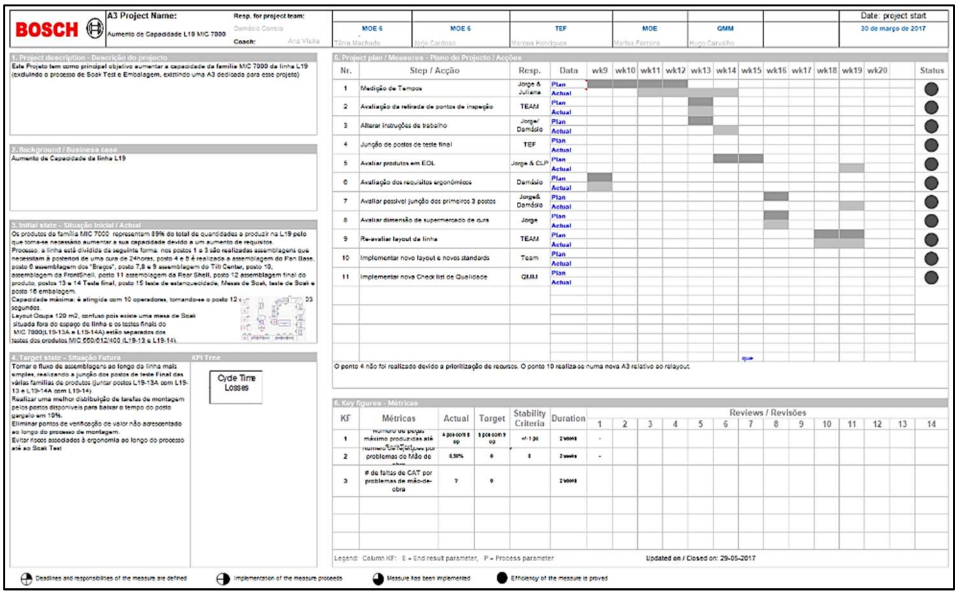


Figure 62 - A3 Project to increase line capacity

In order to be able to explore different layout realities in an efficient and fast way, a methodology not common in this practice of studying new layout configurations was used. Therefore, the method used to select the best layout option with the aim of ensuring the best balance in the production line was an Excel sheet designed to have an easier understanding of the configuration that will give the required results. Thus, to be able to architect this new way of studying layouts, it was necessary to gather some structural information of the production line, such as the total area that is occupied, the correct dimensions of the assembly line, the respective work elements that constitute it and also obtain the 3D model of the line to snapshot each work element. Next, an Excel scaled template was created with the appropriate area and all the work elements separately, as shown in figure 63.

Typically, the traditional method used in workshops to explore different layout options is to have the assembly line printed with a well-known scale and cut out all the elements of the line individually and play with them for different realities. This type of approach makes the layouts creation and selection process more time-consuming and less flexible.

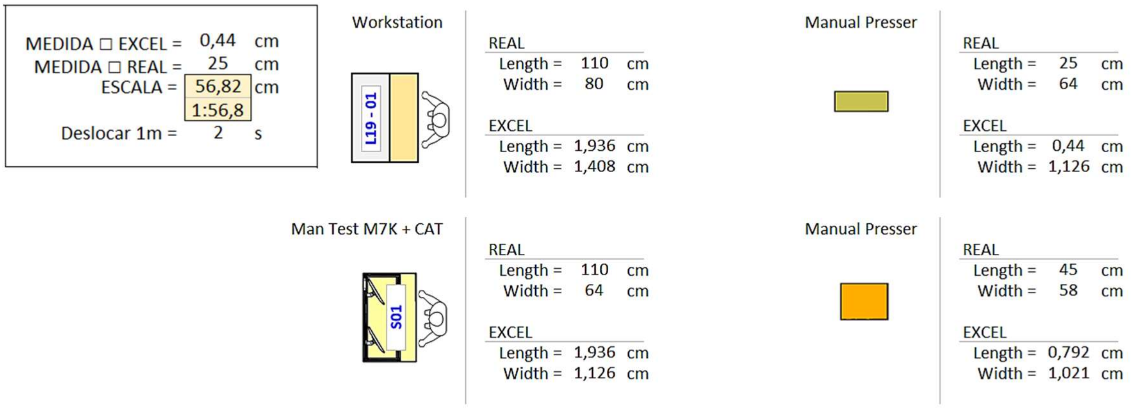


Figure 63 – Example of the procedure used to create a scale process

With the Excel sheet it is possible calculates the best balance with respect to the input data, which can be manually manipulated for further modifications and construct different scenarios. It is possible to modify all input data in a matter of minutes, making visualization of different options and their results in a short time, and bringing in a great flexibility for the evaluation process.

The data input to the model developed in Excel file for this work includes:

- Production type (mixed model),
- Operation names and times (seconds),
- Work zones of operations,
- Product model (important for mixed model balancing),
- Number of stations,
- Number of operators at each station,
- Desired takt time,
- Precedence of operations.

Balance losses at an assembly line are inevitable. There is very small possibility to achieve and preserve a perfect balance of workload at a flow line production system due to the dynamic characteristics of this type of system. Also, it is not possible to distribute the process precisely equally among stations in this system. Therefore, it is clear that at flow line production systems there are always balance losses. However, by understanding the sources of these losses, balance losses at assembly lines can be minimized.

For capacity-oriented balancing, the following should be considered:

- Number of stations should be minimized for a given cycle time and cycle time should be minimized for a given number of stations.
- Flow time and waiting time of pieces should be minimized.

With the knowledge of the assembly operations and their associated times, the design of an assembly system includes the balancing of the desired assembly line considering the number of operators and stations expected in the line and arranging the configuration of the equipment in each station according to the results of the balancing process. Theoretically, balancing and planning an assembly line layout are two dissociated procedures that do not influence each other while designing a production system from scratch.

Alternative layout options for the new configuration of the assembly line are created take in consideration the capacity, line balancing, occupied area and the investments cost. Therefore, while planning the layout, stations with high replacement costs are tried to be kept at their existing locations. Sub-assembly stations are planned after the pre-assembly stations are lined.

1. **First Scenario**

At the first scenario we took in considerations the furthers observations:

- Reduce the flow walk time from the package operator across the Soak tests.
- The cure sub-assemblies go to the workstations where used by the POUP operator.
- Combine the workstations 2 and 3.
- Combine all the workstations in the same area, with the objective of reducing area occupied.
- Less costs in changing the current layout.

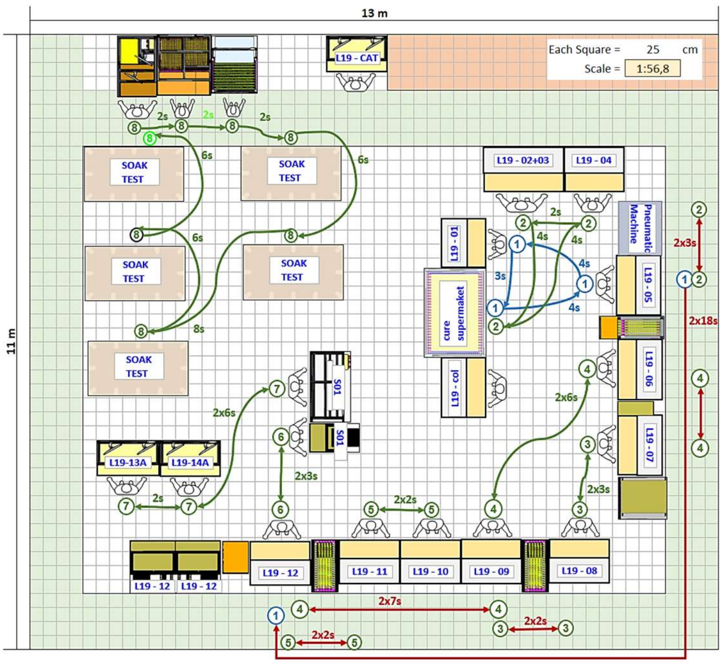


Figure 64 – 1º Option for flow diagram for 8 associates.

2. Second Scenario

At the second scenario we took in considerations the furthers observations:

- Combine all the workstations in the same area, with the objective of reducing area occupied.
- Less costs in changing the current layout.

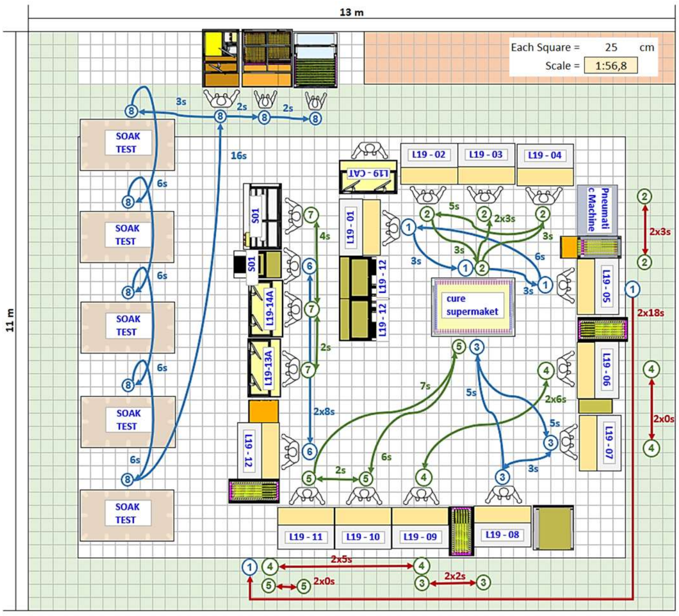


Figure 65 - 2 Option for flow diagram for 8 associates.

3. Third Scenario

The third scenario has many similarities with the first option designed. Nevertheless, one of the differences are the proximity of the soak tests tables to the package operator.

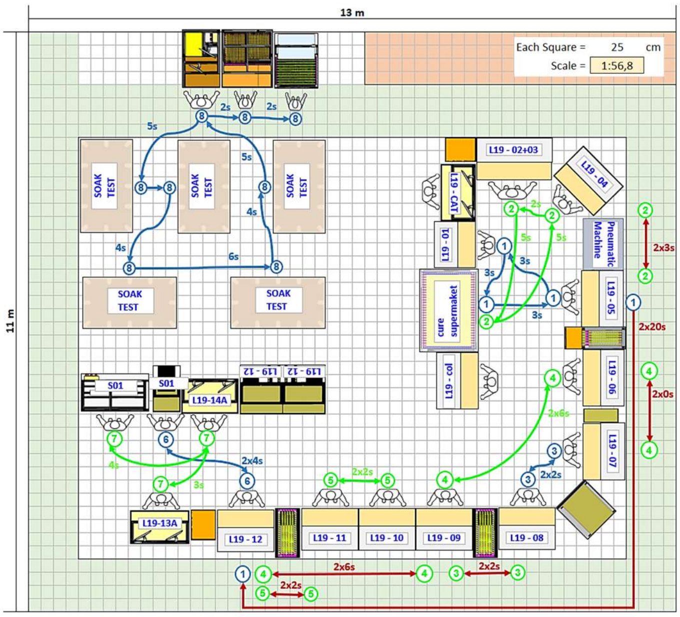


Figure 66 - 3 Option for flow diagram for 8 associates.

4. Fourth Scenario

At the fourth scenario we took in considerations the furthers observations:

- Reduce the flow walk time from the package operator across the Soak tests.
- Reduce the flow walk time across stations at all the entire line.
- The cure sub-assemblies go to the workstations where used by the POUP operator.
- Combine all the workstations in the same area, with the objective of reducing area occupied.
- Better distribution of the operations through the workstations.

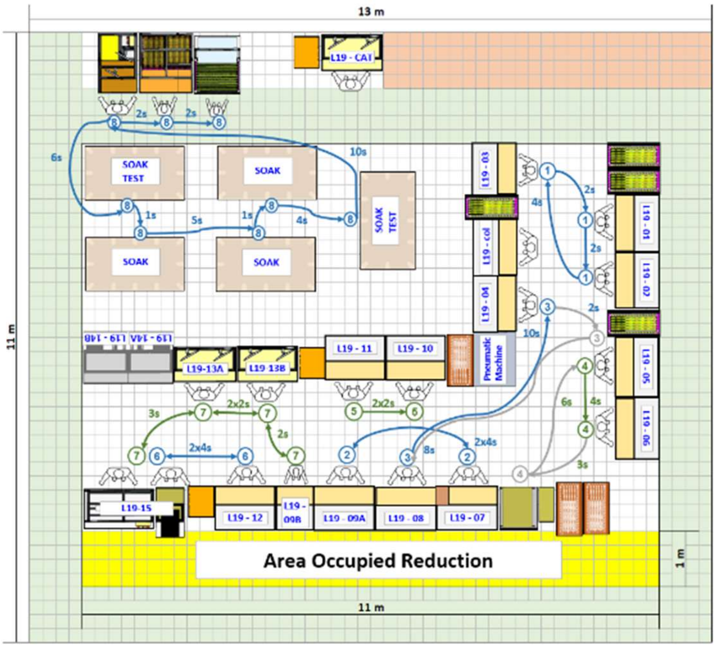


Figure 67 - 4 Option for flow diagram for 8 associates

In summary, four different layout options were designed with the focus on getting the desired assembly line. For this purpose, the strategic location of the workstations, the loops for each operator perform the tasks of assembly on the line, organization of work tools, fixture and material handling setup were considered during the design of a new layout configuration. In this way, to achieve a leaner assembly line, the sources of wastes in the production process are determined.

Therefore, multiple alternative concepts of the layout were developed to select the best approach to be implemented. In Table 13 is registered the different properties took into account to have the most exact decision about wish layout option creates more improvements to the line. The evaluation of layout option concepts implies and involves both comparison and decision making. Thus, for better determination, the assess was determined by a quantitively decision matrix method. Decision matrix method is a useful technique to use for deciding. It's particularly powerful where you have several alternatives to choose from, and many different factors to consider.

Typically, the approach used to evaluate which layout option will be selected is a qualitative evaluation method. This type of procedure determines a decision based on feelings and emotions, which gives rise to a probability of choosing the wrong option. There are pros and cons in this method but what the matrix does is collect all the emotions and thoughts around the decision and put them into a single vision that can force you to evaluate them in the most objective way possible.

Therefore, to reduce the possibility of a poor decision in the layout selection, we chose to choose a quantitative decision matrix method for this analysis. Due to the reason this method is measurable, it is helpful to clarify which is the smarter decision for the business.

