Analysis and improvement of processes using variability analysis tools

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Abstract

Nowadays industrial companies compete in an environment where productive efficiency and minimization of waste are critical factors in capturing opportunities and expanding business in a fast changing global marketplace. Variability is an enemy of efficiency, leading to either waste or excess production cost. Thus, reducing it must be on companies top priorities. While a controlled production process is key to keep customers satisfied while maintaining high levels of flexibility, in order to keep a competitive edge in the market, a strategy of continuous improvement is also essential.

The present dissertation is part of a project of continuous improvement developed in a company that manufactures industrial equipment, framed in a strategy of growth and future expansion. The main goal was to achieve the stabilization of the production process, by defining measures that ensure the minimization of variability. The approach to this problem was based on the DMAIC methodology, where empirical and quantitative data was collected and analyzed applying variability analysis tools. During the project, visual management methodologies and lean tools, such as visual management boards, value stream mapping, the 5s methodology and standard work were also used.

First, demand variability was analyzed, showing that it behaved unpredictably, as all products demand coefficient of variability (CV) were significantly higher than 1. Regarding lead-time variability, it was found that there was significant inter- and intra-operators variation. The main causes identified were related to lack of standardization, lack of materials, and quality problems (60% related to threading). Furthermore, the state of the assembly process revealed a poor performance, as only about 60% of activities were adding value. Notably, talking, rework, and movements accounted for about 80% of Non-Value added (NVA) activities. Besides that, it was concluded that cleaning and packing was excessively time-consuming, accounting for about 27% of assembly activities. Finally, the registration system was proven to be unreliable, as the times measured were very distant from the times registered in the system (with differences ranging from -62% to 37%). The problems aforementioned demonstrated an enormous potential of improvement.

Thus, a vast improvement plan was defined and some of the actions were already implemented, namely the reorganization of the threading section, the creation of a standard work for the threading process, the implementation of a visual management board in the automation section, the optimization of the packing process, and the resizing of the border of lines.

From the implementation of these actions, highlights improvements in the performance of the production process verified with the implementation of the 5s methodology, visual management techniques, standard work, and an optimized packing procedure (about 50% time reduction).

As stated before, variability has a severe impact on revenue, cost, and margins. Through the actions planned and implemented, improvements in productivity and organization are expected, as well as a reduction of variability, thus increasing the company competitiveness.

Resumo

Atualmente, as empresas industriais competem num ambiente onde a eficiência produtiva e a minimização de desperdício são fatores críticos na captura de oportunidades e na expansão dos negócios num mercado global em rápida mudança. A variabilidade é inimiga da eficiência, levando a desperdícios ou a custos de produção excessivos. Portanto, a sua redução deve estar no topo das prioridades das empresas. Enquanto um processo de produção controlado é a chave para manter os clientes satisfeitos, mantendo altos níveis de flexibilidade, a fim de manter uma vantagem competitiva no mercado, uma estratégia de melhoria contínua também é essencial.

A presente dissertação faz parte de um projeto de melhoria contínua desenvolvido numa empresa que fabrica equipamentos industriais, enquadrado numa estratégia de crescimento e expansão futura. O principal objetivo era conseguir a estabilização do processo de produção, definindo medidas que garantissem a minimização da variabilidade. A abordagem a este problema foi baseada na metodologia DMAIC, onde dados empíricos e quantitativos foram recolhidos e analisados utilizando ferramentas de análise de variabilidade. Durante o projeto, metodologias de gestão visual e ferramentas *lean*, também foram usadas.

Em primeiro lugar, a variabilidade da procura foi analisada, demonstrando-se que esta era muito imprevisível, pois todos os produtos apresentavam coeficientes de variabilidade da procura significativamente maiores que 1. Quanto à variabilidade do *lead time*, constatou-se que havia variabilidade inter- e intra-operadores significativa. As principais causas identificadas estavam relacionadas com a falta de padrões de trabalho, faltas de materiais e problemas de qualidade (60% relacionados com a roscagem). Para além disso, o estado do processo de montagem apresentava uma performance medíocre, já que apenas 60% das atividades acrescentavam valor. Notavelmente, conversas, retrabalhos e movimentos, representavam cerca de 80% das atividades de valor não acrescentado. Para além disso, concluiu-se que a limpeza e o embalamento eram excessivamente demoradas, correspondendo a cerca de 27% das atividades de montagem. Por fim, o sistema de registo de tempos mostrou-se pouco fiável, pois os tempos medidos eram muito diferentes dos tempos registados no sistema (com diferenças de -62 % a 37 %).

Assim, um vasto plano de melhorias foi definido e algumas das ações já foram implementadas, nomeadamente a reorganização da secção de roscagem, a criação de um *standard work* para o processo de roscagem, a implementação de um quadro de gestão visual na secção de automação, a otimização do processo de embalamento e o redimensionamento dos bordos de linha.

A partir da implementação dessas ações, destacam-se as melhorias no desempenho do processo de produção verificados com a implementação da metodologia 5s, técnicas de gestão visual, *standard work* e um processo de embalamento otimizado (redução do tempo em cerca de 50%).

Conforme supramencionado, a variabilidade tem um impacto enorme na receita, custo e margens de uma empresa. Através das ações planeadas e implementadas, são esperadas melhorias de produtividade e organização, além de uma redução da variabilidade, aumentando, assim, a competitividade da empresa.

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"O caos é uma ordem por decifrar."

José Saramago

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Acronyms and Symbols

ATO	Assemble to Order
BOM	Bill of Materials
BVA	Business-value added
CTQ	Critical to Quality
CV	Coefficient of Variation
DMAIC	Define, Measure, Analyze, Improve and Control
ETO	Engineering to Order
KPI	Key Performance Indicator
LT	Lead Time
LSS	Lean Six Sigma
MTS	Make to Stock
NVA	Non-value added
PO	Production Order
SW	Standard Work
VA	Value Added
VSM	Value Stream Map
WIP	Work in Progress

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Chapter 1

Introduction

This master dissertation is part of a proposal for intervention in the scope of operational improvement on an industrial company, namely the exploration of variability causes on the manufacturing and assembly of complex products and how they can be reduced.

In this chapter, a presentation and contextualization of the project in question is made, as well as a description of the objectives defined, the methodology adopted for their consummation and the document structure.

1.1 Context

In a world of shrinking product cycles, product proliferation, global competition, mass customization, and volatile demand, companies need strategies and tools to better control processes to get the desired results.

If a company wants to keep customers satisfied, meeting deadlines and providing a quality products, it needs to operate with a high level of predictability, implying that processes need to be stable and under control. Furthermore, in order to sustain good performances and to retain a competitive edge, it is crucial to always be on the lookout for improvement opportunities.

However, when the opposite happens, this is, companies not going beyond the *status quo* and keeping high levels of variability in its processes, performances usually cutback and customers get unsatisfied. Consequently, every company should make it one of its priorities to focus on reducing as much as possible the factors that create variability and constantly looking for improvement opportunities, leveraging all sorts of management tools available to do so.

Despite the economic crisis in Portugal, the company in analysis has been growing, mainly due to its policy of continuous improvement. To act as a lead partner for multinational companies, high focus on costumers and commitment to meet deadlines are essential goals. As mentioned above, reducing process variability is essential to achieve this level of performance and allow the company to keep growing.

1.2 Problem and Objectives

Studies in the field of process improvement have identified a problem that, without appropriate treatment, can pose a threat to the goal of meeting client's deadlines: high variability.

This issue is specially relevant since the company in study manufactures complex products, this is, products that undergo several different operations, require heavy machinery work, and with many parts to be assembled in the final stage. One cannot belittle this, since the more stages a process has, and more parts incorporate the final product, the greater the incidence of variability.

This, combined with the high unpredictability of customer demand, requires a very well defined and robust production strategy.

After making a diagnosis to select a segment of products representative of the problem, the standard products were studied, in which procedures were developed and practices were implemented with the main objective of analyzing the process variability. Then, it was studied how to improve the company's performance through the improvement of production processes.

Taking into account the objectives, it was intended to answer the following key questions:

- What are the main causes of high variability in production times?
- How can these causes be controlled or eliminated?
- What is the current state of the process: how can activities that add little or no value to the process be reduced?

Having obtained an answer for these questions, a plan of actions can be defined and implemented to improve the processes and it is possible to replicate the same approach in the future for the remaining product segments.

1.3 Methodology

This project was developed in accordance with a plan defined by the company (Appendix A), based on the DMAIC methodology. The problem was approached through a mixed strategy of empirical and quantitative analysis.

To start, some time was spent in every department of the company in order to better understand the business processes and to present the ongoing project to the team.

Afterwards, the first step was to identify the most significant products in terms of production, as well as understand their demand patterns. Taking into account the short-term nature of the project, this allowed choosing a small number of products to be tracked on the next phases.

The measure phase consisted, entirely, in fieldwork. The manufacturing of the components of the selected products and the assembly of the same were followed through direct observation, in order to record production times, occurrences and identify possible causes of variability. Particular importance was given to the understanding of the assembly of the products by each operator, in order to understand if the way of doing of each one induced a lot of variability. Additionally, types of activities (value-added (VA), business-value-added (BVA) and non-value-added (NVA)) were registered, to quantify the process state and understand the impact of these activities in production time variability.

In addition, in parallel with this project, an action was taken to collect occurrences in the assembly section (quality problems, lack of materials, wrong bill of materials, etc.).

After collecting all the data, started the analyze phase. All the data was summarized in graphs and tables, in a way that could easily be understood by other people. A failure-cause-solution analysis was made in a brainstorm session in order to understand the root of the failures and to suggest possible solutions.

Finally, after identifying the main problems a plan of action was defined. All proposed improvements were classified according to their execution time, difficulty, cost, and impact. Thereby, the sequence of the improvement actions was defined. Afterwards, the implementation phase started, with some actions already implemented by the end of this study.

1.4 Structure

The dissertation is developed over 6 chapters, giving a more detailed explanation of the whole context and methodology of the project.

In this chapter, an introduction to the project, the problem in study, its objectives and the research methodology outlined is presented.

Chapter 2 presents the theoretical framework of the concepts and methodologies that supported the development of the entire dissertation.

Chapter 3 characterizes the initial situation (*AS IS*) with a higher focus on the problem's description, describing the company's business and products, the production process and the various sections of the shop floor.

In Chapter 4 a variability analysis is conducted, through data collected from the production process to quantify and qualify the causes and withdraw conclusions.

Chapter 5 describes the solutions proposed to solve the problem, as well as the main results of its implementation, the challenges faced and the actions triggered for the continuous vision of improvement (*TO BE*).

Finally, in Chapter 6, the main conclusions are presented, and suggestions for future works are given.

Chapter 2

Theoretical Framework

This chapter reviews the theoretical foundations that have served as a basis for the development of the project, as well as the main methodologies adopted.

2.1 Variability

Variability is the extent to which data points in a statistical distribution or data set diverge from the average value as well as the extent to which these data points differ from each other. Since variability exists in all production systems and can have an enormous impact on performance, it is important to assess if its presence is significant or not, as it can lead to quality problems, unmet specifications and out of control processes (Hopp and Spearman, 2008).

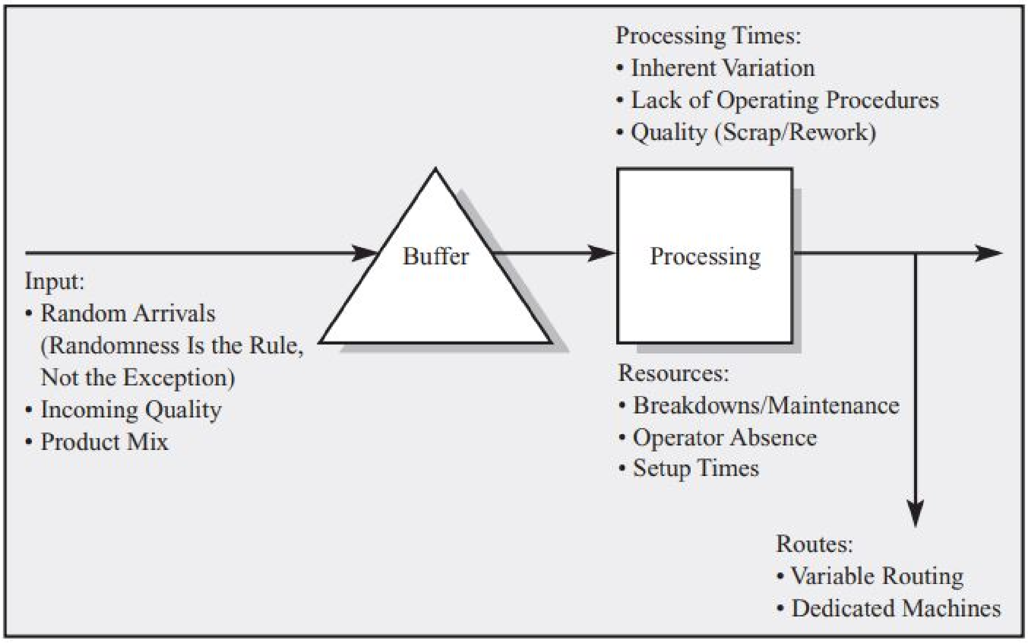

Figure 2.1: Sources of variability (P. Cachon and Terwiesch, 2009)

2.1.1 Measures and Classes of Variability

In general, any form of variability is measured based on the standard deviation. However, the problem with this approach is that the standard deviation provides an *absolute* measure of variability, making it difficult to compare the degree of variability between processes in different contexts. For this reason, it is more appropriate to measure variability in relative terms. Specifically, we define the *coefficient of variation* of a random variable as:

$$\text{Coefficient of variation} = \text{CV} = \frac{\text{Standard deviation}}{\text{mean}} \tag{2.1}$$

Since both the standard deviation and the mean have the same measurement units, the coefficient of variation is a unitless measure.

Variability levels are defined according to the CV value as described in Table 2.1.

Table 2.1: Variability Classes (Adapted from Hopp and Spearman (2008))

Variability Class	**Coefficient of Variation**	**Typical Situation**
Low (LV)	$CV < 0.75$	Process times without outages
Moderate (MV)	$0.75 \leq CV < 1.33$	Process times with short adjustments
High (HV)	$CV \geq 1.33$	Process times with long outages

2.1.2 Processing Time Variability

The random variable of primary interest when analyzing the variability of manufacturing systems is the effective process time (EPT) of a job at a workstation. The concept of effective process time was first introduced by Hopp and Spearman (2008). They define the EPT as the time spent by a lot at a workstation from a logistical point of view, taking into account processing and waits, machine failures, setups, etc., as illustrated in Figure 2.2.

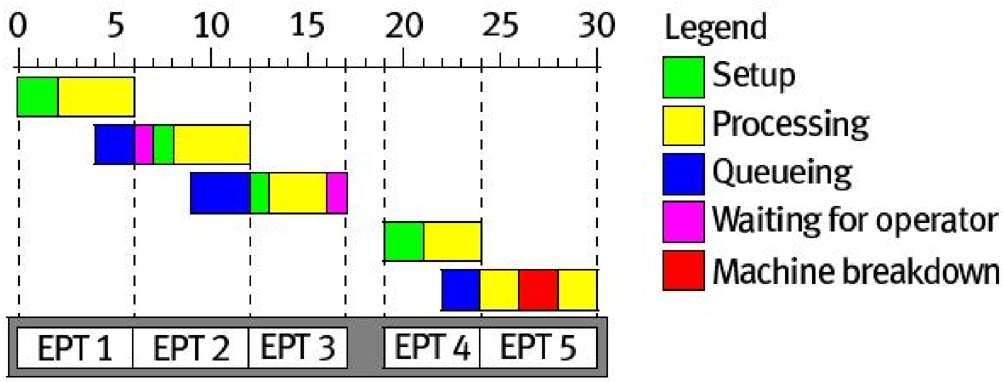

Figure 2.2: Concept of EPT (Kock, 2008)

Hopp and Spearman (2008) also identified and characterized the most prevalent sources of variability in manufacturing environments:

- **Natural Variability:** is the variability inherent in natural process time, which excludes random downtimes, setups, or any other external influences. Ideally, only random variation (or natural variability) should be present in a process, because it represents the acceptable amount of variation (in most systems, natural process times are LV and $CV < 0.75$). A process that is operating with only natural variability is said to be "in a state of statistical control" (Shewhart and Deming, 1986).

- **Variability from Preemptive Outages:** is the variability resulting from unscheduled downtimes, which can greatly inflate both the mean and the CV of effective process times, being considered by Hopp and Spearman (2008), in many systems, as the single largest cause of variability.

