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Operations management and production cells implementation:

Operations Management, Energy Optimization, Kaizen, Lean, Production Cells

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Abstract

Lean thinking has brought some of the most significant changes in areas like supply chain management and operations management. This project consists of applying the Lean tools that better fit the necessity in a major international company in the automotive area, Yazaki.

The main approaches in this project consist of reducing the lead time while improving the production system by implementing a Lean tool, the production cells. These are known by the possibility to improve job shop production systems while maintaining some of its flexibility in production. The other approach is focused on reducing raw material stock by introducing a new control and request process in order to increase the available space in the warehouse.

While working to achieve the objectives mentioned in the last paragraph, the necessity of other improvements in the process and new tools emerged, so, were also developed three visual basic/excel macros and a technical tool exclusively to fit the needs of this project.

In the end, were achieved some good results in both approaches. Being Yazaki, a Japanese company, these Lean values are very familiar in the company culture and employees mentality, which proves that there is always room for improvement, Kaizen.

Keywords: Lean Thinking, Kaizen, Cells Production, Supply Management, Production Management, Operations Management

Resumo

A metodologia Lean trouxe algumas das maiores mudanças na area de gestão de cadeias de abastecimento e gestão de operações, este projecto consite em aplicar as ferramentas Lean que melhor se adaptam à necessidade numa companhia internacional do ramo automóvel, a Yazaki.

As duas principais abordagens neste projecto consistem em reduzir o lead time de produção através da melhoria dos processos de produção, para isso vai ser utilizada a criação de células de produção. Estas células criam a possibilidade de aumentar a productividade da produção, mantendo alguma da sua flexibilidade. A outra abordagem é focada na redução de stock na fábrica, para isto será necessário implementar um novo controlo de stock e actualizar o processo de encomenda de material.

Durante o projecto e de maneira a atingir os objectivos, foram surgindo outras necessidades de melhoria por isso ainda no âmbito deste projecto foram criadas macros em excel/visual basic e uma ferramenta técnica exclusivamente para essas necessidades.

No final foram obtidos excelentes resultados. Sendo a Yazaki uma empresa Japonesa a metodologia Lean já era algo familiar e presente na cultura da empresa. Isto mostra-nos a que existe sempre espaço para melhorar, Kaizen.

‘The greater danger for most of us is not that our aim is too high and we miss it, but that it is too low and we reach it. ’

Michelangelo

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I would like to thank all the people that accompanied me during the realization of this project. Starting by Yazaki, I would like to show special thanks to Eng. Ricardo Relhas for being my mentor and for his availability to help to solve every kind of problem. My Team Leader Eduardo Gonçalves for all the help given and for being so comprehensive on how this project affects the typical working day. To Eng. Maria Gonzalez for being so kind as to review the work done. To everyone in the Crimping Centre office that provided different ideas and opinions. To everyone in the Crimping Validation Production, for helping to measure the times and all the suggestions about their working environment. Moreover, I want to thank my family for being always there, the strength given, and all the support. My girlfriend for the endless patience and support in the all the stressful times . To my roommates for the support provided when I was working long hours. My mentor, Prof. Afonso Clito, for the opportunity of realizing this project in my work environment. And finally to all my friends from VR and from FEUP that act like a support in my everyday life.

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Abbreviations and Symbols

PTC	Porto Technical Centre
CC	Crimping Centre
OEM	Original Equipment Manufacturer
RD	Research and Development
DD	Design Development
DV	Design Validation
HEV	Hybrid Electrical Vehicle
EV	Electrical Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
OEE	Overall Equipment Efficiency
TPS	Toyota Production System
VSM	Value Stream Mapping
FSM	Future State Map
JIT	Just in Time
PDCA	Plan Do Check Act
TPM	Total Productive Maintenance
KPI	Key Parameter Indicator
CH	Crimping Height
MC	Micro-Cut
PF	Pull Force
PTC-CC	Porto Technical Centre - Crimping centre
WIP	Work in Progress
TT	Takt Time
CT	Cycle Time
CO	Changeover Time
FIFO	First in first out
CONWIP	Constant Work in Progress

Chapter 1

Introduction

1.1 Presentation of Yazaki Company

Yazaki's timeline of success dates back to 1929 when Sadami Yazaki began selling wiring harnesses for automobiles. After significant changes in governmental regulations in 1935, Japanese companies were allowed to start domestic automotive production bringing positive effects for Yazaki: In 1939 the business could be expanded and in 1941, Yazaki Electric Wire Industrial Co. Ltd. was established with around 70 employees. At this time, automotive engineering was a promising branch of industry and so in 1949, Sadami Yazaki made an important strategic decision: to focus on the production of automotive wiring harnesses. This was a groundbreaking decision, which resulted in today's global leadership. The competencies Yazaki developed in the automotive business were used to establish various types of equipment for the city gas industry, amongst others, also the world's first solar-powered absorption cooling system, designed and built, in 1974. Since then the company has developed and provided a large number of products that support the supply and utilization of various energy sources, such as electricity transmission cables, gas security systems, air-conditioning equipment and the aforementioned absorption chillers. As a result, Yazaki began to cater for a safe and environmentally friendly society. These products are now integrated under the environment energy equipment operations, the second biggest sector in the Yazaki Group, emphasizing its continued commitment to an environmentally friendly future.

Figure 1.1: Yazaki Worldwide

Nowadays, Yazaki employs over 249,000 people worldwide in 45 countries and 143 locations. "We care for our employees by promoting a corporate culture that complies with their needs and expectations" (Yazaki, Shinji).

1.2 Porto Technical Centre

PTC is a Technical Centre for Yazaki in Europe and worldwide. Focused on high labour content technical activities which do not need to be co-located with the customer.

Figure 1.2: Porto Technical Centre

The Yazaki RD strategy was always in the sense of concentrating this activity close to the customer development centres. This strategy created a large growth of these centres, due to the OEM strategy to outsource such activities. This also generated significant cost increases and high supporting manpower fluctuations between launch and production phases.

This created a need to centralize RD activities developed in Europe, thus minimizing fluctuation impacts, through cross-allocation of engineering staff to different projects and customers, without having to physically displace them. The decision to create the Yazaki European Technical Centre was analysed in detail, with Portugal being chosen on the grounds of already having a Design team in place and a technological centre with excellent product knowledge, as well as development activities closely coupled with productive know-how.

1.3 Crimping Centre

1.3.1 Activities

Crimping Centre is a centralized resource, inside PTC, to supply, control, and give support to all Yazaki's Wire Harness Plants in Europe concerning applicators, crimping tools, and crimping standards creation, registration, and distribution.

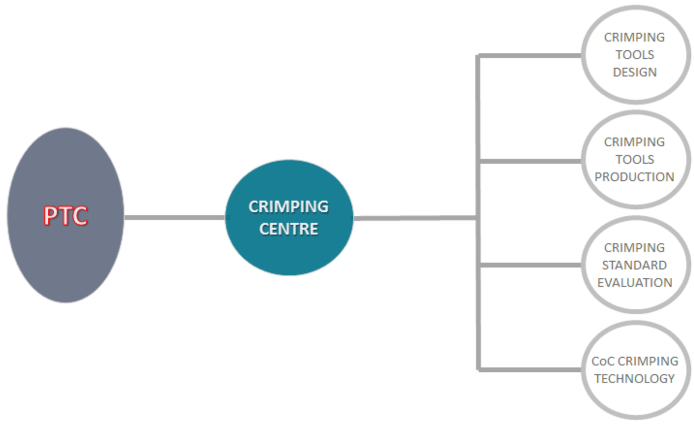


Figure 1.3: Crimping Centre Department

Crimping Tools Production:

- Crimping tool drawing management;
- Applicators development and production;
- Crimping hand-tools development

Centre of Competence - Crimping Technology:

- Crimping technology expertise and YEL support
- New crimping process, tools research, and development
- Crimping technology benchmarking
- Ultrasonic Welding Design Development (DD) and Design Validation (DV)
- New Connections Technology (HEV, EV, and PHEV)

Crimping Validation:

- Crimping test samples preparation;
- Testing and evaluating those samples.
- Crimping standard creation and registration.

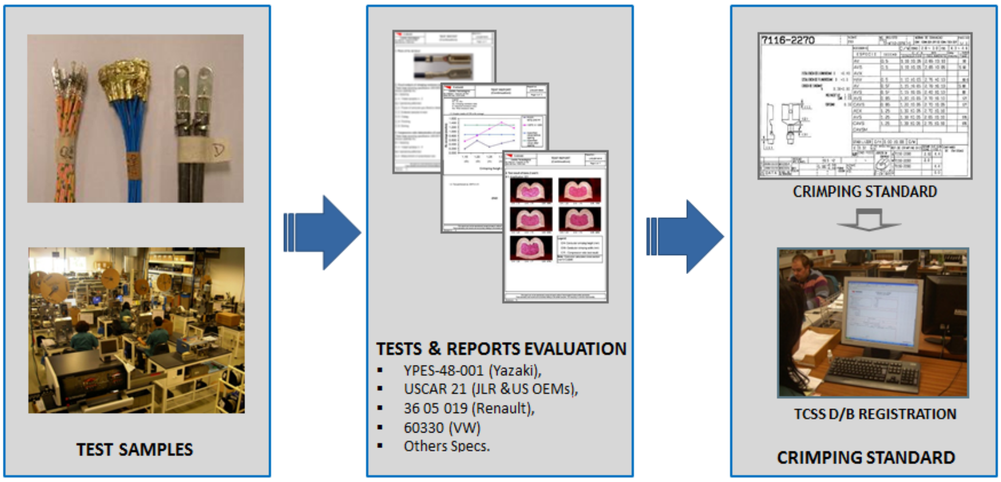


Figure 1.4: Crimping Validation Actions

Although the other sections are also mentioned in this project, the crimping validation is the main focus, so that explanation will be a little bit more elaborated, to present a more precise idea.

Then it is provided a flowchart to allow a better understanding of where these actions fit in the whole panorama by pointing out this section with a red border.

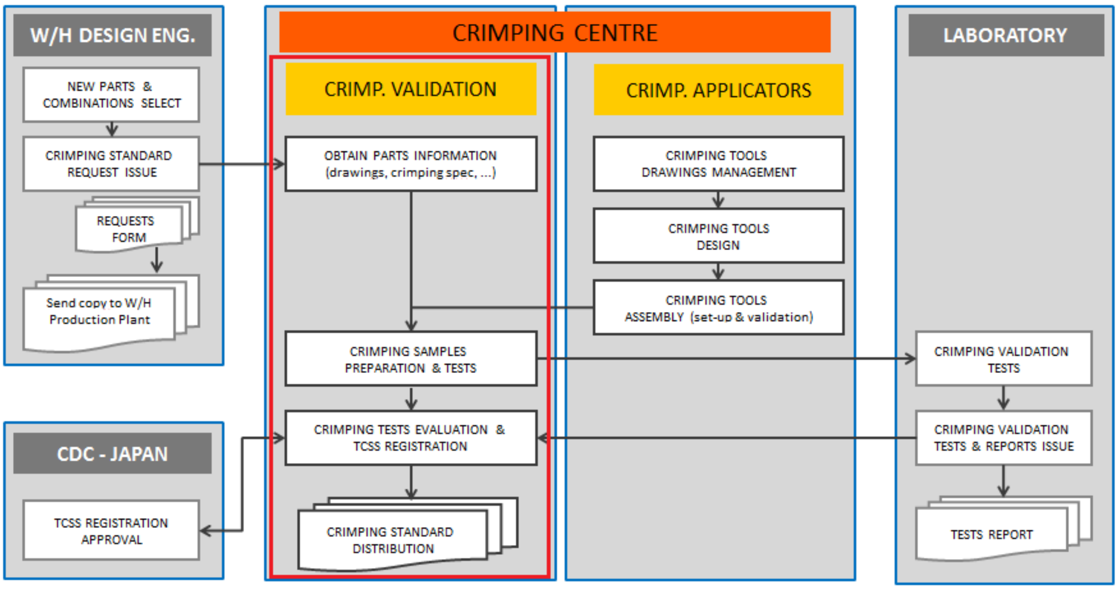


Figure 1.5: Crimping Centre Flow

1.4 Motivation

This project started with the need to reduce extra hours performed by operators and also gain space in the warehouse because it is completely packed. While trying to fix these problems, all the surrounding processes will be affected.

Preparing samples, which are combinations of wires, terminals, and accessories creates countless possible outputs. In cases like these, the production system that fits better is, in fact, the job shop system, as the crimping Centre has been producing since its creation.

However, since the start of this project, while trying to look for the bigger picture, it was realized that these countless possibilities of combinations are one, and only one family of products. Moreover, dividing the production into two processes, we can see that the combinations that belong to the same process go through the same operations, and through the same machines, in almost every case. This discovery means one thing, we can have a production system with higher productivity than a job shop system. However, we have to keep in mind that this is a testing production site, causing most machine parameters to change almost in every combination, and some combinations give bad results unpredictably and need to be changed. This indicates we also need to keep some of the flexibility of the job shop production system.

In order to do so, and after much research, it was possible to establish that the system that would better suit this site, according to the restrictions, is the cells production system. It consists of a group of people, machines, and methods where the next stage of the production process is close by, it works sequentially, and the sections are linked to each other. The implementation of production cells goes directly to the point of lean manufacturing, which is described as a system of organization, production management, quality, and logistics trying to maximize the value with the lesser amount of resources possible. It defends as main goal the elimination of all kinds of waste, through continuous improvement, or kaizen, the elimination of all activities that do not add value to the product, using cheap, efficient solutions assisted by the creativity of the operators.

Applying changes in the production leaves no doubt that the production scheduling and control will have to be adapted. The changes considered to reduce the stock in the warehouse are also a good help when trying to improve the production.

1.5 Objectives

Taking into account the motivations, the main objective with the realization of this project is the improvement of the overall production system related to the crimping validation, so the operators do not have to perform extra hours. Although it is not easy to eradicate the extra hours, after some estimations, our goal is to reduce them in at least 90%. The actions taken towards accomplishing that objective are:

- Implement Cell Production System:
  - Adapt the layout.
  - Define Cells.
  - Improve the actions of every cell.
  - Improve the OEE of the machines used.
  - Production planning.
  - Test the changes and understand the results.
- Reduce and organize stock:
  - Improve the process of requesting material.
  - Reduce the quantity of stock in the warehouse.

It is possible to point out two significant objectives, starting with the implementation of the new production system, it requires a deep focus on every detail of the production process. The actions that it includes need to be divided according to the value they add in the product to allow changing the process without jeopardizing the quality levels.

After creating the cells, the layout also requires changes to fit the cells in the production site, and these cells actions will be improved by kaizen approaches to reduce the cycle time and improve productivity.

Regarding the stock reduction, again, it requires a deep understanding of all the process actions. The goal is to improve the process, allowing that improvement to show clearly the unnecessary amount of stock accumulated so far, while also providing a better control of the material available.

1.6 Layout

In this chapter, it can be found the introductory and organizational sections containing the motivation and the objectives with some details of the work ahead, all that based on the company's needs.

The second chapter presents the theoretical principles that were followed and allowed the realization of this project.

The third chapter presents the problems and explains the current state of the production, basically the situation at the start of the project.

The fourth chapter contains the proposed solutions to the problems exposed in the third chapter explaining every action with the data acquired to support it.

The fifth chapter presents the obtained results and compares them to the initial state.

The final chapter contains the conclusions taken on this project and also the perspectives for future work.

Chapter 2

Background Theory

2.1 Introduction

This chapter presents the entire literature review and covers all theoretical concepts that enabled the execution of the practical work developed throughout this study.

- Lean, Kaizen and Six Sigma
- Lean Manufacturing
- Lean Tools
- Production Systems
- Production Cells
- Crimping

2.2 Lean, Kaizen and Six Sigma

In the last years, these three words have lost their identity.(Kaizen, 2020) What many people fail to realize is that each concept/tool is used to solve specific problems as opposed to the answer to every problem. Just because you have the tool does not mean you should use it. No tool should be picked up or used until one can properly understand its purpose(Kaizen, 2020)

- **Lean** - Lean can be resumed as the elimination of the waste. By focusing on mapping a business process flow and identifying all areas with the opportunity to improve, it really can reduce time, cost, and non-value adding activities.
- **Kaizen** - Kaizen is a Japanese word meaning 'change for the better' and is also known as 'continuous improvement'. Some consider it a mindset rather than a tool. Kaizen defends that everything can be improved, that every individual should be encouraged to identify and solve problems within the organization from top to bottom employees. It is more focused on particular problems that appear at the production site.
- **Six Sigma** - Six Sigma can be summed up as the tool to remove variation of the process. It is used to solve the control problems of the process. It focuses on measuring the outcomes, align those outcomes with the expectations, and then improve the

process in order to achieve that alignment. A Six Sigma approach usually divides into five steps: Define, Measure, Analyse, Improve, and Control.

- **Main purposes - Lean** is more about eliminating waste to increase the speed and quality of the process.

  Kaizen focuses on trying to improve a business, creating standards, increasing efficiency one way at a time.

  Six Sigma is focused on quality output(final product). In order to do so, it tries to eliminate the causes of the defects that originate variation.

2.3 Lean Thinking

According to (Womack et al., 1990), after World War I, Henry Ford and Alfred Sloan, the latter, president of the General Motors group between 1923 and 1937, transformed the small-scale production, which was characteristic at the time in the European industry, in the age of mass production. Through this evolution, the United States of America started their path to dominate the world economy.

After World War II in Japan, Eiji Toyoda and Taiichi Ohno devised and developed an innovative production system, called the Toyota Production System (TPS). In fact, in 1950, after a three-month stay in Detroit at the industrial complex known as Ford River Rouge Complex, at the time the most efficient in the world, young engineer Eiji Toyoda along with talented Taiichi Ohno found some possibilities for improving Toyota's production system. This gave birth to the Toyota Production System, whose main purpose was to eliminate all forms of waste. This concept is very evident to Ohno's through the statement he makes, saying that this production system has been developed through a very specific analysis of all the activities in the process, from the moment the customer places an order until the respective payment, including the consequent elimination of all activities that do not add any kind of value in the process.

As a result, Toyota Production System (TPS) managers began implementing revolutionary production techniques and new ways of thinking at Toyota plants retaining special attention on the production system's ability to respond quickly to market variations, motivated and skilled labor, and reduction of all types of waste. This translated to a very different involvement of the operators in the process, allowing them to be conscious of the workload they have pending, which is fundamental to make them feel some pressure, responsibility, and motivation since one of the objectives of this philosophy is to avoid reworking and rectifying products at the end of production, which corresponds to a very high cost of many companies. This responsibility has been passed onto operators having full confidence in their capacities.

The following decades were fundamental for the uprising and improvement of the Lean Manufacturing tools and methodologies, as the results were becoming visible and kept becoming better, in the 1990s the term Lean became known in the book "The Machine that Changed the World" (Womack et al., 1990). This book made Lean achieve a global dimension, and many industries around the world tried to adopt this philosophy. In "Lean Thinking," (Womack and Jones, 2003), the authors presented five fundamental principles that any organization wishing to implement the philosophy has to follow in order to achieve the same success that Toyota has achieved. Therefore, the five key principles of Lean philosophy, shown in image 2.1 are:

- Identify Value - To specify and identify what creates value from the perspective of the customer, in each product or service, as this can make the difference when he is making a decision.

- Map the Value Stream – Identify and define the steps taken by the product or service to be concluded according to the request provided by the customer.
- Create Flow - Eliminate all the steps and actions that have no customer value so the process can run more smoothly.
- Establish Pull - Produce only what has been ordered by the customer(just-in-time), avoiding wastes and accumulated stocks.
- Seek Perfection - This principle has like a priority, the elimination of every waste, always be ready to improve, and has to be practiced by everyone participating in the process.

Figure 2.1: Lean Key Principles

2.4 Muda

Lean means manufacturing without waste. Waste ("muda" in Japanese) according to (Imai, 2012) has seven types:

- **Muda of Overproduction** - It can be due to the mentality of the area supervisor, since while being worried with problems like rejects, machines failing and absenteeism feels pressured to produce more than necessary in order to feel safe. Also, when a machine is involved while trying to make it more profitable, there is overproduction. Produce more than necessary can result in tremendous waste: consumption of raw materials before they are needed, wasteful input of personnel and utilities, additions of machinery, an increase in interest burdens, the need for additional space to store excess inventory, and added transportation and administrative costs.(Imai, 2012) It gives people a false sense of security, helps to cover up all sorts of problems, and obscures information that can provide clues for Kaizen on the shop floor. It should be regarded as a crime to produce more than necessary.(Imai, 2012)

- **Muda of Inventory** - Inventory in general, finished or not, does not add value. Instead, they increase the cost of operations, in terms of additional material, time, and personnel to transport it, in terms of space like warehouses or other facilities. Moreover, we can also consider that if the product has a short lifetime, it can lose value or even deteriorate. Inventory results from overproduction. If overproduction is a crime, inventory should be regarded as an enemy to be destroyed.(Imai, 2012) Inventory can hide problems on the production, so when lowering this number, it can be easier to identify the areas needed to improve and is more likely that the problems will be addressed as they appear.

- **Muda of Defects** - It is known that defects are not desired at all in a production environment. They bring a significant waste in resources and effort and, in some cases, can also mean the malfunctioning of a machine, so that is a problem that needs to be addressed with a significant priority before it can escalate to higher proportions. Defects can also damage expensive jigs.

- **Muda of Motion** - While any employee is walking, there is not any value added to the product, in fact, any physical exertion performed should be avoided not only for the added waste of time but by its difficulty. By observing an operator working, it is easy to conclude that the value-adding moments can be less than a few minutes per hour, the remaining time is used for motion that does not add value. Picking the piece or the tool and putting it down, the transportation or the search for it, among many others. To identify muda of motion, we need to have a good look at the way operators use their hands and legs. We then need to rearrange the placement of parts and develop appropriate tools and jigs.

- **Muda of Processing** - This kind of waste can be caused by inadequate technology or design. An unduly long approach or overrun for machine processing, unproductive striking of the press, and deburring are all examples of processing muda that can be avoided. Processing means a modification done to a work-piece or piece of information. Elimination of this kind of muda is most times achieved with some commonsense combined with low-cost techniques.

- **Muda of Waiting** - Happens when the hands of the operator are idle(Imai, 2012) when an operator is waiting in a queue or monitoring a machine. This can be easy to detect and improve, but really hard to eliminate. This waste can mean there are problems in the process standard when one operator is waiting for another to use the machine or waiting for another operator work.

- **Muda of Transport** - In a production site, there are all sorts of transports, from human transportation to conveyors and forklifts. This transportation is a significant waste first because it adds no value to the product, and in some cases, the product can be damaged along the way. This is a waste that can be easily identified, so as much as it is possible, linear processes should be implemented.

2.5 Value Stream Mapping

Value Stream Mapping, shown in the image 2.2 is a Lean tool proposed by (Rother and Shook, 2003) used by production sites to achieve a clear understanding and optimize the flow of both materials and information needed to take the product from the raw material to the client delivery. VSM's biggest purpose is to identify the operations in the flow that add no value and find ways to eliminate those operations. This tool can be divided into four steps (Rother and Shook, 2003):

- Select and characterize the product to analyze
- Construct the VSM for the actual situation
- Construct the VSM for the improved situation
- Plan and implement the improving actions

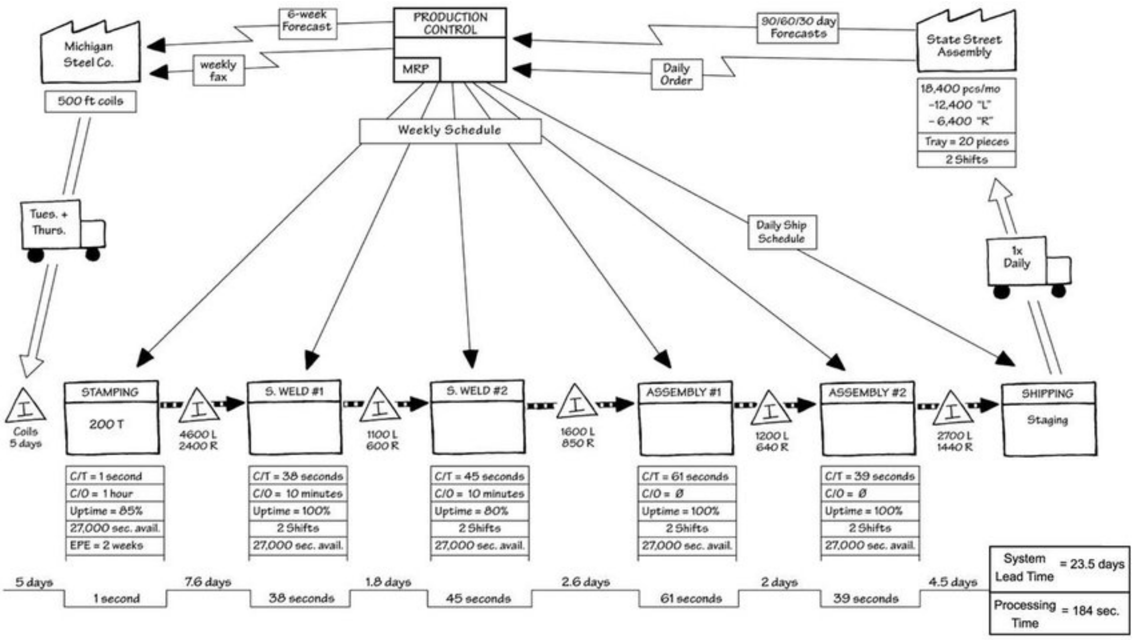


Figure 2.2: Value Stream Map (Shararah et al., 2020)

The first VSM diagram representing the actual situation it is very useful to identify the waste(muda) that can be reduced or eliminated along the process.