1. Properties collection of layouts purpose

On the table 13 are specified the four layout options presented on previous figures. All the factors relevant needed to consider are in the column's headings. The factors took in consideration were area occupied, ease of implementation, capacity required, unbalancing, etc.

Table 13 - Properties data collect of the different Layouts options

LAYOUT	Area Occupied [m^2]	Ease of Implementation [€] **(1)**	Capacity Required [pcs/wd]	Walking [m]	Unbalancing [%]	Target Cycle Time [s]
Option 1	93,8	2000	32	76,5	7	857
Option 2	93,8	3000	32	98	7	857
Option 3	93,8	2500	32	75,5	7	857
Option 4	**82,8**	**6000**	**35**	**50,5**	**2**	**784**

(1) Ease of Changing from current layout, take in account the Cost (Investments), Man Power, Time

2. Attributes table

The next step is scoring each option for each of the factors determined in previous table. Score each option from 0 (less important) to 5 (more important). Note that is acceptable having the same rate for different factors. The most relevant factor in this analyse is the capacity required and the less significant is the ease of implementation (costs, manpower and time to implement). The table 14 shows the correlation between each property and to determine the importance index (ω_i) is need:

- Compare the properties to each other in terms of importance;
- If property 1 is more important than property 2 then, in the comparison between these two properties, value 1 is assigned to prop1 and value 0 to prop2, for instance.
- The ω_i value will be obtained by summing all values 1 to be divided by the number of possible combinations of properties.
- The possible combinations are: N × (N-1) / 2 (N: number of properties).

Table 14 – Attributes table for each property.

N	5
Possible Combinations	10

+ Important 1 - Capacity Required
2 - Area Occupied
3 - Operator Flow 4- Balancing
- Important 5 - Ease of Implementation

	1	2	3	4	5	6	7	8	9	10		
	1-2'	1-3'	1-4'	1-5'	2-3'	2-4'	2-5'	3-4'	3-5'	4-5'	∑	ω
Capacity Required	60	70	70	80							280	0,28
Area Occupied	40				55	55	70				220	0,22
Operator Flow		30			45			50	60		185	0,185
Levelling			30			45		50		60	185	0,185
Ease of Implementation				20			30		40	40	130	0,13
										∑	1000	1

3. Matrix selection method

The performance index (γ) is an algebraic formula that expresses a compromise between two characteristics or properties. In its simplest form, a performance index is usually a multiplication between these two variables, having on one side the importance index (ω) of each layout option and the other variable is the Weighted Index (β), also of each option. Thus, for each property determined for different represented layout options, it is necessary to calculate the performance index, thus, after obtaining all performance index results independently, the final performance index is the sum of all. Table 15 shows all the calculated values to obtain the option that has the highest performance index, which is the most adequate for the implementation.

The performance index (γ) is obtained by the follow equation:

$$\gamma = \sum \omega_i * \beta_i$$

Where,

ω – Importance index related to each layout option.
β - Weighted index related to each layout option.

Table 15 – Matrix selection method

	PROPERTIES / ATTRIBUTES										
	Capacity Required ↑		*Area Occupied* ↓		*Operator Flow* ↓		*Balancing* ↓		*Ease of Implementation* ↓		Preformance
Layout	ω1-	0,28	ω2-	0,22	ω3-	0,19	ω4-	0,19	ω6-	0,13	γ
Option 1	32,000 / 91,43	25,60	93,750 / 88,27	19,42	76,5 / 66,01	12,21	7 / 28,57	5,29	2000,000 / 100,00	13,00	75,52
Option 2	32,000 / 91,43	25,60	93,750 / 88,27	19,42	98 / 51,53	9,53	7 / 28,57	5,29	3000 / 66,67	8,67	68,50
Option 3	32,000 / 91,43	25,60	93,750 / 88,27	19,42	75,5 / 66,89	12,37	7 / 28,57	5,29	2500 / 80,00	10,40	73,08
Option 4	35,000 / 100,00	28,00	82,750 / 100,00	22,00	50,500 / 100,00	18,50	2,000 / 100,00	18,50	6000 / 33,33	4,33	**91,33**

3.5.1.3 Conclusion and discussion

As found in the matrix calculation method, the option with the highest performance index was option 4, with a result of 91.33, thus being the best layout to implement.

The re-layout of this manual assembly line is planned to preserve almost all the stations from the previous assembly line layout, in order to reduce reorganization cost. Therefore, the key notion of this layout planning was to generate the minimum possible area required for the occupation of this assembly line, ensuring that all workstations were close to each other, without increasing station setup costs. The new plan suggests an assembly line with the U-shaped configuration, with the main proposal of reducing the distance between the stations and also the improvement of the flow of material.

Theoretically, balancing and layout planning of an assembly line are two dissociated procedures that do not influence each other while designing a production system from scratch. Take in consideration that one of the objectives of using lean line design approach, is to increase the production capacity of the assembly system, so it is relevant to assume that in this case the balancing technique and the layout planning are strongly associated, so we are facing a re-layout of the current line.

Regardless of the cycle times known from the current layout for each workstation, the purpose of Option 4 layout was to increase the production capacity of this manual assembly line, taking into account some balancing operations, as described below:

- Transferring some tasks from station L19-05 to the previous workstation;
- Divide the station L19-09 into two.

In the figure 68 are detailed the cycle time for each station.

PROCESS STEPS		Manual	Machine
Description	Detailed	seconds	
L19-01 - Pan Motor Preparation		160,0	
L19-02 - Tilt Motor Preparation + Nexus Soldering + Power Soldering		265,0	
L19-03 - Wipper Motor Preparation		217,0	
L19-04 - Pan Stage I Assembly		363,0	
L19-05 - Pan Stage II Assembly		474,0	
L19-06 - ARM´s Preparation		296,0	
L19-07 - Tilt Center I Assembly		370,0	
L19-08 - Tilt Center II Assembly		310,0	
L19-09a - Camera Module I Assembly		321,0	
L19-09b - Camera Module II Assembly		200,0	
L19-10 - Front Shell Assembly		321,0	
L19-11 - Rear Shell Assembly		386,0	
L19-12 - Final Assembly		592,0	
L19-13A - Final Test		926,5	463,3
	Place on test	51,1	
	auto		80,5
	Manual	23,5	
	auto		77,7
	Manual	14,2	
	auto		126,6
	Manual	124,3	
	auto		409,4
	Manual	19,3	
L19-15 - Leackage Test		608,0	
L19-15.1	Place on the Leak	68,0	
L19-15.2	Auto		358,0
L19-15.3	Remove from Leak	112,0	
L19-15.4	Place on Soak Test	70,0	
L19-16 - Packaging station		665,0	

Figure 68 - Cycle time for each workstation for the propose layout selected.

After the cycles time distribution improvements verified in the figure 68, its time to represent the new the stack workflow for each operator obtained in the layout option 4, considered the scenarios of 6 and 8 associated.

In the table 16 is shown the future state flow assembly sequence with the condition of being working 8 operators in the line. The walking time for each operator gives a total of 101 seconds moving across stations, comparing with the actual state this reduction of loop time needed to cross stations, represents a gain improvement of 45.41%.

Table 16 – 4 Option flow assembly sequence for 8 associates

Operator	Flow Assembly Sequence			Walking [s]	Operator Time [s]
Operator 1	L19-01	L19-02	L19-03	8	**650,0**
Operator 2	L19-07	L19-09a		8	**699,0**
Operator 3	L19-04	L19-08		20	**693,0**
Operator 4	L19-05	L19-06		13	**783,0**
Operator 5	L19-10	L19-11		4	**711,0**
Operator 6	L19-12	L19-15.3	L19-15.4	8	**782,0**
Operator 7	L19-09b	L19-13	L19-15.1	9	**740,3**
Operator 8	L19-16			31	**696,0**
			Total =	**101**	

The future condition of the layout with the cycle times of all the operations is plotted in the Operator balance chart as shown in the figure below.

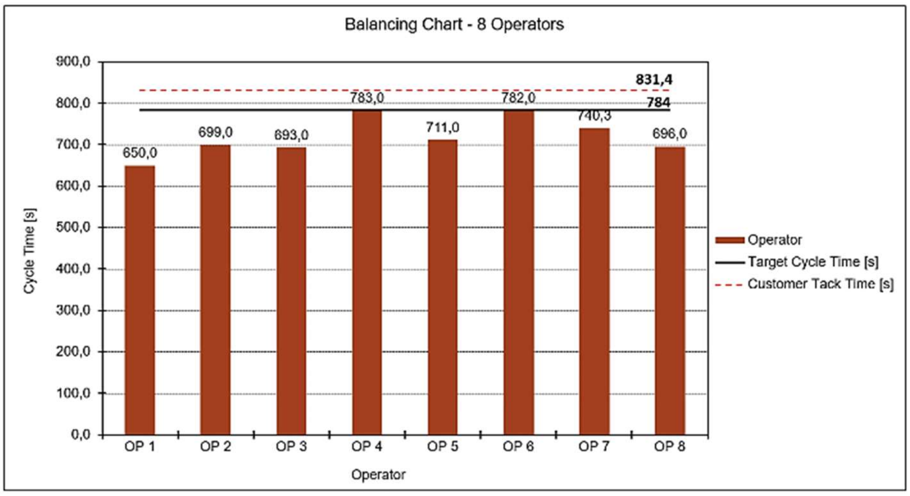


Figure 69 – 4 option Line Balance chart for 8 operators.

The operator line balancing chart plotted for the future condition has a bottleneck loop whose cycle time is close to the Customer Takt Time, which is the loop made by the operator 4. The cycle times of all operations are less than the Cycle Time Target. This line is unbalanced by 2% and the production capacity is 35 pcs/wd, the calculation of these values can be verified in the balance sheet in Annex 7. Comparing with the current layout this version permits an unbalanced decrease from 7% till 2%, and also a increase of the daily production capacity from 32 pcs/wd till 35 pcs/wd.

In the table 17 is shown the future state flow assembly sequence with the condition of being working 6 operators in the line. The walking time for each operator gives a total of 124 seconds moving across stations, comparing with the actual state this reduction of loop time needed to cross stations, represents a gain improvement of 30.34%.

Table 17 - 4 Option flow assembly sequence for 6 associates.

Operator	**Flow Assembly Sequence**			**Walking [s]**	**Operator Time [s]**
Operator 1	L19-02	L19-03	L19-04	12	**857,0**
Operator 2	L19-01	L19-05	L19-08	24	**968,0**
Operator 3	L19-06	L19-07	L19-09a	16	**1003,0**
Operator 4	L19-09b	L19-10	L19-13	14	**998,3**
Operator 5	L19-11	L19-12	L19-15.1	14	**1060,0**
Operator 6	L19-15.3	L19-15.4	L19-16	44	**891,0**
			Total =	**124**	

The future condition of the layout with the cycle times of all the operations is plotted in the Operator balance chart as shown in the figure below.

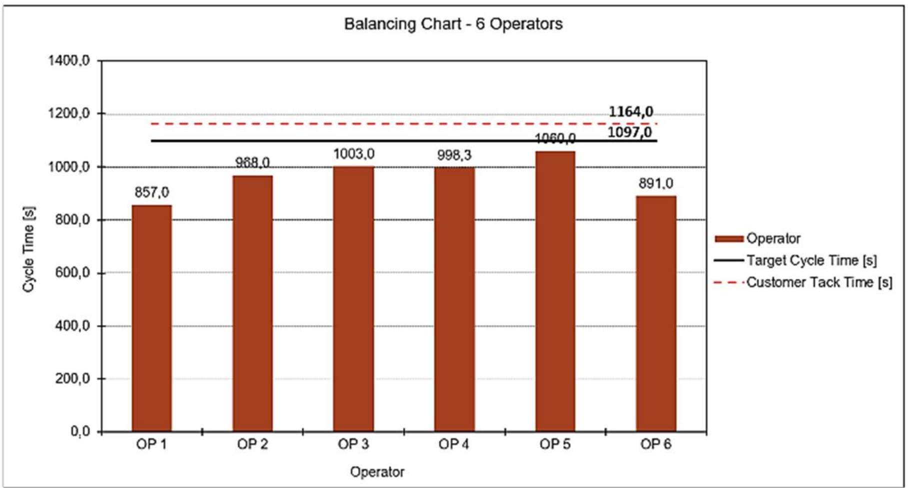


Figure 70 - 4 option Line Balance chart for 6 operators.

The operator line balancing chart plotted for the future condition has a bottleneck loop whose cycle time is close to the Customer Takt Time, which is the loop made by the operator 5. The cycle times of all operations are less than the Cycle Time Target. This line is unbalanced by 3% and the production capacity is 26 pcs/wd, the calculation of these values can be verified in the balance sheet in Annex 8. Comparing with the current layout this version permits an unbalanced decrease from 7% till 3%, and also an increase of the daily production capacity from 24 pcs/wd till 26 pcs/wd.

3.5.2 Production Process Optimization

3.5.2.1 Current state analysis

Before proceeding to identify possible improvement solutions, it is time to analyze the current state of the assembly tools and the previously identified process tasks, which are the completion of the quality checklist and the application of a glue to the screws. To assist in the process of analyzing these problems, we use a very useful quality tool to analyze all the possible causes that may influence an unfavorable design and use of fixation systems and the unnecessary activities of operations that do not add value to the mounting process. Thus, in figure 71 below is the analysis of the current state using the Ishikawa Diagram.

1. **Assembly fixtures**

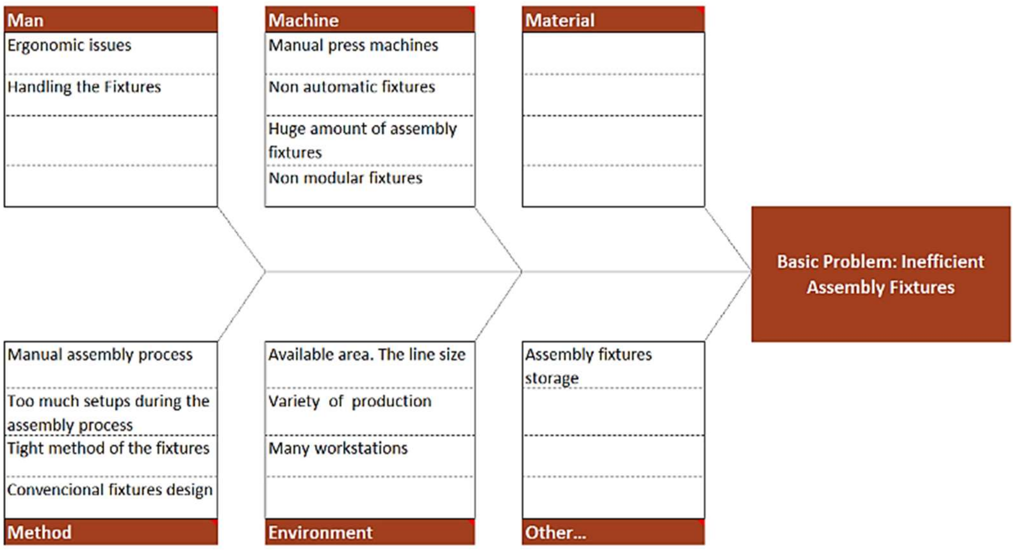


Figure 71 - Ishikawa Diagram showing issues for inefficient assembly fixtures.