- **Variability from Non-preemptive Outages:** is the variability represented by predictable stoppages, that is, downtimes that "will inevitably occur but for which we have some control as to exactly when" (Hopp and Spearman, 2008). Setups, breaks, meetings and preventive maintenance are some examples of non-preemptive outages.

- **Variability from Rework:** is the variability arising from quality problems. Like setups, rework robs capacity and affects effective process times. Thus, the CV of effective process times increases as the fraction of rework increases, making it a disruptive problem indeed.

2.1.3 Effects of Variability on a Single Workstation

In the case of one single resource and one buffer with unlimited space (see Figure 2.3), the flow time of an unit in the system is equal to the time spent in the queue, plus the processing time, as described in Equation 2.2.

$$\text{Flow Time} = \text{Time in queue} + \text{Processing Time} \tag{2.2}$$

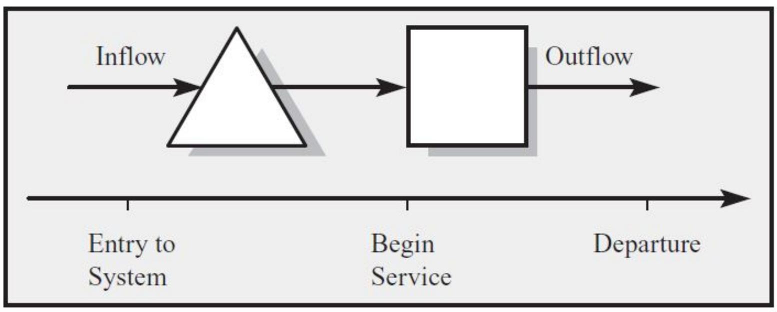

Figure 2.3: A simple process with one queue and one server (P. Cachon and Terwiesch, 2009).

As described by Kingsman's formula (Equation 2.3), the time in queue is the product of three factors: the first factor captures the amount of variability in the system, and the higher its value, the longest the time in queue is; the second factor represents the utilization effect. This factor is nonlinear and it moves towards infinity as the utilization level is increased closer to one; The last factor, is the effective production time. Although, as expected, flow time increases as the effective production time grows, it doesn't increase linearly as equation 2.3 suggests, since it also directly influences the utilization (Hopp and Spearman (2008) and P. Cachon and Terwiesch (2009)).

$$\text{Time in Queue} = \underbrace{(\frac{c_a^2 + c_e^2}{2})}_{\text{variability factor}} \times \underbrace{(\frac{u}{1-u})}_{\text{utilization factor}} \times \underbrace{t_e}_{\text{EPT factor}} \tag{2.3}$$

Where:

c_a^2, is the squared coefficient of variation of batch arrival

c_a^2, is the squared coefficient of variation

u, is coefficient of utilization

t_e, is the mean of effective processing time

Without variability and if utilization is below 100 percent, the time in queue will be zero and the flow time will be equal to the processing time. On the other hand, if the utilization is above 100 percent, naturally the queue will grow forever towards infinity, as there isn't sufficient capacity to meet the demand. In Figure 2.4 its possible to visualize the effects of both variability and utilization in cycle time.

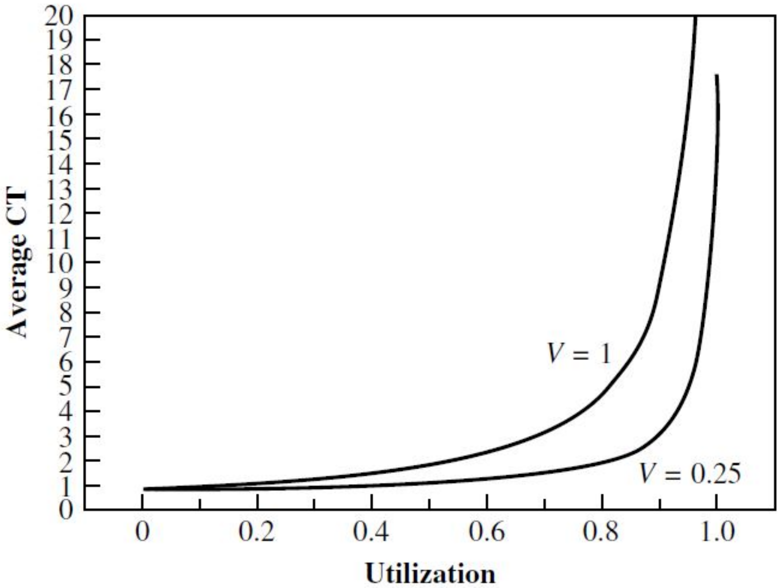

Figure 2.4: Relation between cycle time and utilization (Hopp and Spearman, 2008).

In the case of multiple workstations in line, its important to note that although variability effects look worse at downstream processes, as it is where all sources of variability are concentrated, they are more concerning at upstream processes, since variability effects propagate through the phases of the process (Hopp and Spearman, 2008).

2.1.4 Effects of Variability on Multiple Workstations

After analyzing waiting time in the presence of variability for an extremely simple process, consisting of just one buffer and one resource, is now analyzed a waiting time model of a process consisting of one waiting area (queue) and a process step performed by multiple, identical resources (see example in Figure 2.5).

For this situation, the utilization is directly influenced by the number of parallel workstations, as the capacity of the system is now the capacity of one workstation times the number of parallel workstations (assuming that all workstations have the same capacity), and thus, if the demand rate remains the same, reduces the utilization. The utilization for this case can be obtained by Equation 2.4.

$$\text{Utilization} = \frac{\text{Flow Rate}}{\text{Capacity}} = \frac{\text{Flow Rate}}{\text{(Number of Resources / Processing Time)}} \tag{2.4}$$

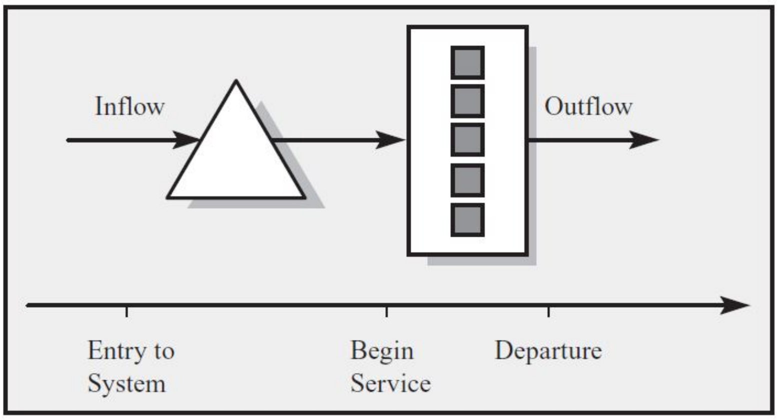

Figure 2.5: A process with one queue and five parallel servers (P. Cachon and Terwiesch, 2009).

Regarding flow time, the system behaves as before, the total flow time is the sum of waiting time and processing time (Equation 2.2), as described previously in Section 2.1.3.

As in the case of one single resource, the time in queue is expressed as the product of the processing time, a utilization factor, and a variability factor. Therefore, considering m as the number of parallel workstations available, the time in queue can be computed by Equation 2.5.

$$\text{Time in Queue} = (\frac{c_a^2 + c_e^2}{2}) \times (\frac{u^{\sqrt{2(m+1)}-1}}{1-u}) \times \frac{t_e}{m} \tag{2.5}$$

Where:

c_a^2, is the squared coefficient of variation of batch arrival

c_a^2, is the squared coefficient of variation

u, is coefficient of utilization

t_e, is the mean of effective processing time

m, is the number of resources available

Considering the systems represented in Figure 2.6, the following question arises: does pooling lead to lower average flow times?

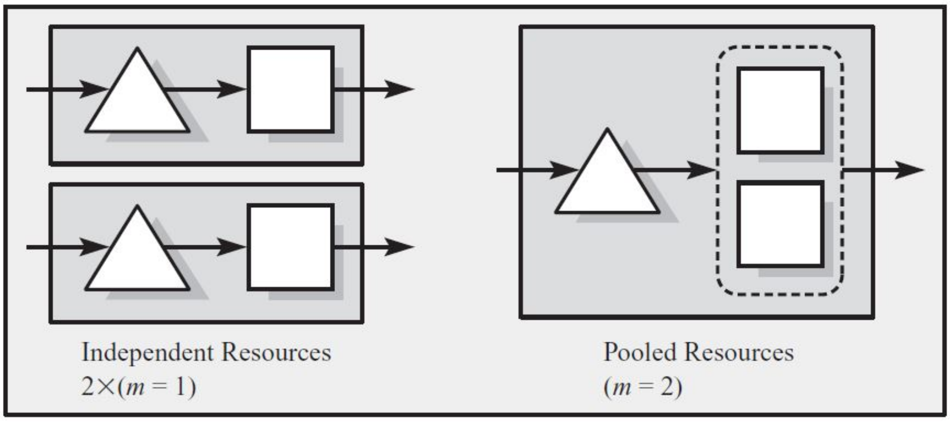

Figure 2.6: Concept of pooling (P. Cachon and Terwiesch, 2009).

According to Hopp and Spearman (2008) and P. Cachon and Terwiesch (2009), for a given level of utilization, the waiting time decreases with the number of servers in the resource pool, this being especially important for higher levels of utilization, as illustrated in Figure 2.7.

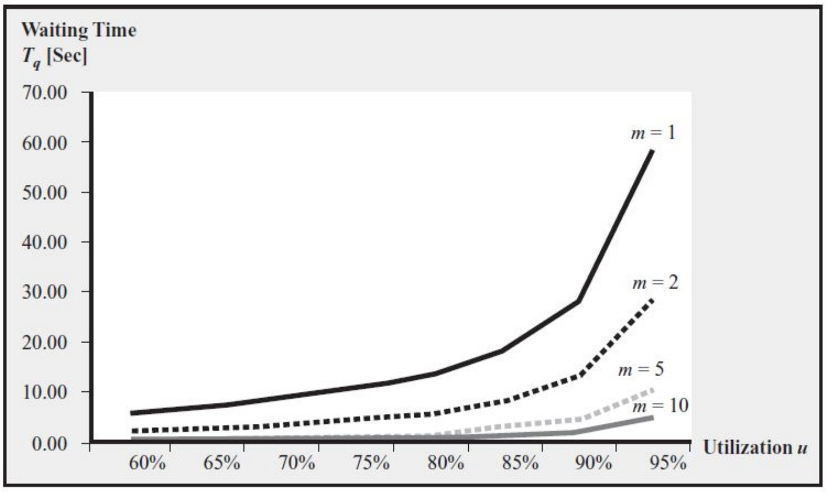

Figure 2.7: Effects of pooling on waiting time (P. Cachon and Terwiesch, 2009).

To sum up, if companies do not pay to reduce variability, they will pay in one or more of the following ways (Hopp and Spearman, 2008):

- Lost throughput
- Wasted capacity
- Inflated cycle times
- Larger inventory levels
- Long lead times and/or poor customer service

2.2 Product Segmentation

Nowadays, most industrial companies have a broad product range, being an example the company in study. In order to define better stock management, companies need to understand which products have the greatest impact in their strategy and which are of minor importance.

2.2.1 ABC Analysis

The Pareto Principle, named after economist Vilfredo Pareto, specifies that 80% of consequences come from 20% of the causes. Following this logic, in any set of products, approximately 20% of the items represent 80% of the total value. Based on this principle, the ABC analysis categorizes items into three different groups (A,B,C) under a defined criterion. The annual cost of consumption, the annual consumption, the average unitary cost or lead-time are some examples of criteria (Flores et al., 1992). The groups are defined as described in Table 2.2.

Table 2.2: ABC Categories (Crespo de Carvalho et al., 2010)

Category	Percentage of items	Percentage of total production
A	20	80
B	30	15
C	50	5

Once properly divided, each item should receive a treatment corresponding to its class: A-items should have tight inventory control, more secured storage areas and better sales forecasts; reorders should be frequent, with weekly or even daily reorder; avoiding stock-outs on A-items is a priority.As for B-items, they benefit from an intermediate status between A and C; an important aspect of class B is the monitoring of potential evolution toward class A or, in the contrary, toward the class C. Reordering C-items is made less frequently; a typical inventory policy for C-items consists of having only few units on hand, and of reordering only when an actual purchase is made; this approach leads to stock-out situation after each purchase which can be an acceptable situation, as the C-items present both low demand and higher risk of excessive inventory costs (Delić, 2013).

2.2.2 XYZ Analysis

The ABC analysis can be complemented with a XYZ classification that classifies the products according to demand fluctuation. This is done using the coefficient of variation (CV), that is given by equation 2.3. Afterwards, the groups are defined according to the CV value as described in Table 2.3.

Table 2.3: XYZ classification

Classification	Values	Description
X	$CV < 0.75$	Uniform demand, high predictability
Y	$0.75 \leq CV < 1.33$	Varying demand, medium predictability
Z	$CV \geq 1.33$	Abnormal demand, low predictability

The characteristics of the nine different material classes after combining the ABC-Analysis with the XYZ-Analysis are summarized in Table 2.4.

Table 2.4: ABC/XYZ Matrix (Adapted from Stojanović and Regodić (2017))

	A	B	C
X	high value, high predictability continuous demand	medium value, high predictability continuous demand	low value, high predictability continuous demand
Y	high value, medium predictability fluctuating demand	medium value, medium predictability fluctuating demand	low value, medium predictability fluctuating demand
Z	high value, low predictability irregular demand	medium value, low predictability irregular demand	low value, low predictability irregular demand

In addition to that, different inventory strategies are also identified. The matching target inventory levels are shown in Table 2.5.

Table 2.5: Safety stock in the Combined ABC-XYZ-Matrix

	A	B	C
X	low safety stock	low safety stock	low safety stock
Y	low safety stock	medium safety stock	medium safety stock
Z	medium safety stock	high safety stock	high safety stock

According to Dhoka (2013), a big challenge with XYZ classification is the total period for which the analysis should be done (yearly, weekly, daily, etc). Not only company's product portfolios are increasing, product life cycles are reducing meaning that a yearly or quarterly analysis wouldn't be very useful. Likewise, the total period of analysis shall be defined carefully, as the number of active items proportionally increases with time. Also, it has some shortcomings:

- New items frequently are classified as Z, as their demand patterns are not yet established. The easier way is to exclude all new items in the XYZ analysis, but if their contribution to inventory costs and sales percentages are significant, there must be ways of quantifying this volatility created by the new items;

- The XYZ analysis doesn't take into account benchmarks or industry standards, so, irrespective of type of industry, if 'X' category has significant variation in demand, it can affect overall inventory as it defines the predictability of the demand among the items;
- It can overlook seasonal items, so it's necessary to remove these items from the analysis.

ABC analysis helps set inventory management systems and processes based on the consumption value of stocked items. However, it takes no account of consumption volatility. So, by combining ABC with XYZ approaches, and understanding its shortcomings, stock management policies, systems and procedures can be better tailored by taking into account both demand volatility and consumption value.

2.3 Six Sigma and DMAIC Methodology

Over the last decades, the focus on quality improvement lead to the existence of several new methodologies, such as Statistical Process Control (SPC), Total Quality Management (TQM), Quality Management Systems (QMS) ISO 9000, Kaizen, and Six Sigma. Having in common the objective of reducing costs and enhance customer satisfaction, they differ essentially on their emphasis and tools (Dedhia, 2005).

2.3.1 What is Six Sigma?

Albeit several definitions can be found on literature review, Six Sigma, as defined by Pande et al. (2000) is "a comprehensive and flexible system for achieving, sustaining and maximizing business success. Six Sigma is uniquely driven by close understanding of customer needs, disciplined use of facts, data, and statistical analysis, and diligent attention to managing, improving, and reinventing business processes."

As a continuous improvement tool, Six Sigma aims to achieve maximum quality by reducing variability and consequently satisfy the customer. In fact, the sigma measures the variability or non-conformity of a process (a low sigma means low variability). Achieving a six sigma level means reducing the defect rate to 3.4 parts per million (PPM) or 3.4 defects per million opportunities (DPMO) (Pyzdek, 2003).

2.3.2 DMAIC Methodology

Six Sigma's most used methodology is the Define–Measure–Analyze–Improve–Control (DMAIC) problem-solving approach. DMAIC builds on three fundamental principles (Hambleton, 2007):

- Results-focused and driven by data, facts, and metrics;

- Project-based (short-term in nature, with length depending on scope and complexity);
- Inherent combination of tools-tasks-deliverables linkage that varies by step in the method.