The second is useful so you can see what you can improve in terms of productivity or costs, and by seeing good results, people tend to get more motivated to achieve those changes. (Rother and Shook, 2003):

2.6 Just-in-Time(JIT)

The Just-in-Time production system aims at eliminating non-value-adding activities of all kinds and achieving a lean production system that is flexible enough to accommodate fluctuations in customer orders(Imai, 2012). JIT is a pull production system, which means that the production is planned according to the orders to minimize waste. This way, products are assembled just before they are sold, sub-assemblies are just made before they are assembled, and so on. Although being considered a non-stock production system, it is not always either possible or practical to keep a zero inventory, still this system runs with very low inventory.

The main advantages of JIT production are:

- First, one can sense an invisible line connecting the customer and the production process. The short lead time allows production to begin after an order has been received, and employees can keep the customer in mind while making the product. It is almost as if the customer is waiting in the next step to receive the finished product(Imai, 2012).
- Second, this system allows great flexibility to meet customer needs. With the use of Kanban, popular models, are replenished as soon as they are sold, thus minimizing inventory.(Imai, 2012)
- Third, JIT permits flexible production scheduling. The company does not start production in anticipation of future demand, and before the daily minimum, allowable inventory is determined. On the other hand, once production begins, stagnation in the form of work-in-process is not allowed, and the product must be finished within the shortest possible time and shipped directly to the customer right away. (Imai, 2012).

2.7 Continous Flow

Continuous flow refers to producing one piece at a time, as Figure 2.3 shows, with each item passed immediately from one process step to the next without stagnation. Continuous flow is the most efficient way to produce. (Rother and Shook, 2003)

At a first approach some times you'll want to limit the extent of a pure continuous flow because connecting processes in a continuous flow also merges all their lead times and downtimes. A good approach can be, to begin with, a combination of continuous flow and some pull/FIFO. Then extend the range of continuous flow as process the process reliability is improved, changeover times are reduced to zero, and smaller, in-line equipment is developed.(Rother and Shook, 2003)

Figure 2.3: Continuous Flow (Rother and Shook, 2003)

There are often spots in the production system where continuous flow is not possible, and batching is necessary. According to (Rother and Shook, 2003) to there are several reasons for this, including:

- Some processes are designed to operate at very fast or slow cycle times and need to change over to serve multiple product families.
- Some processes, such as those at suppliers, are far away, and shipping one piece at a time is not realistic.
- Some processes have to much lead time or are too unreliable to couple directly to other processes in a continuous flow.

2.8 Pull Systems

The purpose of placing a pull system between two processes is to have means of giving accurate production instruction to the upstream process, without trying to predict downstream demand and scheduling the upstream process. Pull is a method for controlling production between flows. Rother and Shook (2003)

2.8.1 Supermarket Pull

Supermarket pull is an excellent way to control production between processes. It consists of having an inventory of all possible parts that can be used in the next process.

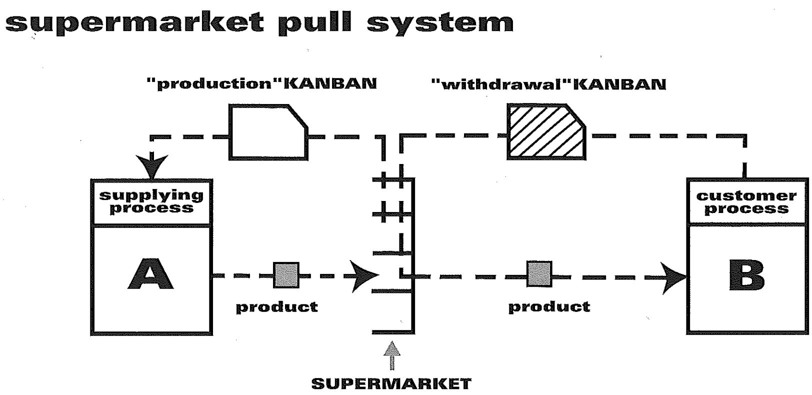


Figure 2.4: Supermarket Pull (Rother and Shook, 2003)

As shown in Figure 2.4, the customer process goes to the supermarket and withdraws what it needs, when it needs. The supplying process produces to replenish what was withdrawn. On the plant floor, supermarkets should ordinarily be located near the supplying process to help that process maintain a visual sense of customer usage and requirements. (Rother and Shook, 2003)

Sometimes it is not practical to keep an inventory of all possible part variation in a pull system supermarket. Examples include custom parts, parts that have a short shelf life, and costly parts that are used infrequently. (Rother and Shook, 2003)

2.8.2 Sequenced Pull

Instead of a complete supermarket that has all components represented in it, sometimes you can install a sequenced pull between two processes. Sequenced pull means that the supplying process produces a predetermined quantity (often one sub-assembly) directly to the customer process' order. This works if the lead time in the supplying process is short enough to produce to order, and if the customer process follows strict ordering rules. (Rother and Shook, 2003)

2.9 FIFO lane

FIFO lanes, also known as CONWIP, are used between two decoupled processes as a substitute to the supermarket and maintain a flow between them, as shown in Figure 2.5. The FIFO lane can only hold a certain amount of inventory. If the FIFO lane gets full, the supplying process must stop producing until the customer has used up the inventory. In this manner, the FIFO lane prevents the supplying process from overproducing, even though the supplying process is not linked to the customer via continuous flow or a supermarket. When the FIFO lane is full, no additional kanban is released to the upstream process. (Rother and Shook, 2003)

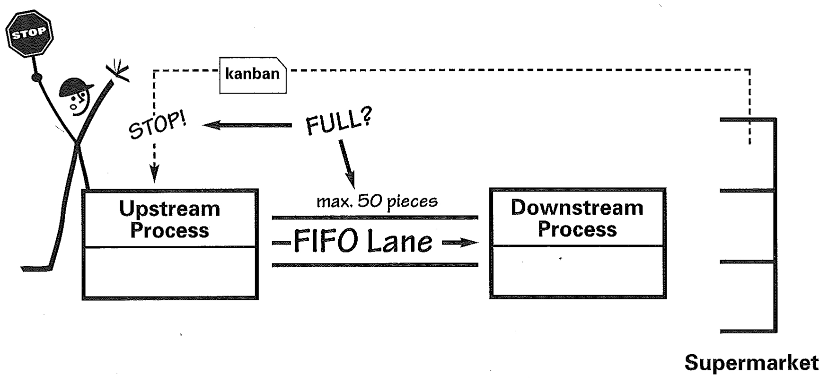


Figure 2.5: FIFO lane (Rother and Shook, 2003)

2.10 Kanban

Kanban is the Japanese word for sign or card, and it is a visual management tool originated by the pull flow system. This technique facilitates the control of production and the transport of materials between the different sections of work. This control is made by a card or some other kind of sign, boxes, free spaces... (Moura, 1989)

The Production Kanban signals the type and quantity of components that the previous workstation should produce to replace the consumption of that component in a subsequent process. It works as a production control device, replacing traditional production orders (Moura, 1989). This way, it synchronizes production, since it does not allow the production of a new batch until the previous one has already been consumed, giving the production line a constant rhythm. The Production Kanban circulates only in work centers that manufacture parts. According to (Moura, 1989), this system follows five essential rules:

- The downstream operation takes from the upstream operation, the components it needs, in the desired quantities, and in the time required, which should be accompanied by its Kanban.
- the previous process should make their products in quantity required, never more than the existent number of kanbans.
- Once a defect is identified, these pieces should not be sent to the next section of the production. It should be corrected right away. Otherwise, the production may stop.
- Kanban can help in detecting fluctuations in the orders. If changes happen in the order quantities, it will be easily identified, with the lack of accumulation of kanbans in the lines. Making possible a response to that fluctuation.
- The number of kanbans should be the smaller possible.

The number of items in stock is determined by multiplying the number of cards by the number of items in each standard package. To determine the total number of Kanbans, (Moura, 1989) proposes the following calculation:

$$N = D * L * (1 + a) \tag{2.1}$$

Where:

- N - is the number of Kanbans
- D - is the daily number of orders, in number of batches
- L - is the Lead time, expressed in days to produce one batch
- a - is the safety factor

Regarding Kanban's calculation expression, (Shingo, 1989) emphasizes the importance of actions to improve the system, in order to minimize the number "N":

- perform production in extremely small batches and minimize the size of each production batch by reducing setup times.
- use these measures to reduce lead times to a minimum.
- eliminate to a minimum the stocks that are maintained as security against instability in production.

2.11 Kaizen

As referred before, Kaizen means continuous improvement in Japanese, Furthermore, it involves every worker on the production site. The beauty of this process is that it requires meager expenses and achieves excellent results if people are committed to it. According to (Slack et al., 2012), this philosophy more than achieving productivity improvements, cost reductions also results in a continuous improvement of the conditions for the operators of the site. One of the more essential tools to achieve Kaizen is the PDCA cycle.

Figure 2.6: PDCA Cycle

This cycle is defined by four steps, as can be seen in image 2.6. Each step should be applied in the right order to allow it to work.

- Plan - This first step is to define goals, but also the tools and methods to achieve those goals. It is a crucial phase that will establish the path to be followed.
- Do - This is the step where it is executed, everything that was though in the last step. Achieve every goal, using the best tools that suit the problem in order to get the best results possible.
- Check - In this step, it is performed the follow up of the project, every method used, and procedures created. It includes data gathering to analyze the results in every phase and find corrections or deviations in order the correct the upcoming errors and avoid problems to the project.
- Act - This step follows the check made before and acts on the errors found before while redefining the standards, it also works as an evaluation do the project deciding if the goals where achieved or not, still Kaizen never stops so the evaluation decides if the Kaizen moves to another project or if it is needed to run the cycle on this one again.

2.12 The 5S

It has become a famous saying among companies adopting a kaizen to say "The first step is 5S." This quote is true enough because at the most basic level, 5S requires that an organization ask the questions, "Do we have all that we need in the Gemba?" and "Do we need all that we have in the Gemba?" and then do kaizen whenever the answer is "No." (Imai, 2012) The five S (5S) are shown in the image 2.7.

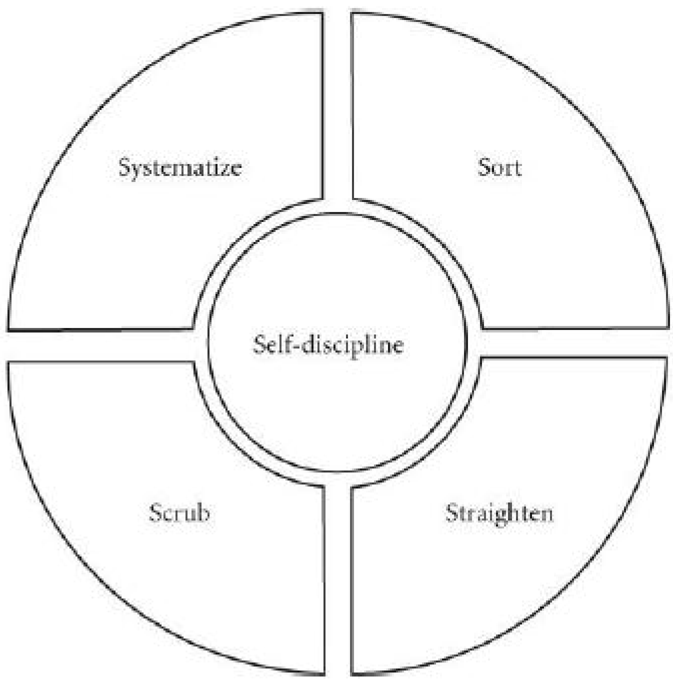


Figure 2.7: The 5S (Imai, 2012)

2.12.1 Seiri(Sort)

The first S in the five S's stands for Seiri, which means Sort in Japanese, and it consists of separating the items in the work site by necessary or unnecessary, and of course, a maximum number of necessary items should be established. You can find all sorts of objects in a production site, and with a closer look, it is visible that most of them are pretty useless on the daily work, and many of them will not be used in a distant future. An easy rule of thumb is to remove anything that will not be used within the next 30 days.(Imai, 2012)

2.12.2 Seiton(Straighten)

After the first step, with the unnecessary items removed from the production site, we are left with only the necessary ones. But the first step will not have the pretended effect if they are too far from the workstation or in a place that takes too long to find them. This brings us to the next stage of 5s, Straighten, or Seiton in Japanese means classifying items by use and rearranging them accordingly to minimize search time and effort. (Imai, 2012)

2.12.3 Seiso(Scrub)

Scrub or Seiso in Japanese means cleaning the work environment, including machines, tools, floors, walls, and any other areas in the workplace. This is very important because when an operator is cleaning a machine, he can find many malfunctions. When the machine is covered in oil or dust, it is difficult to identify if any problem is happening or developing. However, if a machine is clean is easier to identify an oil leakage, a crack, or a loose nut. Once these problems are identified, they are easily fixed. But if those problems are not identified, they can lead to greater problems like machine breakdown or defects in the products. (Imai, 2012)

2.12.4 Seiketsu(Systematize)

Systematize or Seiketsu in Japanese, means keep working on seiri, seiton, and seiso continually and every day. For instance, it is easy to go through the process of seiri once and make some improvements, but without any effort to continue such activities, the situation soon will be back to where it started. To do Kaizen just once is easy, to keep following it continuously, day in, day out, is an entirely different matter. Management's commitment to and involvement in 5S is essential. They also must determine, for example, how often seiri, seiton, and seiso should take place and who should be involved. (Imai, 2012)

2.12.5 Shitsuke(Standardize)

Shitsuke means self-discipline. People who practice seiri, seiton, seiso, and seiketsu continuously acquire self-discipline. 5S are sometimes called a philosophy, a way of life in the daily work. The essence of 5s is to follow what has been agreed on. It begins with discarding what we do not need(seiri) and then arranging all the necessary items in an orderly manner(seiton). Then a clean environment must be sustained so we can quickly identify abnormalities(seiso), and these three steps must be maintained on a continuous basis (seiketsu). Employees must follow established and agreed-on rules at each step, and by the time they arrive at shitsuke, they will have the discipline to follow such rules in their daily work. This is why the last step of 5S is called self-discipline.(Imai, 2012)

2.13 Total Productive Maintenance (TPM)

TPM aims at maximizing equipment efficiency through the equipment's life cycle. It motivates people for plant maintenance through small-group and autonomous activities and involves such basic elements as developing a maintenance system, education in basic housekeeping, problem-solving skills, and activities to achieve zero breakdowns and an accident-free gemba. Autonomous maintenance by workers is one of the important elements of TPM(Imai, 2012). 5S is an entry step of TPM, as can be seen in Figure 2.8.

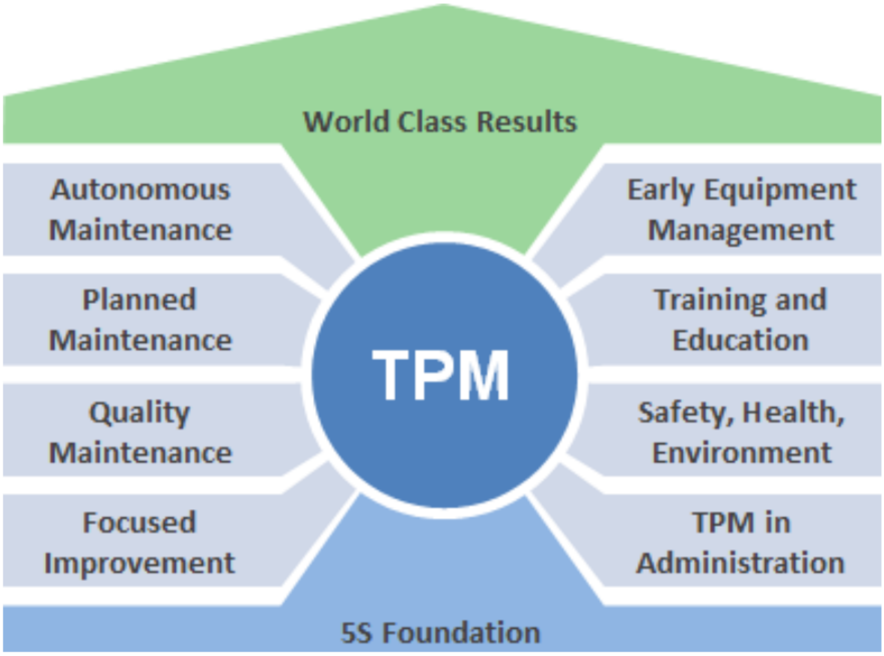


Figure 2.8: TPM Pyramid (Chandegra and Deshpande, 2014)

To achieve maximum efficiency, we have to eliminate the waste related to the quality and availability of the equipment. According to (Willmott and McCarthy, 2001) the major wastes are:

- Malfunctions or non-programmed stoppages.
- Small breaks that happen frequently.
- Time lost in reference changes.
- Time lost in starting the production.
- Wastes of material and reworks.

2.13.1 Overall Equipment Efficiency(OEE)

OEE is the method that allows to measure the productivity of equipment, and it divides the losses in three groups:

- Losses in availability - takes into account the events that stop planned and unplanned production.
- Losses in performance - takes into account anything that causes the manufacturing process to run at less than the maximum possible speed.
- Losses in quality - takes into account manufactured parts that do not meet quality standards, including parts that need rework.

$$Availability = \frac{PlannedProductionTime - Stoptime}{PlannedProductionTime} \tag{2.2}$$

$$Performance = \frac{IdealCycleTime * TotalCount}{RunTime} \tag{2.3}$$

$$Quality = \frac{GoodParts}{TotalCount} \tag{2.4}$$

Then to have a value for OEE, it is just needed to multiply these three numbers.

$$OEE = Availability * Performance * Quality \tag{2.5}$$

OEE is a significant number, but he needs to be accompanied by the three other values to give a full insight into the nature of the losses. As an example, an enterprise may decide to do not increase the OEE if it means an increase in availability and a decrease in quality.

2.14 Visual Management

Visual management is how information is presented. An excellent visual management is beneficial in a production site in terms of passing information into the operators, and to control the production for managers. There is not a single way to achieve it. You have to understand the ways that suit your process better.

On the operator side it is helpful to have the parameters and clear indicators of important steps on their processes, posted on their workplace since they are more likely to remember and memorize it.

Figure 2.9: Visual Management using KPIs (Visual Management, 2017)

On the other side, this is also very important for controlling the process. Since it is the easiest way a person retains and processes information, management should have data about their department's production values in the form of charts or tables, as seen in image 2.9. In that way, it is easier to recognize patterns and recognize the variations and causes of the departments' work.

2.15 Production Systems in Organizations

The Production System is the activity where the resources flow inside a defined system, where they are combined and transformed in order to obtain the final product. The production systems used in a site vary according to the Production volume and Product variety, among others, moreover these two are considered the criteria in most of the cases. According to this criteria, the production systems can be classified between four types (Kumar and Suresh, 2009):

- Job Shop - This is a production system characterized by manufacturing individual pieces or small quantities of it, which implies a high variability in the products ordered, generally in this kind of production the products are designed according to the desire of each client according to the costs and time initially established (Kumar and Suresh, 2009).

- Batch Production - It is characterized by the manufacturing of a limited amount of products in a regular amount of time to keep stock. The batch will then follow a route defined by the Organization (Kumar and Suresh, 2009).

- Mass Production - This production is characterized by a continuous process of manufacturing individual pieces or assembly. It is used in sites and products that require a large volume of production, and normally the production is made in line and by product(Kumar and Suresh, 2009).

- Continuous Production - This kind of production is organized according to the operations required from the raw material to the desired output. In this production, the items flow through this sequence assisted by automated transportation (Kumar and Suresh, 2009).

  However, a new kind of production system arrived from the Lean ideology, the cell manufacturing system.

- Production cells - Basically, it consists of making essential components for sub-assembly areas. Sub-assembly cells assemble units for final assembly. The cell processes are build according to the sequence of processes and operations required to manufacture a group or family of products. The manufacturing cells are built for flexibility. It is typically arranged in a U-shape, so workers can move from machine to machine, loading and unloading parts, with the distance being as short as possible. The first step in forming these cells is to restructure the archaic functional job shop by systematically converting it, in stages, into lean-production cells. Then these cells can be linked to each other by using a pull production with kanban (Black and Hunter, 2003).

2.16 Production Cells

Production Cells are a group of people, machines, or methods, shown in Figure 2.10, where the steps on the process flow occur sequentially, where the components are processed in a continuous flow. This type of manufacturing is connected to a product or family of products. The operator in a cell should have multiple knowledge on how to perform the different tasks inside the cell.

According to (Pinto, 2006), the implementation of a manufacturing cell should follow these steps:

- Identify the products with similar flows and characteristics.
- Group machines in cells according to the family product
- Create and locate the cells in order to minimize the movement and transportation of materials
- Identify the machines shared by many families and locate them in a way it serves both cells and minimizes transportation and stocks.

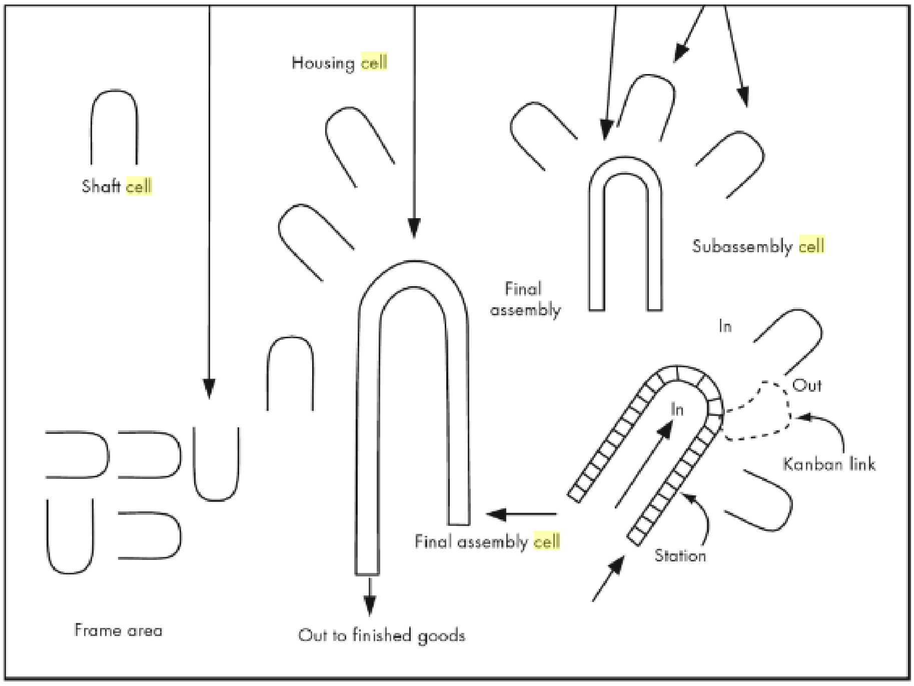


Figure 2.10: Production Cells (Black and Hunter, 2003)

A very important aspect of a cell is its layout. The movement of the operators and the flow of materials will depend on it. So it should be optimized in a way that achieves the best efficiency in the smaller area possible. According to (Rother and Harris, 2001) this is what you have to take into account the layout of a manufacturing cell:

- As referred above, rearrange the cells and machines in a way it minimizes the distance between operations
- Remove obstacles that may be in the path of the operators
- Keep at least 1.5 meters wide inside the cell so operators can move freely and have a good positioning in each operation performed.
- Eliminate spaces and places that may lead to the creation of stock between processes.
- Use the force of gravity in a way it helps the operators every time it is possible.
- Install electrical grids and compressed air networks in the ceiling to predict future changes in the layout.
- Make sure the cell is safe.
- Promote the use of small equipment that performs simple tasks instead of large ones with multiple tasks.
- Avoid production of batches, instead promote the piece-by-piece workflow.
- Inserting sensors that control the malfunction or breakdown of a machine.
- Create devices for a quick change of tools

The flow of the materials should also be taken into account in the creation of cells, and it created a standard for it in order to improve efficiency. There is not a single way to define a good material flow, but according to (Rother and Harris, 2001), it should follow the following patterns:

- Always store the raw material the closest possible to the first call, but in a way, it does not obstructs any operator path.
- Keep the pieces close to the operator's fingers to avoid exchange time.
- Use anti-error systems to prevent look-a-like pieces from being switched.
- Do not keep the stock inside the cell because it makes the flow more confusing.
- Use Kanban to regulate the supply and production.
- Create a supply that does not stop the operator's work.