All these possible causes are closely related with one another and have a considerable impact on the assembly line performance as well as production cost. The possible causes detected for the problem can be from different types and the most critical will be analyzed and mention on further.

- **Man**

In terms of causes related to the associates, we identified:

- Some ergonomic issues present in the line as the tools needed to press fit some components of the product.

- Another subject that could have impact is the handling of the fixtures. The operator needs to use a lot of fixtures to execute the assembly desired, and the probability of having errors is higher.

- **Machine**

In terms of causes related to the machine, we identified:

- In this production line exists 6 manual press machines, which have a certain impact in relation of the occupied area, the time needed to press fit the components and also the precision of those operations.
- Due to a low volume production system, most of the tools and fixtures used in the process are fully manual utilization.

- **Method**

In terms of causes related to the method, we identified:

- In this assembly line the mount process required to build this kind of complex electronic products are identified as very manual sequences. Thus, the current assembly tools used in this line is all of manual handling, having no associated automatism that allows a faster operation. One of the consequences of this type of assembly is in the influence on the cycle time of each workstation. So, it is clear that the handling of the assembly tools has a time percentage related the cycle time.
- When observing the assembly process of this product, it was identified the need to use different assembly tools for each workstation, which in some cases, it is necessary to setup the support tools, in order to guarantee the correct construction of the unit.
- In some workstations, the mounting fixings need to be fixed with screws to the work table, the reason for this is to verify that in certain assemblies of the product it is necessary to apply forces and torques to ensure the correct assembly of the product, take this in account it is important that the assembly equipment is really stable. Therefore, during the changeover process of the production line this operation of fixing the assembly fixtures to the work table requires a certain time. Being one of the factors that contributes to that the time of changeover of this assembly line is elevated.

- **Environment**

In terms of causes related to the environment, we identified:

- Take in consideration that in this assembly line are manufactured some versions variety, that belongs at one product family. So, due to this reality of manufacturing the number of fixtures needed for the building of those different versions is high.

- Another aspect is the quantity of workstations on this assembly line. This aspect has impact in the number of fixtures required for each workstation to execute properly the attach of the parts.

2. Process activities analyzed.

Concerning the analyzed of the tasks of filling the quality check list and the applying of the liquid threadlocker in each screw needed on the product, it is relevant to understand the importance for the product the execution of those tasks and how much impact those tasks have on the cycle time of each workstation.

- **Quality checklist**

Due to the need for quality control of the many assembly steps of a complex unit, in the past, one of the quality actions implemented in this assembly line was the introduction of checklist in a paper format, which has the consequence of managing these documents and the time that is used to fill in.

After the investigation carried out on the importance of using a checklist for production control, the following conclusions were reached:

- In terms of PFMEA perspective, when analysing the checklist detection method used in this approach, was found that it does not reduce greatly the probability that operators neglect to perform this operation because it remains a manual task.
- The real influence and positive gains of this approach is when you start manufacturing a new product, not a well-known product with some level of maturity on the assembly line. usually this kind of methods as checklist, after a time of production, begins to be filled without any care or attention, due to experience developed by the operators.
- Most of the steps validated during the assembly process by the list document will be identified by the functional tests, which perform evaluations of the most diverse functional features of the product and the whole test is recorded in a file.

- **Liquid threadlocker task**

With regard to the operation of placing a drop of threadlocker on a screw, the importance of the design was verified to ensure the locking of almost all screws in the product. However, this task does not add value to the product and the reasons for it are:

- There is a need for cleaning preparation for the use of this type of adhesive, which is the application is used solvent to all the screws, ensuring there is no dust or oil.
- Obviously, liquid thread lockers are messy. Usually the use of this liquid requires some attention from operators, due to this type of chemicals cause a lot of gloves dirty and also the uniform. It should be noted, that the handling of these solutions

origins operators to take care to avoid contamination in other components of the product during the assembly process.

- If operators forget to place the liquid, there is no longer any method to detect this type of deviations, so due to be a manual operation there will always be a chance to fail.
- The time required to perform this task is significant, influencing in a certain way the time of the cycle time of each workstation.

3.5.2.2 Improvements solutions

To achieve an optimized assembly line regarding the assembly process, it is important to eliminate factors that cause losses, the wastes. Thus, in order to implement new solutions for issues identified through the analysis of the current state described, it is important to apply a structure method.

It is therefore structure how will be the implementation. So, in this case it was also used the PDCA cycle, managing techniques for continuous. Each step is explained below:

- **Plan:** Design just one assembly fixture assuring the possibility of mounting two assemblies from two product versions. With this in mind, one of the objectives is reducing the cost of fixtures manufacturing and eliminate the chance of duplicate the fixtures, reducing the need of occupy space.
- **Do:** Implement the action plan. In this step, all the changes are made, and the new data is collected.
- **Check:** It is time to check the functionality of the new assembly fixtures and the reduction of some process tasks got in the previous step. Therefore, it will be necessary to analyze data trends and other deviations occurrences happen.
- **Act:** Apply any needed corrective measures to the improvements done. If something in the new process is not running according to plan and can be easily fixed, it should be done in this step.

1. **Assembly fixtures improvement.**

In order to overcome this drawback, the new design concept for the fixtures was based on modular fixtures systems those consist of using interlocking standardized elements such as dowel pins, clamps and connections. Flexibility is achieved through the interchangeability of different modules, which enables a modular fixture to be easily disassembled and re-assembled. The great benefits of this design are: reducing the setup time (SMED improvements); be easier to maintain, having spares to change when needed; reducing costs of new fixtures with the same configurations, only need to design some elements to new models and a better 5S implementation.

6.4 Workstation 01 – Pan Motor Preparation.

In this station the assembly fixture development took in considerations some aspects in order to fulfil the follow aspects:

- Design just one mainly assembly fixture has been assured.
- The only changeover for this JIG is two adaptors illustrated as item 01 in the figure 72, which the only need, in an easier way, is placing those adaptors on the square hole of the main fixture.
- The requirement for the pinion position is guaranteed by the item 04, this is a mobile part of the fixture, could rotate and moves axially.
- For a future new product version, normally is only necessary to design and buy the item 03 and 01, reducing the costs of tools.

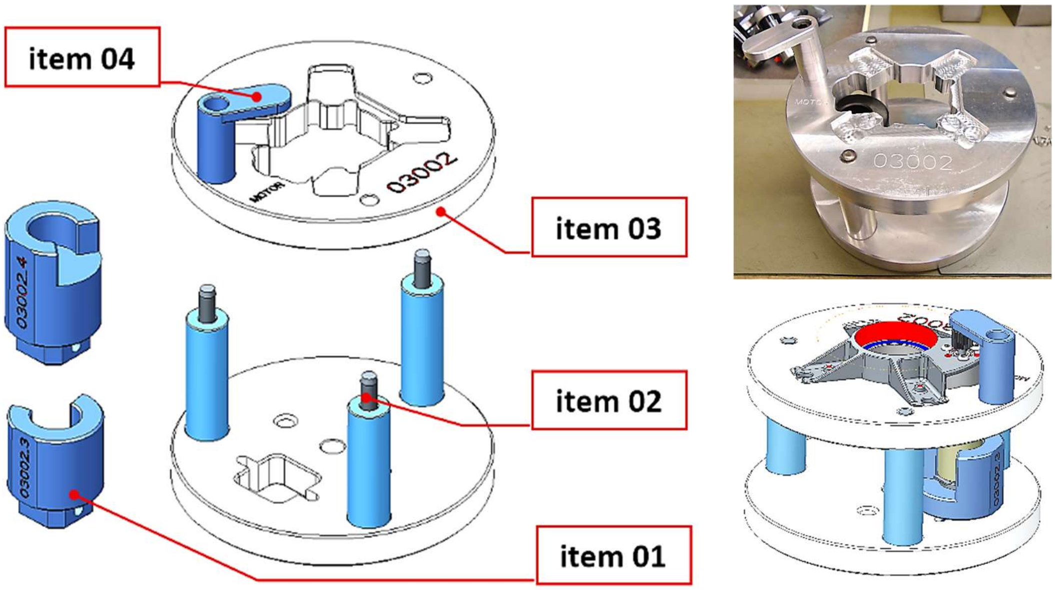


Figure 72 - New assembly fixture to workstation 01.

6.5 Workstation 02 – Tilt Motor Preparation.

In this station the assembly fixture development took in considerations some aspects in order to fulfil the follow aspects:

- The design concept follows the same approach as the previous workstation. In figure 73 is the fixture used in this workstation.

- The only difference between the previous workstation is the need of flipping the part identified as item 03 when its needed to perform changeover for another product.

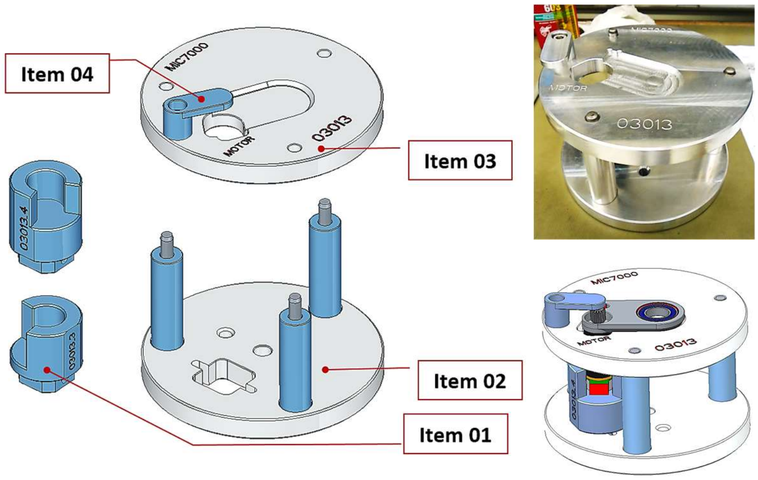


Figure 73 - New assembly fixture to workstation 02.

To press fit tasks, these two workstations share the same manual press arbor. Taking this into account, the tools designed to accurately press the bearings fulfilled the following aspects:

- Only one plate to ensure the correct orientation and position of all the pieces diversity.
- The placement of the used press adapter in the equipment is made by a quick indexing plunger showed in item 03 of figure 74. With this action, the adapters changeover is easier and can reduce the time of the operation.

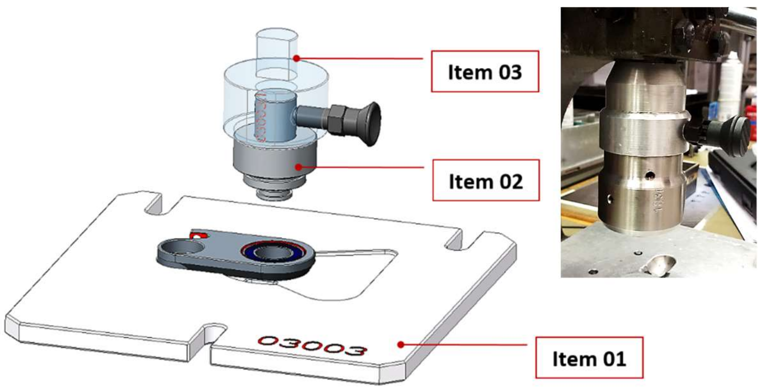


Figure 74 - New press tools to workstation 01 and 02.

6.6 Workstation 03 – Wiper Motor Preparation

In this station, the same design architecture already described in the previous workstation was assumed.

6.7 Workstation 04 – Pan Stage I Assembly

The 04 workstation was one of the most changing assembly stations on tis line, having a huge impact on reducing the changeover time and improving ergonomic aspects. Thus, the new changes in this station are:

- The improvement action with the greatest impact on product quality and assembly process was the automatic pneumatic press shown in figure 75. With this investment it was possible to eliminate three manual press equipment's.
- The tools designed for this machine considered the need to press different product versions. Thus, the used adapters placement in the machine is done by a rapid indexing approach.

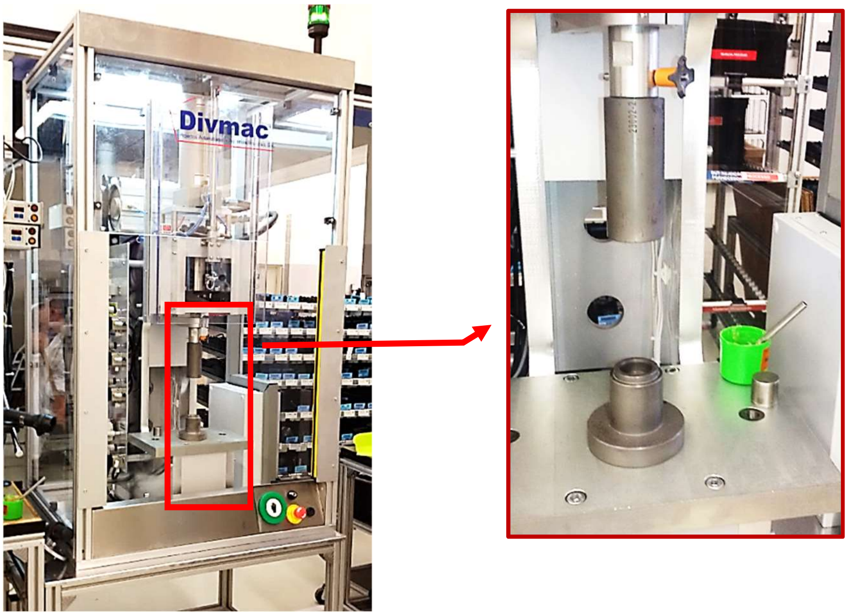


Figure 75 – Press pneumatic machine for workstation 04.