The DMAIC methodology uses a process-step structure. The steps are usually sequential, however, it is possible for some activities to occur simultaneously in some steps or may be iterative. The DMAIC five steps are (Shankar, 2009):

- **Define**: At this stage of the project, the project manager prepares a team that includes members from different departments with whom the problem is related in some way. The team clearly defines the problem, quantifies its financial impact, a goal statement with the achievements to be done and definition of timeframes. It also defines the metric that allows quantifying the impact of the problem in the past, as well as documenting the observed improvements as the problem is solved.
- **Measure**: This phase is meant to quantify process variables through data collection from several sources. It's a transitional phase, as it serves to validate the problem and provide data to search for root causes. The team identifies potential causes for the problem using a wide variety of tools such as Pareto charts, histograms or scatter plots. The data collected at this stage is of particular importance since it is essential to substantiate future decisions.
- **Analyze**: At this stage of the problem the actual causes of the problem are determined. In order to get at the causes of the problem, a wide variety of statistical tools are used to test hypotheses and to test the process. As soon as the relationships between causes and effects are perceived, the team can determine how to best improve the process and what benefits these improvements can bring.
- **Improve**: It is at this stage that the necessary changes are implemented to promote an increase in the process performance. Using the metrics previously developed, the team monitors the process to verify the expected improvements.
- **Control**: At this stage the team selects and implements methods to control future process variation. These methods include documented procedures or methods of statistical process control. This step is vital to ensure that the same problem will not return in the future.

The main causes of failure in the implementation of Six Sigma are poor leadership, inadequate training, incorrect definition of objectives and goals, insufficient resources and the great complexity of the tool. The benefits described with the successful implementation of the methodology include improvement in the quality and capacity of processes, increasing productivity, and reducing costs and waste.

2.4 Lean Fundamentals

The evolution of the Lean Manufacturing philosophy was accompanied by enormous economic and social changes, leading to the widening of the scope of the philosophy beyond manufacturing processes. Womack and Jones (1996), after more than a decade studying the success of Japanese companies, coined the term Lean Thinking to refer to the evolution of Lean Manufacturing and the consideration of new concepts developed during the 1990s, considering it a philosophy of leadership and management, which aims to systematically eliminate waste and create value. Lean Thinking's growing popularity results from the recent slowdown in the world economy, leaving many companies struggling to survive (struggling in every way to reduce costs without penalizing quality and customer service).

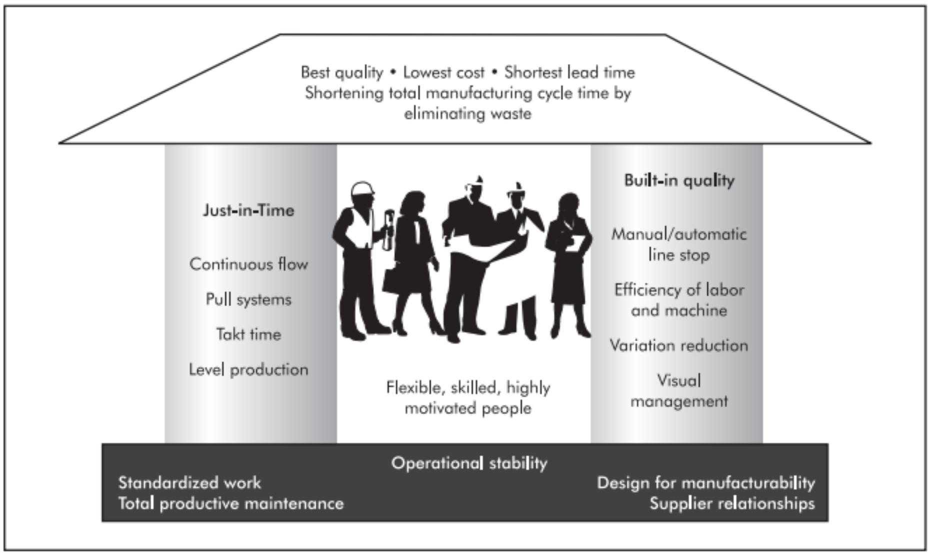

Figure 2.8: The house of lean (Allen and Robinson, 2001)

According to Pinto (2006), the Lean Thinking philosophy opens new windows of opportunity for organizations to adapt and develop in an increasingly complex and unstable world. This philosophy has reached a huge worldwide reputation, being applied in all areas of economic activity, and corroborated by the success of Toyota Motors Corporation, which, in 2007, dethroned General Motors from the top of the automobile industry which, since 1930, was classified as largest company in the sector.

2.4.1 Wastes

Lean Manufacturing is an initiative that seeks to eliminate waste, that is, to exclude what is of no value to the customer and to speed up the company's processes, thus reducing lead times. At the heart of Lean Manufacturing is the reduction of the seven types of waste (*muda* in Japanese) identified by Taiichi Ohno (1912-90) and Shigeo Shingo (1909-90) during the development of Toyota Production System (TPS), which are:

1. Defects - producing parts that fail to meet product specifications;
2. Waiting - people or operations waiting because of lack of material, equipment, or information;

3. Motion - the movement of material, equipment, or personnel that does not add value to the product;
4. Over-processing - performing operations not required to manufacture or assemble the product;
5. Over-production - making more product than the customer demands;
6. Inventory - excess raw material, work-in-process, or finished goods inventory; and
7. Inefficiency - people wasting time, efforts, or ideas, equipment waste in capacity, or using more material than is required to complete the job.

Although Taiichi Ohno initially identified only seven *mudas*, Liker (2003) later proposed adding an eighth: unused employee creativity, which is, losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to employees.

2.4.2 Lean Principles

From its initial development to the present day, the Lean Thinking philosophy has been evolving; however, the five principles identified by Womack and Jones (1996) continue to be considered and are as described in Figure 2.9.

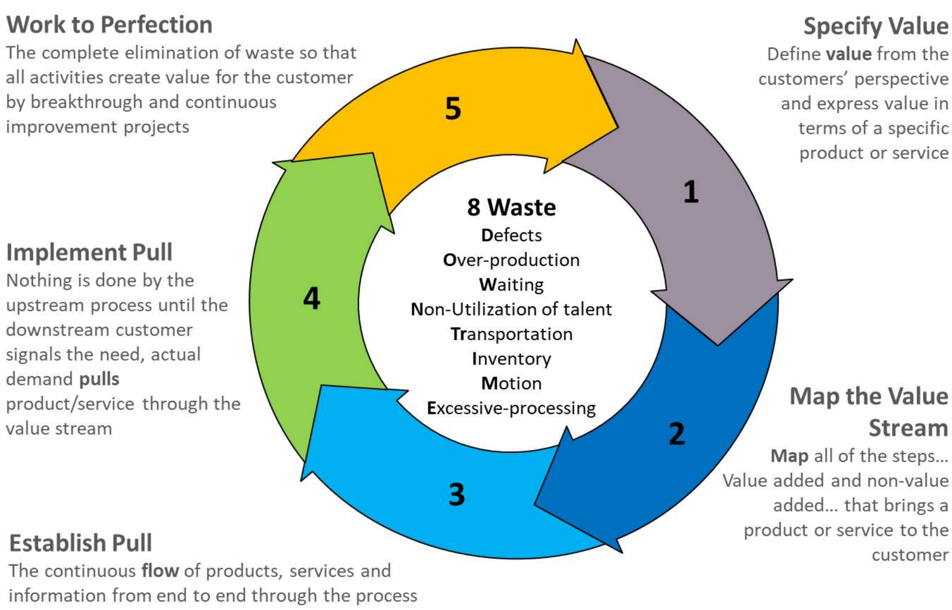

Figure 2.9: The five lean principles (Asia, 2019)

More recently, the Portuguese Lean Thinking Community, attentive to the radicalism carried out by some companies that implement this philosophy, proposed the introduction of two more principles. Pinto (2006) clarifies them:

- Know the stakeholder: a company must consider the interests of all parties, whether they are the workforce, the shareholders, the environment or the end customer;
- Always innovate: in order to create value, the organization should always seek to innovate in offering new products, services or processes.

2.4.3 Lean Tools

The Lean Manufacturing philosophy uses a number of tools that have been developed over the years that characterize *lean* thinking. These allow organizations to create bases for implementing and sustaining change. In this sense, the tools that were employed in the development of this project were the following:

Value Stream Mapping (VSM)

VSM is a feature widely used in Lean environments, both in industries and service companies, being an efficient and simple tool that contributes to detect waste and its origin. The map includes the flow of materials and information, helping to understand the current process state and the visualization of the future situation, focusing on the lead time of processes and reduction of operating costs.

Rother et al. (2003) segment this methodology into four phases: recognition of the product family (articles that present similar processes and use the same equipment); map of the current situation; map of the future situation; and work plan.

Visual Management

Much of the information that humans collect is through sight, making it crucial to have problems and processes visible.

Creating standards of how to perform certain tasks is the most efficient way to accomplish a task. However, in the first place, it is crucial to define the most efficient way to accomplish it. If a task is not normalized, it is prone to variability (Coimbra, 2013), and so, the visual aspect of the normative is also important. A standard based on intuitive photographs, drawings and visual signals, offers greater autonomy to employees in order to prevent errors and waste of time.

Visual management also involves other types of information such as charts, tables, lists and performance indicators so that everyone in the organization is continually focused on improving quality, reducing cost and lead time.

5S

The name "5S" comes from five Japanese words beginning with the letter S: *Seiri, Seiton, Seiso, Seiketsu and Shitsuke*, that, translated into English have the meaning of sort, set in order, shine, standardize and sustain, respectively. According to Hirano (1995) these are the five steps towards a good work place:

1. *Seiri* (sort): separation of unnecessary items in the daily activities of production and disposal. The immediate benefits are better space utilization, inventory control and cost reduction.

2. *Seiton* (set in order): creation of locations for all tools and their respective identifications so that when they are necessary they are easily found;. This phase will result in reduction of lead time and decrease of *muda* of movement, increasing productivity.

3. *Seiso* (shine): as a means of maintaining the workplace organized, the daily cleaning is essential. The team should also inspect equipment and machines regularly.

4. *Seiketsu* (standardize): standardization of good practices in order to maintain what has been achieved so far. This step usually includes the definition of a color-code and the display of standards in the workstations, visible to the whole organization;

5. *Shitsuke* (sustain): Ensure that the 5S philosophy is rooted in the organization and that the behaviors of continuous improvement have continuity. For this, it is important to train employees and perform audits regularly.

The arrangement and organization of workstations should be among the first steps that management should take to improve shop-floor operations. By implementing this type of philosophy in the workplace, it is possible to achieve increased productivity (as a good job organization reduces lead times) and the reduction of costs through a better use of materials and human resources.

Also, the 5S's are directly related to obtaining discipline in production. If, for example, production control, maintenance or quality control are not well executed, the problems will easily be related to a disorganized workplace. On the other hand, a tidy and organized workplace will result in better planning compliance, fewer machine failures, lower defect rates, and rapid identification of problem (Suzaki, 2010).

Standard Work

According to Taiichi Ohno (1912-90), "without standards there can be no improvement". Thus, standardizing work procedures must be a priority when it comes to reducing variability and implementing improvements.

The creation of work standards guarantees that a set of tasks is always carried out in the same way, allowing to level the knowledge of the team, establishing the best way to do a task and bringing an increase of the organization results. By definition, a standard work is the safest, simplest and most efficient way known to perform a task ensuring the best cost and quality (Imai, 2012).

In addition to the increased productivity and higher level of service resulting from adopting the best way to conduct a process, the following customers of this process are assured of the absence of errors due to the stability obtained. In companies where the processes are normalized there is a preservation of knowledge within the organization, creating documentation for training new employees, an increase in autonomy and polyvalence within the teams, and a basis for audits.

The five steps of the standard work improvement process are summarized in Figure 2.10.

Steps of the Standard Work Improvement Process	How They Are Achieved
1. Define the target for improvement.	Define the Cycle Time reduction target according to the needed *Takt* Time
2. Observe the work.	Observe carefully the movements of the operator and the time each movement takes. Observe carefully the following *muda*: • Non-value-added operator movements • Materials waiting between operations (WIP—work in process) • Quality defects and rework Observe carefully how abnormalities and difficulties are handled by the operator.
3. Improve the work.	Plan and implement improvement countermeasures to eliminate the various *muda*.
4. Standardize the work.	Standardize: • Operator movements • Cycle time • WIP Present the standard in a visual form: • Charts • Posters • Videos
5. Consolidate the work.	Maintain respect for the new standards by creating strong work habits supported by visual standards.

Figure 2.10: The standard work improvement process (Coimbra, 2013)

Chapter 3

Case Study

In this chapter the problem is presented in more detail. A description of the products and the production process is also presented to better understand the purpose of the study.

3.1 Characterization

The company in study is specialized in the design, manufacture and assembly of industrial and metalworking automation solutions, and operates in two main fields:

- Industrial automation: design, execution and assembly of industrial projects involving automation software, robotic solutions and electricity;
- Metalworking: design, production and assembly of mechanical components, especially stainless steel conveyors, palletizers, and accessories for the food industry;

Thus, it's important to distinguish between the two core businesses: product manufacturing and the design of industrial solutions.

Based on an Engineering-to-Order (ETO) approach, the design of industrial solutions or Special Projects (as termed by the company) are typically long-lasting projects since they are carried out from scratch in accordance with customer requirements and commonly involve several adjustments and testing.

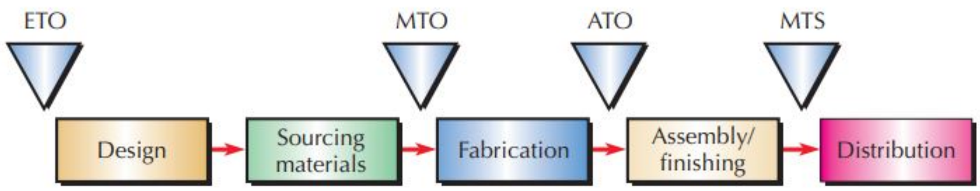

Figure 3.1: Production strategies in the supply chain (Bozarth and Handfield, 2015)

On the other hand, on a daily basis, the company manufactures and assembles parts for industrial conveyors, internally denominated as Standard Products. This set of products follows a hybrid production strategy, in a mix of Make-to-Stock (MTS) and Assembly-to-Order (ATO): products with higher manufacturing lead-times or higher supplier delivery times are manufactured and stored in a supermarket according to the *kanban* system. The other products, are assembled with the parts kept in stock, but only when there is an order confirmation.

Standard products are made either for a direct sale or for a project. In the first, the client purchases only the components separately; in the latter, the client purchases the components and the workforce to install them in their facilities. Although this type of products follow a more structured process, they are still quite complex products, since they have many components, undergo several operations and have a complicated assembly.

Figure 3.2 presents an example of a standard product and Appendix B schematizes an example of the assembling process of one of the simplest products.

Figure 3.2: Example of a standard product: wheel curve

All the standard products are divided by 9 families, according to their function: conveyors, wheel curves, switches, adjustable conveyor links, belt brakes, package traps, chain tensioners, transfer units and hose breaks.

Giving the administration's goals, this study regards only the production of standard products, its processes and how can they be improved.

3.2 Production Process

The production process consists of four main operations: cutting, fabrication, pre-assembly and assembly. Each operation has a specific location on the shop-floor, as shown in Figure 3.3.

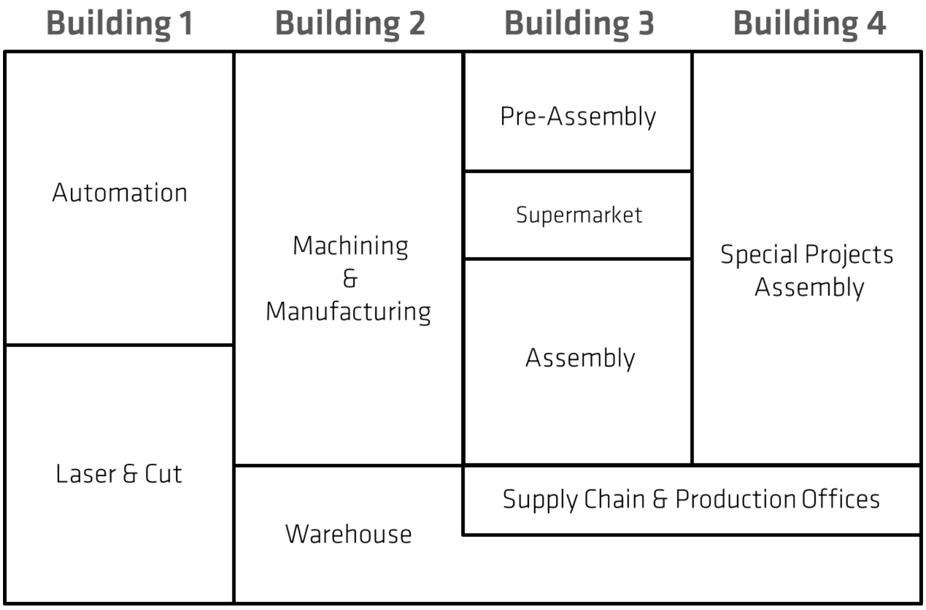

Figure 3.3: Shop-Floor Layout

Although all operations are well defined, the manufacture of a product does not necessarily include all operations and is, therefore, not a linear process. For example, a product may only need to be cut, its production process starting and ending in the cutting section; as the company operates under an ATO strategy, some products only need to be assembled, hence the production order (PO) is only for this operation. This feature is best understood in the Value Stream Map (VSM) shown in Figure 3.4.