Many reasons are convincing organizations to adopt the cell production in their production sites, according to (Pinto, 2006), these are the reasons:

- Flexibility
- Possibility to adjust to different production volumes.
- Simple to manage
- Reduced area when compared with the functional layout.
- Less quality errors
- Autonomy

However, Production Cells also create some difficulties like the creation of families to insert in the new cells or new products that don't fit the existing cells.

2.17 Crimping

Crimping is a method used to obtain an electrical connection between a wire and typically a terminal, this is very used, especially in the automotive industry for their wire-harness. The mechanical crimping is obtained by removing a part of the insulation of the pretended wire, exposing the wire strands and placing it inside the terminal barrel, and then use a tool to deform the terminal into close contact with the wire (Europe, 2003).

Advantages of crimping method:

- Efficient processing of connections at each production level;
- Processed by fully-automatic or semi-automatic crimping machines, or manually
- No cold-soldered joints
- No degradation of the characteristics of female contacts by the soldering temperature;
- No health risk from heavy metal flux steam;

- Preservation of conductor flexibility behind the crimped connection;
- No burnt, discolored and overheated wire insulation;
- Easy production control.

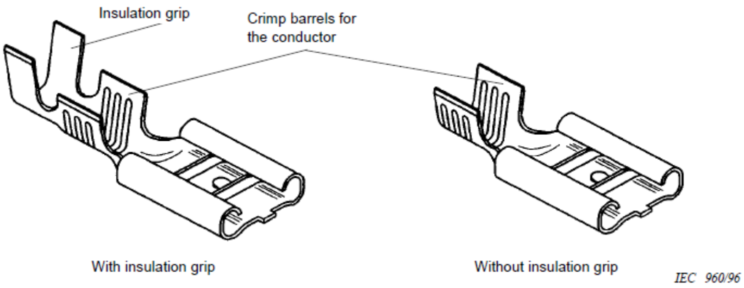


Figure 2.11: Terminal Piece Parameters (Europe, 2003)

This implies that the tooling system needs to be adapted to each terminal, consequently for each terminal, a specific crimping die must be designed.

Nowadays, Automotive Industry is a very competitive industry, and they get pressured to get higher quality, so every aspect of crimping connections from wire-terminal are controlled in detail to assure that quality.

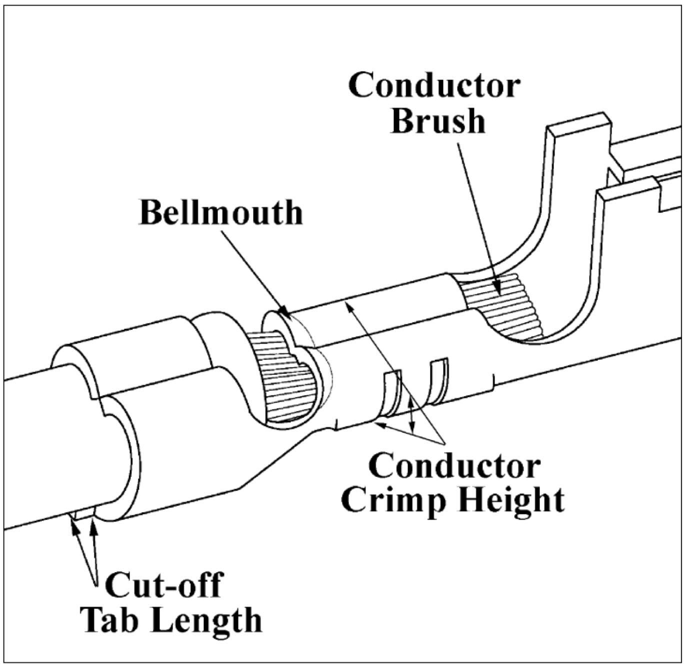


Figure 2.12: Crimped Terminal Parameters (Europe, 2003)

This are the more common controlled details in a crimped connection, most of them can be seen in image 2.11, 2.12 and 2.13:

- Bellmouth - The flare that is formed on the edge of the conductor crimp acts as a funnel for the wire strands. This funnel reduces the possibility of a sharp edge on the conductor crimp will cut or nick the wire strands.

- Conductor brush - The conductor brush is made up of the wire strands that extend past the conductor crimp on the contact side of the terminal. This helps ensure that mechanical compression occurs over the full length of the conductor crimp. The conductor brush should not extend into the contact area.

- Conductor Crimp - This is the metallurgical compression of a terminal around the wire's conductor. This connection creates a common electrical path with low resistance and high current carrying capabilities.

- Conductor crimping height - The conductor crimp height is measured from the top surface of the formed crimp to the bottom-most radial surface. Do not include the extrusion points in this measurement. Measuring crimp height is a quick, non-destructive way to help ensure the correct metallurgical compression of a terminal around the wire's conductor and is an excellent attribute for process control. The crimp height specification is typically set as a balance between electrical and mechanical performance over the complete range of wire stranding, coatings, terminal materials, and platings.

- Cut-off tab length - This is the material that protrudes outside the insulation crimp after the terminal is separated from the carrier strip. A cut-off tab that is too long may expose a terminal outside the housing, or it may fail electrical spacing requirements.

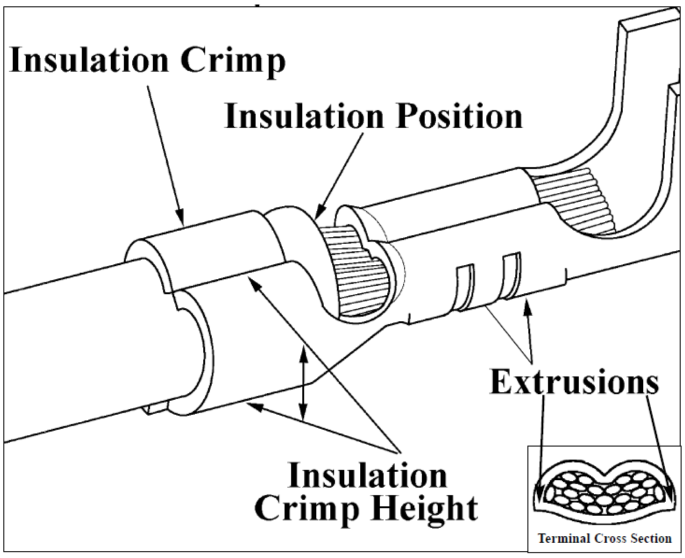


Figure 2.13: Crimped Terminal Parameters and Cross Section (Europe, 2003)

- Insulation Crimp - This is the part of the terminal that provides both wire support for insertion into the housing and allows the terminal to withstand shock and vibration. The terminal needs to hold the wire as firmly as possible without cutting through to the conductor strands. The acceptability of an insulation crimp is subjective and depends on the application. A bend test is recommended to determine whether or not the strain relief is acceptable for each particular application.

- Insulation Crimping Height - Most terminals are designed to accommodate multiple wire ranges. Within the range of the terminal, an insulation diameter may not completely surround the wire or fully surround the diameter of the wire. This condition will still provide an acceptable insulation crimp for most applications.

Chapter 3

3 Characterization of the Initial Situation

This chapter focuses on explaining how the company, especially the crimping centre department works, in order to do that, it is necessary to understand the process flow.

3.1 Crimping Centre Facilities

The Yazaki Crimping Centre is installed in the Porto Technical Centre in the industrial site of Ovar. It is constituted by a production site, an office, a technical area, and a tools manufacturing room, as it shows Figure 3.1.

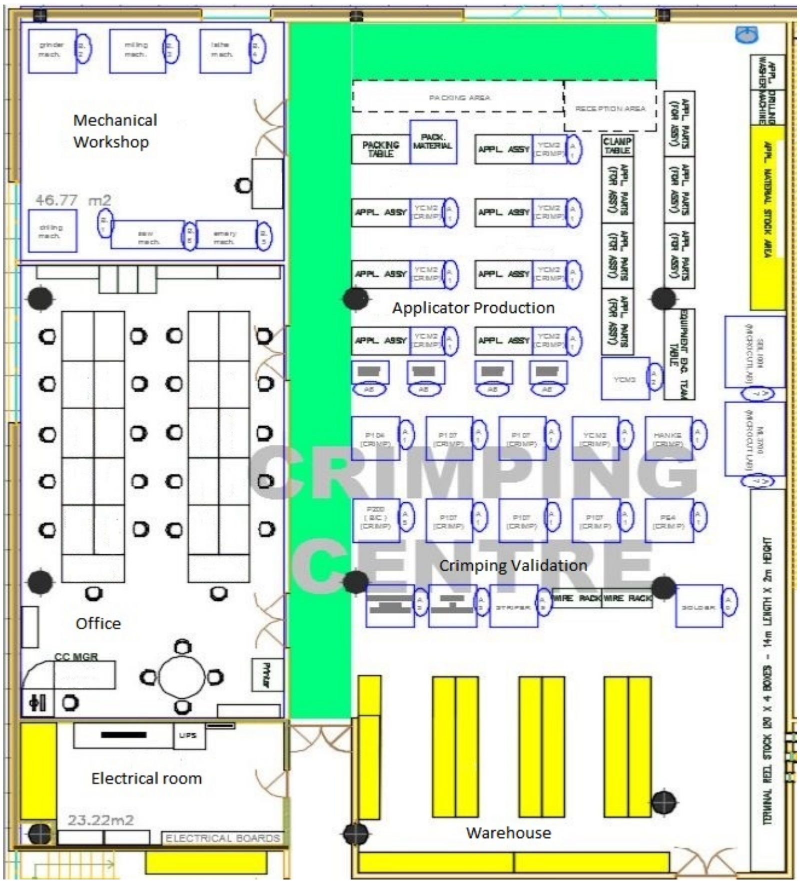


Figure 3.1: Crimping Centre Layout

The production site can be separated into three sections:

- Warehouse - Where most of the materials are kept, wire, terminals, seals, and also some applicators.
- Applicator Production Section - Where the applicators are assembled and validated according to the required parameters.
- Crimping Validation Section - Here is where the samples are prepared according to the defined parameters for each combination wire/terminal, and if applicable, the accessory.

3.2 Crimping Validation Production

At this initial situation, the crimping validation production works as a job shop production system where an operator picks the order and prepares the samples from the raw material until it is ready to go to the laboratory.

The crimping validation production requires having many operators working beyond the established eight hours a day. To understand the magnitude of this need, a few calculations were performed according to the data of the last five years:

1. It was summed all the extra hours worked from January 2015 until August 2019 (4,67 years), with both these months included. This summed up to 12105 extra hours.
2. It was calculated the average extra hours per year:

$$\frac{ExtraHours}{Year} = \frac{12105}{4.67} = 2592.1 hours/year \tag{3.1}$$

3. It was calculated the number of hours per operator, assuming they all worked the same hours, but to do that the need to calculate an average of working operators in these five years emerged, since there were three years with seven operators and 2 years with eight operators:

$$AverageOperators = \frac{7*3+8*2}{5} = 7.4 operators \tag{3.2}$$

$$\frac{ExtraHours}{Year * AverageOperators} = \frac{2592.1}{7.4} = 350.3 hours \tag{3.3}$$

4. To conclude, it was passed the hours into days and reached the final value of:

$$350.3/8 = 43.8 days \tag{3.4}$$

So, after this calculation, it can be stated that the average operator of the crimping validation production works nearly forty-four extra days every year.

Product Characterization

The product achieved in this production site is a batch of samples. A sample is a crimped combination of wire, terminal, and, if applicable, accessory (seals, shrinks). Every batch of samples is constituted by:

- Pull Force - 100 samples
- Micro-cut(conductor) - 20 samples

- Resistance - 85 samples
- Micro-cut(insulation) - 15 samples
- Bending - 25 samples

These samples sum up to a total of 245 per batch. Note that this is the standard amount. In some batches, this number may vary, which still is not significant, so these are the numbers that will be considered in this project.

These batches are very unlikely to be produced ever again, it is a one-time production, and from batch to batch, it is required a lot of different setups. For these reasons, it makes no sense to divide the batches into pieces, and it will be used one batch as our basic unit for our production system.

3.2.1 General Process Overview

The Crimping centre supplies the Yazaki European plants with two different products:

- Applicators tool
- Crimping Standards

When the applicator is ready to be used at the plant, the crimping standards must also be available. Still, these two have a big difference. The applicator is a physical tool that needs to be sent to the plant, which implies transportation time. On the other hand, the crimping standard is information, it is uploaded online, so it does not require this transportation time.

In this project, the goal is to improve the crimping validation operations, therefore improving its lead time is one of the primary objectives. However, having the crimping standard ready before the applicator is ready to use at the plant adds no value because, without the actual tool, the crimping parameters are worthless.

Notice that the image 3.2 shown below only applies to crimping samples production (Process A), the one that requires the applicator to crimp samples.

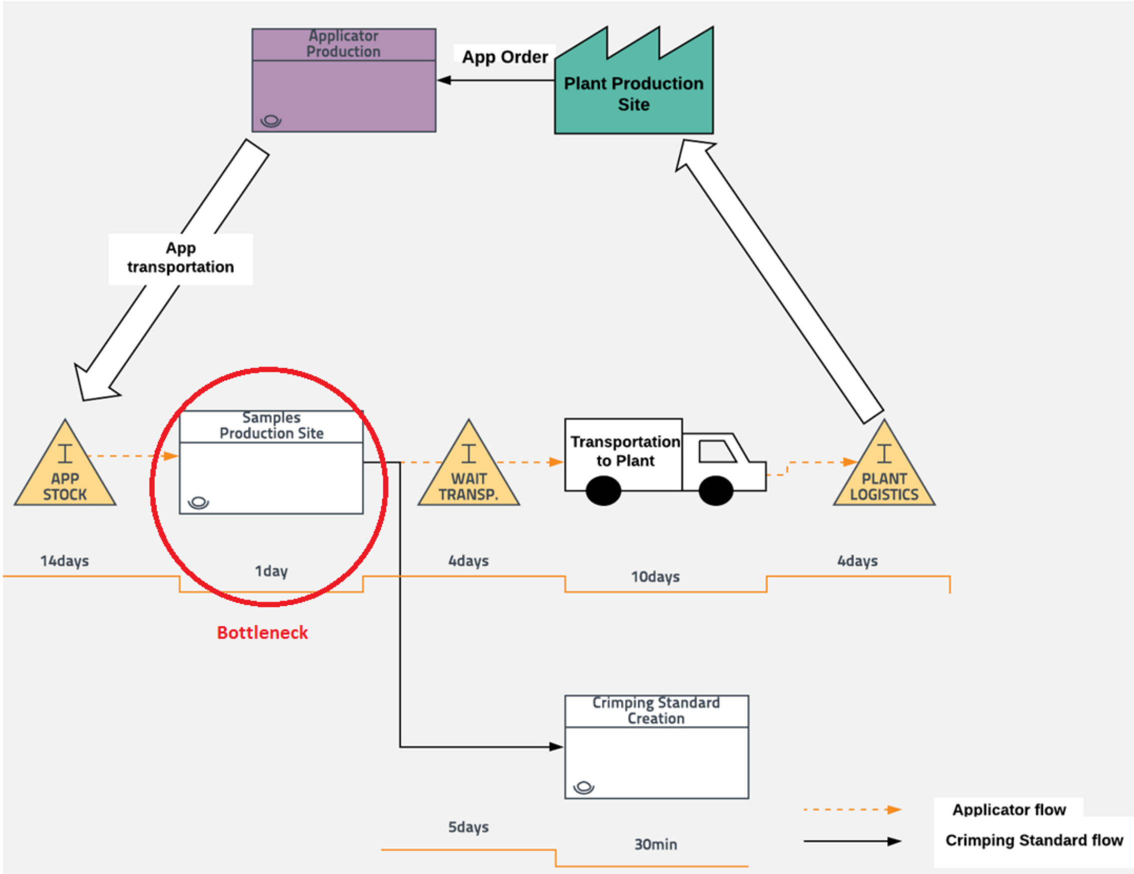


Figure 3.2: General Flow Crimping Centre VSM

Image 3.2 represents a VSM for the Crimping Centre general flow, focused on the period since the applicator is ready for production until both applicator and crimping standards are available to the plant.

It is seen the existence of a bottleneck in the Samples production, causing a 14 days delay in average, with this it is possible again to see the need of improving the production lead time.

Again in the VSM, it is possible to understand that the crimping standard preparation time is almost three times quicker than the applicator transportation. Showing there is a time window parallel to the applicator transportation where it would be possible to fit some actions from the production site where the bottleneck is occurring in order to reduce the lead time.

Process Overview

In order to better understand the Crimping Centre process, a complete flowchart has been created. However, in this project, Crimping Validation Production will the main focus, so a more simple flowchart that groups most actions is shown in Figure 3.3 to make possible explaining the two main processes of the Crimping Validation production.

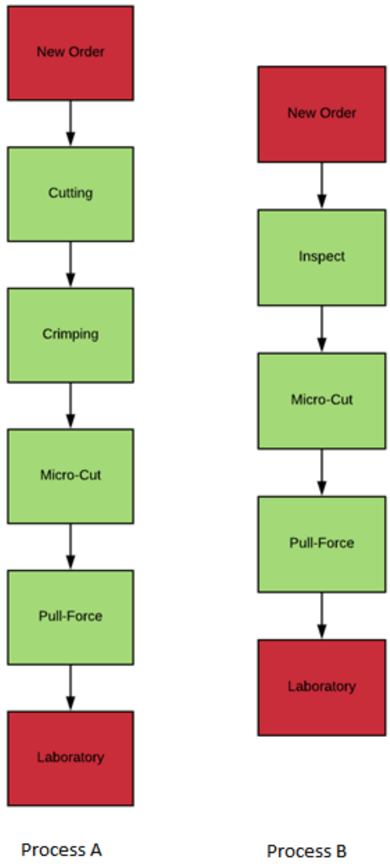


Figure 3.3: Crimping Validation Production Flow

According to last year's requests(attachment A.3), the crimping samples production will be named as process A, and it corresponds to 41.2% of the orders and 68.2% of the production working hours. The crimped samples inspection will be named as process B, and it corresponds to 58.8% of the orders and 31.8% of the production working hours.

The current lead time for process A is 8h, and the current lead time for process B is 2.62h. The first was calculated according to data acquired from the last two years(attachment A.4) using weighted averages, and the latter was measured.

After these flowcharts, the following step is to create something like a Value chain customized for the production of both processes. Since the actual production is based on a job shop production system, all the activities in each process were separated and evaluated. They were separated according to:

- Direct Value - Activities that add direct value to the product(marked as blue).
- Indirect Value - Activities that do not add value directly to the product but are crucial to the proper functioning of the process(marked as green).
- Non Value - Activities that do not add value to the product neither directly or indirectly(marked as red).

3.2.2 Process A

Process A was separated into three sections to be easier to analyze and understand.

Cutting

The cutting section consists in cutting the wires that are going to be used to crimp the terminal, the number of samples per combination can have a small variation as mentioned before, but it is not significant. The machine that cuts the wire also does the stripping length required for the next section. The activities in this process can be seen in the flowchart in Figure 3.4.

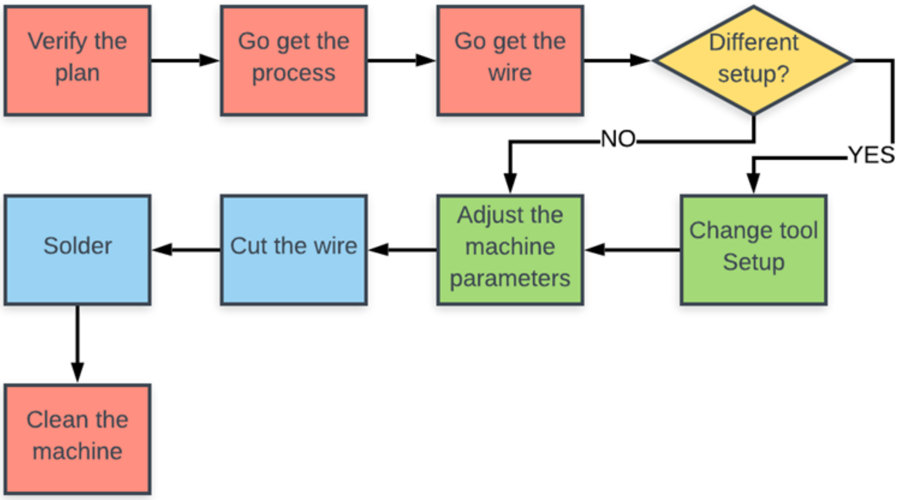


Figure 3.4: Cutting Section Flowchart

This is the first step in process A, so here are also considered the times consumed by the employee while consulting his work plan. Next, the activities have been separated, as explained before:

- Non-Value-adding activities - The first two steps in the flowchart are actions performed by the operator with the only purpose of understanding what he has to do, and both of them involve a waste of machine working time and waste of motion. The third step involves waste in transportation. The last one, cleaning the machine, is necessary, but not as often as in every combination. It should be performed once at the end of each day, but due to the constant changes in the person operating the machines, they feel obliged to leave the machine clean for the next person, which seems reasonable.
- Indirect Value - The tool setup change is needed depending on the sectional area of the wire to cut. Performing this step brings better quality to the wire cut and prevents the malfunctioning of the machine. The adjustment of the machine parameters is needed when the wire or its size is changed.
- Direct Value - The direct value-added in this section is resumed to the machine cutting the wire and applying the solder to the samples. Only some part samples in a batch require the welding, so the operator starts by cutting those samples, and

while the machine is cutting the rest of the samples, he applies the solder to the first ones. Here are the results obtained on this section:

Table 3.1: Cutting Section Results

Direct Value Time	23.5min
Indirect Value Time	42min
Non Value Time	14.5min
Lead Time	80min
Machines	1
Tool Setup Change	7min
Walking Motion	81m
Material Motion	28m

Notice that there is a significant disparity between walking motion and material motion, caused by the tools' setup since these are located too far from the actual machine. Then by the values obtained, it is possible to calculate a Direct Value Adding Time of 29.38%. To conclude, it also seems that there are no standard parameters to the machine inputs like feed and cutting speed. So the operator makes the inputs based on experience, which can allow some errors, and lack of efficiency.

Crimping

The crimping section includes all actions from getting the terminal from the warehouse, placing seals, if applicable, adjusting the applicator, preparing the samples, label them, and evaluating them. This is the most extended section on process A, and also the one with more steps, as it shows the following flowchart.

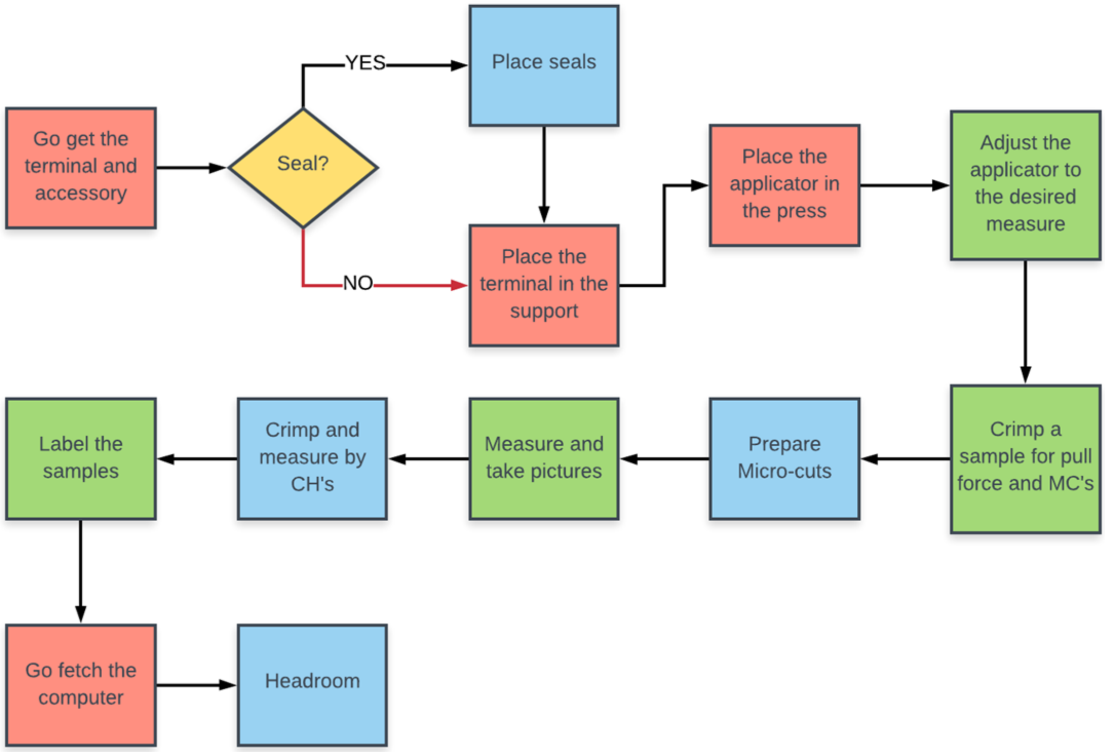


Figure 3.5: Crimping Section Flowchart

This section is the trickiest one, and it is tough to standardize it, so the flow changes from operator to operator, which is bad. For a better understanding of the steps, they are separated according to the value-added:

- Non Value Adding - Again, the first step in this section adds no value, as it is a material transportation step to acquire the terminal. Moreover, the condition of the terminal received from the plants, most times, requires to be improved to fit the support on the crimping machine. Then again, the operator has to get the matching applicator and bring it to the crimping machine. The last non-value-adding activity is again associated with muda of transportation, fetching the computer for the Headroom Test.