In spite of the press tasks performed on the press machine, it is necessary to complete the remaining assembly operations on the workbench, and for this some other tools have been redesigned with the intention of improving the remaining assembly process. Thus, the new changes in this station are:

- Due to the human effort required to make this assembly, the equipment used needs to be really stable. Thus, an adapted workbench was designed with an aluminum plate machined in the middle. In figure 76 it is possible to see how easy it is to attach to this worktable all the mounting fixtures for this station.
- Other improvements were the tools defined as items 01 and 02 in figure 76. The accessory identified as item 02 is to fix the product assembly firmly, and for this the clamps work with springs to lightly tighten the product. The only step required to configure this fixture is the change of item 03, which is also a spare part due to the fatigue of the tool.

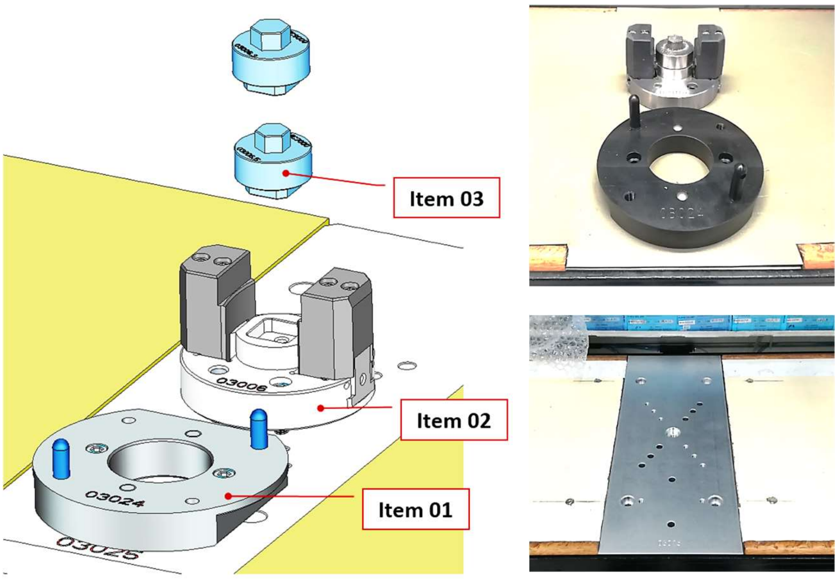


Figure 76 - New assembly fixtures to workstation 04.

6.8 Workstation 05 – Pan Stage II Assembly

In this workstation, the optimization of the devices was based on avoiding a quality gate and improving the way to press a ferrite in a hole of a plastic component. So, those improvements are:

- A manual press is designed to ensure an easier procedure to press the ferrite into the hole and also improve the accuracy of the ferrite position and reduce the force required by the operator to correctly press the ferrite. See figure 77.
- Another optimization was to eliminate the use of quality fixture to check the previous assembly. The reason for this is that this quality check is already done by functional testing.

Figure 77 - New tool the press fit the ferrite.

6.9 Workstation 07 – Tilt Center I Assembly

In this station the challenge was greater comparing the rest of the workstations. The designed tools play a very critical role in relation to the accuracy of this assembled product, so this fixture must meet the following characteristics:

- The design has reduced the need to use three fixtures to correctly run the right amount of pressure fitting on this workstation. Therefore, only one mounting device is designed as shown in figure 78.

- All attach of the adapters used in this tool are made by pins, guaranteeing good geometric position and fast fixing.
- Changeover of this tool to a different version of the product is faster, you only need to make small adjustments.

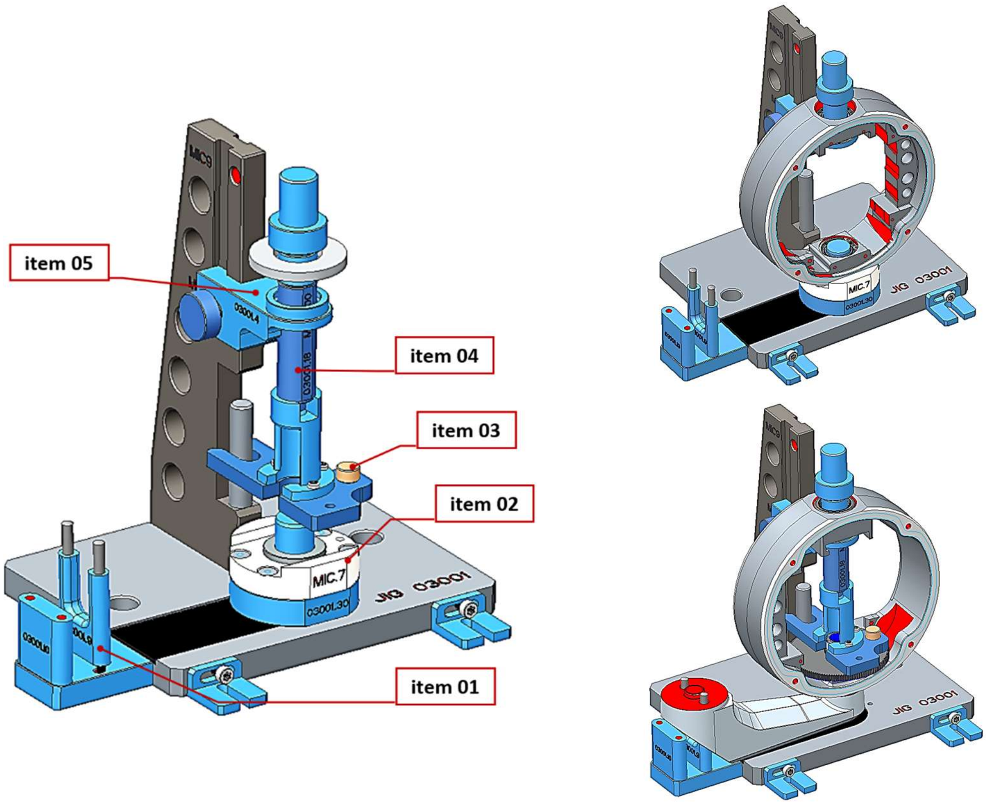


Figure 78 - New assembly fixture to workstation 07.

After all the pressure fit operations performed, the next task is to assemble the product arms. This tool needs to ensure stability during the arms tightening process, and also this workstation has a workbench similar to the aluminum plate made for the workstation 04. This fixture may be easier to rotate the arm assembly.

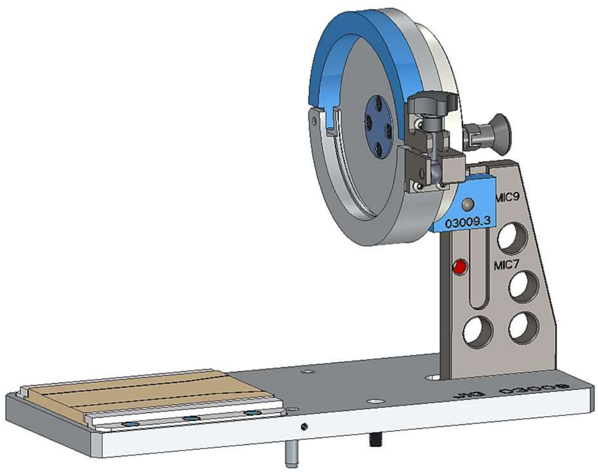


Figure 79 - New assembly fixture to workstation 07 for tight the arms.

6.10 Workstation 08 – Tilt Center II Assembly

In the workstation 08 the only design developed was one fixture to maintain the previous assembly in vertical position. The concept of the tool is the same observed on the previous fixtures.

6.11 Workstation 09 – Camera Module Assembly

In this station the new fixture design took in consideration the follow aspects:

- The changeover of this fixture is to change the item 02, 03 and item 04, and the setup of those parts is simply and quick.

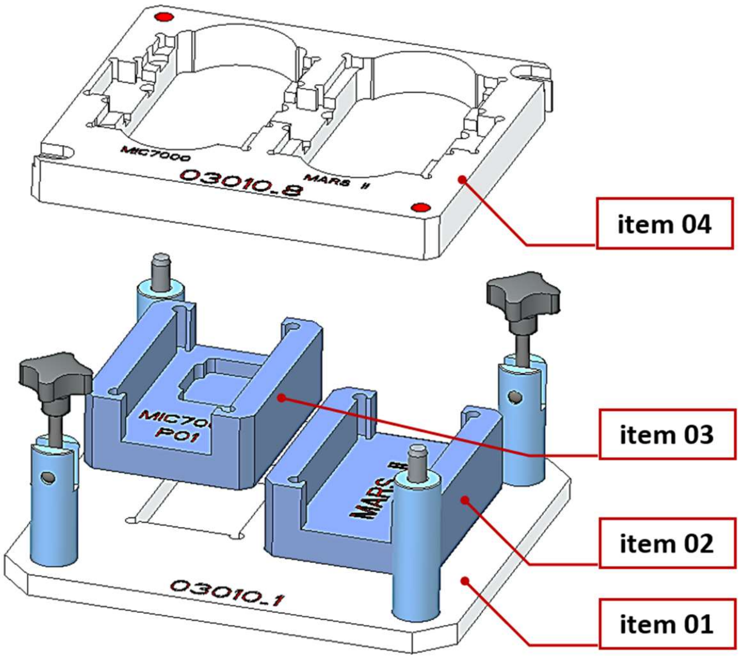


Figure 80 - New assembly fixture to workstation 09.

6.12 Workstation 10 – Front Shell Assembly

In this station the new fixture design took in consideration the follow aspects:

- A vertical press fit toggle clamp was added to this fixture with the intend to eliminate the movement by the operator to another place to press fit the bushing.
- The changeover for a different product version is to take off the item 02, 04 and sweep the item 03 to another holes. All the attaches are done by fast plugs.

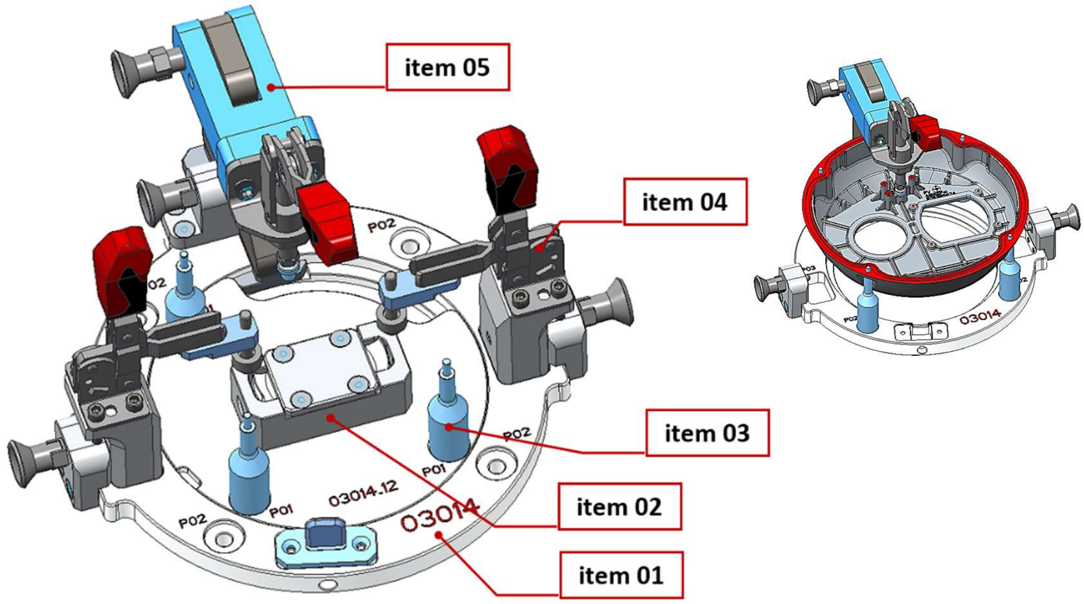


Figure 81 - New assembly fixture to workstation 10.

6.13 Workstation 11 – Rear Shell Assembly

In the workstation 11 the only design developed was one fixture to maintain the previous assembly in vertical position. The concept of the tool is the same observed on the previous fixtures.

6.14 Workstation 12 – Final Assembly

In this station the new fixture design took in consideration the follow aspects:

- The design has reduced the need to use two fixtures quite similar on this workstation. Therefore, only one mounting device is designed as shown in figure 82. The real gain is the reduction of the area occupied, due to the size of the fixture.
- Eliminate the ergonomic issue associated of handling this assembly fixture and the complete unit. So, the idea is to reduce the weight of the fixture and design one structure to minimize the need to handling the product.
- The new design of this fixture contains a feature that permits adjust the inclination of the item 02 illustrated in the figure 82. The advantage of this is to have better configuration of the fixture.
- The changeover for a different product version is to take off the item 03, 04, 05 and item 06. All the attaches are done by fast plugs.

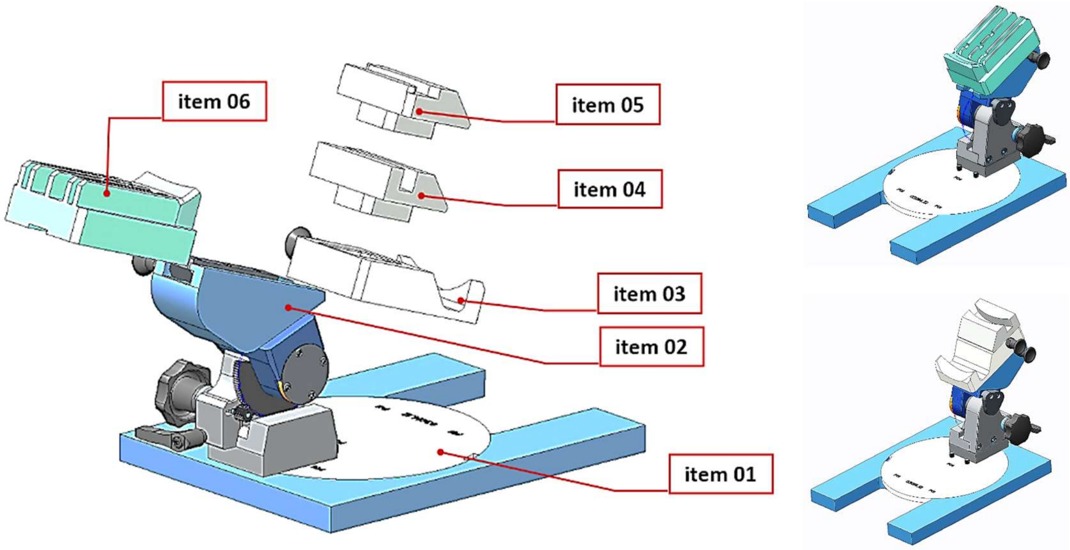


Figure 82 - New assembly fixture to workstation 12.