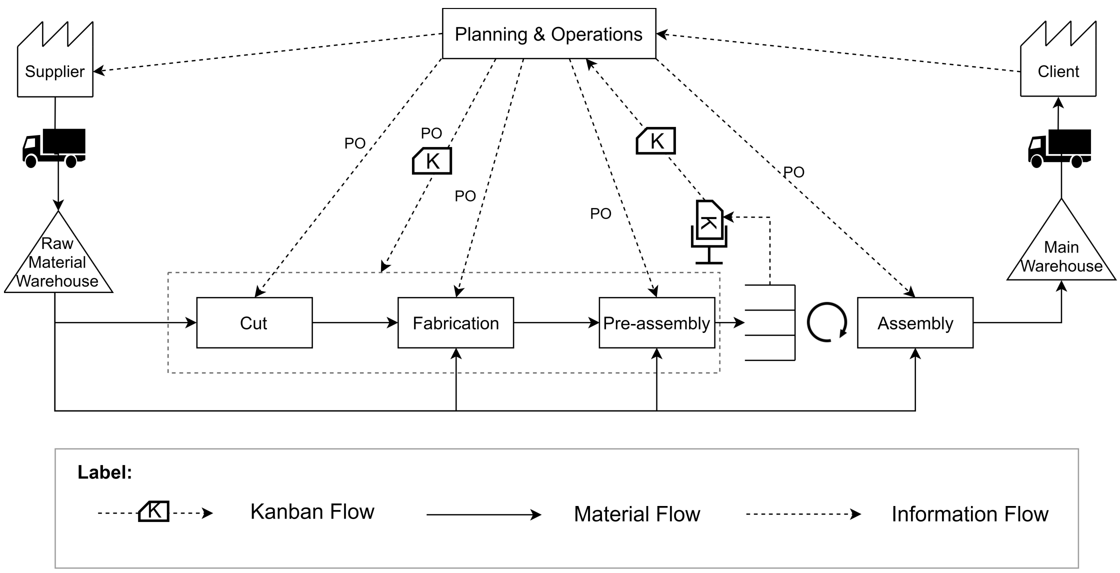

Figure 3.4: Standard Products VSM

The process starts when a PO is released. The PO can be either to cut, to fabricate, to pre-assemble or to assemble. A PO example can be observed in Appendix C.

As shown in the VSM, the process has a *Kanban* system. This system is used for parts that are commonly used in the assembly phase. *Kanban* cards are sent to planning once a minimal quantity of a part in the supermarket is reached, that then launches the PO to produce more parts. Finally, after going through the necessary processes, the parts are pre-assembled and stored in the supermarket, that then feeds the assembly workstations.

Although only the main warehouse and the supermarket are represented in the shop-floor layout, the material for each operation can come from four different warehouse types, with different functions, as described in the Table 3.1 and schematized in Figure 3.5.

Table 3.1: Types of warehouses

Warehouse Number	Designation	Main Functions
1	Main Warehouse	Storing raw materials and finished products
7	Border of Line	Storing small pieces in front of the operators in the work stations (screws and nuts, for example)
8	Supermarket	Store *Kanban* components
10	Shop-Floor	Store Work in Progress (WIP)

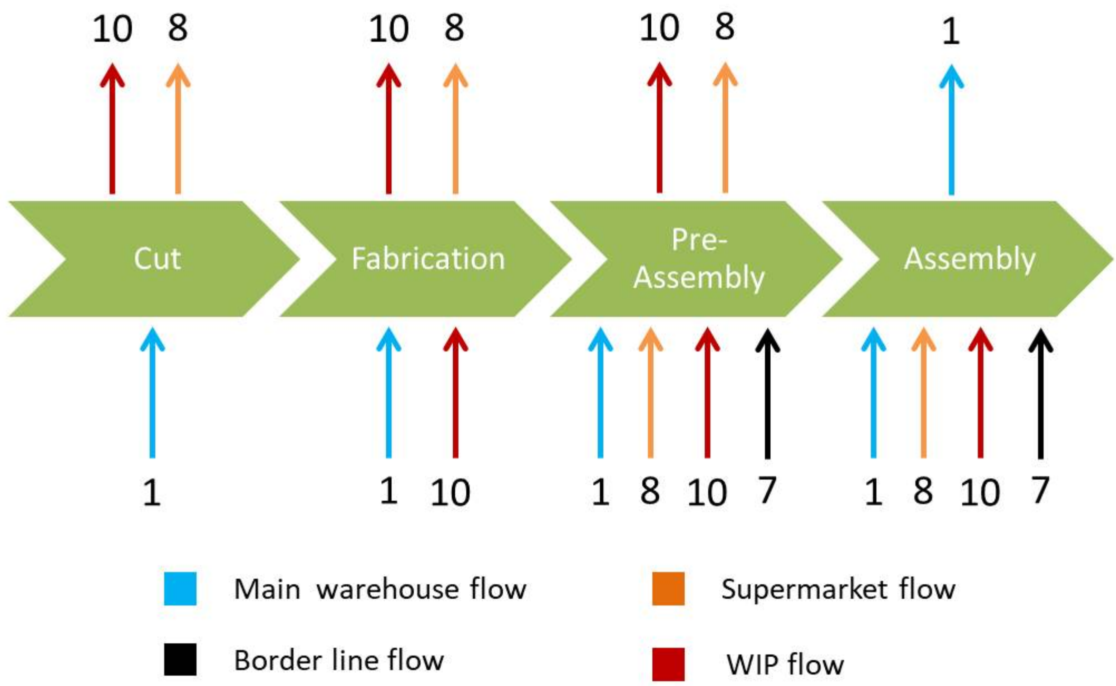

Figure 3.5: Warehouses flow

Each product (that has a unique reference code) has a defined bill of materials (BOM) that contains a list of all components needed, the order of the required operations and an estimation of production times. An example of a BOM can be found at Appendix D.

Because the understanding of the production process is crucial to the problem in study, each operation is detailed and a more complete description is given.

Cut

This section contemplates two main operations, two different types of cutting, depending on the type of part needed: steel sheets or pipes and rods.

Steel sheets are stored in a specific location in building 1. When there is a PO to cut, an operator gets the sheet with the thickness required and places it on the laser cutting machine. When the parts are done cutting, they go thought a sander machine, or, when they are too small, they are worked manually on a grinding wheel to soft the edges. It is important to note that the protective film of the parts is not withdrawn at any time, to avoid scratches when storing or transporting.

As for rods and pipes, the raw material needed is kept in the main warehouse, and when a PO is released is transferred to the workstation. There, it is cut on an industrial saw according to the requirements of the PO.

Once the ordered parts are produced (either sheets, pipes or rods), they are placed on a pallet to be transported by the logistic operator to the next destination.

In addition, it is important to note that also in this section (building 1) other operations are made, such as sliding profile cutting, pickling, countersinking and threading. This implies that certain parts go from cut to fabrication and return, since operations such as pickling or threading have to be made after operations such as bending, for example.

Fabrication

Fabrication includes four different operations: bending, milling, turning, and welding.

Due to the high number of different parts produced and all possible combinations of operations, this part of the process varies a lot, as there isn't a sequence of operations common to all. Nevertheless, in every workstation there's a specific place for products to be processed and for products already processed. These products are managed by the logistic operator, who's responsible for delivering the parts to the processing workstation and then take them to the next station.

Pre-assembly

In this section components of final products or products that are frequently produced are pre-assembled, and after are either stored in the supermarket or transferred directly to the assembly section.

Although similar to the assembly section, this section only concerns the assembly of small parts and simple operations, with the main purpose of feeding the supermarket, thus buffering the assembly section.

Assembly

The assembly section, as its name suggests, has the sole purpose of assembling final products. However simple as it may seem, it still is the most complex one.

When assembles are ordered, all the materials are placed on the material entrance side of the assembly stand. Afterwards, the operator opens the 3D model and the standard work of the product (if it exists) and starts the assembly. As soon as this is done, the operator cleans the product and waits for the assembly section responsible, who then inspects the products. If the products have no defects, the operator wraps them in cling film and places them in the finished products side of the workstation (normally a pallet) to be transferred to the warehouse by the logistic operator.

Each assembly stand in the assembly section is designed to assemble certain types of products: there are two assembly stands to assemble conveyors and adjustable conveyors, three for wheel curves, two for drive units and transfer units, two for switches, belt brakes, package traps, chain tensioners and hose breaks, and two for drive unit structures and lower drive units. Each assembly stand has only the tools needed to assemble the corresponding products, identified by colours and with an identified place for each tool. Also, there is a light code composed of three lights (blue, yellow, and red), with the intent to signal the situations described in Figure 3.6.

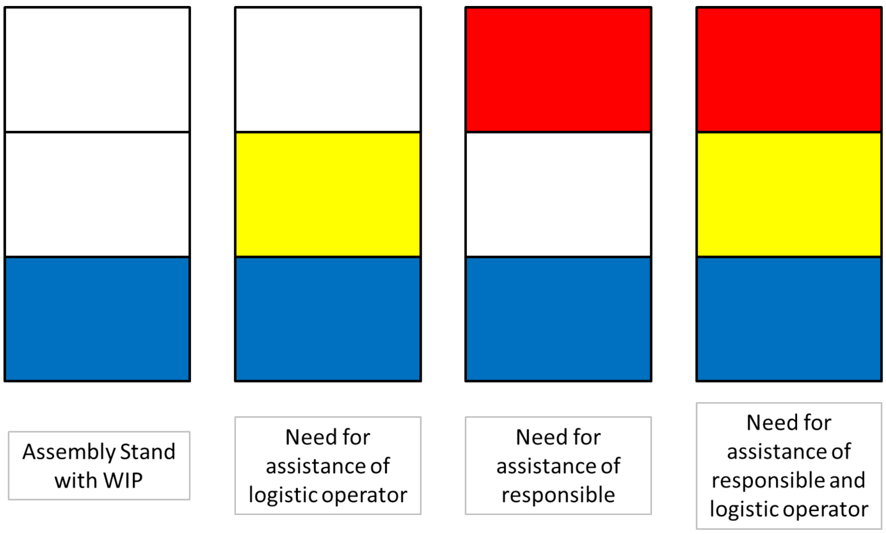

Figure 3.6: Light colour code

3.3 Problem Description

The company in question, due to the big portfolio of products it produces and their inherent complexity, needs to operate with above-average levels of flexibility in order to be able to manage the work in progress to satisfy new orders and still meet deadlines with other clients. Thus, to succeed, it is necessary to have a reliable definition of production lead-times, so production planning can assure the products being delivered on time. In order to achieve that, reducing variability is key.

This study investigates the reasons that cause production time variability, which consists in the difference between total production times of a product, since other sources of variability, such as the variability of total lead times, is dependent from many other variables (for example: number of special projects in parallel, deadlines of products, number of workers available) and can be mitigated with better planning.

In order to understand which products had the biggest impact on production and its demand patterns, an ABC/XYZ analysis (Appendix E) was made. This analysis considered the data for standard products which were both produced and ordered at least once, from the year prior to the beginning of this study. In total, 199 references were analyzed. References classified as A were identified (46 in total), and since tracking all would be unfeasible due to the short-term nature of the project, inputs from the administration and from more experienced workers were taken into account. References selected for production analysis are depicted on Table 3.2.

Table 3.2: References selected for production analysis

Reference [a]	**Product type**
A	Conveyor
B	Wheel Curve
C	Drive Unit

[a]For confidentiality reasons the real references are not mentioned.

Currently, production times are estimated and defined by the technical department when creating the BOM for a product. The company also has a computer system that allows the workers to register when they start and end an operation of a PO, so the production time of each operation is registered in the system. However, as the examples in Figure 3.7, Figure 3.8, Figure 3.9 show, there's high variability of production times registered in the system versus the time estimated.

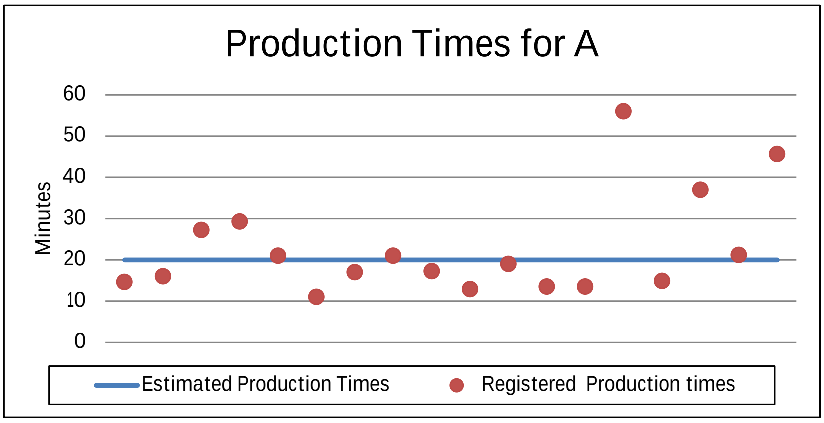

Figure 3.7: Production time variability of reference A (historical data)

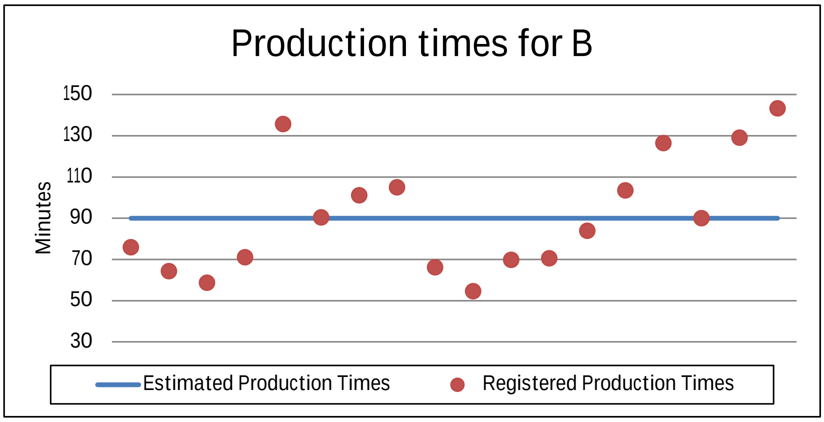

Figure 3.8: Production time variability of reference B (historical data)

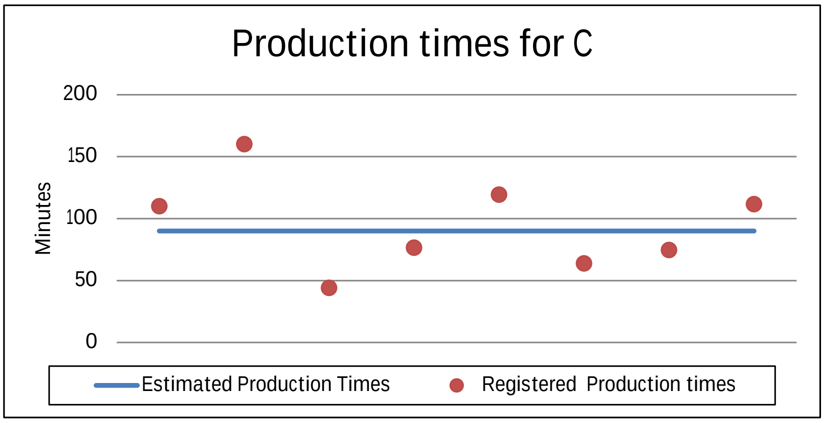

Figure 3.9: Production time variability of reference C (historical data)

This variability coupled with the need to also produce special products has a major impact on production planning, often leading to one of two situations:

1. The company is unable to meet deadlines;
2. Operators need to do extra hours to meet deadlines.

These two situations have a huge financial impact, either indirectly by causing dissatisfied customers and harming the reputation of the company, or by the increased cost of labor due to overtime.

Therefore, considering the impact of the problem on the company performance, the main objective of this study was to quantify the variability and identify its causes for the products with the most impact on the company production, followed by an improvement action plan and implementation.

3.4 Synthesis

This chapter provides a characterization of the company and the problem in study. Operating in the field of industrial automation, the products manufactured are of great complexity, as they go under several operations: cutting, bending, milling, turning, welding and assembling.