- Indirect Value - Adjusting the applicator to the desired CH, can sometimes take more than 60min. This long setup happens because the applicator production does not necessarily validate the applicator to the same wire section and type of the crimping validation. Other times, the applicator is just tricky, and it is hard to adjust. This step also works as a quality assurance to the applicator production process, since it guarantees the applicator can crimp the measures asked by the plant for the validation.

Before initiating the crimping and measure samples by CH's, some employees make a run to the pull force machine for each CH. Typically there are five CH's, so there are five runs to the pull force machine. Other operators do just one pull force and one micro-cut, there is not a standard here, which is terrible. This happens because they want to confirm if the crimped samples will pass the next test because if they do not, the operator can change the parameters right away or stop that combination. While doing this, there is much waste added, like motion, transport and waiting waste. This needs to be thought and dealt with, to be able to create a standard.

After preparing the Micro-Cuts, there is the need to take pictures of it and other different measures of the crimping samples, like bell mouth, bending, and others. To do this, the operator has to keep repeating the information of the combination in every photo taken and save them in specific folders. These actions work as insurance but takes some time, which could be done automatically.

After having the samples crimped, the employee has to label them in groups according to the tests that will be performed on them in the laboratory. To do that, they have to apply tape to every different group and every different CH. This consumes a reasonable amount of time that, even though it is indispensable, should be thought of as something to improve.

- Direct Value - The direct value-adding actions in this section are placing seals (or other accessories, seals are the most common ones) in the wire, which happens in 35% of the combinations, according to the data gathered from different projects of different brands(see attachment A.5). The MCs preparation consists of crimping a sample to the desired CH, then use an electric saw to cut and sand it in the crimping barrel, allowing it to be ready to take pictures with the magnifying glass. Crimping and measuring every sample for the desired CH takes some time because it is required to adjust the applicator for each CH between crimping every group of samples. To conclude this section, there is a final test to send to the plants, the headroom test. This test is used to understand how easily this combination can be monitored in production. Here are the results obtained in this section:

Table 3.2: Crimping Section Results

Direct Value Time	189min
Indirect Value Time	103min
Non Value Time	18min
Lead Time	310min
Machines	11
Setup Change	35min
Walking Motion	156m
Material Motion	112m

In this test section, it is tough to define a standard, but there are ways it can improve. Notice there are 11 available crimping machines, six of a more standard type(P107) and five of them present unique characteristics for different kinds of samples, higher section wires and terminals(P80), used in high voltage applications and battery cables(P200), and tiny sections(HANKE). They cannot be dispensed because of the need for their capacities, but they have a low occupation ratio. To conclude, this section has a direct value ratio of 60.9%, which means a good opportunity for improvement.

Pull Force

The last section of process A is the pull force test. And contains the following actions:

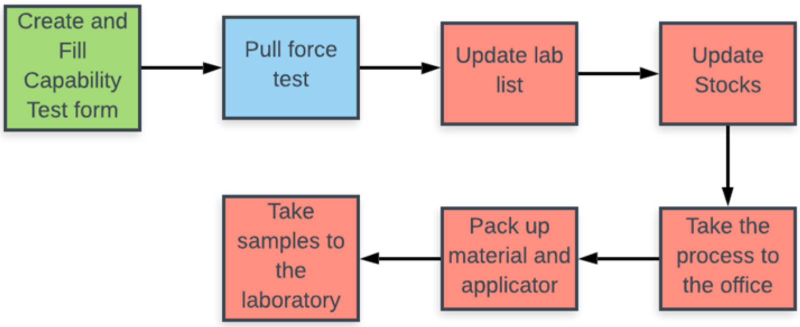


Figure 3.6: Pull Force Flowchart

- Non Value adding - After performing the pull force test, being this one in the last section, there are some actions to perform in terms of process control and paperwork to close the process. Having these steps performed by the same operators that add value to the product means a stoppage in the value-adding and the production flow. These actions, like updating lists, bringing the papers to the office to be signed, and taking the samples to the laboratory, that do not add any value to the product, should be grouped and performed separately.

- Indirect Value - Before performing the pull force tests, the operator has to create a form in the computer and complete it according to the combination specifications, so after this, the pull force machine can complete the right fields with the proper results. This form also acts as the report of the pull force test and could be done automatically.

- Direct Value - The only direct value action is the actual pull force test, this test is performed for a certain number of samples and with a certain velocity according to the standard each brand requires.

Table 3.3: Pull Force Section Results

Direct Value Time	48min
Indirect Value Time	5min
Non Value Time	17min
Lead Time	70min
Machines	3
Setup Change	1min
Walking Motion	158m
Material Motion	70m

The pull force test is the one with a lower time variation on the actual test. The direct value-adding time of 68.5% could be improved by removing the steps that follow it to conclude the process. With this, the Process A sections are concluded.

3.2.3 Process B

Process B is more related to quality assurance. It starts with the already crimped samples, verifies the requested measures, the quality of samples by visual inspection, and then performs the tests of micro-cuts and pull force just like process A. So, process B can be defined as a variant of the process A, more simple, with a shorter lead time and besides having the same final product, the actions involved are different. However, in this case, there is no need to divide it into sections to explain it. Here are the actions involved in process B:

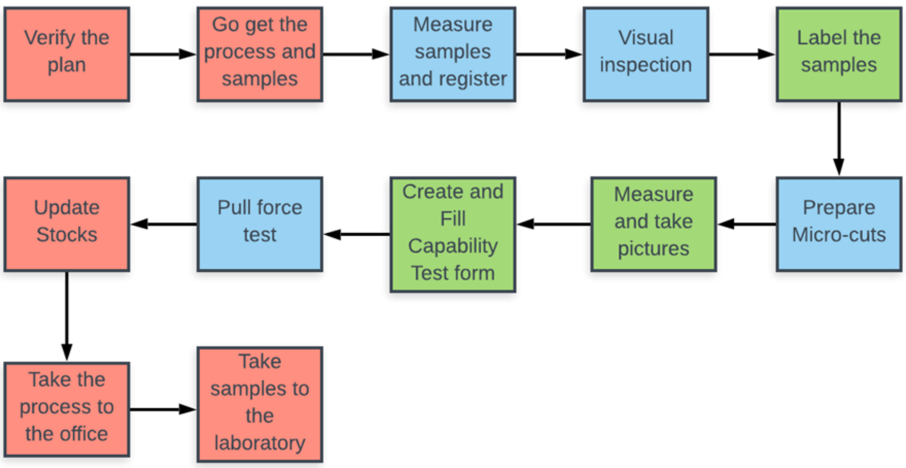


Figure 3.7: Process B Flowchart

Divided into the previously established value-adding actions:

- Non Value adding - The actions that fit in this category are the usual walking and transportation actions, and in addition to those, the update stocks action.
- Indirect Value - It is possible to find indirect value actions that also appear in process A, the labeling samples, measuring, taking pictures, and creating the form for the

pull force tests.

- Direct Value - The actions that add value in this process are, measuring the parameters previously established to assure the plant sent the requested measures, perform a visual inspection on the samples and then perform the same tests as in the process A, micro-cut and pull force.

Table 3.4: Process B results

Direct Value Time	100min
Indirect Value Time	33min
Non Value Time	17min
Lead Time	150min
Setup Change	2min
Walking Motion	217m
Material Motion	177m

This process time could be easily reduced if the plants that send the samples had more knowledge of how to do it. So, in this process, it is achieved a Direct Value Adding ratio of 66.67%, which also shows a good possibility for improvement.

3.3 Value Stream Mapping

Value Stream Mapping is an essential tool. It enables the possibility to see beyond the waste, what causes it. Trying to create a VSM for the initial state led to the realization that it was not clear how to define an ordinary VSM for job shops. Both processes had to be divided by each section as done before for process A activities. Notice that Crimping Centre works with batches of 245 pieces, and for a more straightforward explanation, this batch will be used as the base production unit.

In order to create the Value Stream Map, it was necessary a clear understanding of the flow, from both information and material. It was then measured all the times correspondent to the processes that the product goes through, allowing the creation of the value stream map shown in figure 3.8, showing all the activities that transform the raw material into the final product. To conclude, an evaluation of the value stream map was performed with particular attention to the waste found.

3.3.1 Initial State VSM

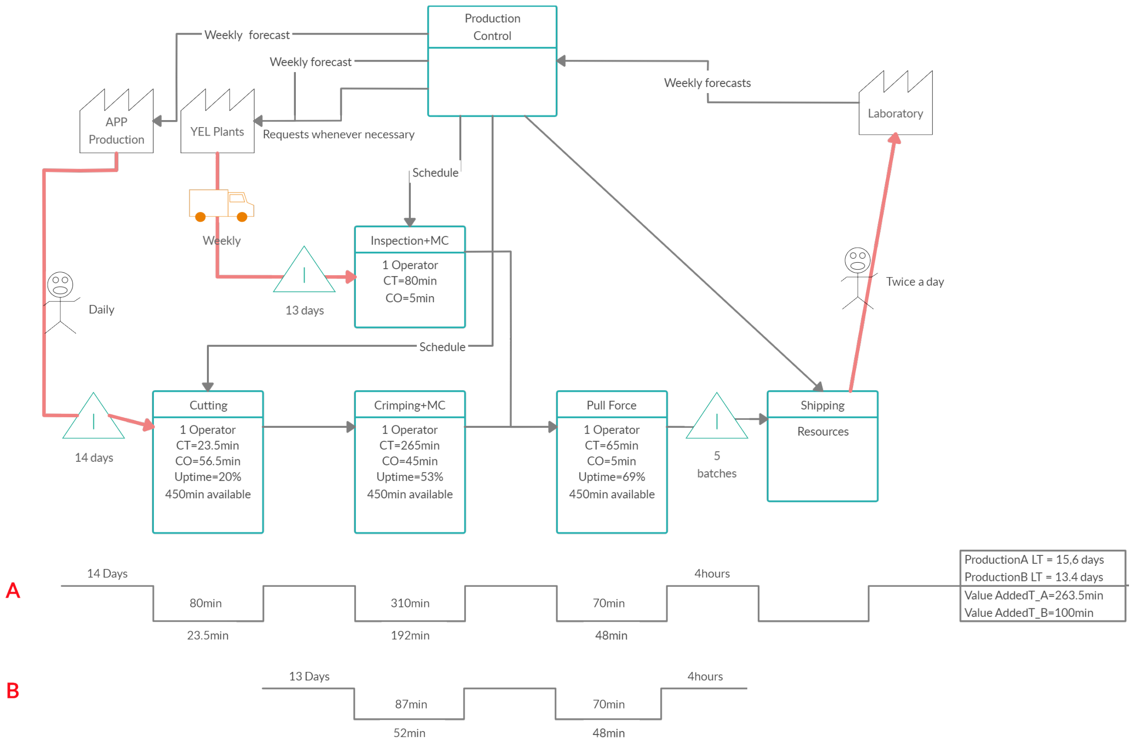


Figure 3.8: Initial State VSM

Through a brief look at the bottom of the value stream map is possible to identify some evident problems. Considering the times taken above the line as the lead time and below the value adding time, it can be seen that the lead time of both processes is too high, 15.6, and 13.4 days for processes A and B, respectively, compared to the short value-adding time. A large amount of inventory just sitting at the beginning of each production (the calculation of this inventory is shown in attachment A.1), is an indicator that the production may not have the necessary capacity to deal with the orders that are leading to the significant, consistent amount of extra hours.

Furthermore, the large amount of inventory waiting to be processed can also be an indicator of significant variations in the production volume. So, even if the production capacity can respond to the average amount of orders, the lack of a decent production management system or even some flaws in the supplier deliveries can increase the orders for a specific period. This temporary increase of volume can lead to peaks of production orders that require extra hours to be controlled and for the orders to be shipped in time.

On the other hand, despite the lack of capacity, it is possible to see some advantages of the job-shop production, the nonexistent work in progress between production processes and the significant flexibility when changing priorities. A high priority order will, in the worst-case scenario, be ready for shipping in 2 days (8 hours waiting if the operators have just started another order and 8 hours more for the production of the actual order), even with the enormous amount of different batches that can be produced.

3.4 Layout

The actual layout for crimping validation production is not designed to reduce the operator walking distance. Through a modified spaghetti diagram, it was designed the walking motion of an employee for a single combination on each process. The arrows have been added to allow the understanding of the walking destination, which was useful on this project.

Using a job production system, like in this case, makes the material motion very similar to the walking motion, so there was no need to create one.

3.4.1 Process A

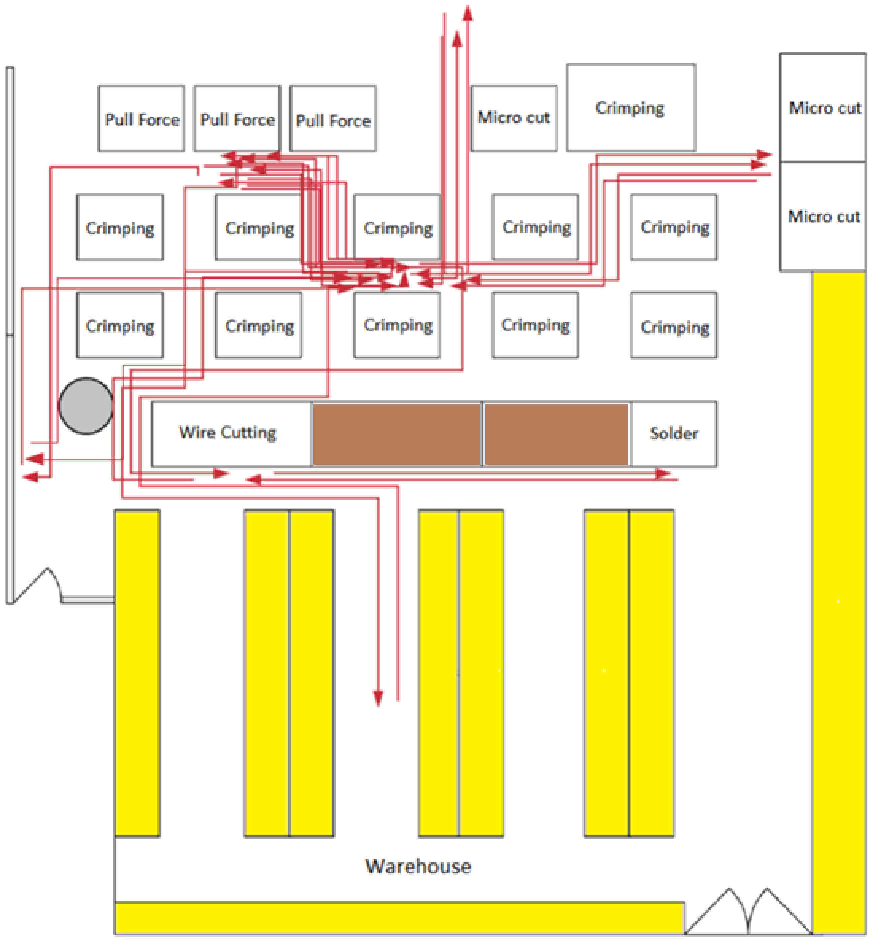


Figure 3.9: Walking Motion Process A

Through the calculation of each distance in the spaghetti diagram, shown in Figure 3.9, it was achieved a walking distance per batch in the process A of 395 meters. In one day, considering eight people and one combination per person, the walking distance is 3160 meters. Notice that it was not taken into account any obstacles nor other people appearing in the way. Also, it was not considered the appearance of defects that may lead to repeating some steps. So this is the absolute minimum distance.

3.4.2 Process B

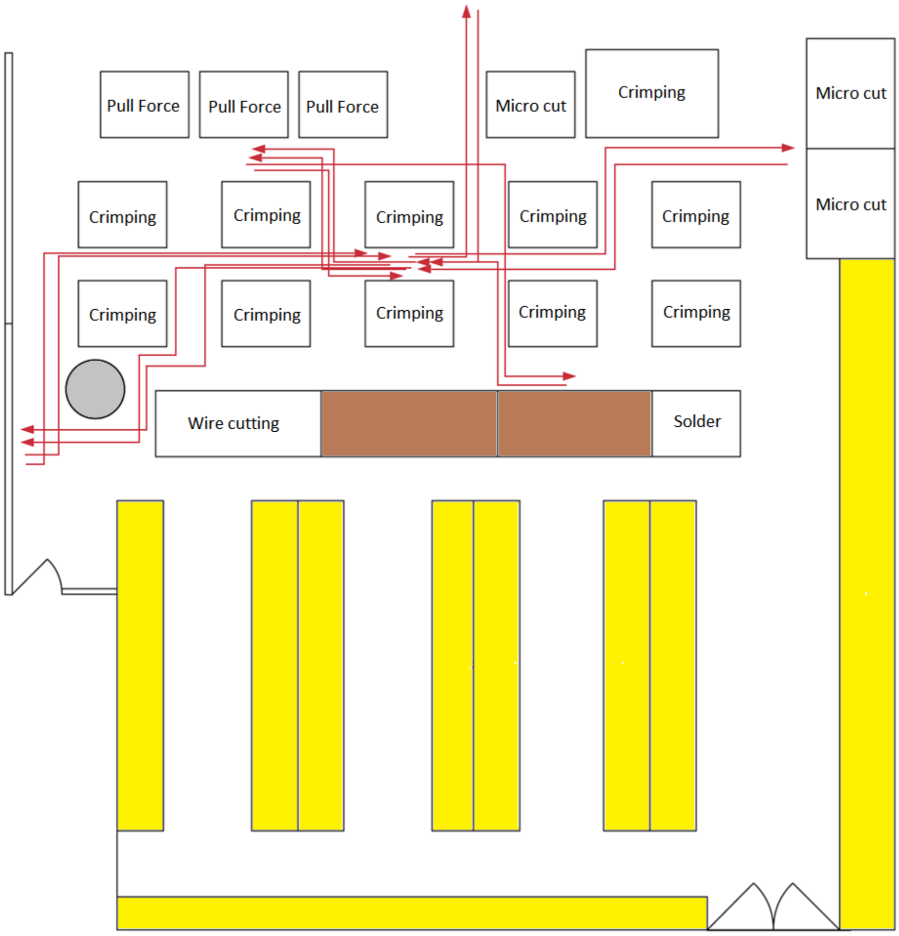


Figure 3.10: Walking Motion Process B

Using the same method for process B in Figure 3.10, it was achieved a walking distance per batch of 217 meters. In one day, considering eight people and three combination per person, the walking distance is 5208 meters. Notice that it was not taken into account any obstacles nor other people appearing in the way. Also, it was not considered the appearance of defects that may lead to repeating some steps. So this is the absolute minimum distance.

3.5 Stock

As mentioned in chapter 1, the Crimping Centre warehouse is completely packed. Since the workload seems too low compared with the amount of raw material stock, some calculations were made in order to understand the real situation.

- First, were summed all the terminal pieces available in the stock sheet used to control the stock in the crimping centre department and were obtained the following values.

Table 3.5: Total Stock

Total stock	
Terminal(pieces)	wire(m)
3338734	518971

It is important to remember that the terminal and wire obtained are used by crimping validation production, but also by the applicator production.

- To understand the dimension of available stock, it was decided to turn the available stock into production time. To be able to achieve that, it were summed all the crimping validation and applicator orders completed in the last year:

Table 3.6: Material used per year

Crimping Validation Production		Applicator Production	
Production in 2018	Material/comb	Production in 2018	Material/comb
1118 combinations	700 pieces and 80m	1898 applicators	300 pieces and 20m

- With the results obtained, it is now possible to turn the available stock into production time. Starting with the terminals:

$$Terminal/year = 1118 * 700 + 1898 * 300 = 1352000 pieces \quad (3.5)$$

$$Timeofproduction = \frac{Availableterminal}{Terminal/year} = \frac{3338734}{1352000} = 2.47 years \quad (3.6)$$

$$Wire/year = 1118 * 80 + 1898 * 20 = 127400 meters \quad (3.7)$$

$$Timeofproduction = \frac{AvailableWire}{Wire/year} = \frac{518971}{127400} = 4.07 years \quad (3.8)$$

In terms of quantity, Yazaki crimping centre has enough capacity to supply the production of both validations and applicators for 2.47 years with terminal and for 4.07 years with wire. Note it does not apply to real production. These calculations were made assuming the hypothetical case where all the orders match the terminal and wire in stock. It is possible to identify muda of inventory, in terms of space and transportation that cause an increased cost of operations. Also, the terminals and wires staying in stock for so long might lose fundamental properties, making them unable to use.

3.5.1 Stock Process

The massive amount of surplus stock reflects the lack of control in the process behind it. So, here it will be explained how the stock process is defined at the actual situation and, in the next chapter, the proposed solution to it.

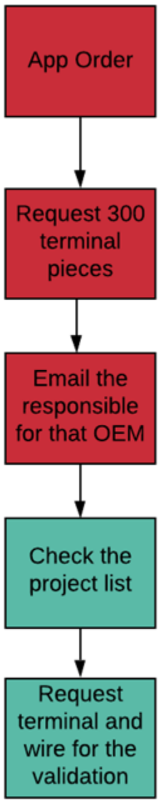


Figure 3.11: Requesting Raw Material Stock Process

In the crimping centre the raw material requests are not assigned to a specific person. They are divided into two orders, performed by two different teams, as illustrated in picture 3.11. Actions in red belong to the applicator development team, and the blue ones belong to the crimping validation team. Having multiple people doing it leads to mistakes, nonexistent control of the total orders, and lack of efficiency in the process.

- First, the need to ask for raw material stock starts with an applicator order. The person that receives this order from the applicator production team asks the client for 300 terminal pieces per applicator. This request is the first stock order.

- Secondly, this person sends the order attached by email to the person on the crimping validation team responsible by the brand that requires the applicator. Then, the person in charge of that OEM has to request the terminals and wire stock according to the combinations in his project list. Concluding the second-order, performed by a different team than the first one.

As explained, it can be identified a lot of time wasted. Moreover, there are two people receiving applicator orders and eight different people responsible for the crimping validation projects, divided by OEMs. This gives a total of ten different people creating material orders without the knowledge of the other person's requests.

After that, when the material ordered arrives it is located in the warehouse, the problem is that the arriving material is located randomly, and identified only by the factory that sent it, this brings up new problems:

- First, there are many different projects from different brands in each factory, so the material requested for one brand can mistakenly be used in another.
- Second, nothing links the material received to the applicator request, so if the validation of the combination is canceled for any reason, the material will continue in stock for at least a year.

In conclusion, the process has to change in order to have a precise control of the stock.

3.6 Overall Equipment Efficiency

This section will evaluate the overall equipment efficiency of the machines available in the production site. There was a particular interest in measuring this KPI for two main reasons:

- First, the operators are always complaining about the lack of equipment.
- Second, although improving local efficiencies is not a primary concern in this project, but the production system as a whole, it would be interesting seeing the improvements on them.

The machines that will be evaluated are:

Table 3.7: Quantity of machines per section

Cutting Machine	Qty:1
Crimping Machine	Qty:11
Micro-cut Machine	Qty:2
Pull force Machine	Qty:3

Cutting Machine

It is not expected to achieve a great OEE in this machine. The sectional area of the wire changing in almost every combination leads to a significant setup time, and the equipment gets worn out quicker.

First criteria: Availability

$$Availability = \frac{RunTime}{ProductionPlannedTime} \tag{3.9}$$

$$Availability = \frac{55}{80} = 68.75\% \tag{3.10}$$

Second criteria: Performance

$$Performance = \frac{IdealCycleTime * TotalCount}{RunTime} \tag{3.11}$$

$$Performance = \frac{16}{20} = 80\% \tag{3.12}$$

Then, the last criteria: Quality

$$Quality = \frac{GoodParts}{TotalCount} \tag{3.13}$$

$$Quality = \frac{70}{100} = 70\% \tag{3.14}$$

So, with these three values, it is now possible to calculate the OEE:

$$OEE = Availability * Performance * Quality \tag{3.15}$$

$$OEE = 68.75 * 80 * 70 = 38.5\% \tag{3.16}$$

As expected, it was achieved a low OEE, which is bad. Having the inputs and setups of the machine changing almost every time it runs, elevates the setup time, damages pieces that are not appropriated to the necessary parameters of the wire, and forces the machine to run in a lower velocity.