6.15 Workstation 15 – Leak Test

In this station the new fixture design took in consideration the follow aspects:

- It was created a new way to plug the air connection, eliminating the operation of tightening the attach of the air. Thus, the new design permits a real fast plug of the air as it shows in the figure 83a.
- In figure 83b is showed the new fixture for do the leak test. With this new design it is possible to reduce the time needed for this operation.

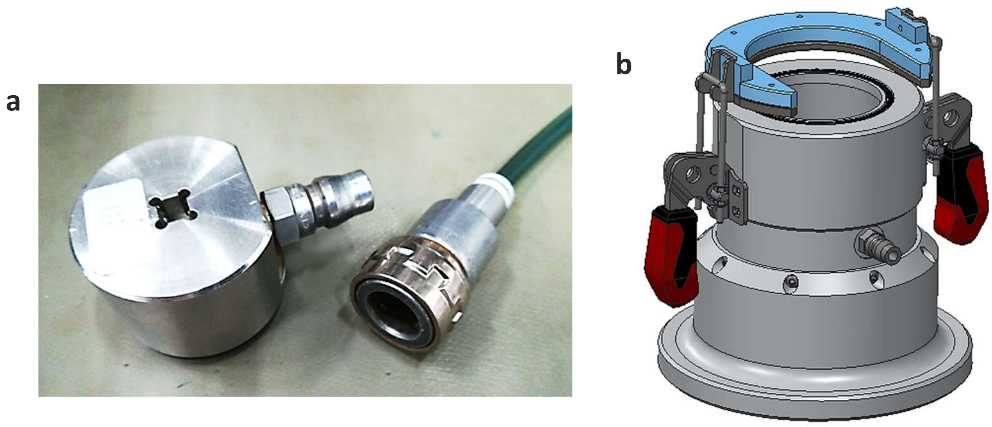


Figure 83 - a) Fast air plug; b) New fixture to test leak.

- After the leak test is necessary to close completely the unit. For that, to avoid the need to development new fixtures it was decided to adapt the current fixture with the objective of assume the same characteristics the previous assembly fixtures. In the figure 84 is possible to see the optimization done.

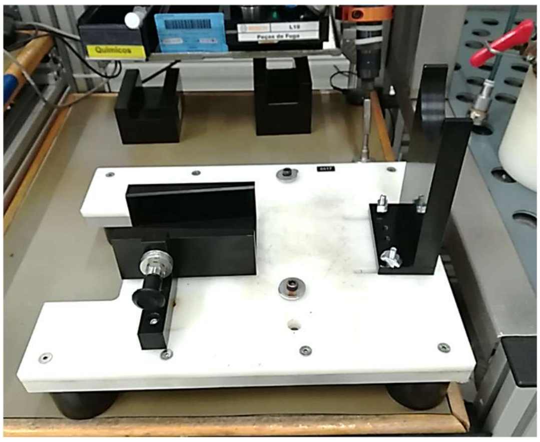


Figure 84 - the adapted fixture to attach the yoke caps.

2. Process activities improvement.

One of the improvements done was eliminate a quality checklist used for having a double process validation by operators in line. Another improvement studied was the practice of dispensing a drop of glue, liquid thread lockers are messy, can be forgotten and the time needed to execute this task is identified as non-value-added, so the main target is to investigate a different solution assuring the specification requisites of the product.

- **Quality checklist**

Theoretically the real objective to improve this task was eliminating the entire quality checklist, but due to the recording of the data from the functional tests is not be simply to use and the read of the test results is not user friendly. Therefore, the improve got was reducing the checklist from 4 pages to 1 page and the time gain with this intervention was 24 seconds.

- **Liquid threadlocker task**

One of the improvements actions with more impact will be changing the practice of applying thread lock glue to the screws for a solution of nylon patch screws, however, this improvement is ongoing by the development team and the intention is to implement this change on the next product generation.

The advantages are clear:

- Exceptional vibration resistance
- Reusable
- Easy to use in assembly. Doesn’t have any clean preparation, so is just applying.
- Non-toxic, assembler friendly

- Environmentally friendly
- Durable
- Cost effective

Figure 85 – Example of screws with nylock.

3.5.2.3 Conclusion and discussion

Generally, regarding the production process improvements it was noticed some gains in the reduction time of the assembly process to build one product.

Concerning the designing of new assembly fixtures the optimization done brought good results as:

- The handling of the fixtures is more simply and fast.
- All the quality fixtures used were eliminated. It is important reveal that all the quality issues continue to be verified.

Comparing the current state with the new reality was observed that with the new solutions implemented got some time reductions.

Table 18 – Time obtained from improve actions.

Classification	Time [min]	[%]
Fixtures Adjustments	1,1	49%
Operation	1,1	51%
Quality Checking	0,0	0%

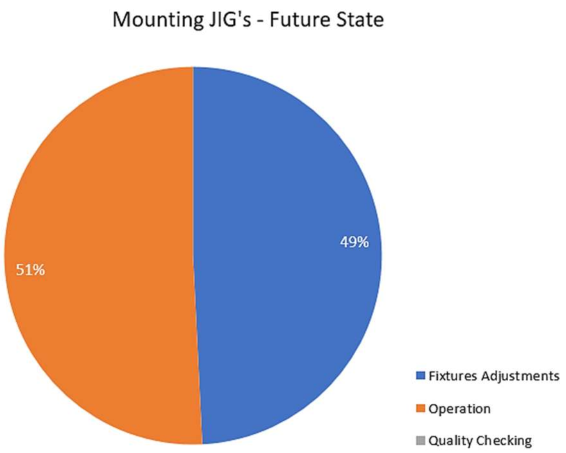


Figure 86 – New fixtures usage.

As it showed in the table 18 and the figure 86 the need of fixtures adjustments to be possible build one unit it was verified a decreasing for 1.1 minutes, this is a reduction of 70% related to the current state. The time reduction associated to the operation of the fixtures is not too significant, just a decrease of 30%. For last, it was eliminated the time needed to check the quality of the product.

Table 19 - Time gain with process improvements.

Improvement Classification	Time [s]	[%]
Fixtures Adjustments	26	9%
Assembly Operation	40	14%
Quality Checking	39	14%
Change to Nylon Patch	182,8	64%

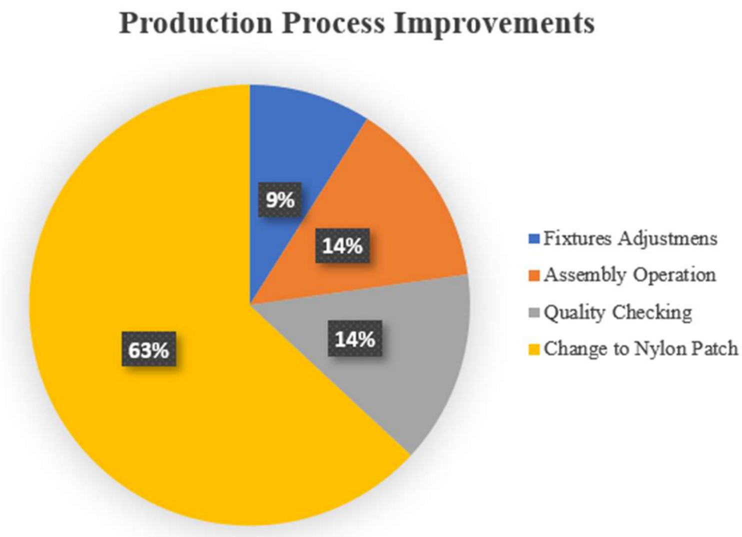


Figure 87 - The different types of improvements.

Analyzing figure 87 and table 19, it is possible to see that a decrease of 289,8 seconds is verified in the duration of the entire process sequences necessary to accomplish a final product. One of the improvements actions with more impact will be changing the practice of applying thread lock glue to the screws for a solution of nylon patch screws, however, this improvement is ongoing by the development team. Nevertheless, these changes represent an improvement of 3% when compared to the results achieved through the LLD implementation, with the following results: 0% of unbalanced; a decrease of takt-time to 808,3 sec/pc comparing with 831,4 sec/pc, with a production capacity of 36 units per day.

CONCLUSIONS

4 CONCLUSIONS AND PROPOSALS OF FUTURE WORKS

4.1 CONCLUSIONS

This study leads the development of methodologies which incorporates an initial drawing of VSM to visualize the improvements needed to be done with the help of methods, such as assembling optimizations and the technique LLD, involving line balancing layout design and walking paths, which have been simulated and verified in an assembly line.

This study shows that an unbalanced assembly line may generate significant capacity loss in a cumulative pattern, which requires a continuous waste elimination and balancing approach in production. From the results, we can infer that improvements determined can increase productivity by approximately 10% with the same manpower by modifying workstations and work methodologies. The process of workstation design plays an important role, in increasing performance and quality indicators into the organizations. Taking this into account, we can conclude that when it is necessary to redesign the layout of a low volume batch production line, the best way to confront this activity is to imagine a possible re-engineering of the process with the aim of reducing waste, according to lean manufacturing principles.

Modular fixturing systems are one of the potentially valuable adaptable fixturing technologies for flexible manufacturing systems. Also, by standardizing the tools and mechanizing the manual operations, the setup times and number of tools used were reduced. So, quick acting tools were used to reduce the setup times.

In conclusion, lean production is usually associated with manual production/assembly systems. This manufacturing concept provides an optimum framework for efficient, competitive production through: reduce inventory, eliminate downtime, reduce space requirements, avoid errors, avoid inefficient processes, avoid overproduction, and shorten transport routes.

4.2 PROPOSALS OF FUTURE WORKS

The quality of the electronics assembly line was enhanced in terms of line balancing, overall labour effectiveness, productivity and elimination of wastes. This research shows that there are many wastes which could be eliminated with simple lean tools. It is not very complicated, but it would bring essential benefits.

It is clear that more research can be conducted at Bosch site. As stated previously many areas of the site can be improved. This also includes future research within those areas. There are also many other topics, which it is not brought up in this report, that can be investigated further.

For one future work, could be a development of a simulation methodology for balancing assembly lines, this should be used in order to model the improvements proposed and validate the results obtained. This would allow testing on many scenarios in a cost effective way and not bleach the random nature of the processes involved.

Another project that should be evaluated will be in the field of ergonomics, the scientific discipline related to understanding the interactions between humans and other elements of a system. In assembly line, one of the main tasks is to plan, design and evaluate workstations with the health of the operator in focus. Workstations must be compatible with people's needs, abilities, and limitations.

After the line is balanced, standardization of works should be done. Other lean tools such as 5S, SMED, or TPM should be studied, which could support setting up the lean environment for these complex production assembly line.

REFERENCES AND OTHER SOURCES OF INFORMATION

5.1 PAPERS IN INTERNATIONAL JOURNALS

5 REFERENCES AND OTHER SOURCES OF INFORMATION

António, A. C. (2009). ASSEMBLY LINE DEVELOPMENT UNDER LEAN LINE DESIGN PARADIGM.

Arunagiri, P., & Gnanavelbabu, A. (2014). Identification of major lean production waste in automobile industries using weighted average method. *Procedia Engineering*, *97*, 2167–2175. https://doi.org/10.1016/j.proeng.2014.12.460

Basu, R. (2008). *Implementing Six Sigma and Lean: A practical guide to tools and techniques*. Elsevier Butterworth-Heinemann.

Battaïa, O., & Dolgui, A. (2013). A taxonomy of line balancing problems and their solutionapproaches. *International Journal of Production Economics*, *142*(2), 259–277. https://doi.org/10.1016/j.ijpe.2012.10.020

Bi, Z. M., Lang, S. Y. T., Verner, M., & Orban, P. (2008). Development of reconfigurable machines. *International Journal of Advanced Manufacturing Technology*, *39*(11–12), 1227–1251. https://doi.org/10.1007/s00170-007-1288-1

Bortolini, M., Faccio, M., Gamberi, M., & Pilati, F. (2016). Including Material Exposure and Part Attributes in the Manual Assembly Line Balancing Problem. *IFAC-PapersOnLine*, *49*(12), 926–931. https://doi.org/10.1016/j.ifacol.2016.07.894

Bosch-Norm. (2011). *Work system design* (No. N62A 2.3).

Bosch - LLD. (2015). *Implementation Guidelines | Lean Line Design*.

Bosch - QCO. (2002). *Quick Changeover (QCO) - Short Description*.

Bosch - QCO. (2003). *Quick changeover*.

Bosch - QCO. (2006). *Quick changeover*.

Bosch - QCO. (2017). *BPS-Element QCO Examples*.

Bosch Group. (2015). *Bosch Production System Always. Doing. Better.*

Costa, R. J. S., Silva, F. J. G., & Campilho, R. D. S. G. (2017). A novel concept of agile assembly machine for sets applied in the automotive industry. *International Journal of Advanced Manufacturing Technology*, *91*(9–12), 4043–4054. https://doi.org/10.1007/s00170-017-0109-4

Costa, T., Silva, F. J. G., & Pinto Ferreira, L. (2017). Improve the extrusion process in tire production using Six Sigma methodology. *Procedia Manufacturing*, *13*, 1104–1111. https://doi.org/10.1016/j.promfg.2017.09.171

Diego Fernando, M. D., & Rivera Cadavid, L. (2007). Lean manufacturing measurement: the relationship between lean activities and lean metrics. In *Estudios Gerenciales* (Vol. 23, pp. 69–83). https://doi.org/10.1016/S0123-5923(07)70026-8

Dolgui, A. (2007). *Operations Research Techniques for Design and Analysis of Lean Manufacturing Systems*. *IFAC Proceedings Volumes* (Vol. 40). IFAC. https://doi.org/10.3182/20070927-4-RO-3905.00005

Dombrowski, U., Ebentreich, D., & Krenkel, P. (2016). Impact Analyses of Lean Production Systems. *Procedia CIRP*, *57*, 607–612. https://doi.org/10.1016/j.procir.2016.11.105

El-Namrouty, K. A. (2013). Seven Wastes Elimination Targeted by Lean Manufacturing Case Study "Gaza Strip Manufacturing Firms". *International Journal of Economics, Finance and Management Sciences*, *1*(2), 68. https://doi.org/10.11648/j.ijefm.20130102.12

ElMaraghy, H., & ElMaraghy, W. (2016). Smart Adaptable Assembly Systems. *Procedia CIRP*, *44*, 4–13. https://doi.org/10.1016/j.procir.2016.04.107

Feld, W. M. (2001). *Lean manufacturing: tools, techniques, and how to use them*. *CRC Press*.