As the production process consists of several steps, the variability affecting the entire process easily increases, making it difficult to obtain correct production times and leading to extra costs.

The analysis of the production process and existent variability, as well as its causes, is presented on chapter 4.

Chapter 4

Variability Analysis

Understanding and quantifying the problem is critical in order to define the most appropriate improvement actions. For this, the logic of the DMAIC was followed, this chapter corresponding to the analysis and results obtained during the Measure and Analyze phases.

4.1 Demand Variability

Understanding how demand behaves is a critical factor for the company to define production strategies that better the company's performance, enabling cost reductions and ensuring that deadlines are met.

Although this type of variability is an external factor to the company, and therefore very difficult to act upon, it is very important to pay attention to its impact on the total variability.

In order to quantify and understand the behaviour of demand, a XYZ analysis was made. The analysis contemplated the weekly quantities produced of each final product reference related to the product families selected, over a period of 1 year prior to this study, presented in Figure 4.1.

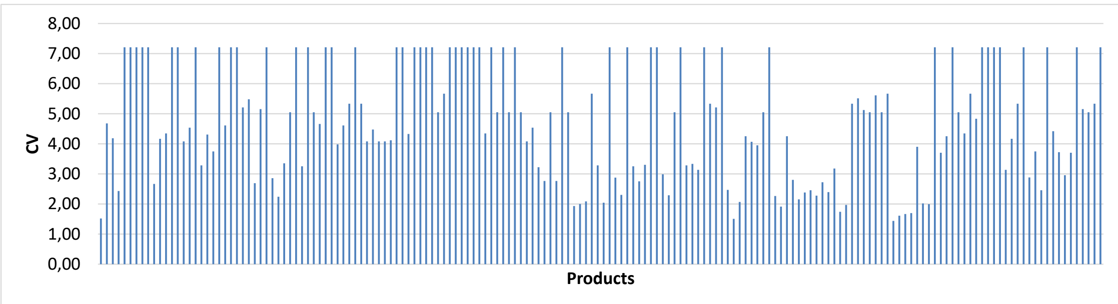

Figure 4.1: Coefficient of variation of demand for the selected products

As shown in the previous figure, all references in analysis (X-axis) have a significantly high coefficient of variability (Y-axis), thus all are classified as Z. This demonstrates the high variability and unpredictability of demand, making it impossible to make forecasts. Thus, this effect has to be amortized in another way, namely in the form of safety stock.

Taking into account the unpredictable nature of demand and hence the difficulty in acting against it, it is critical to minimize the variability of the process in order to reduce overall variability.

4.2 Lead-time Variability

Lead time is the latency between the initiation and execution of a process, which, in terms of work, is the total amount of time necessary to produce a specific product. As previously stated in chapter 3, the production process of the company in study was under high variability.

As stated before, POs were followed through direct observation, registering production times and occurrences that could lead to variability. Then, registered production times were compared with the ones estimated in the bill of materials and with the ones registered in the system and between each other.

Due to the high demand variability, the flexible nature of production planning and also because many assemblies take very long (more than one day), it was no feasible to do this procedure in all steps of the process, and so this procedure was only followed in the assembly process.

Since operators usually do a specific step of the assembly for several parts in row and do not process them one by one (for example, cleaning all pieces at the beginning instead of cleaning only the pieces needed for the assembly of an entire product), in order to measure production times, the total amount of time was registered, and it was divided by the quantity of parts assembled, thus obtaining the medium production time of a unit, with each PO representing one sample.

For the given reference of conveyors, the different production times per product are presented in Figure 4.2 (see Appendix F).

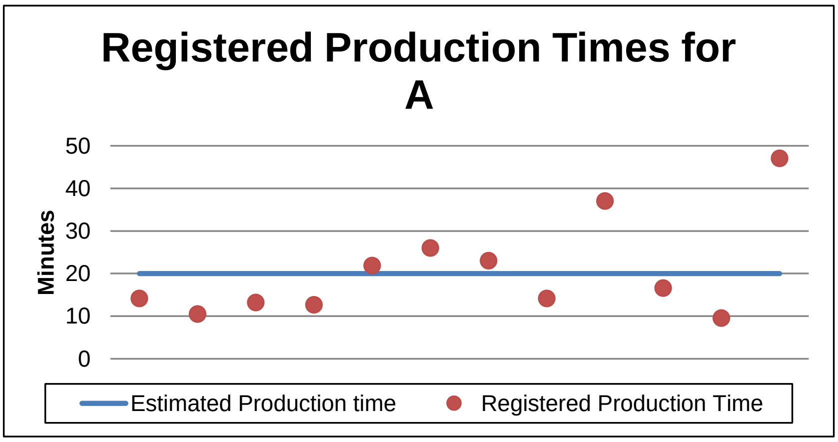

Figure 4.2: Registered assembly times per product of conveyor A

As can be seen, there is high variability present in the production times (the difference between the maximum and minimum values is 37.5 minutes/product) and a significant gap between the estimated and actual times (there is an average deviation of 43.4% from the estimated time). The calculated CV of these times is 0.56, confirming that there is significant variability in this process.

The same analysis was made for the other products followed and the conclusion was the same: there is significant variability in the assembly process, regardless of the assembled product.

Since, as stated in Section 2.1, variability effects propagate through the phases of a process, it is specially important to analyze the upstream processes in order to understand the variability present in the assembly section.

Due to the complexity and number of different operations that occur before the assembly, it was infeasible to measure times to quantify variability, as was done for the assembly. Therefore, in order to have a bigger sample encompassing the entire process, the intention was to analyze the historical data from the system. This was made intending to know if the process was under control, by building control charts.

The problem with this analysis was that, as shown in Appendix F, there was a significant difference between the real times and the times registered in the system, with deviations ranging from -62% to 37%. This problem was already identified by the managers, being the data unreliable for variability quantification.

Thereafter, a more empirical approach was taken, registering occurrences and spending a lot of time in the *gemba*. Occurrences observed and potential causes were summarized in a Ishikawa diagram, as represented in Figure 4.3.

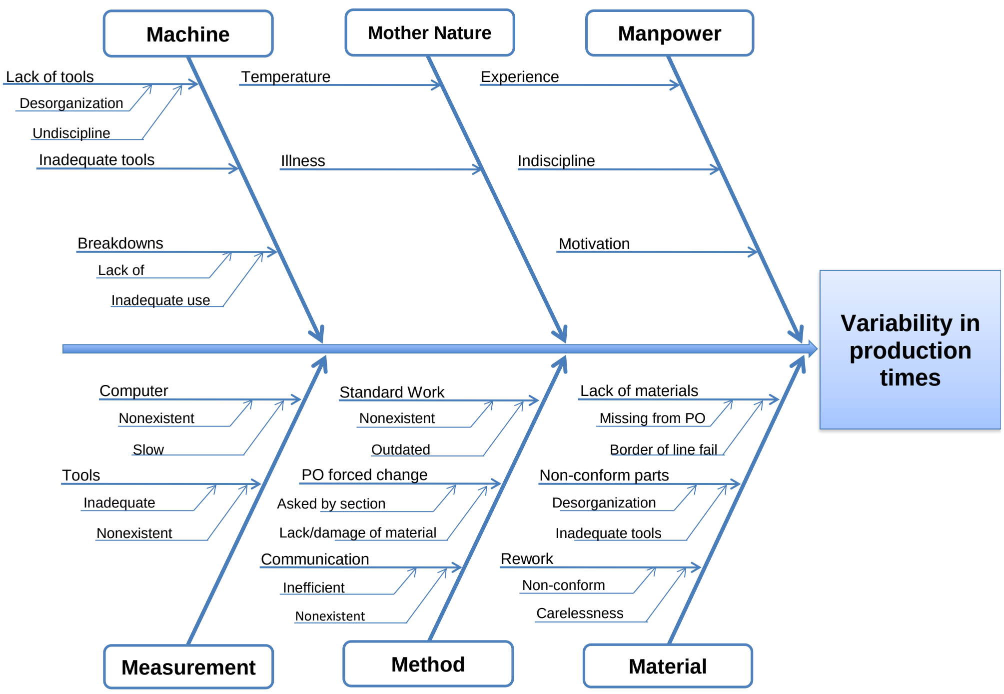

Figure 4.3: Ishikawa Diagram

4.2.1 Lack of Standardization

The first important observation was the clear lack standardization in the assembly process. Not only operators assemble the products in different ways (for example, some operators clean the parts as they need them, others clean all the parts at the beginning, some assemble one part at a time, others assemble multiple simultaneously etc.), but also the assembly *per se* is different, that is, products have various ways of assembling, and not all operators do it the same way.

In order to prove that this was indeed a cause for variability, the data collected was analyzed, but this time distinguishing between operators, as presented in Table 4.1.

Table 4.1: Registered times per operator

Operator	**Average assembly time**	**CV**	**Average deviation from estimated time**
1	13.52	0.13	-32%
2	23.6	0.31	18%
3	19.44	0.33	3%
4	31.65	0.29	58%

As expected, operators do have significant differences assembling the same products, showing a clear lack of standardization and the impact of the operators having different levels of experience.

Anyways, variability was still significantly present, even after distinguishing the times by operator. This was a problem already identified by the managers and confirmed while on the shop floor. Assembly times were being affected by failures which were not the responsibility of the operators, such as lack of materials or quality problems, which caused reworks, waits and stops.

These occurrences were already being registered by the operators on the assembly stations (see Appendix G) since the previous year of this study, thus making it possible to use the data to analyze the main causes of variation, resulting in the Pareto chart in figure 4.4.

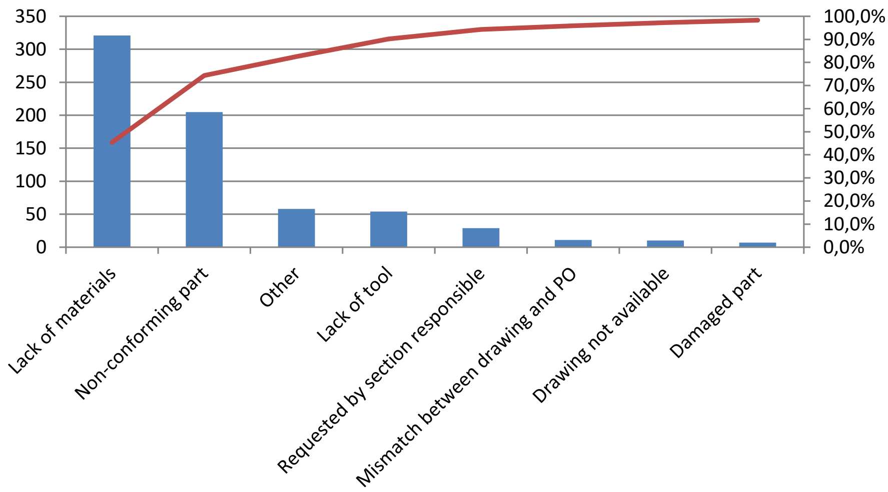

Figure 4.4: Pareto chart of variability causes

Therefore, the most critical to quality (CTQ) causes identified were the constant lack of materials and many non-conforming parts, representing about 80% of the occurrences registered.

In order to understand these problems, it was necessary to go deeper. Analyzing the data more thoroughly, it was possible to extract more specific information to the main problems identified.

4.2.2 Non-Conforming Parts

Concerning the non-conforming parts, the most common problems were identified, resulting in the Pareto chart in Figure 4.5.

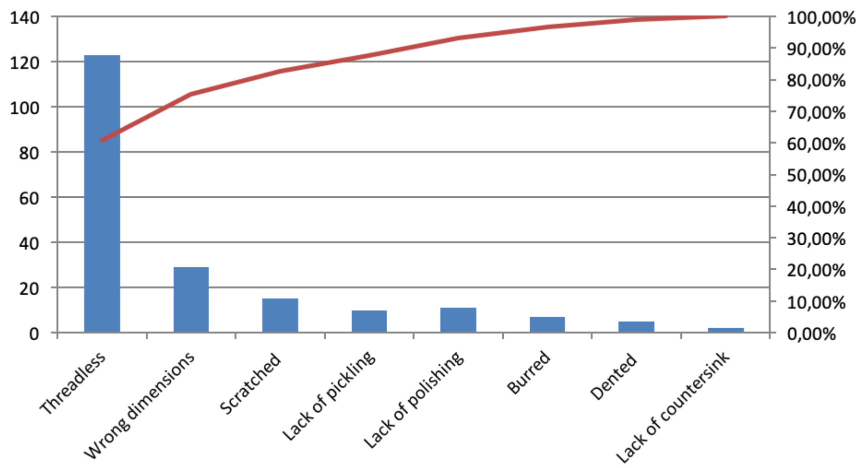

Figure 4.5: Pareto chart of quality problems

The most common quality problem identified was threadless (or with damaged thread) parts, representing more than 60% of the occurrences. To understand if there were parts in which this problem was more frequent, another analysis was made, resulting in the Pareto chart in Figure 4.6.

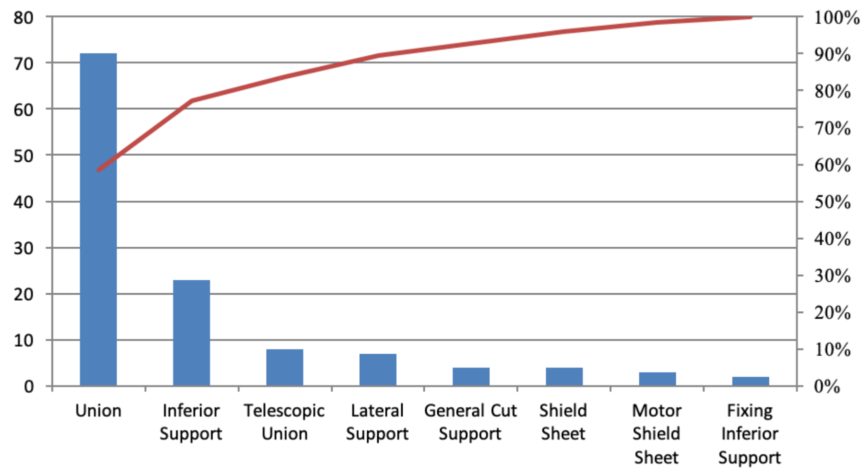

Figure 4.6: Pareto chart of most common threadless parts

As its possible to conclude, two products commonly cause problems: unions and inferior supports. This can be explained because unions are parts that are used in a wide variety of products, thus being frequently subject to the threading operation. The inferior supports, being big parts that were really hard to fix when threading (due to the lack of a proper fixing vise or jig), and being subject to pickling after the threading, where very susceptible to threading problems.

In Figure 4.7 its illustrated the threading and sinking workstation.

Figure 4.7: Threading and sinking workstation

In order to understand why there were so many threading quality problems reaching the assembly section, it was essential to analyze the threading workstation, located in the Laser & Cut section.

The immediate perception was the clear lack of organization and cleanliness of the workstation. The tools were unidentified, had no place of their own, and it was all dirty. Additionally, there were a lot of parts, namely jigs and tapping males, that nobody knew what they were for, even the section responsible, all spread in the table were the threading operation was made. Even more critical, was the condition of the vise used to hold the parts, which didn't hold the parts properly, meaning that operators had to use their hands to help fix the parts, and sometimes ask other operator for help.

After monitoring the threading process for some time, the problem of lack of standardization and visual supports was clear. Parts were threaded because operators *knew* they had to be threaded, most of them didn't have an indication in the BOM or PO. When it came to decide which tapping male they should use, again, the operators *knew* or had to ask the responsible.

Also, many times the tools needed weren't available, because either they weren't in the workstation or because they were hidden somewhere, making operators waste time looking or asking for them.

Additionally, the operation of threading itself, was consistently changing operators, as it was a relatively simple operation, that apparently anyone could do. Thus, when there were parts in need of threading, any operator who was available was assigned. Since there wasn't any visual support or information in the workstation, when an inexperienced operator was assigned, it had to look for the section responsible and ask for his assistance, making errors in the process.

4.2.3 Lack of Materials

Regarding failures in the internal logistics, namely lack of materials, the same logic was applied. To understand what were the most common fails in the supply of materials, a Pareto chart was made, represented in Figure 4.8.