Crimping Machine

First criteria: Availability

$$Availability = \frac{RunTime}{ProductionPlannedTime} \tag{3.17}$$

$$Availability = \frac{125}{310} = 40.3\% \tag{3.18}$$

Second criteria: Performance

$$Performance = \frac{IdealCycleTime * TotalCount}{RunTime} \tag{3.19}$$

$$Performance = 100\% \tag{3.20}$$

Then, the last criteria: Quality

$$Quality = \frac{GoodParts}{TotalCount} \tag{3.21}$$

$$Quality = \frac{97}{100} = 97\% \tag{3.22}$$

So, with these three values, it is possible to calculate the OEE:

$$OEE = Availability * Performance * Quality \tag{3.23}$$

$$OEE = 40,3 * 100 * 97 = 39.11\% \tag{3.24}$$

For the crimping machine, it was also achieved a low OEE of 39.11%. For this calculation, it was assumed a performance rate of 100% since the machines are monitored continuously, and it is really unusual for them to have some kind of problem.

Pull Force

For Pull Force these are the OEE values;
Criteria: Availability

$$Availability = \frac{RunTime}{ProductionPlannedTime} \tag{3.25}$$

$$Availability = \frac{48}{70} = 68.67\% \tag{3.26}$$

Criteria: Performance

$$Performance = 90\% \tag{3.27}$$

Criteria: Quality

$$Quality = \frac{97}{100} = 97\% \tag{3.28}$$

$$OEE = Availability * Performance * Quality \tag{3.29}$$

$$OEE = 68.67 * 90 * 97 = 60\% \tag{3.30}$$

The pull force section is by far a process simpler than the others, so it is not surprising that it achieves the best OEE.

Chapter 4

Proposed Solution

In this chapter, the proposed solutions and the improvements that come along are presented and explained. The proposed solutions can be separated in:

- Changes in the Production System
- Future State Map creation
- Layout alteration
- Implementation, standardization, and kaizen approaches on work cells and OEE.
- Production Planning
- Stock Reduction

4.1 Changes in the Production System

To a better understanding of the solution, a few points have to be explained. This project scope is to reduce costs by reducing the extra hours, which is an operational expense while maintaining the throughput. As shown clearly in the initial state VSM, this can only be obtained by increasing productivity since the levels of work in progress are almost minimum, and also no parts are produced to inventory.

Cellular production is usually seen as a hybrid approach between job-shop and flow-line paradigms, reducing the major disadvantages of these two paradigms: the low productivity of job-shops and the low flexibility (in terms of products' variety) of the flow-lines.

In order to create these cells, the processes A and B will be divided by smaller parts of the same family in production cells.

Dividing the production into cells will also allow the applicators to have a shorter lead time by reducing the time they are required in CC, introducing the concept of "building directly to shipping". Moreover, the productivity improvement achieved in the crimping process will also affect their work in progress time, as can be seen in figure 4.1(the times presented in this figure are the ones achieved at the end of this project).

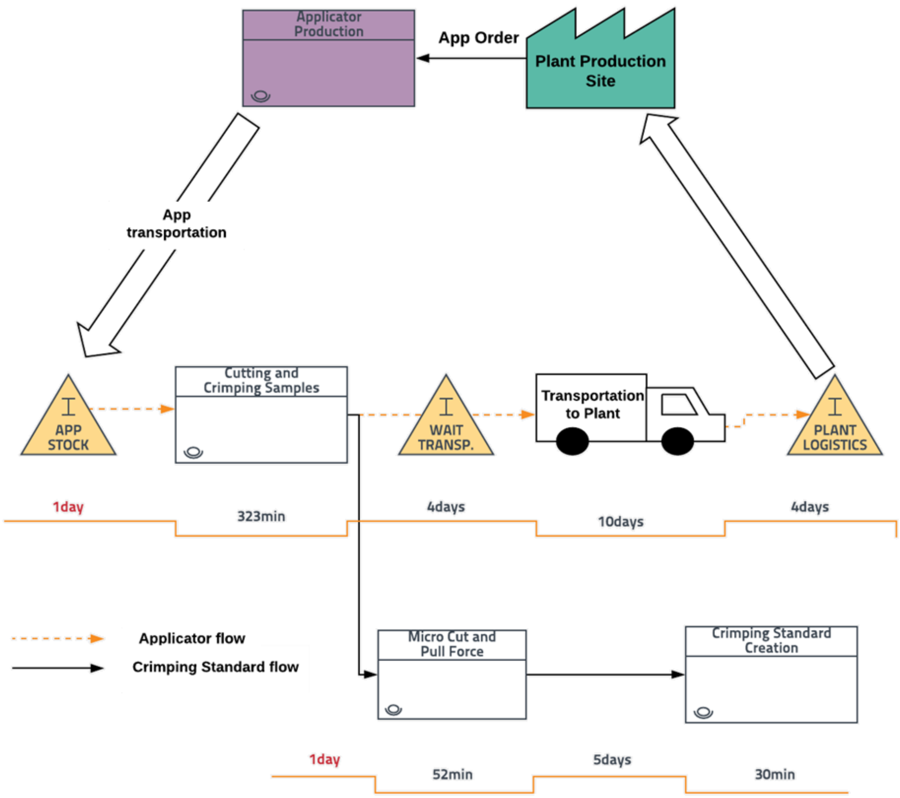


Figure 4.1: New bottleneck caused by applying the changes in priority

4.2 Future State Map

Creating a Future State Map is a great way to avoid deviations from the scope. Nevertheless, in order to create one, it is required to define some points about the production system.

4.2.1 Takt Time

There is the need to calculate the takt time for each process to align the production with the orders.

In CC's site, three different takt times calculations are required, one for process A, another to process B, and finally one for both.

The sections that correspond to process A exclusively are the Cutting and the Crimping. The one exclusive for process B is Inspection. Finally, for both processes, we have MC's and Pull Force.

Cutting and Crimping Takt Time

In order to obtain the takt time, it is necessary to know the product orders. In this case, it has been used the weighted averages method in orders of the last five years obtaining 116 orders/month for process A, which leaves us with 5.8 orders per day.

$$TaktTime = \frac{AvailableTime}{NumberofOrders} \tag{4.1}$$

$$TaktTime(year) = \frac{HoursWorkedperday * minutes}{Dailyorders} \tag{4.2}$$

$$TaktTime(year) = \frac{7.5 * 60}{5.8} = 77.5min/combination \tag{4.3}$$

Inspection Takt Time

The calculation of the inspection takt time follows the same method of the Cutting and Crimping. It just presents different values on the orders.

So for the inspection cell the takt time is:

$$TaktTime(year) = \frac{7.5 * 60}{6.15} = 73.17min/combination \tag{4.4}$$

Pull Force and Micro Cuts Takt Time

The calculation of the Pull Force and MC's takt time follows the same method of the above. It just presents different values on the orders.

$$TaktTime(year) = \frac{7.5 * 60}{6.15 + 5.8} = 37.65min/combination \tag{4.5}$$

4.2.2 Balancing the work

The next step to design the Future State Map passed by creating a "operator-balance chart". This chart summarizes the current total cycle time for each process and compares it with the takt time. Figure 4.2 illustrates this chart, having only one operator assigned to each process and with all the operators available on CC. Furthermore, the CC has 7.5 operators available to work in this production process. The 0.5 comes from the warehouse operator that has half of his day occupied receiving materials and some other tasks.

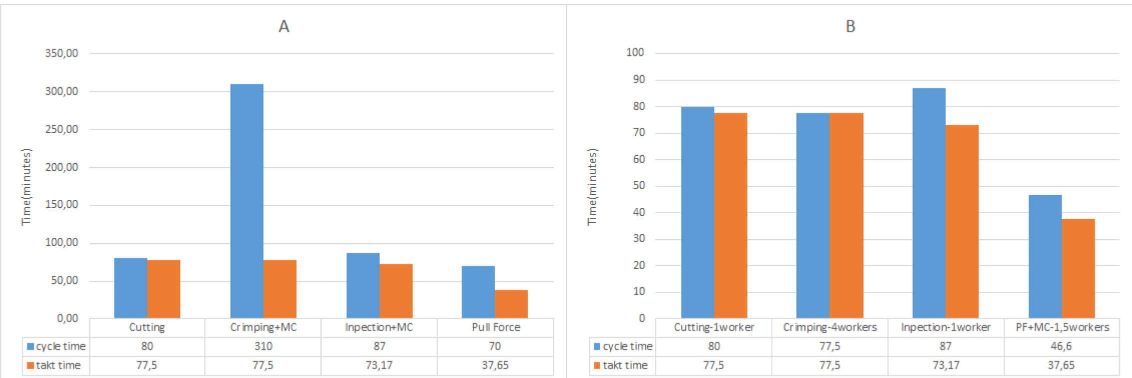


Figure 4.2: Cycle Time vs. Takt time with A-)one operator in each section, B-)every operator in CC allocated

It can be seen in figure 4.2 that all the production processes have the takt time lower than the cycle time, except Crimping with the allocation of 4 workers. The higher difference is in the Pull Force, this process will require more operators to run. Moreover, it clearly shows that in the current state, CC can not produce as fast as demanded by the orders.

The first attempt to solve this problem will pass by a redistribution of the work, more specifically with the creation of a distributor role that will perform all the actions that require walking motion to fetch materials or deliver parts to the next process. This distributor allows the production processes to have more availability. The person in charge of this task will be the same that receives the material, so the amount of availability this person will have to work in production will be reduced from 0.5 to 0.4/day since this extra work will take him nearly 1 hour per day. In the layout section, this route will be described in more detail.

Furthermore, while mapping the flow in the previous chapter, it was noticed that having the MC operation aggregated with the Crimping and Inspection brings unwanted interruptions to it, and introduces wastes of waiting and motion. To be able to avoid that waste, it was decided that the action causing it would be removed from both Crimping and Inspection processes and incorporated in the Pull Force, where these wastes are minimized, contributing to a better flow. This action has been timed and takes on average 17 minutes.

Table 4.1: Improvements in cycle time by introducing the distributor role

Time(minutes)	Actual Production CT	Cells Production CT	Improvements
Cutting	80	66	14
Crimping	293	280	13
Inspection	70	67	3
PF+MCs	87	74	13

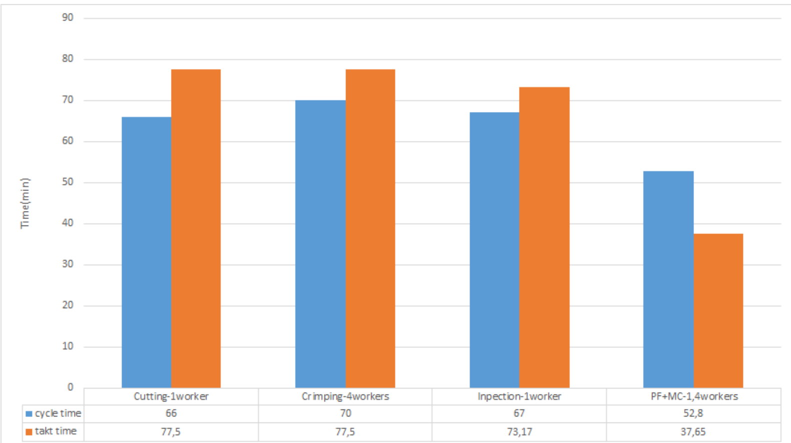


Figure 4.3: Cycle Time with the distributor position added vs Takt time

Table 4.1 shows the benefits of introducing the distributor role and takes into account the MCs action incorporated in the PF. However, as Figure 4.3 shows, PF+MCs cycle time is still superior to the takt time. Since it is no longer possible to redistribute work, it is necessary to eliminate waste through Kaizen approaches. It would be expected to only apply Kaizen activities to the processes that present a cycle time superior to the takt time, but since different wastes have been found in all of the processes and also to be better prepared for variations in the orders, it was decided to expand to all production processes. However, some approaches are still on going and will be mentioned, but they will not be considered as improvements in this project. These Kaizen activities are going to be further described in a section ahead within this chapter

After the Kaizen approaches provisional cells were created (the steps taken are described in chapter 4.4) and times were measured, achieving the following results:

Table 4.2: Improvements on Cycle Time after the Kaizen Activities

Time(minutes)	Actual CT	Cells after Kaizen CT	Improvements	Kaizen(Qty)
Cutting	80	61	19	1
Crimping	293	262	31	0
Inspection	70	54	16	0
PF+MCs	87	52	35	2

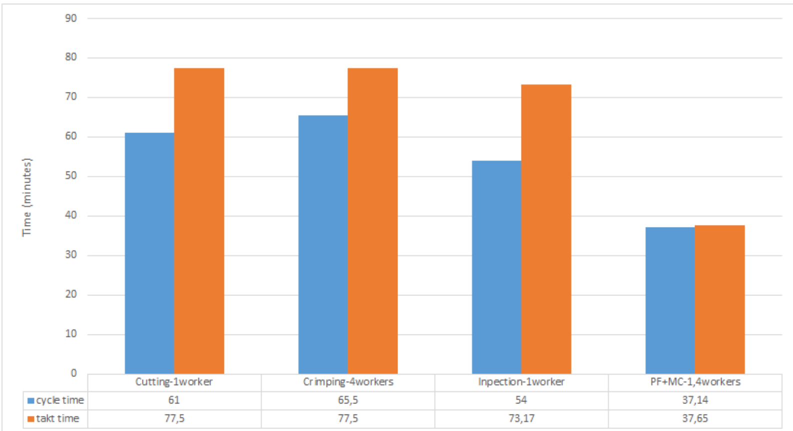


Figure 4.4: Cycle Time of provisional cells with Kaizen approaches vs. Takt time

Introducing the cells combined with the kaizen approaches made it possible to obtain cycle times lower than Takt Times in all processes, as it can be seen in figure 4.4, even if it was only for a few seconds in the PF+MC cell. This cell, that is the closest to the takt time will be our bottleneck, which is not necessarily a problem because now that it has been identified it will be possible to monitor it, maybe even introduce a buffer in his input.

4.2.3 Pull System

The continuous flow is known to be the most efficient way to produce (Rother and Shook, 2003). However, it does not fit our needs since CC's production is too dependant on batching. This means it will be used pull production.

In chapter 2.8 were described the following pull systems:

- Sequenced Pull
- Supermarket Pull

The supermarket system does not fit in CC's production due to the massive amount of custom parts that can be produced. However, the Sequenced Pull System seems a good fit since the customers supply strict plans.

The next step will be deciding where to introduce Sequenced pull. Ideally, the best option would pass by adopting this pull production from the last process PF+MC until the first one, Cutting. However, for the following reason, it is not possible to establish pull between PF+MC and the previous cell, Crimping:

- The crimping cell has a lead time much higher than the one on PF+MC.
- The applicator delivery dates need to be taken into account while scheduling the orders, and it would be much harder to control it from a process that does not require it. Moreover, this brings dependencies in some orders. When the same tool is used to crimp different batches, they need to be produced together to release the tool to be shipped.

On the other hand, between the cutting and crimping process, it is possible to perfectly fit the Sequenced pull system, mainly because the cutting process has a significantly lower lead time than crimping.

4.2.4 Selecting the Pacemaker Process

Using pull systems typically means that it is only required to plan one point of the flow. This point is called the pacemaker process because this plan will extend to all the upstream processes.

Note that material transfers from the pacemaker downstream to finished goods need to occur as a flow, causing the pacemaker to be preferably chosen as the last process. However, because of the reasons enumerated ahead, this will not happen in CC, the pacemaker process was defined to be the Crimping and the Inspection processes. Since both needed planning to simplify the flow, it was arranged to join these processes in the same cell.

This merge brought the creation of a new cell the Crimping+Inspection, which also added the operators assigned to each one, leaving this merged cell with five operators.

After clearing all these details, it has been achieved the following Future State Map.

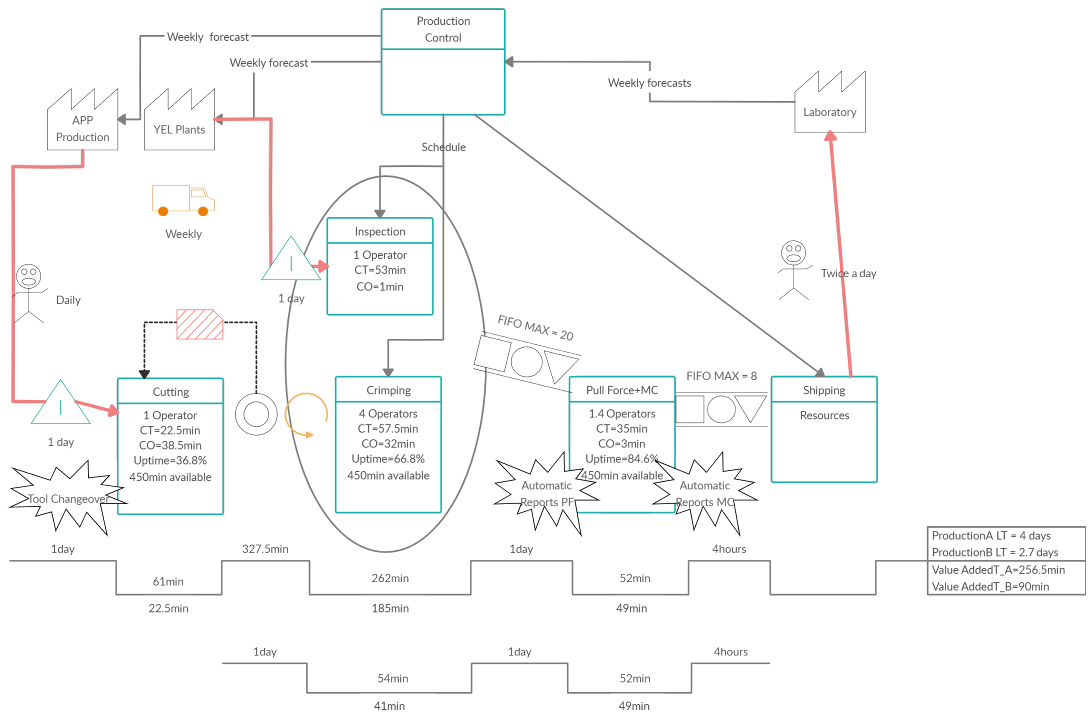


Figure 4.5: Future State Map

When comparing the summary statistics for CC's current state and future state, the results are striking. In particular, with the introduction of cell concepts that empowered the Kaizen approaches and the pull system combined with FIFO lanes.

Having such a reduction on the lead time through its shop floor, the pacemaker operating consistently with the takt time, and the buffer created with the FIFO lane that supplies the bottleneck, CC can comfortably reduce, probably even annul the amount of required extra hours.

4.3 Layout Alteration

Previously, while describing the initial layout was concluded that there was an excessive muda of transportation and walking due to the production system and the layout. In order to minimize that waste and improve productivity, it has been decided that the solution would be to create production cells.

The point of this new layout is to incorporate the new cells, minimize walking motion, material motion, and to have the following step as close as possible, with a unidirectional flow.

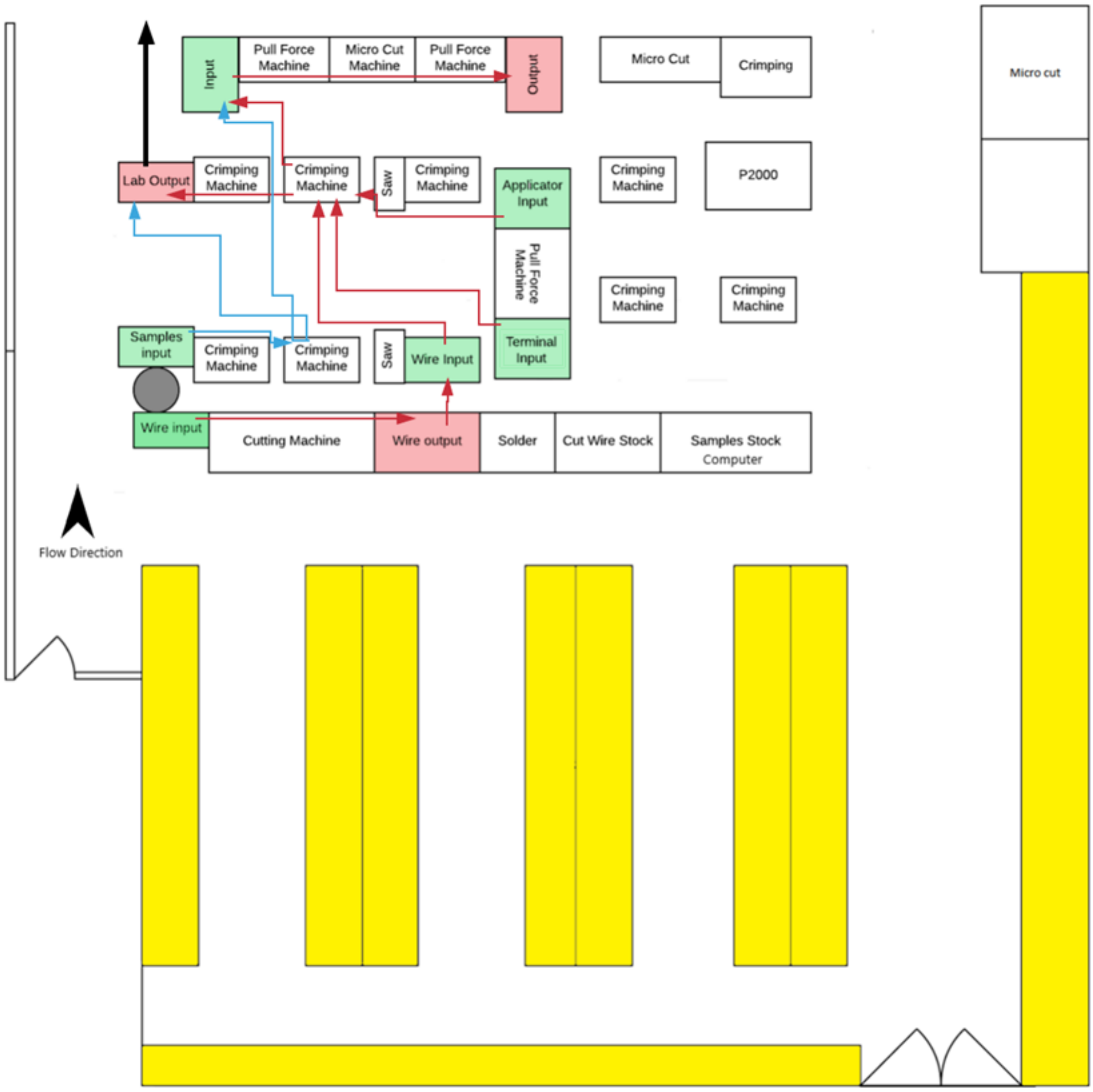


Figure 4.6: Material Motion, Blue - Process B, Red - Process A

In figure 4.6, the material flow can be seen for both processes with the new layout. In red, it is described the material flow of process A, and in blue the same for process B. It is easy to understand the differences. The new layout has the input from one cell as close as possible from the output of the previous one, reducing the distance between them. Moreover, the new layout has been designed in a way that the flow direction is always the same. This may seem a small thing, but it is a great help for controlling the process.

In Figure 4.7, it is possible to see the usual walking route of the distributor, assuring the inputs and outputs of each cell have the correct quantities, and delivering the necessary materials. The orange route is done at the start of each shift, and the green at the end.