Gowda, V. P., Kulkarni, M., & S, S. (2013). Integrating Assembly Lines based on Lean Line Design Concept, *2*(6), 2177–2185.

HIRANO, H. (2009a). *JIT Implementation Manual - The Complete Guide to Just-In-Time Manufacturing: Volume 2*. CRC Press.

HIRANO, H. (2009b). *JIT Implementation Manual - The Complete Guide to Just-In-Time Manufacturing: Volume 4*. CRC Press.

Ignall, E. J. (1965). A Review of Assembly Line Balancing. *Journal of Industrial Engineering*, *16*(4), 244-.

Jonsson, M., & Ossbahr, G. (2010). Aspects of reconfigurable and flexible fixtures. *Production Engineering*, *4*(4), 333–339. https://doi.org/10.1007/s11740-010-0256-z

Koppal, V., & Arunkumar, N. S. (2013). Line Balancing and Lean Line Design for Common Rail Pump Housing Manufacturing, 74–77.

Lam, N. T., Toi, L. M., Tuyen, V. T. T., & Hien, D. N. (2016). Lean Line Balancing for an Electronics Assembly Line. *Procedia CIRP*, *40*(1), 437–442. https://doi.org/10.1016/j.procir.2016.01.089

Lean Manufacturing Tools. (2017). Lean Manufacturing Definition. Retrieved July 2, 2017, from http://leanmanufacturingtools.org/34/lean-manufacturing-definition-2/

Li, H., Chen, W., & Shi, S. (2016). Design and Application of Flexible Fixture. *Procedia CIRP*, *56*, 528–532. https://doi.org/10.1016/j.procir.2016.10.104

Liker, J. K. (2004). *The Toyota Way*. McGraw-Hill.

Locher, D. A. (2008). *Value stream mapping for Lean Development*. n: CRC Press.

Nagi, M., Chen, F. F., & Wan, H. Da. (2017). Throughput Rate Improvement in a Multiproduct Assembly Line Using Lean and Simulation Modeling and Analysis. In *Procedia Manufacturing* (Vol. 11, pp. 593–601). The Author(s). https://doi.org/10.1016/j.promfg.2017.07.153

Nguyen, M. N., & Do, N. H. (2016). Re-engineering Assembly Line with Lean Techniques. In *Procedia CIRP* (Vol. 40, pp. 591–596). Elsevier B.V. https://doi.org/10.1016/j.procir.2016.01.139

Ortiz, C. A. (2006). *Kaizen Assembly: Designing, Constructing, and Managing a Lean Assembly Line*. CRC Press.

Our Company | Bosch Portugal. (n.d.). Retrieved June 4, 2017, from http://www.bosch.pt/en/pt/our_company_10/our-company-lp.html

Rahani, A. R., & Al-Ashraf, M. (2012). Production flow analysis through Value Stream Mapping: A lean manufacturing process case study. *Procedia Engineering*, *41*(Iris), 1727–1734. https://doi.org/10.1016/j.proeng.2012.07.375

Rohani, J. M., & Zahraee, S. M. (2015). Production Line Analysis via Value Stream Mapping: A Lean Manufacturing Process of Color Industry. In *Procedia Manufacturing* (Vol. 2, pp. 6–10). Elsevier B.V. https://doi.org/10.1016/j.promfg.2015.07.002

Rother, M., & Shook, J. (2003). *Learning to See: Value Stream Mapping to Add Value and Eliminate Muda (Lean Enterprise Institute)*. *Lean Enterprise Institute Brookline*.

Sabuncuoglu, I., Erel, E., & Alp, A. (2009). Ant colony optimization for the single model U-type assembly line balancing problem. *International Journal of Production Economics*, *120*(2), 287–300. https://doi.org/10.1016/j.ijpe.2008.11.017

Shirinzadeh, B. (2002). Flexible fixturing for workpiece positioning and constraining. *Assembly Automation*, *22*(2), 112–120. https://doi.org/10.1108/01445150210423143

Venkataraman, K., Ramnath, B. V., Kumar, V. M., & Elanchezhian, C. (2014). Application of Value Stream

Mapping for Reduction of Cycle Time in a Machining Process. In *Procedia Materials Science* (Vol. 6, pp. 1187–1196). Elsevier B.V. https://doi.org/10.1016/j.mspro.2014.07.192

Wilson, L. (2010). *How to Implement Lean Manufacturing*. *McGraw-Hill*.

Womack, J. P., & Jones, D. T. (1990). *The Machine That Changed the World*. Harper Collins Publishers, New York, USA.

Womack, J. P., & Jones, D. T. (2003). *Lean Thinking-BANISH WASTE AND CREATE WEALTH IN YOUR CORPORATION*. *Simon & Schuster Inc.*

ANNEXES

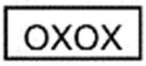
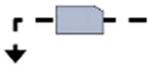
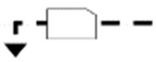
6.1 ANNEX A: VSM Drawing Symbols

6 ANNEXES

6.1 ANNEX 1: VSM Drawing Symbols

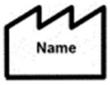
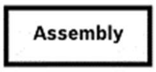
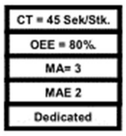
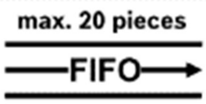
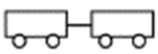
6.1.1 Drawing symbols for the information flow

Table 20 - Drawing symbols for the information flow (Bosch-Norm, 2011)

Drawing symbols	Description
	**Manual Information Flow:** Information delivered as a list. Coverage and update cycle to be written inside the rectangular box.
	**Electronic Information Flow:** Information delivered as an electronic signal. Coverage and update cycle to be written inside the rectangular box.
	**Levelling:** Equal distribution of the volumes or orders to be produced in a defined period of time according to a regular pattern.
	**"Go see"-Production Control:** Employees do frequent and irregular on-site checks, in order to make unscheduled changes to the production sequence on the basis of current stock assessment and to gather information on the status of production.
	**Production Control:** Production control with indication of the data processing system.
	**Transport Kanban:** Kanban that enables withdrawal of defined amount of parts from supermarket ("shopping list").
	**Production Kanban:** Kanban which starts defined volume of production.

6.1.2 Drawing symbols for the material flow

Table 21 - Drawing symbols for the material flow (Bosch-Norm, 2011)

Drawing symbols	Description
	**External Process:** Symbol of processes outside Bosch (e.g. supplier, extended workbench, customer, etc.).
	**Process Box:** Used for manufacturing processes, production planning and shipping.
	**Data Box:** Typical metrics of a process. Place directly below related process box.
	**External Transport:** Transport “Supplier → RB”, “RB → Supplier”, “RB → 3rd party sorting”, or “RB → Customer”. Shipping Frequency (and additional data if required) to be put in “Data Box”.
	**Material Flow PUSH:** Material which is produced and transported before it is required by the next process step. The symbol is only used internally.
	**Supermarket:** Defined and stable inventory, used to regulate an upstream production process. Icon to be placed with open side towards supplier.
	**FIFO (First In – First Out):** Equipment for limiting inventory and ensuring FIFO material flow between two processes. When quantity limit is reached the up-stream process stops.
	**Milkrun:** Cyclical material transport with defined schedule and route.

6.2 ANNEX 2: VSM chart

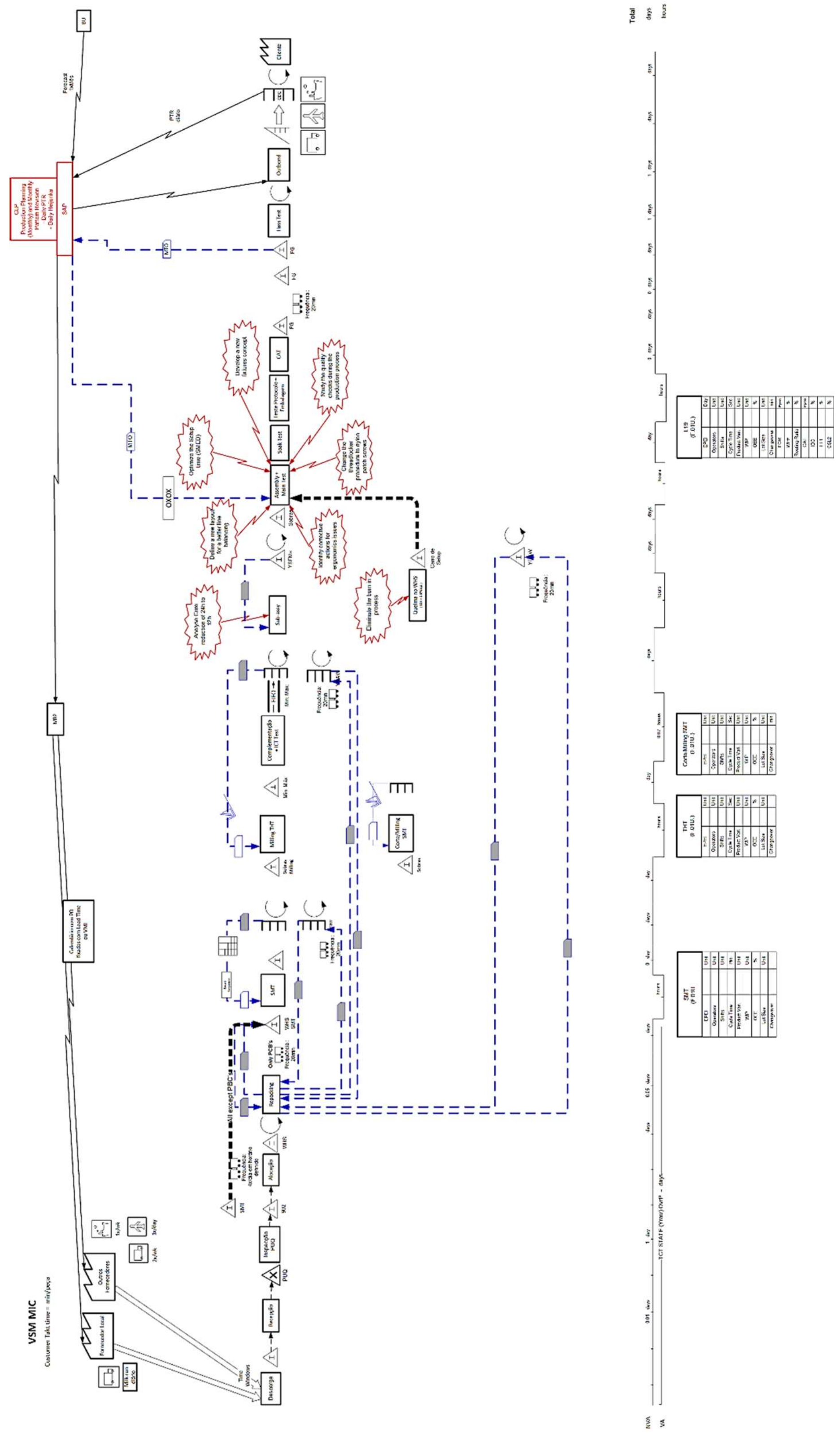
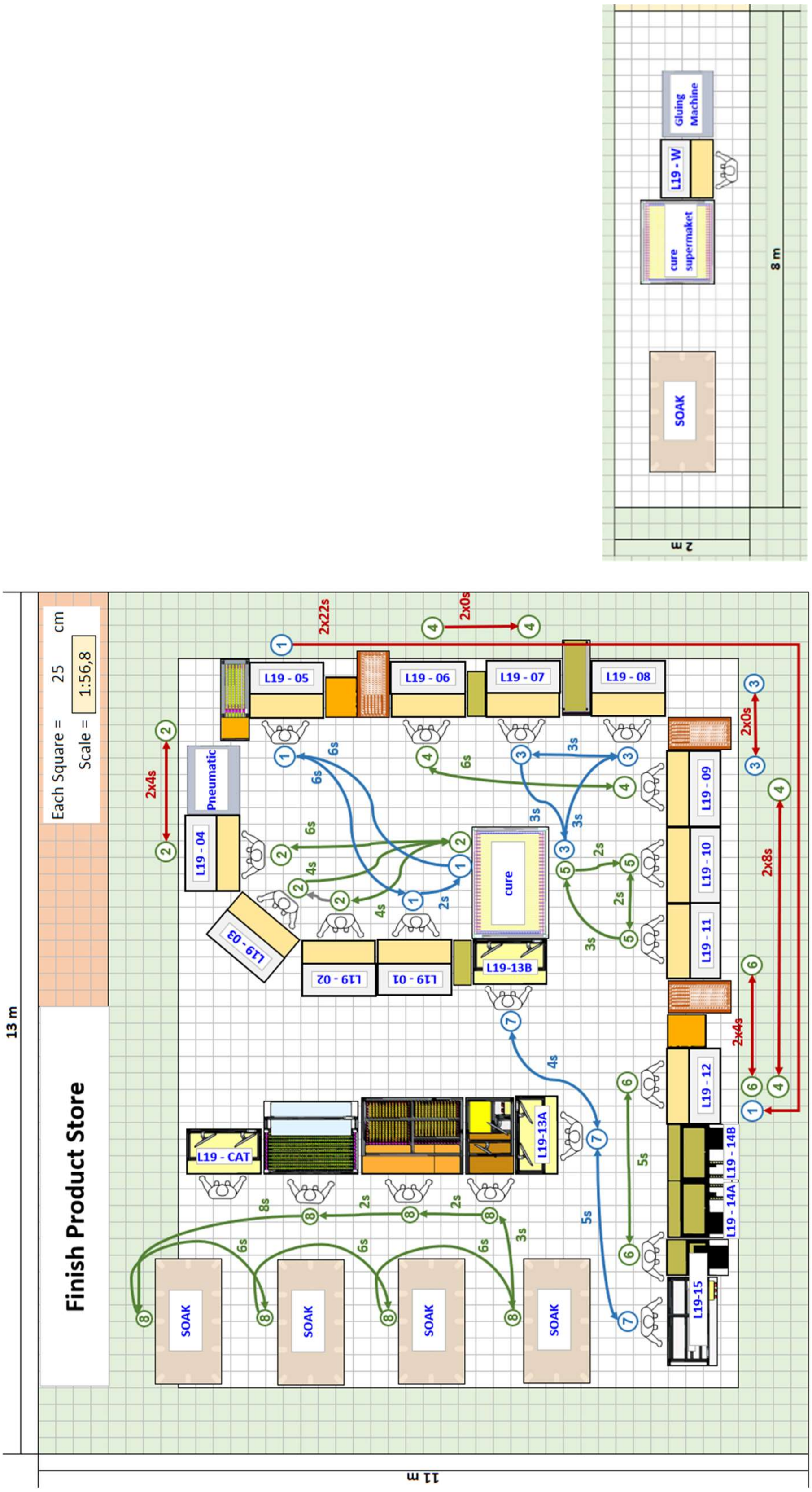


Figure 88 – VSM Chart of one MIC product.