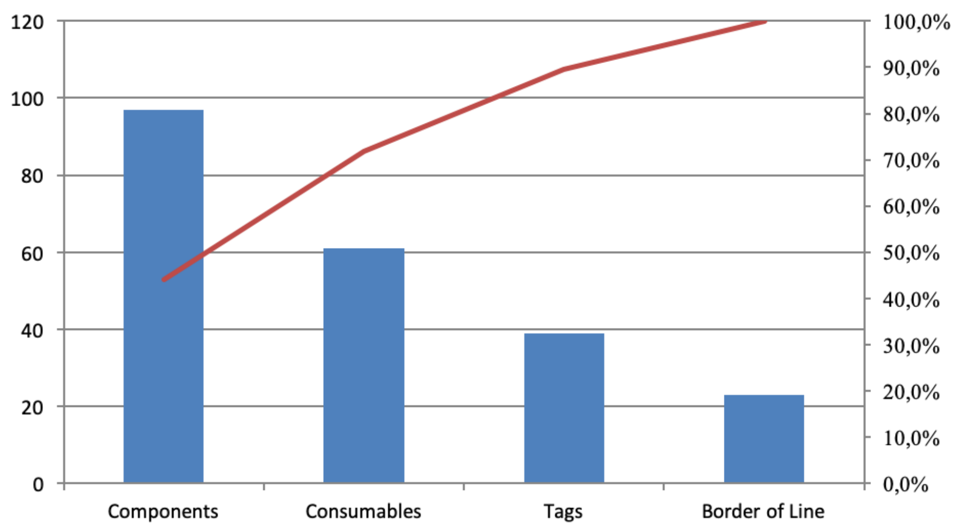

Figure 4.8: Pareto chart of most common fails in the supply of materials

While on the shop-floor, this problem was very noticeable, especially in the assembly section, where the logistics operator took, on average, 4.5 minutes to attend the operator in need. Typically, one of the following situations happened:

- Border of line failed;
- Incorrect separation of materials by the logistic operator, being detected during the PO;
- Lack of materials before a PO started.
- Waiting for identification and validation tags;

Regarding the first point, the border of line seemed to fail either because the logistics operator forgot about asking the warehouse to replenish the containers, or because, although having asked, it still wasn't replenished.

Anyways, it was noticed that the border of lines were failing very fast, not giving the warehouse or the logistics operator enough time to replenish them before failure, and thus making production stop. This was mainly because, as logistics operators thought the warehouse was going to take too long to replenish the containers, they simply took a full container from another workstation that wasn't in use, and replaced it with the empty container from the workstation in need. This obviously was causing early and unexpected fails in the border of lines, as when operators started using another workstation, it was possible that the border of lines would be empty, or with fewer parts.

The second point is a problem that occurred mainly because of the wrong definition or outdated bills of materials. This situation made the logistics operator wrongfully separate the materials, thus making production stop, because of lack of materials. Identification tags were a common problem related to this, as commonly the BOM had the quantities wrong or didn't refer them at all.

Also, there was the problem when materials where lacking before the PO had even started. This happened most of the time for three main reasons: either the warehouse didn't separate the material on time, the material hadn't arrive yet or the logistics operator made a mistake.

Lastly, in almost all POs time was wasted waiting for validation tags. These were provided by the section responsible after inspecting and validating the products. On average, the section responsible took 3 minutes to provide the tags. This happened because the responsible was in charge of other parallel projects in other buildings, thus not being available or in the assembly building all the time.

4.3 Non-Value Added Activities

While on the shop floor, it was noticed that there was a lot of wastes in the assembly process. Since the main goal of this study was to improve process performance, it was decided that this was a problem that needed to be addressed.

As so, it was compulsory to quantify the amount of waste in the process, i.e., the amount of NVA activities. .

Value Adding Activities (VA) are any activities that add value to the customer, that is, something the customer cares or would pay for. Non-Value added (NVA), on the other hand, represent incresed costs that the customer would not pay for and should therefore be eliminated. Activities that are necessary for future or subsequent steps, but still add no value to the customer, are called Business Value Added activities (BVA).

Activities like cleaning the workstation or making resgistrations in the software are some examples of BVA, and activities like talking, looking for tools or reworks were considered NVA.

In order to be able to quantify the activities, during one week several POs were followed up, and the times of each occurrence were recorded on an occurrences sheet (see Appendix H).

Subsequently, with the collected data it was possible to determine the weight of each occurrence and thus characterize the state of the process, being this analysis summarized in the pie chart in Figure 4.9.

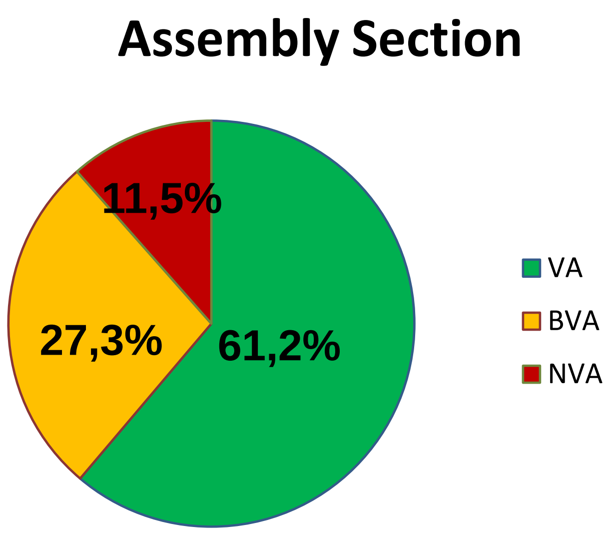

Figure 4.9: State of the assembly process

This analysis revealed the mediocre performance of the assembly section (only 61% of activities add value to the product), something that was already expected during the observation and monitoring of the POs.

Given this result, it was crucial to understand which activities were worsening the process performance, namely NVA activities, which must be eliminated, and also BVA, which may be targets for improvement and optimization.

For the purposes of analyzing these activities, Pareto Charts were made for NVA (Figure 4.10) and BVA (Figure 4.11).

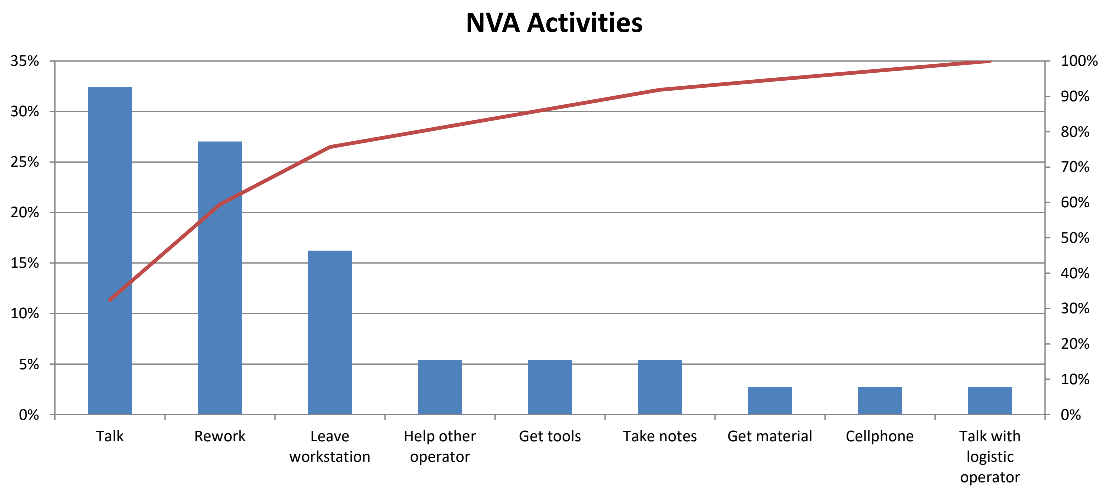

Figure 4.10: Pareto Chart of NVA activities

Regarding Non-Value Added activities, as expected, talking was a big issue, accounting for more than 30% of all NVA. Thus, its important to understand why it happens, because it can indicate other problems, such as insufficient instructions or even lack of work to do.

Additionally, a lot of movements were noticed, with operators frequently leaving their workstation, either to help other operators, get tools or perform reworks.

In the case of reworks (problem already addressed in Section 4.2.2) it was observed that operators performed operations done before on a constant basis, mainly because they were not done well at first or not done at all (for example, cleaning the parts after threading or the threading itself).

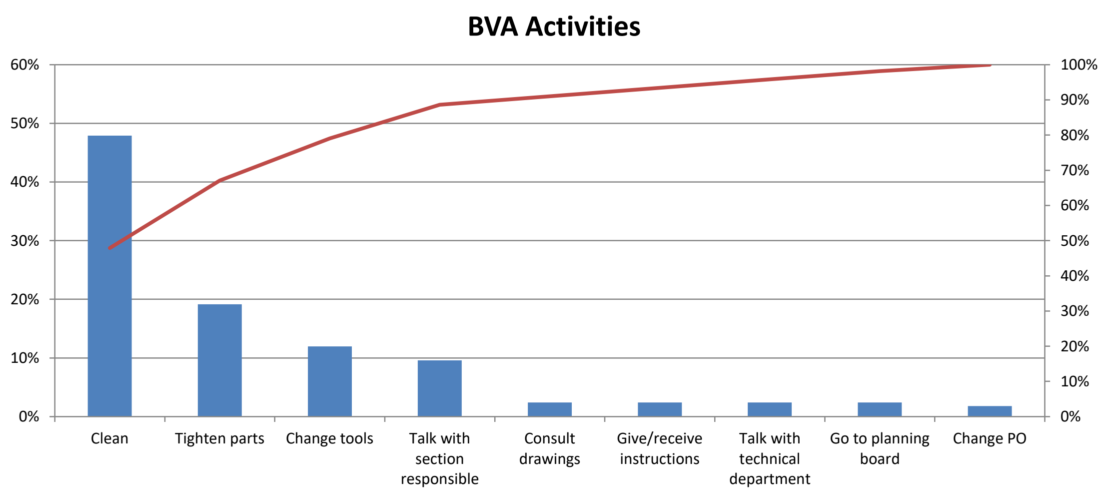

Figure 4.11: Pareto Chart of BVA activities

As for the Business-Value Added activities, three activities stand out: cleaning of the parts, tighten of the parts and the change of tools. Although all activities were essential to the process, it was identified room for improvement in the cleaning of the parts and the removal of protective film (which represented about 48% of BVA). In order to understand the weight of this activity in the process, a graph with all the activities and its weight was made, presented in Figure 4.12.

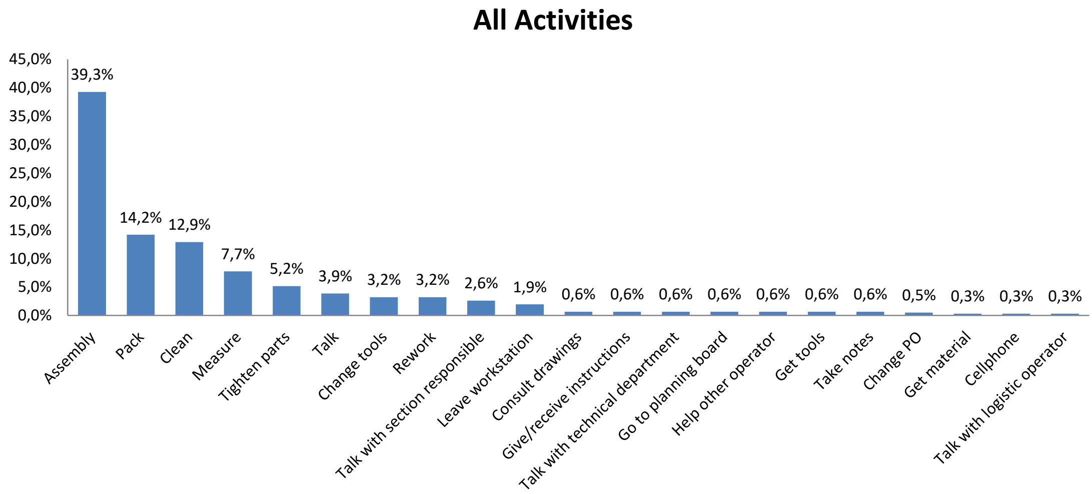

Figure 4.12: Weight of all activities in the assembly process

While on the shop-floor, it was clear that the removal of protective film and the cleaning of the parts was excessively time-consuming and uncomfortable for the operators, especially for an operation with little value added. This situation analogous to the packing of the products, which was also an operation that was clearly taking to long and was very uncomfortable for the operators, especially when it came to bigger products, as they were harder to handle, sometimes even requiring the help of another operator.

4.3.1 Main Causes of Waste

Giving the analysis of the process, the main question to be answered are:

- Why do the NVA activities with higher impact occur?
- Why does cleaning account for about 50% of all BVA?
- Why does the packing represent 14% of the process activities?

In order to answer these questions, the section responsible and the operators were questioned, and the problems identified were observed again. The main reasons identified were:

- Talking between operators in the assembly section occurs in three main occasions: when an operator finishes a PO, its required for him to go to the planning board (sometimes located more than 100 meters from its workstation). This makes talking very probable as operators pass by each other and feel the need to relax after a job is done. Another common situation is when there is the need of assistance of the logistic operator, who after providing assistance, stays for a little to talk. Finally, another big reason for talking is the need of instructions or help from another operator. This situation is common when operators are assembling new or uncommon products, or aren't familiar with the products.

- Reworks happen very frequently because of operations under performed in the steps before the assembly, namely the threading, the cleaning after the threading, the riveting and the cut of sliding profiles. The typical situation is as follows: operator is in the middle of the assembly of a product and notices a part is non-conform. He stops the operation, proceeds to remove the part (sometimes requiring to remove other parts) and analyzes if its possible to correct the situation by himself (although the rule defined by the management is to set the part aside and call the responsible). If its possible, he corrects the part and reassembles the product;

- The problem with reworks is that many times it creates other problems, above all operators leaving the workstations. This happens when operators need to perform operations that were incorrectly done before. For example, when parts are wrongly threaded, operators need to leave the workstation to get adequate tapping males, returning them afterwards, or when sliding profiles aren't riveted they need to get or ask for the riveting machine, which is located in another section, returning it afterwards, or also when the sliding profiles aren't cut correctly, they need to use a machine located in building two, causing lots of movement wastes;

- The cleaning of the parts is a problem that depends on the supplier of the metal sheets, as some, after the laser cut, make the protective film really hard to remove. Additionally, the cleaning of some parts is repeated several times along the process, for example, some parts are pre-assembled and thus cleaned there. Afterwards, these same parts are used in another assemble, and thus cleaned again. Finally, they are used in the final assembly, and cleaned for the third time, which makes the 2 previous cleanings irrelevant;

- The packing of the products is made with adherent paper rolls, making it really time-consuming and physically intense for the operators, especially with big parts. This problem already has a solution inside the factory, which is a semi-automatic packing machine, which requires just the operator to hold and move the part while the machine rolls the adherent paper around it. The problem is that the machine isn't being used, either because the section responsible thinks it isn't efficient (the machine is located in the middle of the building, thus making the need for operators to move there and risking conversations), or because it requires the help of another operator when packing bigger parts.

4.4 Synthesis

In this chapter, an in-depth analysis of the production process was carried out, with the aim of quantifying the variability and identifying its main causes. Either through direct observation or through quantitative data, several problems were identified, and since all of them contribute, directly or indirectly, to the existence of variability, all needed to be addressed.

The main causes identified were the constant lack of materials, a high number of quality problems, that lead to reworks, and the clear lack of standardization. Additionally, after analyzing the state of the process, it was possible to identify why it was having a mediocre performance (only 61% of Value-Added activities): frequent conversations between operators, multiple repeated operations along the process and excessive time spent in the cleaning and packing of the products are some of the wastes identified.

In Chapter 5 an action plan is presented in order to solve or improve the problems identified, as well as the improvements implemented during the course of this study.

Chapter 5

Improvement Actions

After the process was measured and the improvement opportunities identified, it was necessary that they be implemented. Thus, according to the Improve and Control phases of the DMAIC methodology, an action plan was developed in order to improve the process and to involve all the participants in the dynamics of improvement, as well as ensuring that the improvements implemented are sustained.

This chapter summarizes the problems addressed, the improvement plan and the improvements implemented.

5.1 Problems Addressed

The analysis done in Chapter 4 resulted in 11 main problems identified, presented in Table 5.1 (the problems presented are not ranked according to their impact).

Table 5.1: Problems targeted for improvement

#	**Problems**
1	Operators leave their workstation to use computers
2	Operators leave their workstation to look for tools
3	Operators leave their workstation to help other operators
4	High number of non-conforming parts
5	Too much time invested in low added value activities
6	Incorrect registration of times in the system
7	Indiscipline and felling of disconnection with the problems on the shop-floor
8	Nonexistent or outdated standard work
9	Great deviations of production times relatively to the BOM and between operators
10	Too much time waiting for logistics operator when needed
11	Frequent lack of materials during operations

5.2 Improvement Plan

After identifying the problems to be addressed, the first step was to schedule a meeting with each section responsible and with some of the managers in order to discuss these problems and to brainstorm possible causes and solutions. This session resulted in a facts-causes-solutions analysis, presented in Appendix I.