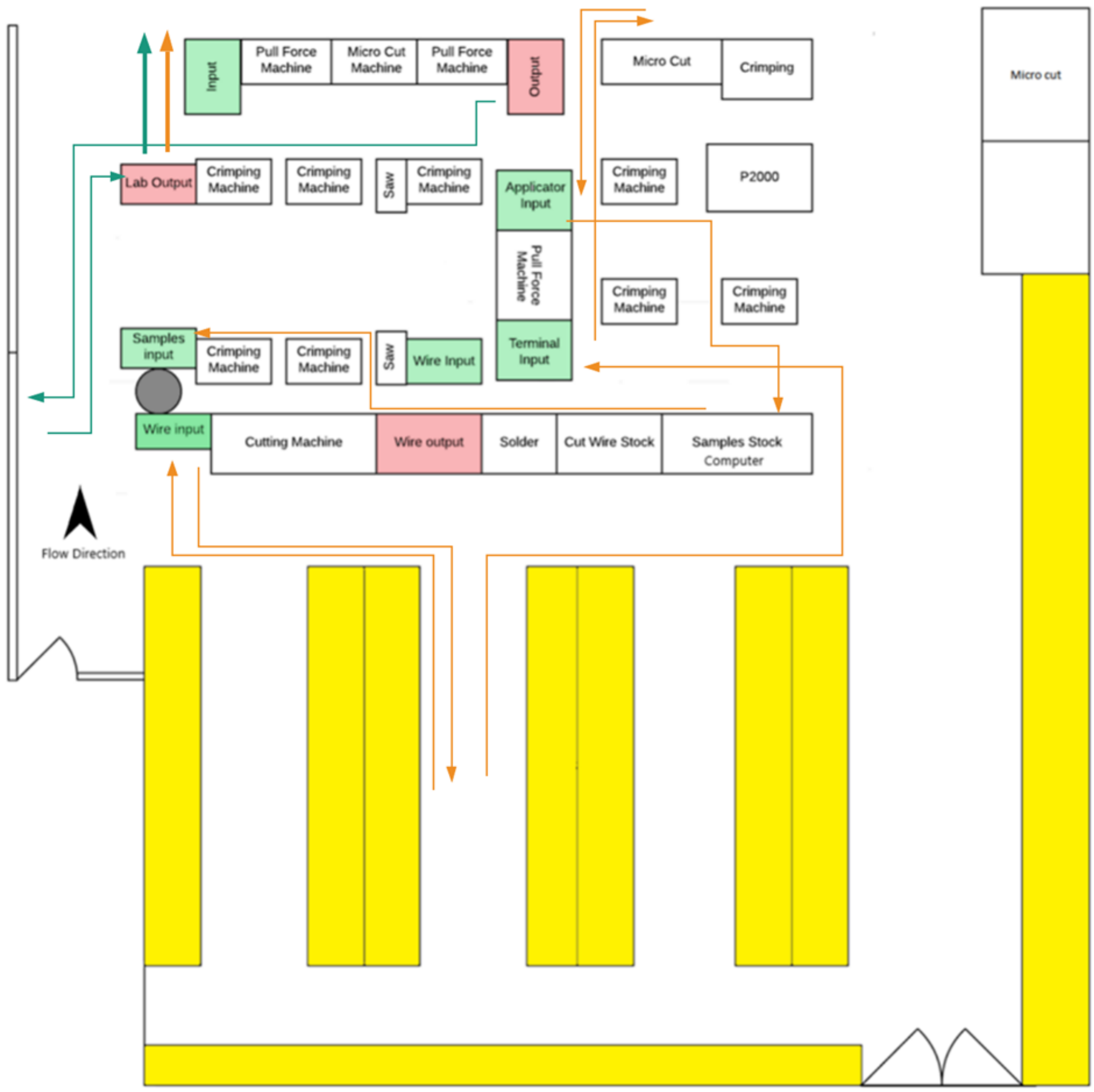


Figure 4.7: Distributor Route Orange - at the start of the shift, Green - at the end of the shift

With this route, the distributor walks a total of 470 meters per day, a vast improvement from previous values that show a motion of 300 meters per batch.

In the next chapter, when each cell is described, this material and walking motion will be identified so that they can be compared to the previous state.

4.4 Implementing the Production Cells

The main proposal in this project is the creation of the production cells. This production cells in the new layout are inserted in the following areas:

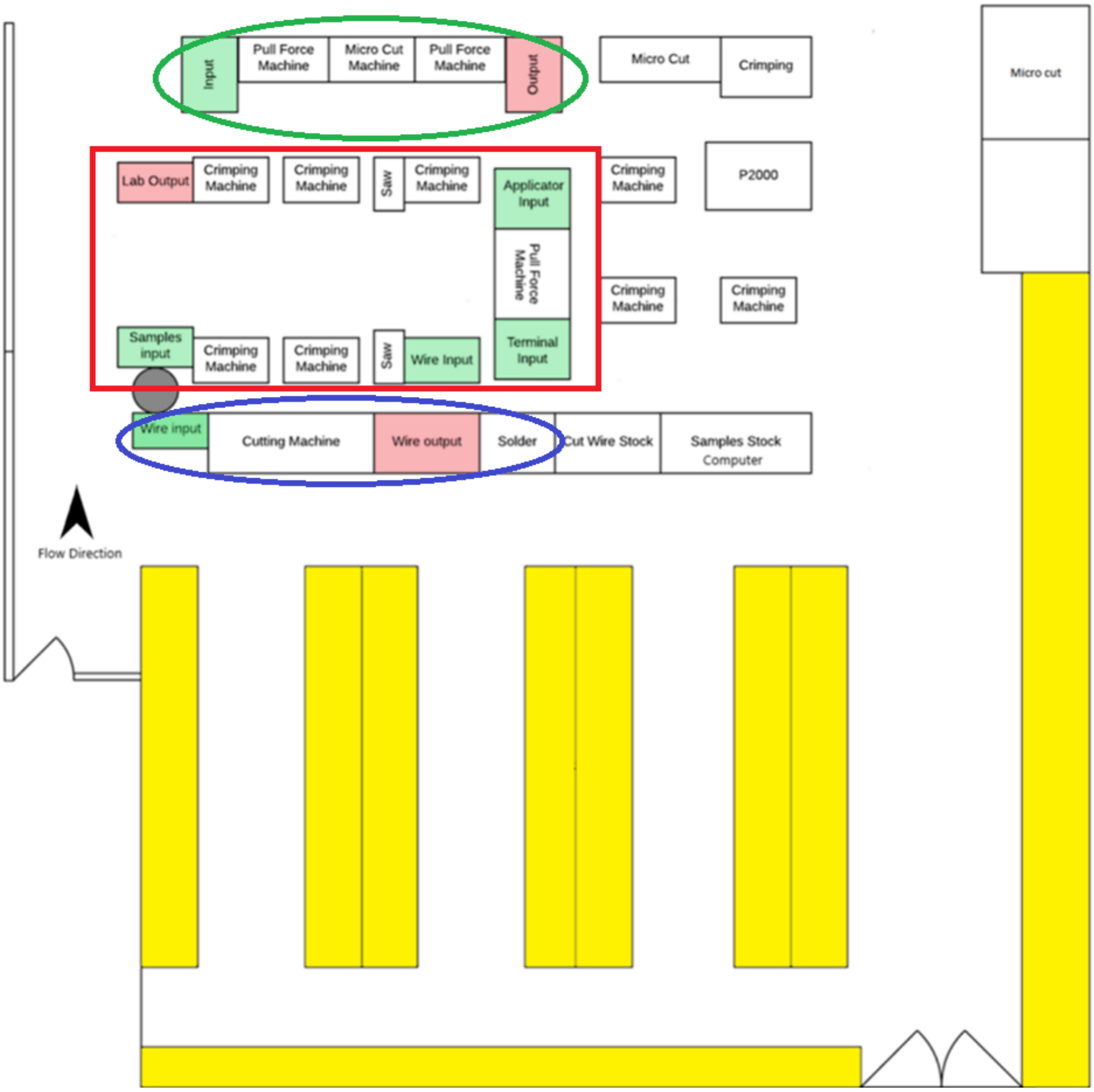


Figure 4.8: Production Cells

Image 4.5 illustrates the three cells that will be created:

- Blue - Cutting Cell
- Red - Crimping+Inspection Cell
- Green - Pull Force + Micro-Cut Cell

Next, it is explained the creation of each cell, the improved actions, and how were accomplished the desired results. Once more, it will be underlined the effects of this implementation reflected in the production lead time and OEE.

To be able to achieve these values, every cell was created, and the times measured for each action are described in the section describing each cell.

4.4.1 Cutting Cell

This cell is projected to one person only, and it is composed by:

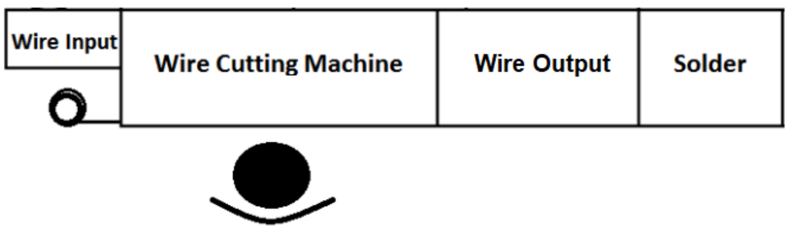


Figure 4.9: Cutting Cell Layout

- Wire Input - where the distributor leaves the wire to be cut, in a way that is well signalized and easy to see. It works like a kanban, the area limits the maximum load, and when there are few wires left in the marked area, the distributor will notice it and replenish the new wire.
- Wire Cutting Machine.
- Solder - The initial idea was to place the solder right next to the cutting machine, but that has been changed to avoid the heat, for the operator that spends a whole day next to the cutting machine.
- Wire Output - where the wire cut by the machine waits for the batch completion to be moved to the next cell.

The actions performed in this cell are:

Table 4.3: Detailed Actions Cutting Section

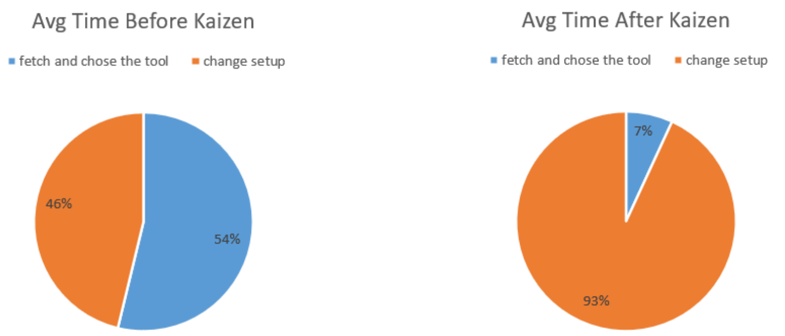
Action	Initial State	Final State
Verify the plan	3,5min	—
Go get process	2min	—
Go get the wire	6min	—
Change Tool Setup	7min	3min
Adjust M. Parameters	35min	35min
Cutting	20min	20min
Solder	3,5min	2,5min
Cleaning	3min	0,5min
Total	80min	61min

These values were obtained by measuring times. They show the time necessary to achieve an entire batch, not only a piece, that is why they are displayed in minutes.

Detail of Actions Improvement

To improve the process, not only were the cells created but also there was an improvement of some actions.

- Starting by the first three actions - These actions were passed to the distributor employee, it may seem that it is the same, but actually, that is not. Moving both those actions to the distributor has three advantages:
  - First, the distributor can join four or five combinations and bring it all in only one trip to the warehouse.
  - Second, the distributor is the person that receives the material, so it is better familiarized with where the received items are kept.
  - Third, there is an increase in the running time of the machine because the production operators have a higher availability.
- The change tools setup - the kaizen approach to the cutting cell was focused on this step. It was noticed while measuring the times that much muda existed in the changes of setup. The set of parts that constitute the setup of the machine were located way too far from the machine itself.
  - The first action proposed was to change the tool setup box to the already existing drawer under the cutting machine, but that drawer was packed with other tools.
  - In order to clean the drawer, the principles of 5S were applied, removing the tools that are not used frequently and creating in the drawer a specific space where the tool setup box can fit. Times were taken before and after the approach (10 measurements), and the following results were obtained:



Time[hh;mm;ss]	Avg Time Before Kaizen	Avg Time After Kaizen
fetch and chose the tool	00:03:48	00:00:13
change setup	00:03:16	00:02:56
Total	00:07:04	00:03:09

Figure 4.10: Cutting Cell Kaizen Approach Results

Figure 4.10 shows the reduction of the waste in the setup change from 54% to 7%, which was a great result.

- Cutting - The cutting action is not improving, that would require better maintenance and new parts for the machine. Some of the existing ones are worn out. The problem is that the new parts would become damaged as well since this machine is designed for mass production, not for changing the wire size so often, as it happens in this kind of sample production.

- Solder - The soldering part is usually performed while the Cutting happens since only the samples for the resistance test need it. With the new layout, the solder is closer to the cutting machine, this not only reduces the time of walking but allows the operator a better control over the cutting machine while applying solder to the samples that require it.

- Cleaning - It is an action that adds no value, but when many people are using the same machine, it seems bad for one operator to do not leave it clean for the next to come. In the cell, this problem is solved and the machine will only be cleaned once a day, which is enough.

Comparing the actual production vs. cell production:

Table 4.4: Cutting Cell Results

	Actual Production	Cells Production	Improvements
Cut. Machines	1	1	—
Setup Parts Change	7min	3min	58%
Lead Time	80min	61min	24%
Walking Motion	81m	6m	93%
Material Motion	28m	6m	79%

This change also improves the OEE:

- Availability:

$$Availability = \frac{RunTime}{ProductionPlannedTime} \tag{4.6}$$

$$Availability = \frac{55}{61} = 90\% \tag{4.7}$$

- Performance will not improve while the machine worn out parts are not changed so, it has been considered the same 80%.
- Quality can be improved by improving the quality of the wire. A solution was presented to the suppliers in order to achieve better quality materials, especially to improve the way it is packed, and a small guide on how to pack wire and terminal, shown in Figure 4.11, was created, and it is now sent in every new stock order. Nevertheless, there is no way to predict the results, so it has been considered the same 70%.

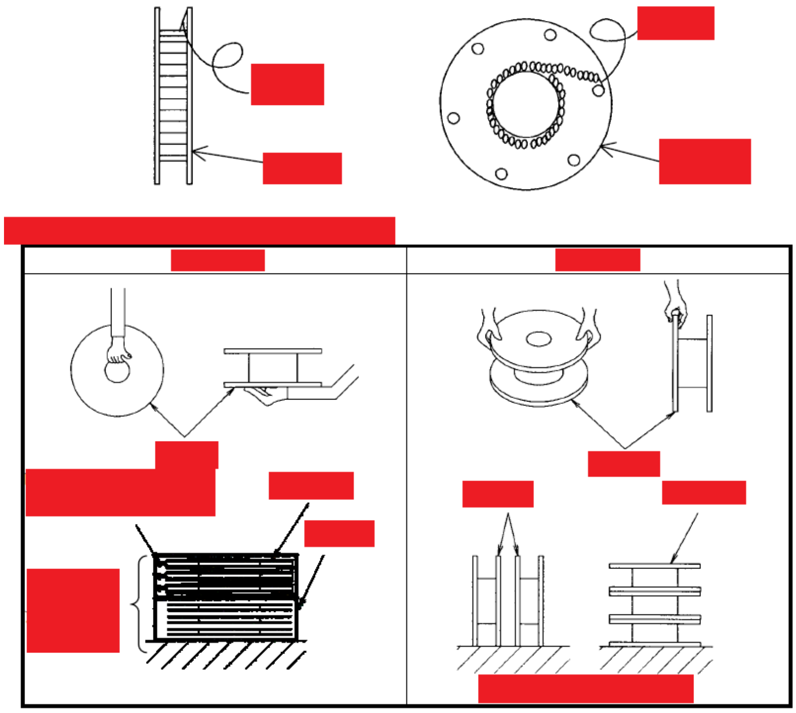


Figure 4.11: Guide on how to ship wire and terminal

Figure 4.11 is censored because it contains instructions to specific parts that are confidential.

So the OEE in Cutting section will improve from 38.5% to:

$$OEE = 90 * 80 * 70 = 50.4\% \tag{4.8}$$

Obtaining an 11.9% improvement in the OEE, and more impressively, a 21.25% improvement in the machine availability.

4.4.2 Crimping and Inspection Cell

This cell was projected for five operators. Still, they do not depend on each other.

The cell layout resembles the following:

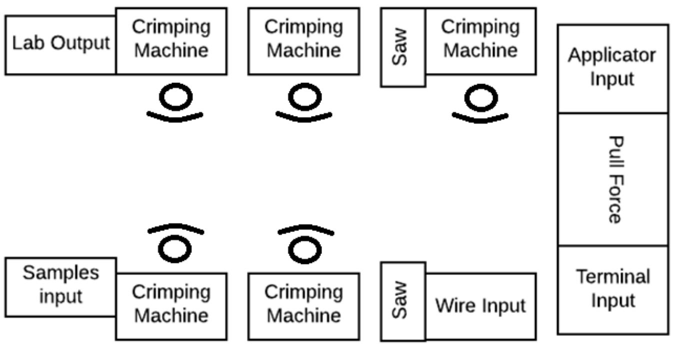


Figure 4.12: Crimping Cell Layout

Moreover, it is constituted by:

- Terminal, Applicator, and Samples Input - Where the distributor leaves the applicators, terminals, and samples. In a way that is well signalized and easy to see. It works like a kanban, the area limits the maximum load, and when there are few pieces left in the marked area, the distributor will notice it and replenish the necessary items.
- Wire Input - The cut wire is supplied in by sequential pull production so, it is the previous cell responsibility to supply the wire as requested by kanban.
- Crimping Machine - There are five crimping machines in this cell.
- Cutting saw - There are two cutting saws in the cell to avoid having to go to the Micro Cut Machine to test the quality of the crimped sample.
- Pull Force Machine - A Pull Force Machine is also present in the cell to avoid having to go to the Pull Force section to test the quality of the crimped sample.
- Lab output - Where the operator leaves the crimped samples that will go to the laboratory.

To describe the actions in this cell, they will be divided into Crimping and Inspection.

Crimping Actions

Detailed Actions Crimping Section

Again, the first action will pass to the distributor, that it is advantageous, as explained in the previous cell.

- Placing the terminal in the support - It is improving because the distributor will assume the responsibility of inspecting the material and correcting it for a better use while taking it to the terminal input.
- Placing and adjusting the applicators - It will be faster because the applicators will be previously selected following the planned production and allocated to a space closer to the crimping cell, the applicator input.

Table 4.5: Detailed Actions Crimping Section

Action	Actual Time	Cell Time
Go get terminal and accessory	5min	—
Place the terminal in the support	5min	2min
Place and adjust the applicator in the press	35min	30min
Crimp samples and test pull force	30min	15min
Prepare Micro cuts	13min	10min
Take pictures and measure	17min	—
Place accessory	10 min	10min
Crimp and measure by CH's	125min	125min
Label the samples	30min	30min
Headroom	40min	40min
Total	310min	262min

- Crimping a sample and test pull Force - This task will suffer a significant improvement, following the new layout the operators will have within a two meters distance a pull force machine for the pull force test evaluation. This inclusion of a PF machine was thought not only because it is faster for the person in the crimping area but also prevents the people assigned on the pull force area to stop their work in order to let the colleague test one sample.

- Prepare Micro Cuts - This action has improved due to the cell new layout, allowing the operators to have within a two meters distance a cutting saw to make a fast preparation of the MCs.

- Take pictures - This action will pass to the PF+MC Cell, as mentioned in chapter 4.2.2.

- Placing accessory - There are no changes in this step.

- Crimping and measuring by CH's - This step also has no changes.

- Labeling the samples - A kaizen approach is ongoing in this step since it requires some investment. Spending half an hour taping samples is an enormous waste, so a tray where the samples can fit following the standard requirements was developed. This tray can be a great solution, both to the crimping centre and laboratory, where they have to remove all the tape to perform the tests. This kaizen approach has not been considered in the times taken for this project because it is still being tested, and it is hard to predict the results. However, in figure 4.13, it is possible to see the proposed tray.

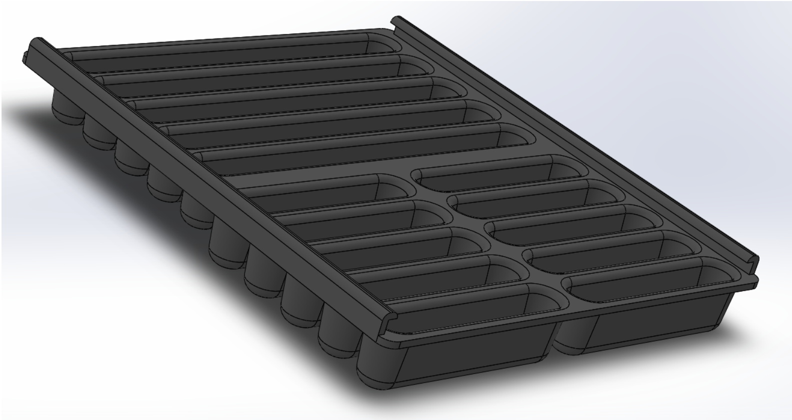


Figure 4.13: Drawing of the proposed tray developed using the program SolidWorks.

- Headroom -this action does not have significant changes

To conclude, it has been made a comparison about the two productions:

Table 4.6: Crimping Cell Results

	Actual Production	Cells Production	Improvements
Crimp. Machines	7	5	29%
Setup Parts Change	40min	32min	20%
Lead Time	310min	262min	16%
Walking Motion	156m	24m	85%
Material Motion	112m	24m	79%

The lead time improvement in this section is 16%, please note that this is the improvement of the time it takes to obtain crimped samples from the cut wire and terminal, despite some actions being transferred to other cells.

Understandably, these improvements will only affect the criteria Availability of the OEE, since there are no changes in the machine, the performance will not change, and the change in quality cannot be predicted by the new terminal and wire shipping guide shown in Figure 4.11.

- First criteria: Availability

$$Availability = \frac{RunTime}{ProductionPlannedTime} \tag{4.9}$$

$$Availability = \frac{125}{262} = 47.7\% \tag{4.10}$$

- Performance 100%
- Quality 97%

$$OEE = 47,7 * 100 * 97 = 46.2\% \tag{4.11}$$

In conclusion, the OEE of the crimping machines in the cell has improved by 7%.

Inspection Actions

With the following actions:

Table 4.7: Detailed Actions Inspection Section

Action	Actual Time	Cell Time
Verify the plan	3min	—
Go get the process and samples	2min	—
Measure samples and register	5min	5min
Visual Inspection	35min	24min
Prepare Micro cuts	13min	10min
Take pictures	17min	—
Label the samples	15min	15min
Total	90min	54min

Detail of Action Improvement

Just like in the cells before the two first actions were passed to the distributor.

Then the actual value-adding actions:

- Measure Samples and Register - This action will not suffer significant changes, because operators are already really experienced using the micrometers, and the lead time of the action is short, so the time spent in measuring the samples will not have significant changes.
- Visual Inspection - This is action suffers a good improvement. The actual time of visual inspection if the samples that arrive from the plant are in good condition, is about 5min. However, according to the measured times, it was possible to understand that only 20% of the samples requested do arrive in perfect state from the supplier. However, the preparation of a presentation to enlighten the supplier on how to prepare the samples showed an increase in good samples received (attachment A.2).
- Lastly, the label samples action, this was discussed already in the Crimping actions, here it has been used the value of 15 min instead of 30 min because it was shown that only half of the times the operators need to take the labels off and put new ones. This also depends on the quality of the samples received. However, with the introduction of the tray for allocating the samples, this time could be reduced.

Table 4.8: Inspection Cell Results

	Actual Production	Cells Production	Improvements
Lead Time	90min	54min	40%
Walking Motion	59m	12m	80%
Material Motion	37mm	8m	78%

Here it was achieved an impressive lead time reduction of 40%.

This section will not have its OEE measured because there are no machines.

4.4.3 Pull force + Micro-Cut Cell

PF+MC cell can be operated by one to three employees, depending on the amount of WIP in the input buffer.

- Input Table - for receiving the samples from Crimping+Inspection cell. It is also used as kanban. It works like a kanban, the area is designed to fit only 20 samples that is the maximum load allowed in the FIFO lane.
- Pull Force Machines - This cell then presents two pull force machines connected with the computer to register the values obtained in the test.
- Micro-Cut Machine - This is not more than a magnifying glass connected with a Computer to be able to take the photos and edit the images.

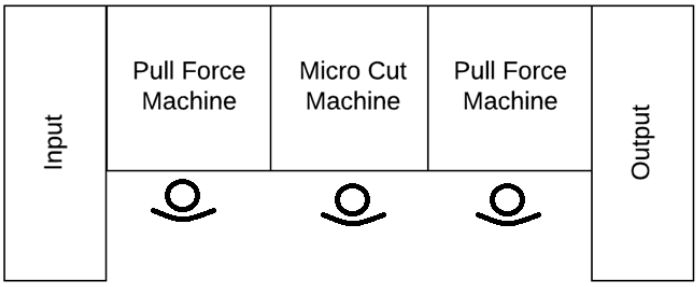


Figure 4.14: Pull Force + MC Cell Layout

The actions attached to it are now:

Table 4.9: Detailed Actions Pull Force Section

Action	Actual Time	Cell Time
Take pictures and measure MCs	17min	5min
Create and Fill the Form	5min	—
Pull Force Test	48min	44min
Update laboratory list	2min	2min
Update Stocks	2min	—
Take the process to the office	5min	—
Pack up the material and applicator	5min	—
Take the samples to the laboratory	3min	—
Total	70min	52min

Detail of Actions Improvement

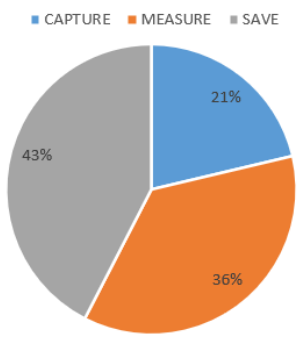
- Take pictures and measure MCs - This action was originally in the Crimping and Inspection section, as explained before it was brought to PF because it was causing much muda. In those previous sections, this action was divided into three parts performed in three different moments, causing transportation muda and also waiting muda due to the queues to use the machine.

After this relocation, it was seen that much waste existed in this action, and it could be avoided. The operator taking pictures of the Micro Cuts and other necessary parameters had to be always repeating the same information and saving those files in a very unpractical way. The desire to eliminate this waste created the first kaizen approach on this cell.