6.3 ANNEX 3: Current assembly line layout



6.4 ANNEX 4: A3 Project to increase production capacity

BOSCH

A3 Project Name:	Resp. for project team:							Date: project start
Aumento de Capacidade L19 MIC 7000	Damásio Correia; Coach: Ana Vieira	MOE 6 – Tânia Machado	MOE 6 – Jorje Cardoso	TEF – Marcos Henriques	MOE – Marisa Ferreira	QMM – Hugo Carvalho		30 de março de 2017

1. Project description - Descrição do projecto

Este Projeto tem como principal objetivo aumentar a capacidade da família MIC 7000 da linha L19 (excluindo o processo de Soak Test e Embalagem, existindo uma A3 dedicada para esse projeto)

2. Background / Business case

Aumento de Capacidade da linha L19

3. Initial state - Situação Inicial / Actual

Os produtos da família MIC 7000 representam 89% do total de quantidades a produzir na L19 pelo que torna-se necessário aumentar a sua capacidade devido a um aumento de requisitos.
Processo: a linha está dividida da seguinte forma: nos postos 1 a 3 são realizadas assemblagens que necessitam à posteriori de uma cura de 24horas, posto 4 e 5 é realizada a assemblagem do Pan Base, posto 6 assemblagem dos "Braços", posto 7,8 e 9 assemblagem do Tilt Center, posto 10, assemblagem da FrontShell, posto 11 assemblagem da Rear Shell, posto 12 assemblagem final do produto, postos 13 e 14 Teste final, posto 15 teste de estanquecidade, Mesas de Soak, teste de Soak e posto 16 embalagem.
Capacidade máxima: é atingida com 10 operadores, tornando-se o posto 12 c... 03 segundos.
Layout:Ocupa 120 m2, confuso pois existe uma mesa de Soak situada fora do espaço de linha e os testes finais do MIC 7000(L19-13A e L19-14A) estão separados dos testes dos produtos MIC 550/612/400 (L19-13 e L19-14).

4. Target state - Situação Futura

Tornar o fluxo de assemblagens ao longo da linha mais simples, realizando a junção dos postos de teste Final das várias famílias de produtos (juntar postos L19-13A com L19-13 e L19-14A com L19-14).
Realizar uma melhor distribuição de tarefas de montagem pelos postos disponíveis para baixar o tempo do posto gargalo em 10%.
Eliminar pontos de verificação de valor não acrescentado ao longo do processo de montagem.
Evitar riscos associados à ergonomia ao longo do processo até ao Soak Test

KPI Tree

Cycle Time Losses

5. Project plan / Measures - Plano do Projecto / Acções

Nr.	Step / Acção	Resp.	Data
1	Medição de Tempos	Jorge & Juliana	Plan / Actual
2	Avaliação da retirada de pontos de inspeção	TEAM	Plan / Actual
3	Alterar instruções de trabalho	Jorge/ Damásio	Plan / Actual
4	Junção de postos de teste final	TEF	Plan / Actual
5	Avaliar produtos em EOL	Jorge & CLP	Plan / Actual
6	Avaliação dos requisitos ergonómicos	Damásio	Plan / Actual
7	Avaliar possivel junção dos primeiros 3 postos	Jorge& Damásio	Plan / Actual
8	Avaliar dimensão de supermercado de cura	Jorge	Plan / Actual
9	Re-avaliar layout da linha	TEAM	Plan / Actual
10	Implementar novo layout e novos standards	Team	Plan / Actual
11	Implementar nova Check list de Qualidade	QMM	Plan / Actual

Weeks: wk9 wk10 wk11 wk12 wk13 wk14 wk15 wk16 wk17 wk18 wk19 wk20 — Status

que

O ponto 4 não foi realizado devido a priorização de recursos. O ponto 10 realiza-se numa nova A3 relativo ao relayout.

6. Key figures - Métricas

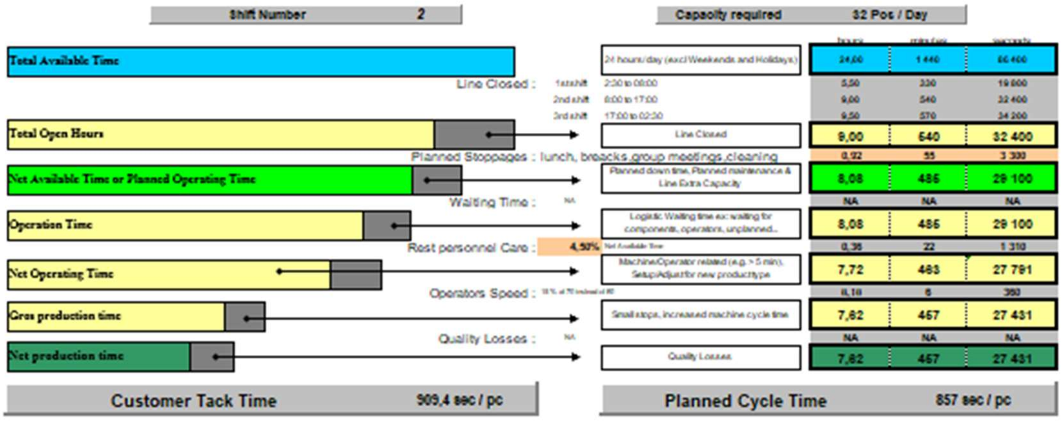
KF	Métricas	Actual	Target	Stability Criteria	Duration	Reviews / Revisões 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Numero de peças máximo produzidas até Soak Test	4 pcs com 8 op	5 pcs com 9 op	+/- 1 pc	2 weeks	-													
2	Numero de rejeições por problemas de Mão de obra	0,50%	0	0	2 weeks	-													
3	# de faltas de CAT por problemas de mão-de-obra	?	0		2 weeks														

Legend: Column KF: E = End result parameter, P = Process parameter

Updated on / Closed on: 29-05-2017

Deadlines and responsibilities of the measure are defined — Implementation of the measure proceeds — Measure has been implemented — Efficiency of the measure is proved

6.5 ANNEX 5: Current Balancing calculation for 8 associates



BASIC TIME STRUCTURE

PROCESS STEPS (times in seconds)

op	description	Manual	machine run time	operator work during machine run time	free time	Tempo Ciclo Posto	FRY %	Needed People	Real People	Available Capacity
1	L19-01 - Preparação do Pan Motor	160,0				160,0		0,19	1	171
2	L19-02 - Preparação Tilt Motor + Soldar Nexus + Soldar Power	265,0				265,0		0,31		
2	L19-03 - Preparação do Wipper Motor	217,0				217,0		0,25		
2	L19-04 - Montar Pan Shaft	263,0				263,0		0,31		
1	L19-05 - Pan Body Assy	574,0				574,0		0,67	1,0	48
4	L19-06 - Preparação dos ARM´s	296,0				296,0		0,35		
3	L19-07 - Tilt Center Assy 1	370,0				370,0		0,43		
3	L19-08 - Tilt Center Assy 2	310,0				310,0		0,36	1,0	83
	Rodar 90º TILT CENTER e no lado do RESOLVER ARM (left), efectuar:									
	Rodar 180º TILT CENTER e no lado do TILT GEAR (roda dentada), efectuar:									
4	L19-09 - Camara Module Assy	521,0				521,0		0,61		
5	L19-10 - Montar Front Shell	321,0				321,0		0,37	1,0	85
5	L19-11 - Montar Rear Shell	386,0				386,0		0,45		
	L19-12 - Montagem Final	592,0				592,0		0,69	1,0	46
	L19-13A - Teste Final + L19-14A	926,5	483,3			926,5	86%	1,27	1	25
	Colocar no teste	51,1								
	auto		83,5							
	Manual	23,5								
	auto		77,7							
	Manual	14,2								
	auto		128,6							
	Manual	124,3								
	auto		403,4							
	Manual	19,3								
	L19-15 - Teste Fuga	538,0				538,0		0,63		
	Colocar na Fuga	68,0				68,0				
	Auto		358,0							
	Retirar da Fuga	112,0								
	Colocar no Soak Test	70,0				70,0		0,08		
	L19-16 - Embalagem	665,0				665,0		0,78		
	Ligar Mic ao teste e realizar algumas operacoes.					0,0				
	Tempo na soak.					0,0				
	Tempo parada.					0,0				
	Aparafusar (6x), acabar a limpeza e passar para a embalagem.					0,0				
	Montar caixa e divisoes.					0,0				
	Embalar (inclui etiqueta na caixa)					0,0				
	Levar para o carrinho.					0,0				
	Tempo de teste IP.					0,0				
	Total	6404,5	830,6			6404,5		7,47	5,0	21
						0,0				
	ttb Productive time that can be influenced									
	ttu Productive time that cannot be influenced									
	operador 1	792,0				792,0		0,92	1,0	35
	operador 2	771,0				771,0		0,90	1,0	36
	operador 3	689,0				689,0		0,80	1,0	40
	operador 4	845,0				845,0		0,99	1,0	32
	operador 5	714,0				714,0		0,83	1,0	38
	operador 6	674,0				674,0		0,79	1,0	41
	operador 7	655,3				655,3		0,76	1,0	42
	operador 8	698,0				698,0		0,81	1,0	39
						0,0				
						0,0				
						0,0				

			max cap
Number of Operators	7,5	8,0	32
	Unbalanced	7%	4,017590369

6.6 ANNEX 6: Current Balancing calculation for 6 associates

Shift Number	2	Capacity required	24 Pcs / Day

Total Available Time		24 hours/day (excl Weekends and Holidays)	24,00	1 440	86 400
Line Closed :	1st shift	2:30 to 08:00	5,50	330	19 800
	2nd shift	8:00 to 17:00	9,00	540	32 400
	3rd shift	17:00 to 02:30	9,50	570	34 200
Total Open Hours		Line Closed	9,00	540	32 400
Planned Stoppages : lunch, breacks,group meetings,cleaning			0,92	55	3 300
Net Available Time or Planned Operating Time		Planned down time, Planned maintenance & Line Extra Capacity	8,08	485	29 100
Waiting Time :	NA		NA	NA	NA
Operation Time		Logistic Waiting time ex: waiting for components, operators, unplanned...	8,08	485	29 100
Rest personnel Care :	4,50%		0,36	22	1 310
Net Operating Time		Machine/Operator related (e.g. > 5 min), Setup/Adjust for new product type	7,72	463	27 791
Operators Speed :			0,10	6	360
Gros production time		Small stops, increased machine cycle time	7,62	457	27 431
Quality Losses :	NA		NA	NA	NA
Net production time		Quality Losses	7,62	457	27 431

Customer Tack Time	1 212,5 sec / pc	Planned Cycle Time	1 143 sec / pc

BASIC TIME STRUCTURE

PROCESS STEPS (no description)	Manual	machine run time	operator work during machine run time	free time	Tempo Ciclo Posto	FRY %	Needed People	Real People	Available Capacity
	seconds								
L19-01 - Preparação do Pan Motor	160,0				160,0		0,14	1	171
L19-02 - Preparação Tilt Motor + Soldar Nexus + Soldar Power	265,0				265,0		0,23		
L19-03 - Preparação do Wipper Motor	217,0				217,0		0,19		
L19-04 - Montar Pan Shaft	363,0				363,0		0,32		
L19-05 - Pan Body Assy	474,0				474,0		0,41	1,0	58
L19-06 - Preparação dos ARM's	296,0				296,0		0,26		
L19-07 - Tilt Center Assy 1	370,0				370,0		0,32		
L19-08 - Tilt Center Assy 2	310,0				310,0		0,27	1,0	88
Rodar 90º TILT CENTER e no lado do RESOLVER ARM (left), efectuar:									
Rodar 180º TILT CENTER e no lado do TILT GEAR (roda dentada), efectuar:									
L19-09 - Camara Module Assy	521,0				521,0		0,46		
L19-10 - Montar Front Shell	321,0				321,0		0,28	1,0	85
L19-11 - Montar Rear Shell	386,0				386,0		0,34		
L19-12 - Montagem Final	592,0				592,0		0,52	1,0	46
L19-13A - Teste Final + L19-14A	926,5	463,3			926,5	85%	0,95	1	25
Colocar no teste	51,1								
auto		80,5							
Manual	23,5								
auto		77,7							
Manual	14,2								
auto		126,6							
Manual	124,3								
auto		403,4							
Manual	19,3								
L19-15 - Teste Fuga	538,0				538,0		0,47		
Colocar na Fuga	68,0				68,0				
Auto		358,0							
Retirar da Fuga	112,0								
Colocar no Soak Test	70,0								
L19-16 - Embalagem	665,0				665,0		0,58		
Ligar Mic ao teste e realizar algumas operacoes.					0,0				
Tempo na soak.					0,0				
Tempo parada.					0,0				
Aparafusar (6x), acabar a limpeza e passar para a embalagem.					0,0				
Montar caixa e divisoes.					0,0				
Embalar (inclui etiqueta na caixa)					0,0				
Levar para o carrinho.					0,0				
Tempo de teste IP.					0,0				
Total	6404,5	1087,4			6404,5		5,60	6,0	26
					0,0				
ttb Productive time that can be influenced									
ttu Productive time that cannot be influenced									
					0,0				
operador 1	1115,0				1115,0		0,98	1,0	25
operador 2	950,0				950,0		0,83	1,0	29
operador 3	1022,0				1022,0		0,89	1,0	27
operador 4	928,0				928,0		0,81	1,0	30
operador 5	862,3				862,3		0,75	1,0	32
operador 6	884,0				884,0		0,77	1,0	31
					0,0				
					0,0				
					0,0				
					0,0				

			max cap
Number of Operators	5,6	6,0	25
Unbalanced		7%	3,044720952

6.7 ANNEX 7: Future Balancing calculation for 8 associates

Shift Number	2		Capacity required	35 Pcs / Day

Item	Detail	Description	hours	minutes	seconds
Total Available Time		24 hours/ day (excl Weekends and Holidays)	24,00	1 440	86 400
Line Closed :	1st shift 2:30 to 08:00		5,50	330	19 800
	2nd shift 8:00 to 17:00		9,00	540	32 400
	3rd shift 17:00 to 02:30		9,50	570	34 200
Total Open Hours		Line Closed	9,00	540	32 400
Planned Stoppages :	lunch, breacks,group meetings,cleaning		0,92	55	3 300
Net Available Time or Planned Operating Time		Planned down time, Planned maintenance & Line Extra Capacity	8,08	485	29 100
Waiting Time :	NA		NA	NA	NA
Operation Time		Logistic Waiting time ex: waiting for components, operators, unplanned...	8,08	485	29 100
Rest personnel Care :	4,50% Net Available Time		0,36	22	1 310
Net Operating Time		Machine/Operator related (e.g. > 5 min), Setup/Adjust for new product type	7,72	463	27 791
Operators Speed :	15 % at 70 instead of 80		0,10	6	360
Gros production time		Small stops, increased machine cycle time	7,62	457	27 431
Quality Losses :	NA		NA	NA	NA
Net production time		Quality Losses	7,62	457	27 431