After this meeting, an improvement plan was elaborated (see Appendix J), having been assigned a responsible for each proposed action and a date of conclusion defined. Additionally, all the steps required to achieve the major actions were defined, and represented in a Gantt Diagram.

Due to the short term nature of this study, only a small number of actions were implemented, namely the ones with a short execution time and easy implementation.

The actions implemented are presented in Section 5.3.

5.3 Improvements Implemented

5.3.1 Packing Procedure

As described before in Chapter 4, when operators finish assembling a product, they need to wrap it with adherent paper, in order to prevent it from getting damaged or scratched.

Although the company owns a semi-automatic packing machine, it is not used. The reason for this is that the section responsible thinks that it is not efficient, arguing that the time gained by the faster packing does not compensate for the time wasted walking and transporting the products to the machine (since it is in the middle of the assembly building). In addition, he states that for larger products (where the time saved packing in the machine is greater), two operators are required to handle the products.

In order to verify if what the responsible claimed was actually true, operators were asked to pack the same product several times manually, measuring the time taken to do so. Afterwards, the same thing was done for the packing in the machine, including the time spent transporting the parts to the machine.

In Table 5.2 the times spent in both situations (for 11 parts) are summarized.

Table 5.2: Packing times

	Manually	**With semi-automatic machine**
Time spent packing (min/part)	5.67	2.49
Time spent in movements (min)	-	1.54
Time spent in movements (min/part)	-	0.14
Total (min/part)	5.67	2.63

This analysis revealed that packing using the machine was clearly advantageous, representing a time saving of approximately 54%, as well as a significant increase in comfort, according to operators. Even for the case of packing just one part, the time spent packing in the machine is lower (-29%), but for this situation it might not be advantageous as the movement to the machine presents a risk of losing time to other situations (talking with other operators, for example). So, in order to maximize the time savings, operators should assemble as many parts as possible, and then take them all simultaneously to the semi-automatic packing machine.

Although it was clearly advantageous in terms of time savings to pack with the machine, there was the problem that, for larger products, two operators were required.

The solution for this was the positioning of two support easels next to the machine, as shown in Figure 5.1, solution that proved to be very effective.

Figure 5.1: Semi-automatic packing machine with two support easels

5.3.2 Threading Section

As shown in Section 4.2.2, the overwhelming majority (60%) of quality problems arise from threading. Not only this represents a quality issue, but it also generates other problems, such as reworks, which may generate movements, which in turn can generate conversations, which in turn generates tremendous amounts of variability.

This, of course, make the threading section a clear and urgent target for improvement. After analyzing the workstation (Figure 4.7), the following situations were clear: there was lack of visual standards, no standard work, disorganization, and some tools were inadequate.

In order to address these problems, it was decided to implement the 5s methodology in the section, as well as the creation of a standard work.

The first step was to define a team for the improvement action, made up of the section responsible and the operators. In order to make everyone in the company aware of the problem and that an action was being taken, an A3 was made and placed in the visual board (see Appendix K).

Afterwards, a standard work procedure was created for the threading process, involving both the operators and the section responsible in its design (see Appendix L).

In Figure 5.2 is presented the algorithm for the new threading process.

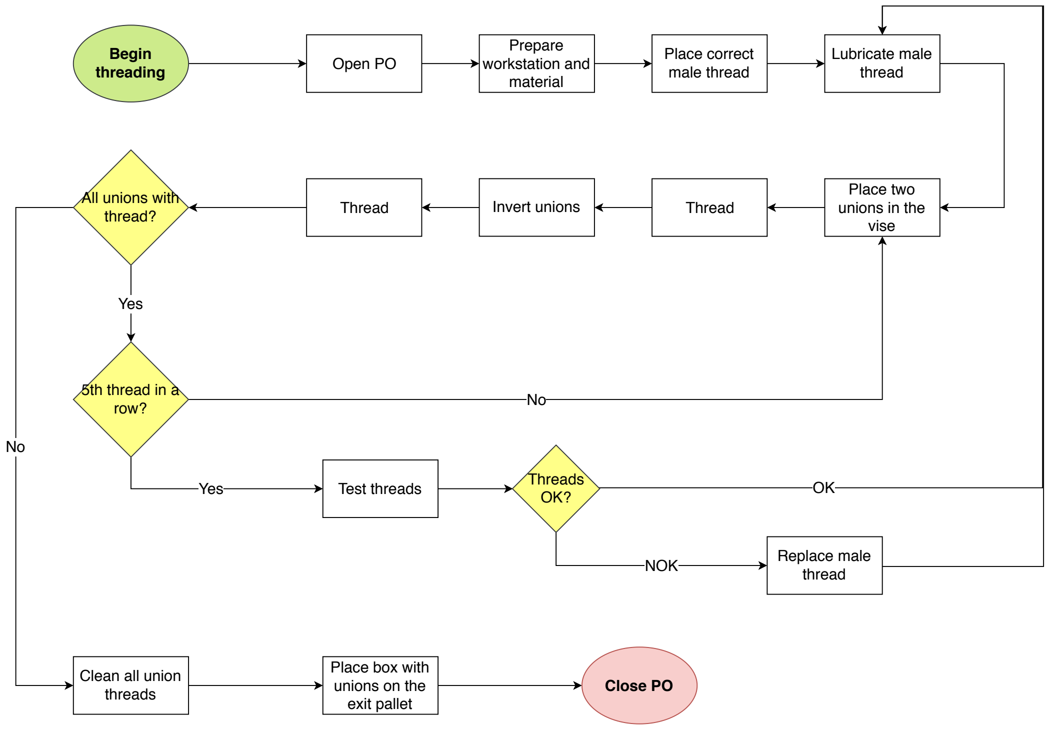

Figure 5.2: New threading process algorithm

After creating the standard work, followed the implementation of the 5s methodology in the workstation. First, the tools needed to execute the operations were identified, and the useless ones were removed. Afterwards, the condition of the tools was verified, and if they were inadequate, it was requested to purchase new ones to replace them. When all tools needed were acquired, it were created locations for all of them and their respective identifications, so that when they were needed they were easily found and reached. Safety information was also placed in the threading machine, as well as visual aids to help with the flow of pallets and parts. Additionally, the standard work, maintenance instructions and other important information were affixed in a visual board placed in the workstation, easily visible to operators. Finally, in order to guarantee the sustainability of the 5s, a 5s audit sheet (see Appendix M) was created, and monthly audits were scheduled, as well as a daily cleaning routine.

When everything was implemented, a new A3 was made and placed in the visual board, displaying the before and after situation in the workstation (see Appendix N).
Although no quantitative data was collected in order to understand if the improvements implemented had impact in the reduction of quality problems, the feedback from the operators using the workstation was very positive: they considered their work easier to do, more organized, felt more comfortable doing it and less prone to make mistakes.

5.3.3 Lack of Materials

Regarding lack of materials, three small actions were implemented: implementation of a visual management board in the automation section, increase the size of the border of line and inclusion of identification tags in the BOM.

The automation section, normally composed by just one operator, was managed by the Machining & Manufacturing section responsible. Since there was no visual management board in this section, POs were started and closed by word of mouth. This was a problem to the internal logistics and warehouse, as not knowing which POs were going to start or which ones were in course, couldn't anticipate the need of materials without having to look for the section responsible to ask.

Thus, in order to facilitate the management of the work by the section responsible and to make the information more visible to all stakeholders, a visual management board was implemented, as shown in Figure 5.3.

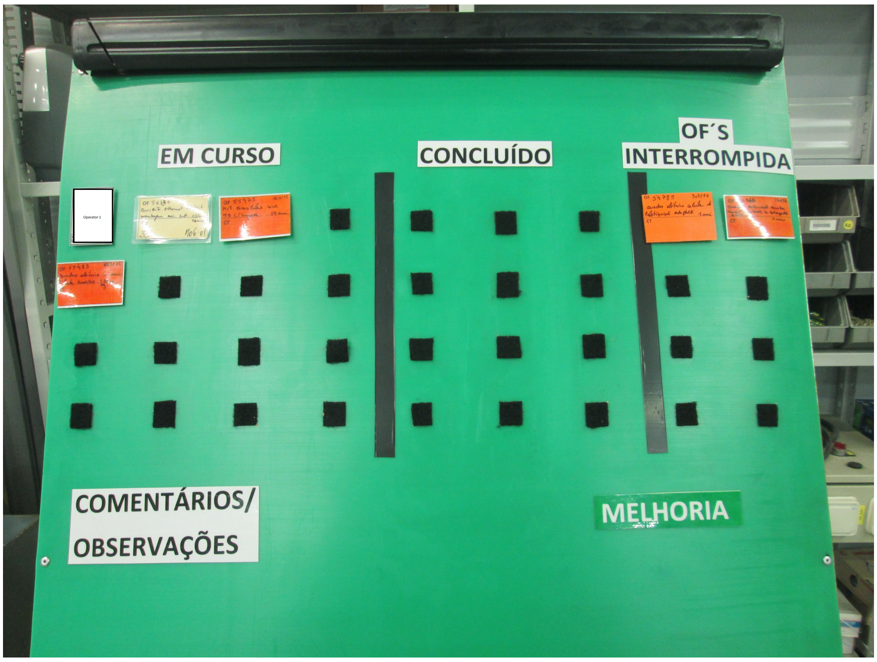

Figure 5.3: Automation section visual management board

This action proved to be very helpful, as logistics operators stated that their work was much easier to do, as they knew in advance what would be needed. The section responsible also referred the same, that his job was simplified and more organized.

Regarding the problem of constant lack of identification tags, it was found that it was caused because either they weren't listed in the BOM or their quantities were wrong. The solution for this, was simple. Include in all BOMs the number of identification tags needed, being the logistic operator responsible for printing them and deliver when a PO starts, together with the rest of the materials needed. This measure started being applied every time a wrong BOM was encountered, being its alteration immediately requested.

As for the border of lines, it was noted that the containers had the capacity to hold almost three times the capacity being used. Since these were failing on a daily basis, it was decided that, instead of filling a specific number of parts per container, instead it would be filled to the maximum capacity, thus giving more time for both the warehouse and the logistic operator to refill the containers.

5.4 Synthesis

In this chapter the problems targeted for improvement are summarized, as well as the improvement plan defined to approach them.

Finally, the improvements implemented are presented, as well the benefits obtained through their implementation.

Chapter 6

Conclusions and Future Works

The present dissertation is part of a project of continuous improvement, framed in a strategy of growth and future expansion. The main goal was to achieve the stabilization of the production process. The approach to this problem was based on the DMAIC methodology, aiming to identify variability causes, quantify waste and its contribution to variability, as well as analyzing the state of the process. Finally, it was defined and implemented an improvement plan, in order to ensure the minimization and control of variability.

6.1 Main Conclusions

Demand variability was analyzed, being the main conclusion that it behaves in an unforeseeable way (CV of all products was significantly higher than 1), thus affecting tremendously the production planning and generating the need of safety stock.

Due to the complex nature of the company products, the assembly process is especially vulnerable to variability. After analyzing the process, it was concluded that it was out of control, with significant variability present.

As for lead-time variability, the main root causes identified were related to lack of standardization, lack of materials, and quality problems. With respect to the first, it was shown that not only there was significant inter-operators variability (CV of 0.56), but also intra-operators (average CV of 0.3). This was proven while on the shop-floor, as it was observed that operators assembled the products in different ways. Regarding lack of materials, it was the most registered occurrence, accounting for about 50% of all occurrences. As for quality problems, they represented about 30% of all occurrences, with threading problems being the most common (60% of quality problems).

An analysis of the state of the assembly process revealed a poor performance, as only about 60% of activities were adding value. Talking, rework and movements where the main causes of waste identified, often being interconnected, as rework generate movements, and movements fancy conversations. Furthermore, cleaning and packing activities were found to take too much effort and time, accounting for about 27% of assembly activities. Although there was equipment available capable of facilitating and drastically reducing the packing time, it was not being used, making packaging difficult, especially for larger parts. As for cleaning, in addition to being a very time-consuming process, it was very dependent on the supplier of metal sheets, as it influenced a lot the quality of the laser cut. Some metal sheets, after being laser cut, left a lot of dirt melted in the part, making it really hard for the operator to remove it. Additionally, it was a process repeated multiple times throughout the process, thus representing, except if made in the final assembly stage, a useless and valueless activity.

Regarding the registration system, it was found that it was unreliable, as times measured weren't coincident with times registered, with differences ranging from -62% to 37%. This makes it difficult to define the lead-times and to estimate the production capacity, as well as making it impossible to use the potential of statistical analysis to control and analyze the process.

After analyzing the whole process in depth and drawing all the conclusions, an improvement plan was designed, with some of the actions being implemented during the course of this study. The main immediate gains were in terms of organization, standardization and time reduction (50% reduction in the packing time), as well as the creation of foundations to continuously improve the processes, namely in the correct definition of the BOMs.

6.2 Future Works

From the conclusions drawn from the project, future work opportunities are vast, as an extensive analysis of the production process was made and an improvement plan designed. Since most of the improvements proposed couldn't be implemented, they should be implemented as soon as possible.

Additionally, the improvements implemented should be monitored to ensure their sustainability and evaluated to better study their real impact, in order to determine whether they should be done in an analogous way in other sections of the factory.

In a long-term perspective, a systematic method of process-state analysis should be implemented, particularly through dynamic key performance indicators (KPIs). One of these KPIs should be able to measure the variability of the process in real-time, for example through the registrations in the information system, indicating if it was in control. This could be applied to every workstation, in order to get more detailed information about the variability on the shop-floor, making it easier to approach the problem and implement improvements.

In addition, an economic study of the hypothesis of acquiring a laser cutting machine also capable of tapping and countersinking, among other operations, should be done, as it could greatly improve productivity as well as reduce the number of operations a product must go through, making the process less susceptible to variability.

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Appendix A

Dissertation Plan

Cronograma de atividades		
Semana	**Foco**	**Entregável do período**
W7	Integração JPM Seguir plano de integração definido	Fluxograma produtivo da JPM para Produtos Standard e Projetos Especiais
W8	Conhecer e aprofundar as ferramentas informáticas utilizadas na Produção & Operações Estudar a lógica e o funcionamento de cada um destes dossiers. Como são criados, qual o seu propósito, como são geridos.	Mapa de representação dos vários dossiers, que represente as seguintes dimensões: - Owners dos dossiers; - Interligação dos dossiers; - Papel e Outputs dos dossiers;
W9 - 10	Análise ABC dos produtos finais standard para o período de 1 ano. - Classificação dos produtos; - Variabilidade da procura; Definir metodologia para análise de variabilidade e conjunto de produtos alvo - criar ferramentas eventualmente necessárias para o registo de informação (Abordagem baseada no DMAIC - SixSigma)	Análise ABC, com conclusões em cada uma das dimensões; Ferramentas de monitorização e análise de variabilidade (Abordagem DMAIC - SixSigma) Ação de formação P&O + T&I - Abordagem DMAIC
W11 - 14	Acompanhamento de referências identificadas: Análise final da variabilidade, quantificando e identificado as suas causas e efeitos. Identificação de possíveis medidas a implementar para melhorar Estruturação do plano de atividades e cronograma para as melhorias	No final de cada semana: Relatório de acompanhamento das referências com: - Análise do que foi feito; - Análise de desvios; - Conclusões; - Plano de ação para a semana seguinte.
W15 - 16	Consolidação e análise aprofundada da informação retirada da análise a cada uma das referências, com identificação e quantificação de desvios, causas e efeitos. Finalização do plano de ação de medidas corretivas para os desvios e respetivas causas identificadas	Relatório final do estudo de variabilidade + Plano de ações c/ cronograma de implementação.
W17 - 19	Implementação do plano de ações.	Relatório de implementação de medidas e análise à sua eficácia.
W20 - 22	Acompanhamento e análise final da eficácia das ações implementadas e do plano em geral. Construção de ferramenta de análise de variabilidade a ser implementada de forma definitiva na gestão da produção.	Relatório de eficácia das ações implementadas. Ferramenta de análise de variabilidade.
W23 - 24	Elaboração do relatório de dissertação	N/A