Figure 4.15: Initial Values from the MC Kaizen approach

Nº of samples tested	Combination	Action Nº	Action	Action Category	Avg Time	Total Time
20	PTC-xxxx-xxxx	1	Photo of cut off tab	CAPTURE	00:01:00	00:17:06
		2	Measure cut off tab	MEASURE	00:00:51	
		3	Save the cut off tab image	SAVE	00:00:25	
		4	Photo of bell mouth	CAPTURE	00:00:26	
		5	Measure Front e Rear bell mouth	MEASURE	00:01:11	
		6	Save the bell mouth image	SAVE	00:00:44	
		10	Photo of exposed conductor	CAPTURE	00:00:15	
		11	Measure exposed conductor	MEASURE	00:00:35	
		12	Save exposed conductor image	SAVE	00:00:24	
		13	Photo of bending	CAPTURE	00:00:08	
		14	Measure bending	MEASURE	00:02:01	
		15	Save the bending image	SAVE	00:00:44	
		16	Photo of superior MC	CAPTURE	00:00:48	
		17	Measure superior MC	MEASURE	00:00:41	
		18	Save info in superior MC	SAVE	00:01:46	
		19	Save the superior MC image	SAVE	00:00:36	
		20	Photo of inferior MC	CAPTURE	00:01:02	
		21	Measure inferior MC	MEASURE	00:00:54	
		22	Save info in inferior MC	SAVE	00:01:53	
		23	Save the inferior MC image	SAVE	00:00:43	

– First, were measured times of the initial state for 20 different batches while also dividing each minor action into a category. Figure 4.15 shows the results.



CATEGOTY	AVG TIME
CAPTURE	00:03:39
MEASURE	00:06:12
SAVE	00:07:15
TOTAL	00:17:06

Figure 4.16: Average time spent in each category

In Figure 4.16, it is highlighted the percentage of time used in each category of actions contained in the main action of this kaizen approach, the take pictures and measure MCs action. The grouping of this smaller action in categories was done following some Six Sigma principles to reduce the variations.

The kaizen approach to this action was focused on creating an excel form that works like a report where all the photos belonging to the same batch can be saved, without having to repeat the information in each photo every time. Figure 4.17 shows the difference between before and after the kaizen.

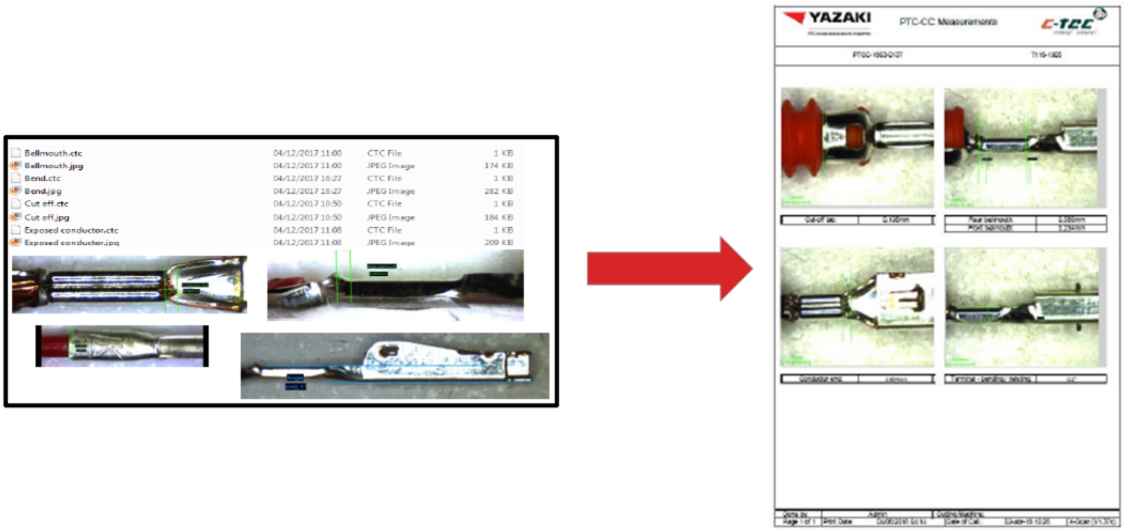
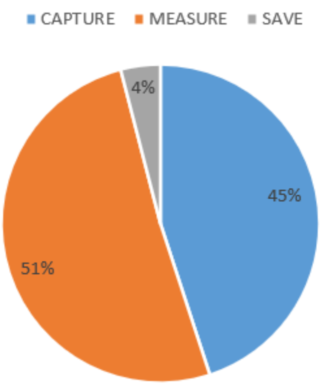


Figure 4.17: Before vs. after kaizen approach

The solution arranged to improve this action was very effective, not only reduced the time spent but also made it more organized and easy to consult. Moreover, it was found that this new method reduced the space occupied by this data in nearly 88%. The extra space is always handy in this data-driven times. The results from the kaizen approach can be seen below in Figure 4.18 and 4.19.

Figure 4.18: Final Values from the MC Kaizen approach

Nº of samples tested	Combination	Action Nº	Action	Action Category	Avg Time	Total Time
20	PTC-xxxx-xxxx	1	Photo of cut off tab	CAPTURE	00:02:14	00:04:58
			Photo of Bell mouth			
			Photo of exposed conductor			
			Photo of bending			
			Photo of superior MC			
			Photo of inferior MC			
		2	Measure the cut off tab	MEASURE	00:02:32	
			Measure the Front e Rear bell mouth			
			Measure the exposed conductor			
			Measure the bending			
			Measure superior MC			
			Measure inferior MC			
		3	Save cut off tab image	SAVE	00:00:12	
			Save bell mouth image			
			Save exposed conductor image			
			Save bending image			
			Save superior MC image			
			Save inferior MC image			



CATEGOTY	AVG TIME
CAPTURE	00:02:14
MEASURE	00:02:32
SAVE	00:00:12
TOTAL	00:04:58

Figure 4.19: Average time spent in each category after kaizen

The kaizen approach reduced the lead time by 70%. Most of this reduction was achieved by eliminating the necessity to save the photos individually, repeating the information. The save category time has been reduced by 98%

- Create and Fill the Form - As mentioned in the initial state, this action was very repetitive, so it was the focus of this cell's second kaizen approach. An excel VBA program was created to create and fill the form needed for this test automatically. The program developed creates this form in a few seconds, so this action was eliminated.

- Pull Force Test - This action has not suffered any major changes. However, the time has reduced because of the cell creation, the samples to test have been allocated to a space closer to the operator's working hand, and there are no interruptions from coworkers trying to test only one sample from other batches.

- Update Laboratory List - This action suffers no alteration since it is mandatory, and this is the last test, so this is the cell that will include it.
- Take process to the office - This action has passed to the distributor since it adds no value.
- Pack up the material and applicator - This action passed to the Crimping Cell since the applicator and material are located there. Still, it will be performed by the distributor.
- Take the samples to the laboratory - This action also passed to the distributor since it adds no value, and he can join a more substantial amount of samples and join them to be able to deliver it to the laboratory.

Table 4.10: PF+MC Cell Results

	Actual Production	Cells Production	Improvements
Machines	5	3	40%
Setup Parts Change	5min	3min	40%
Lead Time	70min	52min	26%
Walking Motion	158m	5m	97%
Material Motion	70m	6m	92.5%

Regarding the OEE for this cell will be considered the changes in the pull force machine.

Both quality and performance do not suffer any changes. Nevertheless, in terms of availability there are some improves:

$$Availability = \frac{44}{52} = 84.6\% \quad (4.12)$$

A great value for Availability has been achieved due to the removal of non-value-adding actions even while adding a new action to this process. From the previous 60% value of OEE, now it has been achieved:

$$OEE = Availability * Performance * Quality \quad (4.13)$$

$$OEE = 84.6 * 90 * 97 = 73.9\% \quad (4.14)$$

4.5 Floating with WIP Limit Kanban

From this study, more particularly in the Future State Map, it is has been seen that the cell with a cycle time closer to the takt time will be the PF+MC cell for the average amount of orders. This means PF+MC cell will be our bottleneck most of the time, not that this brings significant problems because the production system is prepared for that with the creation of the FIFO lane that creates a buffer to assure that the bottleneck is as efficient as possible. However there are variations in the orders and since there are two different processes in a cell, Inspection and Crimping if in a determined period of time the orders raise for the Crimping process, that has a longer lead time than Inspection the bottleneck can change to the Crimping+Inspection cell or even if there is a raise in both amount of orders our bottleneck will have the takt time shorter than the cycle time. This can be avoided by planning the production for limited periods, moving people from one cell to another daily. However, to keep the production system more straightforward and more consistent in these cases, there was the need to standardize when an operator has to float from his designated cell to another one. The solution found passes by moving people from the Crimping+Inspection cell to the PF+MC cell and making them return to the first depending on the amount of WIP in the FIFO lane between the two cells.

Kanban limit WIP is the solution to that problem. In addition to signalizing, kanban is an excellent tool to control the production workload in each cell, understanding where it is getting delayed and the position of the bottleneck. So an operator can easily understand the necessity to move to a different cell when the WIP in his cell has reached a previously established limit. Still, a standard amount of WIP kanban needs to be established for each cell in a way to ensure that every operator behaves the same. In this case, as it is possible to see in the FSM, it has been established a maximum WIP in the FIFO lane of 20 batches. The minimum has been established as five batches. In the first case, an operator will move from the Crimping+Inspection cell to the PF+MC, in the latter, the same operator floats back to Crimping+Inspection cell. This system is an efficient way for the production system to adjust to the orders.

4.6 Stock Process

As explained before, the process of requesting stock has low efficiency and is causing a surplus of raw material, and all the muda that comes with it.

In order to avoid that, an alternative process has been developed, and this includes the following changes:

- An excel-visual basic macro was created with the purpose of merging every new combination that may require crimping samples in the PTC-CC. With this information it is easy to cross-check these combinations with the ordered applicators list. This cross-check result gives us a list of every combination that can be crimped in each applicator. In figure 4.20, it can be seen the applicator number in red and the properties of the combination.

Figure 4.20: Excel sheet created by the macro developed

APP	ID	PTC	Terminal	Acessório	Fio A		FIO B		Marca	Fábrica	Standard	Acessório B	Status
70031570	1	PTC-1901-011	7003-1570	---	HEBCO	30.0			NISSAN	YMO	YPES-48-001-Rev.6		(6 - APPLICATOR ORDERED
7003175602	928	PTC-1907-3099	7003-1756-02	---	YBF-B	35.0			E-GO_LV	YSE-CCS	YPES-48-055 Rev.1		07 - APPLICATOR ORDERED > MISSING COMPONENTS
7003724702	2	PTC-1901-0119	7003-7247-02	---	HEBCO	30.0			NISSAN	YMO	YPES-48-001-Rev.6		(6 - APPLICATOR ORDERED
7003753502	792	PTC-1810-114	7003-7535-02		F3ZZ	40,0			RENAULT	YMM	YPES-48-055-Rev.1		(8 - MISSING COMPONENTS
7003753502	793	PTC-1910-3812	7003-7535-02		NF3ZZ	40,0			RENAULT	YMM			(8 - MISSING COMPONENTS
7003755502	794	PTC-1905-2076	7003-7555-02		NF3ZZ	25,0			RENAULT	YMM			(8 - MISSING COMPONENTS
7003757202	110	PTC-1906-2245	7003-7572-02	---	FLRYB	16.0			MCLAREN	YSE	YPES-48-001 Rev.6		(8 - APPLICATOR ORDERED
7003758802	539	PTC-1910-3814	7003-7588-02	---	A42X	50.0			JLR	YUL	USCAR21-Rev.3		(7 - MISSING COMPONENTS
7003758802	540	PTC-1910-3845	7003-7588-02	---	A39YSC	35.0			JLR	YUL	USCAR21-Rev.3		(7 - MISSING COMPONENTS
7003758902	966	PTC-1903-1257	7003-7589-02	---	PSAH4	25.0	PSAH4	25.0	PSA	YMO	YPES-48-001-Rev.6		02 -WAITING APPLICATOR ORDER
7003760702	495	PTC-1904-1735	7003-7607-02	---	C-FLR2X	35.0			BENZ_MFA2	YTU	MBN_10384_2010-11		13 -MISSING APPLICATOR ORDER
7004126902	796	Not Found	7004-1269-02		A3ZP	2,00+3,00			RENAULT	YTU	YPES-48-001-Rev.6		20-WAITING CRIMPING REQUEST
7004192902	797	PTC-1904-1876	7004-1929-02		A3ZP	4,00			RENAULT	YBE			(8 - MISSING COMPONENTS
7004546702	948	PTC-1812-1710	7004-5467-02	---	ZRDX155S	70.0			SCANIA	YBE-Y	YPES-48-055-Rev.1		> Missing Components
7004549202	929	PTC-1907-3075	7004-5492-02	---	YBF-B	35.0			E-GO_LV	YSE-CCS	YPES-48-055 Rev.1		(8 - APPLICATOR ORDERED
7009121302	949	PTC-1902-0459	7009-1213-02	---	ZFLR308F	4.00			SCANIA	YBE-Y	YPES-48-001-Rev.6		> The Applicator is Ordered
7009130102	798	PTC-1808-0889	7009-1301-02		A3TAH	0,50			RENAULT	YMM	YPES-48-001-Rev.6		14 - ACTIVITY FR0ZEN DUE TO INVESTIGATION RESTRICTION
7009130102	799	PTC-1506-1029	7009-1301-02		A3ZP	0,50			RENAULT	YTU	YPES-48-001-Rev.6		14 - ACTIVITY FR0ZEN DUE TO INVESTIGATION RESTRICTION
7009130102	800	PTC-1811-1419	7009-1301-02		R3CO	0,50			RENAULT	YMM	YPES-48-001-Rev.6		14 - ACTIVITY FR0ZEN DUE TO INVESTIGATION RESTRICTION
7009130102	801	PTC-1903-1223	7009-1301-02		A3TAH	1,00			RENAULT	YMM	YPES-48-001-Rev.6		14 - ACTIVITY FR0ZEN DUE TO INVESTIGATION RESTRICTION
7009130102	802	PTC-1903-1385	7009-1301-02		R3CO	0,75			RENAULT	YMM			14 - ACTIVITY FR0ZEN DUE TO INVESTIGATION RESTRICTION
7009130302	1022	PTC-1909-3157	7009-1303-02	---	A3ZP	2.50	A3ZP	4.00	OPEL	YMK	YPES-48-001-Rev.6		22- SAMPLES PREPARATION REQUEST UNDER PREPARATION
7009135202	425	PTC-0709-1255	7009-1352-02	---	FLRYB	10.0			KIDDEN	YSE-CCS	YPES-48-001-Rev.6		02 -WAITING APPLICATOR ORDER
7009184302	547	PTC-1908-3355	7009-1843-02	---	A22TBD	12.0			JLR	YMO-K	USCAR21-Rev.3		(7 - MISSING COMPONENTS
7009196902	548	PTC-1906-2230	7009-1969-02	---	A39YSC	25.0			JLR	YUL	USCAR21-Rev.3		(7 - MISSING COMPONENTS
7009212502	114	PTC-1906-2223	7009-2125-02	---	FLRYB	16.0			MCLAREN	YSE	YPES-48-001 Rev.6		(8 - APPLICATOR ORDERED
7009228402	115	PTC-1906-2110	7009-2284-02	---	T3ZH	6.00			MCLAREN	YSE	YPES-48-001 Rev.6		07 - APPLICATOR ORDERED > MISSING COMPONENTS
7009228902	116	PTC-1906-2677	7009-2289-02	---	ACW0219	0.75	ACW0219+T3ZI	2.50+250	MCLAREN	YSE	YPES-48-001 Rev.6		(8 - APPLICATOR ORDERED
7009255302	967	PTC-1904-1581	7009-2553-02	---	PSAG4	20.0			PSA	YVL	YPES-48-001-Rev.6		02 -WAITING APPLICATOR ORDER
7009512102	119	PTC-1909-3637	7009-5121-02	---	FLRYB	16.0			MCLAREN	YSE	YPES-48-001 Rev.6		(8 - APPLICATOR ORDERED
7009512102	551	PTC-1908-3356	7009-5121-02	---	A22TBD	20.0			JLR	YMO-K	USCAR21-Rev.3		(4 - APPLICATOR ORDERED
7009512102	552	PTC-1908-3361	7009-5121-02	---	A22TBD	16.0			JLR	YMO-K	USCAR21-Rev.3		(4 - APPLICATOR ORDERED
7009543402	804	PTC-1905-2080	7009-5434-02		F4ZZC	25,0			RENAULT	YMM			(8 - MISSING COMPONENTS
7009543402	805	PTC-1908-3217	7009-5434-02		NF3ZZ	30,0			RENAULT	YMM			(8 - MISSING COMPONENTS
7009543402	806	PTC-1910-3898	7009-5434-02		NF3ZZ	40,0			RENAULT	YMM			(8 - MISSING COMPONENTS
7009550302	807	PTC-1903-1319	7009-5503-02		A3ZP	0.50			RENAULT	YTU			05 - APPLICATOR ORDERED
7009551402	808	PTC-1808-0894	7009-5514-02		A3ZP	3,00			RENAULT	YTU	YPES-48-001-Rev.6		05 - APPLICATOR ORDERED
7009551402	809	PTC-1809-0921	7009-5514-02		A3ZP	1,00+2,00			RENAULT	YTU	YPES-48-001-Rev.6		05 - APPLICATOR ORDERED
7009551402	968	PTC-1210-1517	7009-5514-02	---	T3ZH	4.00			PSA	YMO	YPES-48-001-Rev.6		07 - APPLICATOR ORDERED. MISSING COMPONENTS

- With this process so simplified, it is way easier to request material, so the responsibility of performing it can be allocated to only one person, being the person that makes more sense to perform this action, the employee that receives the applicators' order.
- This macro will affect the storage of the material. The distributor will now be able to group the received material by the applicator, making it way easier to later distribute to the cells.

Chapter 5

Results

In this chapter, the project results will be presented and explained.

5.1 Testing the changes

Initially, in order to understand the results, there will be shown a prediction of how the new production system would have responded to the orders in the last two years. Then with the values obtained, it is possible to compare the new system to the previous one.

Figure 5.1: Process A orders

Process A Orders	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	101	91	144	194	133	61	123	86	99	79	111	49
2018/2019	78	61	91	129	126	86	87	114	104	113	148	104

Figure 5.2: Process B orders

Process B Orders	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	116	65	95	35	71	118	126	209	204	106	109	251
2018/2019	124	55	123	118	100	68	158	242	115	179	91	166

With these orders, it is possible to calculate the takt time for each month and compare it to the cycle time achieved in the cells of the new production system.

Cutting Cell Time

This cell is peculiar because it is limited to one person. This constraint exists because there is only one cutting machine available.

To a better understanding of how it can react to orders variation, it was calculated the takt time for each month in the last two years.

Figure 5.3: Cutting Cell necessary Takt Time to deliver past orders

Takt time Cutting Cell	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	93,56	103,85	65,63	48,71	71,05	154,92	76,83	109,88	95,45	119,62	85,14	192,86
2018/2019	121,15	154,92	103,85	73,26	75,00	109,88	108,62	82,89	90,87	83,63	63,85	90,87

In figure 5.3, the cells marked in yellow represent the months that were a problem to the old cutting process because the old cycle time was 80 minutes, but with the new cutting cell cycle time of 61 minutes, they are no longer a concern. However, there is still one month marked in red where the takt time imposed by the orders is lower than the cycle time achieved by the new cutting cell.

Since this problem occurred only once within these two years, the best approach is to work extra hours on that cell. The necessary work done in extra hours would be:

$$ExtraHours = \frac{(CellCycleTime - Takttime) * Orders}{60} = \frac{(61 - 48,71) * 194}{60} = 39.7h \tag{5.1}$$

Concluding, even with the new cutting cell improved cycle time, there would be the need to work 39,7 extra hours to produce the orders. However, six out of the seven months extra hours required months no longer require extra hours on the cutting cell.

Crimping+Inspection Cell

In this cell, to be able to understand the results, it is necessary a different method because this cell contains two different processes.

Starting by each process takt time:

Figure 5.4: Takt Time Crimping process applied to the orders in each month

Takt time Crimping	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	93,56	103,85	65,63	48,71	71,05	154,92	76,83	109,88	95,45	119,62	85,14	192,86
2018/2019	121,15	154,92	103,85	73,26	75,00	109,88	108,62	82,89	90,87	83,63	63,85	90,87

Figure 5.5: Takt Time Inspection process applied to the orders in each month

Takt time Inspection	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	81,47	145,38	99,47	270,00	133,10	80,08	75,00	45,22	46,32	89,15	86,70	37,65
2018/2019	76,21	171,82	76,83	80,08	94,50	138,97	59,81	39,05	82,17	52,79	103,85	56,93

Next, it is necessary to know how many operators are required to deliver that takt time.

$$\frac{CycleTime}{N^{o}ofOperators} \leq TaktTime \tag{5.2}$$

$$N^{o}ofOperators \geq \frac{CycleTime}{TaktTime} \tag{5.3}$$

Using equation 5.3, the following values have been achieved:

Figure 5.6: Number of workers the Crimping process requires to complete the orders in each month

Crimping nº of operators needed	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	2,80	2,52	3,99	5,38	3,69	1,69	3,41	2,38	2,74	2,19	3,08	1,36
2018/2019	2,16	1,69	2,52	3,58	3,49	2,38	2,41	3,16	2,88	3,13	4,10	2,88

Figure 5.7: Number of workers the Inspection process requires to complete the orders in each month

Inspection nº of operators needed	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	0,66	0,37	0,54	0,20	0,41	0,67	0,72	1,19	1,17	0,61	0,62	1,43
2018/2019	0,71	0,31	0,70	0,67	0,57	0,39	0,90	1,38	0,66	1,02	0,52	0,95

Figure 5.8: Number of workers required in the Crimping+Inspection Cell

Sum Operators Crimp+Insp cell	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	3,46	2,89	4,54	5,58	4,09	2,37	4,13	3,58	3,91	2,80	3,70	2,79
2018/2019	2,87	2,01	3,23	4,25	4,06	2,77	3,31	4,54	3,54	4,16	4,62	3,83

Figure 5.8 shows that there is also only one month, which happens to be coincident with the cutting cell, where the number of operators needed to satisfy the orders is superior to 5.

Although this cell only presents one concerning month, as chapter 4.5 explains, there is a floating operator system from this cell to the PF+MC to increase the bottleneck productivity. In this floating system, the crimping cell lends operators, so in order to understand the number of extra hours needed, it is required to take this lending into account, and for that reason, it has been calculated based on the crimping takt time each month how many operators the Crimping+Inspection cell would need to lend the PF+Inspection cell following the equation 5.4, the results are shown in figure 5.9.

$$OperatorsFloating = OperatorsNeeded - AvailableOperators \tag{5.4}$$

Figure 5.9: Number of workers lent to the PF+MC Cell

Operators lent to the PF+MC Cell	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018								-0,22	-0,27			-0,25
2018/2019								-0,56		-0,21		-0,09

The blank months are the ones were the PF+MC Cells are self-sufficient and do not require any extra workers. The numbers are represented as negative since they are leaving Crimping+Inspection cell.

Next, these values were subtracted in Figure 5.8 to get the real amount of operators needed taking into account the floating system. The results can be seen in Figure 5.10.

Figure 5.10: Number of workers lent to the PF+MC Cell

Real Operators Crimp+Insp Cell	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	3,46	2,89	4,54	5,58	4,09	2,37	4,13	3,80	4,18	2,80	3,70	3,04
2018/2019	2,87	2,01	3,23	4,25	4,06	2,77	3,31	5,10	3,54	4,36	4,62	3,92

We can see, the floating will bring a new problematic month, February 2019. The extra hours corresponding to these operators are going to be considered in this cell. However, the ones in February 2019 could be considered in the PF+MC cell because they are originated there.

$$ExtraHours = \frac{ExtraOperatorsRequired * ProductionTime}{60} = \frac{0,68 * 9450}{60} = 107.1h \tag{5.5}$$

Pull Force + Micro-Cut Cell

The PF+MC cell is the one with the takt time closest to the cycle time, which means that it is the cell with less capacity to the orders. To avoid possible delays, it may cause, to the whole production system, it was created a buffer in its input where the amount of WIP controls the number of workers in this cell.

Figure 5.11: Takt Time PF+MC Cell applied to the orders in each month

Takt Time PF+MC	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	43,55	60,58	39,54	41,27	46,32	52,79	37,95	32,03	31,19	51,08	42,95	31,50
2018/2019	46,78	81,47	44,16	38,26	41,81	61,36	38,57	26,54	43,15	32,36	39,54	35,00

With the equation 5.3, it was achieved the following number of operators each month:

Figure 5.12: Number of workers the PF+MC cell requires to complete the orders in each month

PF+MC nº of operators needed	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2017/2018	1,19	0,86	1,32	1,26	1,12	0,98	1,37	1,62	1,67	1,02	1,21	1,65
2018/2019	1,11	0,64	1,18	1,36	1,24	0,85	1,35	1,96	1,21	1,61	1,32	1,49

As expected, this is the cell with the highest amount of months that cannot fulfill the orders with the assigned number of operators, which is 1.4. As explained before, the floating system solves the lack of workforce in every month marked in red except one.