Customer Tack Time	831,4 sec / pc	Planned Cycle Time	784 sec / pc

BASIC TIME STRUCTURE

PROCESS STEPS

op	description	Manual	machine run time	operator work during machine run time	free time	Tempo Ciclo Posto	FRY %	Needed People	Real People	Available Capacity
		seconds								
*	*	*	*	*	*		*	*		*
1	L19-01 - Preparação do Pan Motor	160,0				160,0		0,20	1	171
1	L19-02 - Preparação Tilt Motor + Soldar Nexus + Soldar Power	265,0				265,0		0,34		
1	L19-03 - Preparação do Wipper Motor	217,0				217,0		0,28		
2	L19-04 - Montar Pan Shaft	363,0				363,0		0,46		
3	L19-05 - Pan Body Assy	474,0				474,0		0,60	1,0	58
4	L19-06 - Preparação dos ARM´s	296,0				296,0		0,38		
2	L19-07 - Tilt Center Assy 1	370,0				370,0		0,47		
3	L19-08 - Tilt Center Assy 2	310,0				310,0		0,40	1,0	88
	Rodar 90º TILT CENTER e no lado do RESOLVER ARM (left), efectuar:									
	Rodar 180º TILT CENTER e no lado do TILT GEAR (roda dentada), efectuar:									
4	L19-09a - Camara Module Assy	321,0				321,0		0,41		
3	L19-09b - Camara Module Assy	200,0				200,0		0,26		
5	L19-10 - Montar Front Shell	321,0				321,0		0,41	1,0	85
5	L19-11 - Montar Rear Shell	386,0				386,0		0,49		
6	L19-12a - Montagam Final	270,0				270,0		0,34	1,0	102
6	L19-12b - Montagam Final	322,0				322,0		0,41	1,0	85
7	L19-13A - Teste Final + L19-14A	926,5	463,3			926,5	85%	1,39	1	25
	Colocar no teste	51,1								
	auto		80,5							
	Manual	23,5								
	auto		77,7							
	Manual	14,2								
	auto		126,6							
	Manual	124,3								
	auto		409,4							
	Manual	19,3								
	L19-15 - Teste Fuga	538,0				538,0		0,69		
6	Colocar na Fuga	68,0				68,0				
	Auto		358,0							
7	Retirar da Fuga	112,0								
7	Colocar no Soak Test	70,0				70,0		0,09		
	L19-16 - Embalagem	665,0				665,0		0,85		
	Ligar Mic ao teste e realizar algumas operacoes.					0,0				
	Tempo na soak.					0,0				
	Tempo parada.					0,0				
	Aparafusar (6x) , acabar a limpeza,e passar para a embalagem.					0,0				
	Montar caixa e divisoes.					0,0				
	Embalar (inclui etiqueta na caixa)					0,0				
	Levar para o carrinho.					0,0				
	Tempo de teste IP.					0,0				
	Total	6404,5	800,6			6404,5		8,17	6,0	26
						0,0				
	ttb Productive time that can be influenced									
	ttu influenced									
	operador 1	650,0				650,0		0,83	1,0	42
	operador 2	699,0				699,0		0,89	1,0	39
	operador 3	693,0				693,0		0,88	1,0	40
	operador 4	783,0				783,0		1,00	1,0	35
	operador 5	711,0				711,0		0,91	1,0	39
	operador 6	782,0				782,0		1,00	1,0	35
	operador 7	740,3				740,3		0,94	1,0	37
	operador 8	696,0				696,0		0,89	1,0	39
						0,0				
						0,0				
						0,0				

			max cap
Number of Operators	8,2	8,0	35
	Unbalanced	-2%	4,335713744

6.8 ANNEX 8: Future Balancing calculation for 6 associates

Shift Number	2		Capacity required	25 Pcs / Day	

			hours	minutes	seconds
Total Available Time		24 hours/ day (excl Weekends and Holidays)	24,00	1 440	86 400
	Line Closed : 1st shift	2:30 to 08:00	5,50	330	19 800
	2nd shift	8:00 to 17:00	9,00	540	32 400
	3rd shift	17:00 to 02:30	9,50	570	34 200
Total Open Hours		Line Closed	9,00	540	32 400
	Planned Stoppages :	lunch, breacks,group meetings,cleaning	0,92	55	3 300
Net Available Time or Planned Operating Time		Planned down time, Planned maintenance & Line Extra Capacity	8,08	485	29 100
	Waiting Time :	NA	NA	NA	NA
Operation Time		Logistic Waiting time ex: waiting for components, operators, unplanned...	8,08	485	29 100
	Rest personnel Care : 4,50%	Net Available Time	0,36	22	1 310
Net Operating Time		Machine/Operator related (e.g. > 5 min), Setup/Adjust for new product type	7,72	463	27 791
	Operators Speed :	15 % at 70 instead of 80	0,10	6	360
Gros production time		Small stops, increased machine cycle time	7,62	457	27 431
	Quality Losses :	NA	NA	NA	NA
Net production time		Quality Losses	7,62	457	27 431

Customer Tack Time	1 164,0 sec / pc	Planned Cycle Time	1 097 sec / pc

BASIC TIME STRUCTURE

PROCESS STEPS no description	Manual	machine run time	operator work during machine run time	free time	Tempo Ciclo Posto	FRY %	Needed People	Real People	Available Capacity
	seconds								
L19-01 - Preparação do Pan Motor	160,0				160,0		0,15	1	171
L19-02 - Preparação Tilt Motor + Soldar Nexus + Soldar Power	265,0				265,0		0,24		
L19-03 - Preparação do Wipper Motor	217,0				217,0		0,20		
L19-04 - Montar Pan Shaft	363,0				363,0		0,33		
L19-05 - Pan Body Assy	474,0				474,0		0,43	1,0	58
L19-06 - Preparação dos ARM´s	296,0				296,0		0,27		
L19-07 - Tilt Center Assy 1	370,0				370,0		0,34		
L19-08 - Tilt Center Assy 2	310,0				310,0		0,28	1,0	88
Rodar 90º TILT CENTER e no lado do RESOLVER ARM (left), efectuar:									
Rodar 180º TILT CENTER e no lado do TILT GEAR (roda dentada), efectuar:									
L19-09A - Camara Module Assy	321,0				321,0		0,29		
L19-09B - Camara Module Assy	200,0				200,0		0,18		
L19-10 - Montar Front Shell	321,0				321,0		0,29	1,0	85
L19-11 - Montar Rear Shell	386,0				386,0		0,35		
L19-12 - Montagam Final	592,0				592,0		0,54	1,0	46
L19-13A - Teste Final + L19-14A	926,5	463,3			926,5	85%	0,99	1	25
Colocar no teste	51,1								
auto		80,5							
Manual	23,5								
auto		77,7							
Manual	14,2								
auto		126,6							
Manual	124,3								
auto		409,4							
Manual	19,3								
L19-15 - Teste Fuga	538,0				538,0		0,49		
Colocar na Fuga	68,0				68,0				
Auto		358,0							
Retirar da Fuga	112,0								
Colocar no Soak Test	70,0								
L19-16 - Embalagem	665,0				665,0		0,61		
Ligar Mic ao teste e realizar algumas operacoes.					0,0				
Tempo na soak.					0,0				
Tempo parada.					0,0				
Aparafusar (6x) , acabar a limpeza,e passar para a embalagem.					0,0				
Montar caixa e divisoes.					0,0				
Embalar (inclui etiqueta na caixa)					0,0				
Levar para o carrinho.					0,0				
Tempo de teste IP.					0,0				
Total	6404,5	1067,4			6404,5		5,84	6,0	26
					0,0				
ttb Productive time that can be influenced									
ttu influenced									
					0,0				
operador 1	857,0				857,0		0,78	1,0	32
operador 2	968,0				968,0		0,88	1,0	28
operador 3	1003,0				1003,0		0,91	1,0	27
operador 4	998,3				998,3		0,91	1,0	27
operador 5	1060,0				1060,0		0,97	1,0	26
operador 6	891,0				891,0		0,81	1,0	31
					0,0				
					0,0				
					0,0				
					0,0				

			max cap
Number of Operators	5,8	6,0	26
	Unbalanced	3%	3,202701756

6.9 ANNEX 9: Current state of the mounting fixtures

Mounting JIG's - Current State	Time per step Seconds [s]	adjustments	Operation	checking
WORKSTATION 1				
Change the press fit adaptor from the manual arbor	15,0	x		
Need of changeover for product B	5,0	x		
WORKSTATION 2				
Change the press fit adaptor from the manual arbor	15,0	x		
Need of changeover for product B	5,0	x		
WORKSTATION 3				
Need of changeover for product B	5,0	x		
WORKSTATION 4				
Press fit the gear into the shaft	10,0		x	
Move to a different press fit and place bearings	10,0		x	
Handling the Pan assembly fixture	5,0		x	
Change the press fit adaptor from the manual arbor	5,0	x		
Need of changeover for product B	30,0	x		
WORKSTATION 5				
Quality check of a specific task from the previous assembly	10,0			x
Press fit ferrite	5,0		x	
Need of changeover for product B	0,0	x		
WORKSTATION 7				
Handling all fixtures used	15,0	x		
Press fit some parts	22		x	
Quality check of the gear position	5,0			x
Need of changeover for product B	60,0	x		
WORKSTATION 10				
Press fit bush	15,0		x	
Need of changeover for product B	5,0	x		
WORKSTATION 12				
Checking arms tightening from previous station	10,0			x
Handling the final assembly fixture	7,0		x	
Need of changeover for product B	30,0	x		
WORKSTATION 15				
Place the leakage fixture in the product	10,0		x	
Plug the air connection preparation	30,0	x		
Take off the leakage fixture in the product	10,0		x	

6.10 ANNEX 10: Current amount of assembly tools used for one product.

Worstation	Fixtures	Classification
L19-01 - Pan Motor Preparation	JIG to assembly Pan Motor assy	Alignment JIG
	Manual press arbor	Press Fit
	Plate for part position	Alignment JIG
	Press adaptor for Pan bearings	Press adaptor
L19-02 - Tilt Motor Preparation	JIG to assembly Tilt Motor assy	Alignment JIG
	Manual press arbor	Press Fit
	Plate for part position	Alignment JIG
	Press adaptor for Tilt bearings	Press adaptor
L19-03 - Wiper Motor Preparation	JIG to assembly Wiper assy	Mount JIG
	Wiper test equipment	Quality check
L19-04 - Pan Stage I Assembly	JIG to tight Pan Base	Fixation JIG
	Manual press arbor	Press Fit
	Adaptor to press Pan gear	Press adaptor
	Adaptor to press bearing into Pan body	Press adaptor
	Adaptor to attach the press arm	Press adaptor
	Shim to help press the Leap seal	Press adaptor
	Special tool to tight Pan base	Tight tool
L19-05 - Pan Stage II Assembly	JIG to assembly Pan Stage II	Mount JIG
	JIG to check previous assembly	Quality check
	Tool for press ferrite	Press Fit
	Special tool to tight pigtail	Tight tool
	Special tool to tight pigtail	Tight tool
L19-07 - Tilt Center I Assembly	JIG to press fit Tilt bearings	Alignment JIG
	JIG to press fit Tilt Gear	Alignment JIG
	JG to support the arms mount	Fixation JIG
	JIG to quality check of gear position	Quality check
	Gauge to control arms gap	Quality check
	Adaptor to press Tilt gear	Press adaptor
	Manual press arbor	Press Fit
L19-08 - Tilt Center II Assembly	JG to support the Tilt stage II mount	Mount JIG
	Gauge to control Tilt motor gap	Quality check
L19-09 - Camera Module Assembly	JIG to assembly camera module	Alignment JIG
	JIG to support camera module into Tilt	Mount JIG
L19-10 - Front Shell Assembly	Manual press arbor	Press Fit
	Plate for part position	Alignment JIG
	JIG to assembly Front shell	Alignment JIG
L19-11 - Rear Shell Assembly	JIG to assembly Rear shell	Mount JIG
	JIG to assembly Rear shell caps	Mount JIG
L19-12 - Final Assembly	JIG to do the final assembly	Mount JIG
	JIG to check the arms screws torque	Quality check
L19-15 - Leakage Test	JIG to tight yoke caps	Fixation JIG
	Jig to leak test	Fixation JIG
	Special cap to plug air	Fixation JIG
	Adaptor to tight yoke caps	Tight tool

6.11 ANNEX 11: Future state of the mounting fixtures

Mounting JIG's - Future State	Time per step (seconds)	adjustments	Operation	checking
WORKSTATION 1				
Change the press fit adaptor from the manual arbor	3,0	x		
Need of changeover for product B	5,0	x		
WORKSTATION 2				
Change the press fit adaptor from the manual arbor	3,0	x		
Need of changeover for product B	5,0	x		
WORKSTATION 3				
Need of changeover for product B	2,0	x		
WORKSTATION 4				
Press fit the operations	10,0		x	
Handling the Pan assembly fixture	5,0		x	
Need of changeover for product B	5,0	x		
WORKSTATION 5				
Press fit ferrite	3,0		x	
Need of changeover for product B	0,0	x		
WORKSTATION 7				
Press fit parts	15,0		x	
Need of changeover for product B	20,0	x		
WORKSTATION 10				
Press fit bush	5,0		x	
Need of changeover for product B	5,0	x		
WORKSTATION 12				
Handling the final assembly fixture	7,0		x	
Need of changeover for product B	15,0	x		
WORKSTATION 15				
Place the leakage fixture in the product	10,0		x	
Take off the leakage fixture in the product	10,0		x	
Total	**2,13**	min		