There will be no extra hours allocated to this cell because they have already been considered in the Crimping+Inspection Cell

Total Balance

Now, it is time to confirm if this new method of production can reduce the extra hours, and if yes, how many.

With the new system it has been predicted the following amount of extra hours:

$$TotalExtraHours = 107.1 + 39.7 = 146.8h \tag{5.6}$$

The extra hours with the Job Shop production in the last two years were 4642 hours. So the extra hours would have a 97% reduction. Note that it has been assumed that every employee works at the same pace in every section.

5.2 Production System Results

5.2.1 Lead Time Results

With the excellent results obtained in the tests performed to the orders in the past, and changing the general process as proposed, it is a step towards achieving Continuous Flow.

This approximation is shown by the new method's ability to respond to the orders much faster. So the improvement on the lead time was:

$$ProcessALeadTimeImprovement = 15.6 - 4 = 11.6DaysImprovement \tag{5.7}$$

$$ProcessBLeadTimeImprovement = 13.4 - 2.7 = 10.7DaysImprovement \tag{5.8}$$

These values show a 75% improvement in the first and 80% in the latter.

5.2.2 Production Rate

The tests performed at the beginning of this chapter reflect the increased production rate and even the production rate per employee since there are no changes in the number of workers in the plant. However, here it will be calculated the actual rate for both production systems. To measure the production rate, it is necessary to differentiate Process A and Process B. To get results closer to the actual orders, a better approximation to the reality, in the Job Shop production system, two workers were assigned to process B and the other 5.5 to process A.

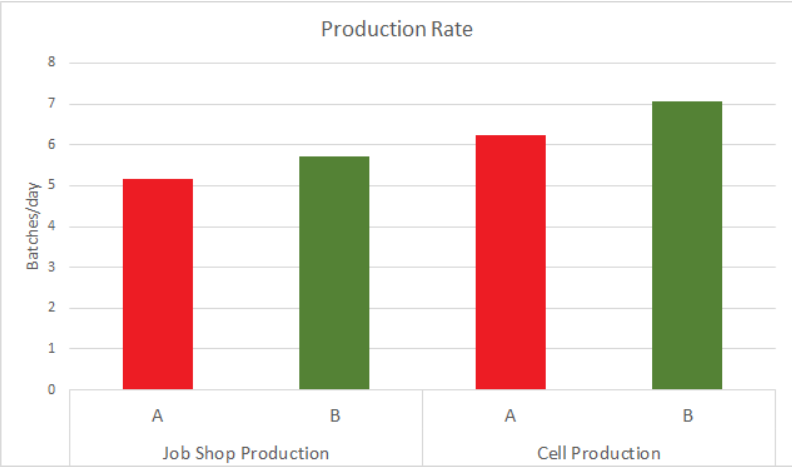


Figure 5.13: Production rate in each production system

The differences in the production rate for both production systems are obvious, with the sum of both processes we have a total of 10,8 batches/day on Job Shop production system and 13.3 batches/day in the Cell production system, a 19% overall improvement in production rate.

5.2.3 Overall Equipment Efficiency

In the job shop production system, it was calculated the following values for the OEE of the following machines:

Table 5.1: Job Shop OEE

Job Shop OEE	Availability	Performance	Quality	Total
Cutting	68.75%	80.00%	70.00%	38.50%
Crimping	40.30%	100.00%	97.00%	39.11%
Pull Force	68.67%	90.00%	97.00%	60.00%

These values are low, but they show that the machines can be better utilized. It is normal to a job shop system production based on creating different kinds of batches to achieve low values on OEE. However, changing to the cell production system it is possible to achieve improvements:

Table 5.2: Cell Production OEE

Cell Production OEE	Availability	Performance	Quality	Total
Cutting	90.00%	80.00%	70.00%	50.40%
Crimping	47.70%	100.00%	97.00%	46.20%
Pull Force	84.00%	90.00%	97.00%	73.90%

Even tho these values were calculated by average values because of the challenge it is to calculate the OEE in the job shop production systems. Evidently, the Availability OEE of every machine will improve with the implementation of cells. This increase is mainly caused by allocating the non-value actions to the distributor. Moreover, it shows that while improving the whole production system, the local efficiencies follow it.

5.2.4 Distances and Occupied Area

Starting by the occupied area for the production, it was reduced from $580m^2$ to $330m^2$ a 43.2% improvement.

Regarding the distances, they will be separated in Walking Distance and Material Distance. Starting by the walking distance, the improvements are shown in the table below:

Table 5.3: Cell Production Walking Distance

Walking Distance	Job Shop Production	Cells Production	Improvement
Cutting	81 meters	6 meters	93%
Crimping	156 meters	24 meters	79%
Pull Force	158 meters	5 meters	97%
Process B	217 meters	22 meters	90%

These were some great results. The motion waste has been almost eliminated with the new production system. On the other hand, these results were possible because of the creation of the distributor role. So, it was calculated the distance per batch after the distributor role is implemented and compared to the previous one.

$$Cells\frac{Distance}{Batch} = 0.53 * 22 + 35 * 0.47 + \frac{470}{13.3} = 64meters/batch \quad (5.9)$$

$$JobShop\frac{Distance}{Batch} = \frac{5.7 * 217 + 5.1 * 395}{10.8} = 295.7meters/batch \quad (5.10)$$

It was considered, the results and the percentage of batches, between process A and B, achieved in the chapter 5.2.2.

5.3 Results in Stock Management

5.3.1 Stock Process

The changes in the stock request process bring some good results. Starting by the time dedicated to request material and its control, it passed from half an hour per week per person(10 people) to only one person requesting everything in an hour per week. This improvement gives us a reduction from 5h to 1h. Although it is harder to quantify the improvements, it is clear that the new process will also bring a reduction in the occurrences of stockout due to the stricter control and also a reduction in requesting repeated material.

5.3.2 Stock Reduction

The new VB Excel macro created to control the stock request also allowed to understand the excess stock in the PTC CC at the moment. It was considered excess raw material all the raw material that arrived more than three months ago and still has no applicator order where it may be used.

Using these criteria were achieved the following results.

Table 5.4: Surplus of Raw Material

Raw Material Stock	Excess	Total
Terminal(pieces)	2101389	3338737
Wire(meters)	458743	518971

Figure 5.14 shows that the Crimping Centre warehouse is storing more unnecessary than necessary material.

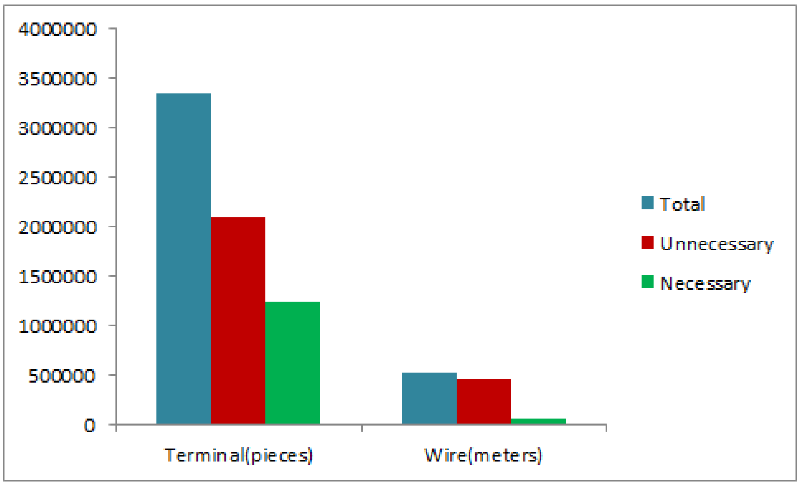


Figure 5.14: Material Necessary vs Unnecessary

To conclude, this brought a reduction in 63% of the terminal pieces, and 88.4% of the wire stored.

5.4 Results Applied to Costs Reduction

To the moment, this chapter showed the excellent results obtained in this project. Now, these results will be translated to cost reductions.

5.4.1 Extra hours Reduction

Paid Hours Reduction

A significant cost reduction presented in this project is the reduction of the extra hours performed by the operators. It has been obtained a 97% reduction compared to the last two years.

Table 5.5: Extra Hours, Actual Production vs Proposed Production

Extra Hours	Actual Production	Proposed Production
Last Five Years	4842h	146.8h
Average per year	2421h	73.4h

So, there is an average reduction per year of:

$$2421 - 73.4 = 2347.6 hours \tag{5.11}$$

Considering that the operators earn around 6 euros an hour in the regular schedule, and extra hours are paid 150%

$$ExtraHourCost = 6 * 1.5 = 9 euros/hour \tag{5.12}$$

This value is the one received by the operator, but the company has to pay taxes on those values, assuming 20% taxes on the extra hours:

$$RealExtraHourCost = 9 * 1.2 = 10.8 euros/hour \tag{5.13}$$

With the assumptions made above, the yearly cost reduction in extra hours are:

$$CostReductionExtraHours = 10.8 * 2347.6 = 25354 euros/year \tag{5.14}$$

Machine Working Time Reduction

The power being consumed by the machines in extra hours was also calculated.

The number of extra hours obtained from the last years was a sum of the extra hours each person worked in that period. One thing that cant known is the time those people worked in extra hours simultaneously, and that affects the cost of some of the machines, like the ones that consume the same power if one or three workers are performing extra hours. In this case, it was assumed that workers perform extra hours in groups of three on average. This case does not affect the Crimping machine. One of those machines is required for each operator all the time.

Table 5.6 shows the results achieved:

Table 5.6: Cost of the machines working in extra hours

MachineCost	Kw	KWh(extra hours)	Cost(euros)
Crimping Machine	3.5	8216.6	1400.63
Computers(2 units)	0.9	704.3	120.05
Lamps(20 units)	1.6	1252	213.43
Welding Machine	1.2	939.04	160.07
Pull Force Machine	0.15	117.4	20.01
TOTAL	7.35	11226.34	1.914.19

So, as it is possible to see in table 5.8, the yearly cost of machines running extra hours is 1914,19 euros. To achieve this cost per hour:

$$\frac{Cost}{Hour} = \frac{1914.19}{2354} = 0.81euros/hour \tag{5.15}$$

Now, to achieve the cost reduction in the machine running time, it is necessary to subtract the extra hours required in the proposed solution.

$$MachineCostReduction = 1914.19 - 0.81 * 73.4 = 1854.7euros \tag{5.16}$$

Total Extra Hour Cost Reduction

Now, that has been calculated every cost reduction associated with the reduction in performing extra hours it is possible to sum these values to achieve the total cost reduction:

$$TotalCostReduction = 1855 + 25354 = 27209euros/year \tag{5.17}$$

It is possible to conclude it was estimated a yearly cost reduction of 27209 euros/year associated with the proposed changes in production.

5.4.2 Stock Reduction

Requesting and Controlling Cost Reduction

The time spent in requesting material and verify the already requested one passed from:

$$10people * 0.5hours = 5hours/week \tag{5.18}$$

To 1h/week one person. At the end of the year, this translates into a cost reduction of:

$$\frac{ReductionHours}{Week} = 5 - 1 = 4hours/week \tag{5.19}$$

$$\frac{ReductionHours}{Year} = 4hours * 52weeks = 208hours/year \tag{5.20}$$

$$\frac{CostReduction}{Year} = 8 * 208 * 1.2 = 1997euros/year \tag{5.21}$$

It was assumed that people working in the office receive 8 euros/hour, and the company pays 20% taxes.

Cost Reduction on Ownership

Owning Stock corresponds to having money stopped in the warehouse. This makes it unavailable to invest. The cost associated with this is usually superior to the interest rate in the bank credit. Moreover, the price paid to insurance is also increased by the amount of stock.

To calculate the cost of owning stock, it has been assumed the bank credit interest rate, plus the increasing of insurance as 5% and that if that money would be invested, Yazaki could be earning more 2.5%, making a total fee of 7.5% on owning stock.

So applying this 7.5% to the reduction of stock gives a cost reduction of:

Table 5.7: Cost of Owning Stock

Raw Material Stock	Unnecessary	Price of Unnecessary Stock(euros)	Cost of owning this Stock(euros)
Terminal(pieces)	2101389	42027.78	3152.0835
Wire(meters)	458743	18349.72	1376.229

These values were obtained by estimating the terminal price as 0.02 euros apiece and the wire price as 40 euros per 1000 meters.

This values show a cost reduction in stock ownership of:

$$CostReduction = 3152 + 1376 = 4528 euros \tag{5.22}$$

5.5 Total Cost Reduction

So after all the cost reduction estimated, they were summed, and the total cost reduction is:

$$CostReductionS + CostReductionPn = 4528 + 27209 = 31737 euros/year \tag{5.23}$$

Some changes in the process are not considered in the cost reduction, like production planning reduction time or yearly scrap reduction from improving the request process, because although they show improvements, it is tough to quantify them. So this is the underestimated total cost reduction.

Chapter 6

Conclusion

6.1 Conclusions

The main conclusions obtained from this project are:

- Regarding the Cell production implementation:
  - The implementation of cells can bring a better response to the variation of the workload and increased productivity. This new system causes a reduction in the general process lead time.
  - Applying the Value chain method, many non-value actions were found. These actions were reduced by improving the layout and grouped by creating the distributor role, causing an improvement in the Availability of the OEE.
  - Introducing the floating system between cells controlled by the WIP limit of the FIFO lane, a solid control of the work in progress can be created.
  - This new production process brings a tremendous reduction in the required extra hours performed by the operators. These reductions were about 97% when applied to the last two years orders.
- Regarding the Stock reduction:
  - The raw material request stock was improved and assigned to only one person. This improvement brings better control of the ordered material and reduces the time spent in those operations.
  - The visual basic/excel macro created to control the excel orders and the material that can be scrapped brings a reduction of 64% in terminal pieces and 88% of the wire in the warehouse.
  - The new process creates the possibility of linking the material in the warehouse to the right order it was requested for, avoiding its usage for different purposes, reducing the out of stock situations.

6.2 Future Work

The production system created in this project was still not tested as a whole, so the future work would pass by picking the proposals presented in this project and implement them in the actual production site. Moreover, the new production system will bring many different changes, and it will bring many different problems that can not be predicted without the actual implementation, creating room for new kaizen approaches over the changes applied.

Furthermore, doing a project like this one in another production site presented in the Crimping Centre, the applicator production could bring many advantages while linking both productions into the same goal, reduce costs while maintaining the throughput.

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Appendix A

Data Considered in the project

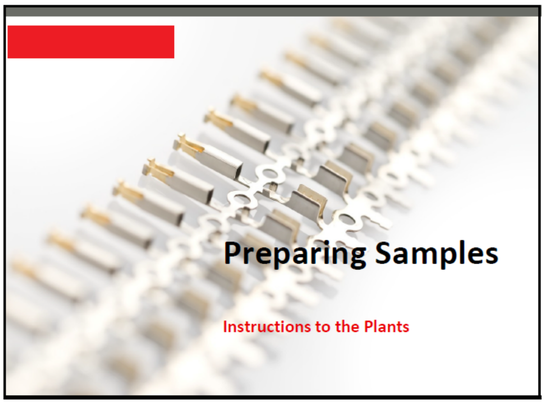
A.1 Inventory waiting to be produced at the beginning of each process

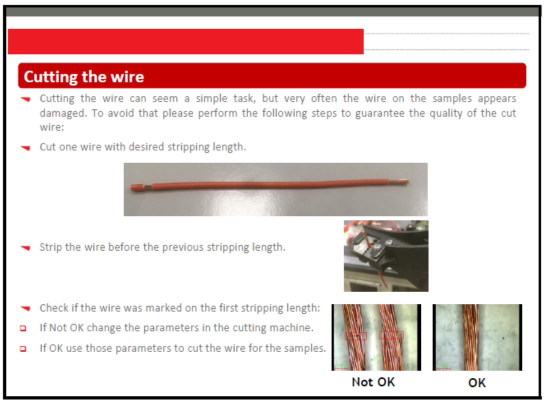
RECEIVED	Responsible	PROCESSO	PLAN			
			WEEK	START	FINISH	LEAD TIME
K	L	M	WEEK	P	Q	
12-jun-19		12-jun-19	W24	13-jun-19	13-jun-19	1,00
11-jan-19		Missing	W8	22-fev-19	22-fev-19	42,00
13-jun-19		13-jun-19	W24	14-jun-19	14-jun-19	1,00
15-jan-19		15-jan-19	W4	21-jan-19	21-jan-19	6,00
28-jan-19		31-jan-19	W6	4-fev-19	5-fev-19	7,00
21-jan-19		23-jan-19	W5	29-jan-19	29-jan-19	8,00
10-jan-19		10-jan-19	W4	24-jan-19	25-jan-19	14,00
4-jan-19		31-jan-19	W6	5-fev-19	5-fev-19	32,00
8-jan-19		11-jan-19	W3	15-jan-19	15-jan-19	7,00
15-fev-19		15-fev-19	W7	15-fev-19	15-fev-19	0,00
3-jan-19		8-jan-19	W3	14-jan-19	14-jan-19	11,00
28-mai-19		28-mai-19	W27	1-jul-19	1-jul-19	34,00
1-mar-19		Missing	W12	22-mar-19	22-mar-19	21,00
15-abr-19		2-mai-19	W20	15-mai-19	15-mai-19	30,00
3-abr-19		3-abr-19	W14	3-abr-19	3-abr-19	0,00
7-jan-19		7-jan-19	W2	8-jan-19	8-jan-19	1,00
20-fev-19		25-fev-19	W9	27-fev-19	27-fev-19	7,00
2-jan-19		3-jan-19	W4	21-jan-19	21-jan-19	19,00
4-jan-19		7-jan-19	W2	7-jan-19	7-jan-19	3,00
4-jan-19		14-jan-19	W3	16-jan-19	16-jan-19	12,00
1-fev-19		5-fev-19	W6	7-fev-19	7-fev-19	6,00
16-jan-19		16-jan-19	W3	16-jan-19	16-jan-19	0,00
16-jan-19		16-jan-19	W3	16-jan-19	16-jan-19	0,00
15-fev-19		18-fev-19	W8	18-fev-19	18-fev-19	3,00
27-fev-19		27-fev-19	W10	8-mar-19	8-mar-19	9,00
5-fev-19		7-fev-19	W8	19-fev-19	19-fev-19	14,00
3-jan-19		7-jan-19	W2	10-jan-19	10-jan-19	7,00
14-jan-19		14-jan-19	W3	18-jan-19	18-jan-19	4,00
15-jan-19		16-jan-19	W4	21-jan-19	21-jan-19	6,00
28-mai-19		28-mai-19	W27	1-jul-19	1-jul-19	34,00
18-jan-19		21-jan-19	W4	24-jan-19	25-jan-19	6,00

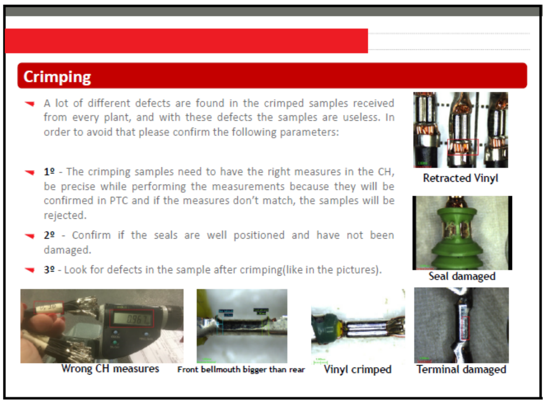
These values were obtained by the production manager. By using a sample size of 2900 samples we obtained the average value of 14 days.

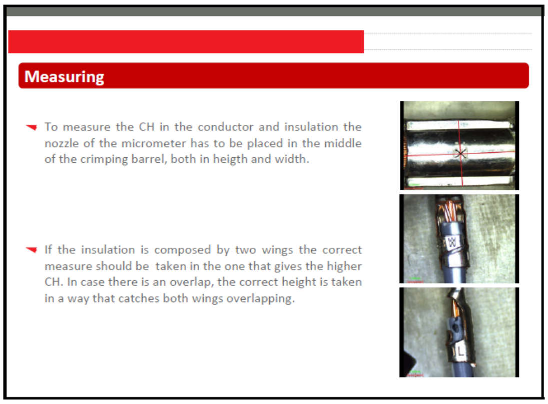
A table similar to this one was also created for the WIP at the input of Process B, and it was achieved 13 days

A.2 Presentation to the plants on samples preparation









A.3 Last Year Orders

Crimped	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2014/2015	98	79	191	157	193	73	111	146	135	92	144	55
2015/2016	97	65	171	168	166	139	152	174	199	194	210	212
2016/2017	191	94	139	128	130	106	169	158	167	98	174	142
2017/2018	101	91	144	194	133	61	123	86	99	79	111	49
2018/2019	78	61	91	129	126	86	87	114	104	113	148	104

From the previous tabl,e it is possible to sum the total crimping orders from January 2018 to December 2018, obtaining an 1118 total crimping samples orders

Samples Received	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
2014/2015	76	24	15	113	16	85	127	133	132	58	73	281
2015/2016	158	87	62	147	59	53	100	113	60	124	80	68
2016/2017	106	110	75	298	239	149	119	120	145	48	108	82
2017/2018	116	65	95	35	71	118	126	209	204	106	109	251
2018/2019	124	55	123	118	100	68	158	242	115	179	91	166

From the previous table, it is possible to sum the total samples inspection orders from January 2018 to December 2018, obtaining a 1593 total crimping samples orders

$$\frac{1118}{2711} = 41.2\% crimping orders \tag{A.1}$$

$$\frac{1593}{2711} = 58.7\% inspection orders \tag{A.2}$$

Multiplying the number of orders by the lead time it is obtained:

$$1118 * 480 = 536640 minutes Process A \tag{A.3}$$

$$1593 * 157 = 250101 minutes Process B \tag{A.4}$$

Turning into percentage time of the year:

$$\frac{536640}{786741} = 68.2\% \tag{A.5}$$

$$\frac{250101}{786741} = 31.8\% \tag{A.6}$$

A.4 Initial Production Lead Time

The lead times mentioned below only start counting from the moment the operator starts to work on that batch, it does not take into account the time in the queue before that. To calculate the initial Production Lead Time from process A and B, the following steps were executed:

1. The Process B times were measured, obtaining an average of 2.62h per combination
2. Having that, the number of orders for process B in the last 2 years, we have records of, were multiplied by the lead time in process B:

$$TimespentinprocessB2017 = 1122 * 2.62 = 2939.64hours \tag{A.7}$$

$$TimespentinprocessB2018 = 1593 * 2.62 = 4173.66hours \tag{A.8}$$

3. Then it is possible to calculate the time spent in crimping samples

$$TimeA2017 = TotalWH2017 - TimeB2017 = 15744 - 2930 = 12804hours \tag{A.9}$$

$$TimeA2018 = TotalWH2018 - TimeB2018 = 13217 - 4174 = 9043hours \tag{A.10}$$

4. Dividing that time per the number of combinations obtained is achieved the time/combination in process A:

$$LeadTimeA2017 = \frac{TimeA2017}{CombinationsA} = \frac{12804}{1632} = 7.85\frac{Hours}{Combination} \tag{A.11}$$

$$LeadTimeA2018 = \frac{TimeA2018}{CombinationsA} = \frac{9043}{1118} = 8.09\frac{Hours}{Combination} \tag{A.12}$$

$$AVGLeadTime = 7.85 * 0.4 + 8.09 * 0.6 = 8hours \tag{A.13}$$

In minutes this gives us:

$$AVGLeadTime = 8 * 60 = 480minutes \tag{A.14}$$

A.5 Defining average of accessories presented in combinations

Picking combinations from lists like the one below, it was calculated the percentage of accessories in 10 different brands containing 15567combinations.

NISSAN	CRIMP REQUEST	TERMINAL	ACESSORY
COMBINATION KEY	APPLICATIONNUMBER	TERMINALYPN	ACCESSORYYPN
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxx1	xxxxxx	xxxxx	1
xxxxxNO	xxxxxx	xxxxx	NO
xxxxx1	xxxxxx	xxxxx	1
xxxxxNO	xxxxxx	xxxxx	NO
xxxxx1	xxxxxx	xxxxx	1
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxx1	xxxxxx	xxxxx	1
xxxxxNO	xxxxxx	xxxxx	NO
xxxxx1	xxxxxx	xxxxx	1
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxxNO	xxxxxx	xxxxx	NO
xxxxx1	xxxxxx	xxxxx	1
xxxxx1	xxxxxx	xxxxx	1

Figure A.1: Example of lists used

The values in the figure have been changed due to confidential purposes. Still, it can be seen that NISSAN was one of the brands. From this combinations 5452 had an accessory leaving us with:

$$\%Of Accessories = \frac{5452}{15567} = 35\% \tag{A.15}$$