Figure A.1: Dissertation plan

Appendix B

Gozinto Graph Example

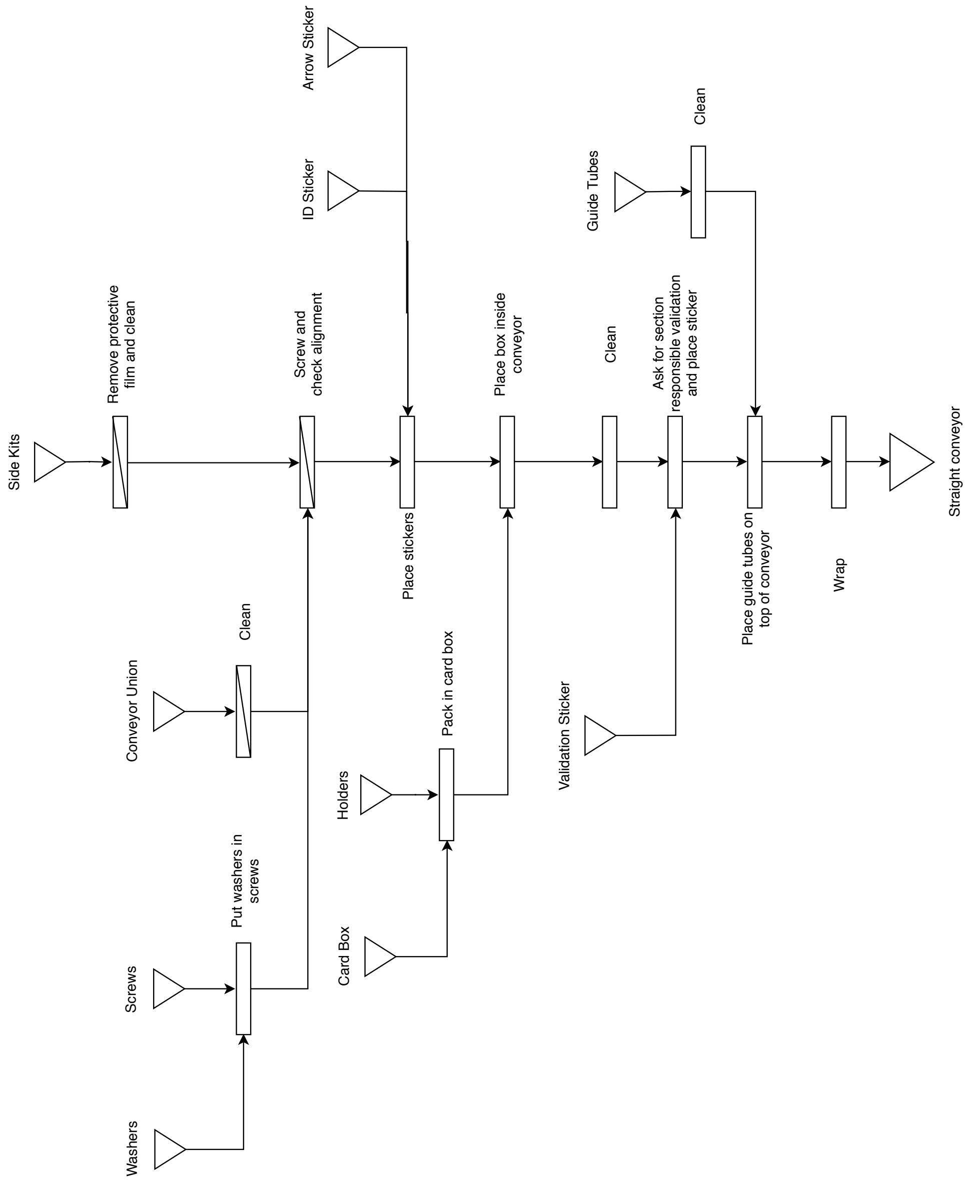


Figure B.1: Gozinto graph of the assembly of a straight conveyor

Appendix C

Production Order Example

Descrição
Straight conveyor

Referência	Desenho nº 401017111.01
0011223344	

Ordem de Fabrico
00055149

Quantidade	Entrega
12	18.03.2019

P07-MONTAR
C23-BANCADAS TROÇOS
3h57m36s

10	104105005	ETIQUETA IDENTIFICAÇÃO DO EQUIPAMENTO	12.00000 UN	
7	200403036	PARAF CAB SEXT INOX DIN933 M8X16	96.00000 UN	
7	200403195	PARAF CAB SEXT INOX DIN933 M8X10	96.00000 UN	
7	201201005	ANILHA PLANA INOX DIN125 M8	96.00000 UN	
8	402902190	KIT SUPORTE VARANDIM	48.00000 UN	402902190
8	402902097	KIT LATERAL 1M C/ PERFIL	12.00000 UN	402902097.00
7	600703008	CAIXA CARTÃO HOLDERS	12.00000 UN	
8	801104001	UNIÃO TRANSPORTADOR	24.00000 UN	801104001.01
8	802001088	TUBO GUIA Ø12x1000MM COM TOPO PLÁSTICO	48.00000 UN	802001088.00
7	200312041	AUTOCOLANTE SETA S/ FUNDO BRANCO	12.00000 UN	

Nº Transf.	Data	Inspecionado por
	___/___/______	

OF 00055149 Página 1 de 1

Figure C.1: PO Example

Appendix D

Bill of Materials Example

Quantity	Level	Operation / Component	Time
1	0	Reference A	60 min
	1	Operation 1	18 min
3	1	Component 1.1	
2	1	Component 1.2	
2	1	Component 1.3	
	2	Operation 2	10 min
4	2	Component 1.3.1	
1	2	Component 1.3.2	
	3	Operation 3	5 min
1	3	Component 1.3.3	
	2	Operation 4	2 min
3	1	Component 1.4	
3	1	Component 1.5	
	2	Operation 5	10 min
2	1	Component 1.6	
1	1	Component 1.7	
	1	Operation 6	5 min
	1	Operation 7	5 min

Figure D.1: BOM Example

Appendix E

ABC/XYZ Analysis

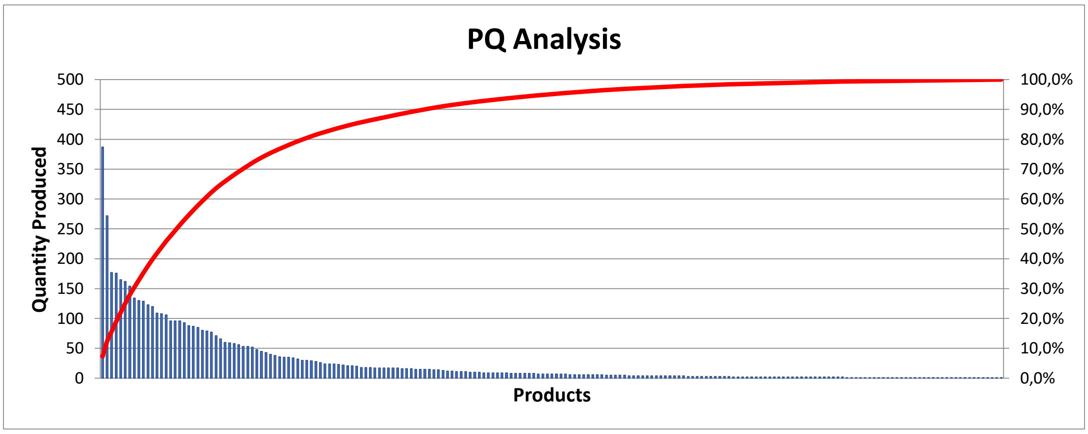


Figure E.1: Pareto chart of ABC Analysis (Product Quantities)

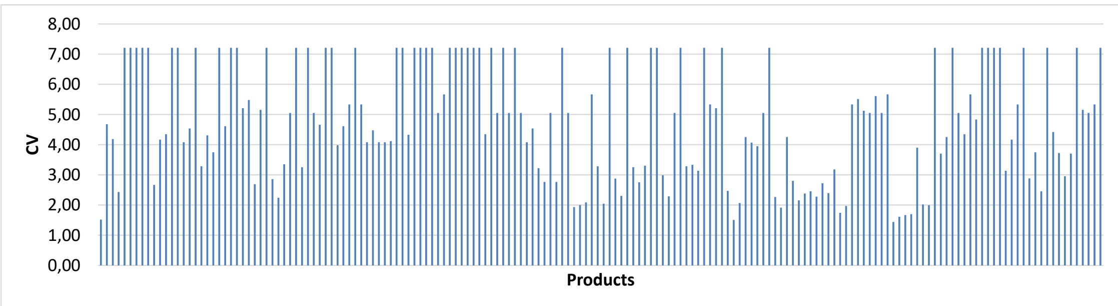


Figure E.2: Demand Variability Analysis

Table E.1: Summary of ABC Analysis (Product Quantities)

	X	Y	Z	%
A	0	0	45	23%
B	0	0	54	27%
C	0	0	100	50%
%	0%	0%	100%	100%

Appendix F

Production Times Registration

PO	Reference	Operator	Predicted Qt.	Produced Qt.	Estimated Time (min/uni)	System Registration (min/uni)	Observed Time (min/uni)	% Deviation (estimated vs observed)	% Deviation (system vs observed)
55351	Conveyor	L	2	2	20	14,78	14,15	29%	4%
55496	Conveyor	L	2	2	20	14,78	10,45	48%	29%
55931	Conveyor	L	2	2	20	14,78	13,15	34%	11%
55611	Conveyor	L	2	2	20	14,78	12,65	37%	14%
55093	Conveyor	R	20	20	20	21,00	21,83	-9%	-4%
55207	Conveyor	R	1	1	20	21,00	26,00	-30%	-24%
55977	Conveyor	R	1	1	20	21,00	23,00	-15%	-10%
55749	Conveyor	L	2	2	20	22,60	14,15	29%	37%
55547	Conveyor	L	2	2	20	22,60	16,55	17%	27%
55330	Wheel Curve	L	15	15	90	69,03	82,27	9%	-19%
55813	Wheel Curve	L	1	1	90	69,03	69,00	23%	0%
55575	Wheel Curve	R	1	1	90	69,03	93,00	-3%	-35%
55355	Wheel Curve	L	1	1	90	69,03	61,00	32%	12%
55345	Wheel Curve	L	1	1	90	69,03	47,00	48%	32%
55517	Wheel Curve	L	1	1	90	69,03	112,00	-24%	-62%
55731	Drive-Unit	P	1	1	90	59,79	52,00	42%	13%
55793	Drive-Unit	P	1	1	90	59,79	75,00	17%	-25%

Figure F.1: Example of production times registration

Appendix G

Occurrences Registration Sheet (Operators)

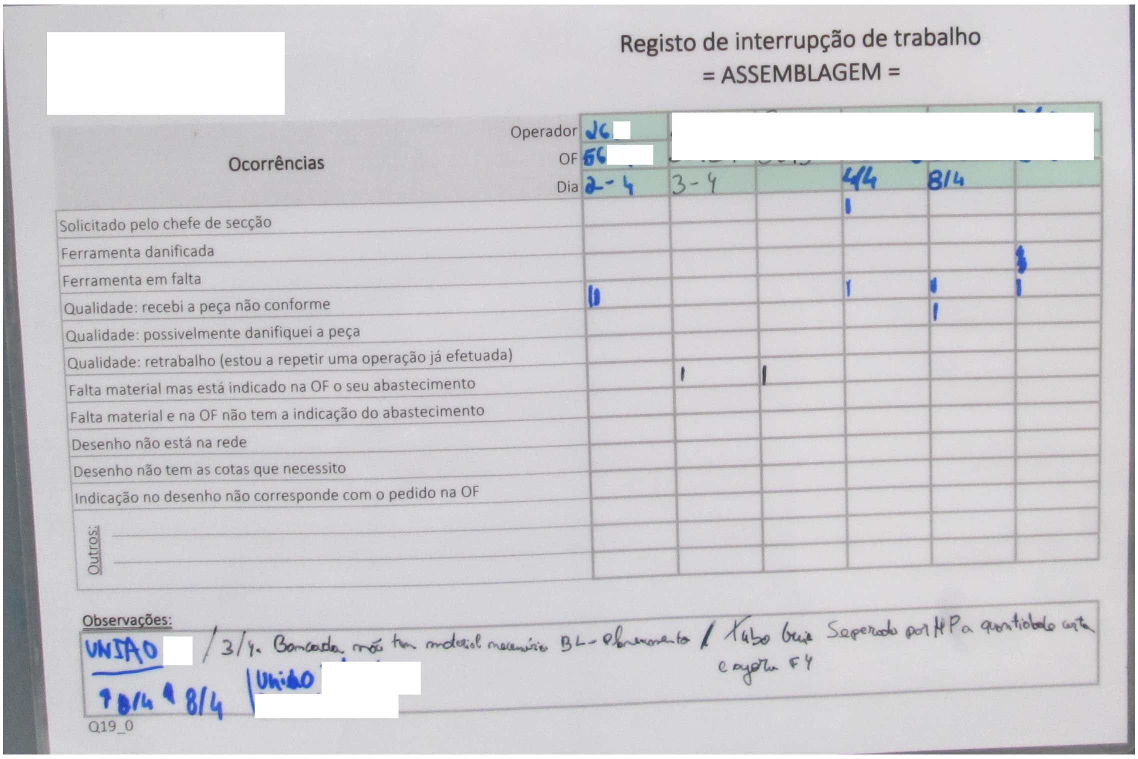
Registo de interrupção de trabalho
= ASSEMBLAGEM =

Ocorrências					
Operador					
OF					
Dia					
Solicitado pelo chefe de secção					
Ferramenta danificada					
Ferramenta em falta					
Qualidade: recebi a peça não conforme					
Qualidade: possivelmente danifiquei a peça					
Qualidade: retrabalho (estou a repetir uma operação já efetuada)					
Falta material mas está indicado na OF o seu abastecimento					
Falta material e na OF não tem a indicação do abastecimento					
Desenho não está na rede					
Desenho não tem as cotas que necessito					
Indicação no desenho não corresponde com o pedido na OF					
Falta de material no bordo de linha					
Falta de consumíveis do bordo de linha					
Outros					
Outros:					

Observações:

Q19_0

Figure G.1: Occurrences registration sheet (operators)



Registo de interrupção de trabalho
= ASSEMBLAGEM =

Ocorrências						
Operador	JC					
OF	56					
Dia	2-4	3-4		4/4	8/4	
Solicitado pelo chefe de secção				I		
Ferramenta danificada						I
Ferramenta em falta						
Qualidade: recebi a peça não conforme	II			I	I	I
Qualidade: possivelmente danifiquei a peça					I	
Qualidade: retrabalho (estou a repetir uma operação já efetuada)						
Falta material mas está indicado na OF o seu abastecimento		I	I			
Falta material e na OF não tem a indicação do abastecimento						
Desenho não está na rede						
Desenho não tem as cotas que necessito						
Indicação no desenho não corresponde com o pedido na OF						
Outros:						

Observações:

Q19_0

Figure G.2: Occurrences registration sheet example (operators)

Appendix H

Occurrences Registration Sheet

Registo de Ocorrências				
Assemblagem				
	Data			
VA	Pré-Montar			
	Montar			
	Medir			
	Embalar			
BVA	Consultar desenhos			
	Mudar Ferramentas			
	Buscar Peças			
	Dar/Receber instruções			
	Apertar Peças			
	Mudar OF			
	Limpar			
	Falar c/ dept téc			
	Falar com Resp.			
	Quadro Planeamento			
NVA	Conversar			
	Telemóvel			
	Ajudar Colega			
	Buscar Ferramentas			
	Ausente Posto			
	Falar com Op. Log.			
	Tirar Notas			
	Buscar Material			
	Retrabalho			
	Fumar			

Figure H.1: Occurrences registration sheet used to evaluate the state of the process

Appendix I

Facts-Causes-Solutions Analysis

Factos		Método de Validação	Possíveis Causas		Possíveis soluções	
F1	Operadores saem do seu posto para usar computadores	GEMBA	C1.1	Inexistência de computador no seu posto	S1.1.1	Colocar computadores em todos os postos ou pelo menos nos postos com mais atividade
F2	Operadores saem do seu posto para ir buscar ferramentas	GEMBA/Medição	C2.1	Inexistência de ferramenta no posto de trabalho	S2.1.1	Adquirir todas as ferramentas necessárias à execução das tarefas nos postos de trabalho
			C2.2	Ferramenta não está no posto de trabalho destinado	S2.2.1	Sensiblizar operadores para a importância de manter as ferramentas nas bancadas destinadas
					S2.2.2	Criar auditoria mensal/quinzenal da organização das ferramentas
			C2.3	Necessidade de ferramentas não previstas por causa de não conformidades/retrabalhos	S2.3	Instruir operadores a não retrabalhar as peças nas bancadas
						Garantir a conformidade das peças a montante
F3	Operadores saem do seu posto para ajudar outros operadores	GEMBA	C3.1	Não existem os suportes necessários para a movimentação de peças de grande dimensão	S3.1.1	Garantir que todas as peças podem ser movimentadas só com um operador, ou caso seja necessário mais, arranjar forma de não interromper o trabalho de outros
					S3.1.2	Instruir o operador a pedir ajuda a outra pessoa que não esteja a produzir
			C3.2	Operador tinha dúvidas	S3.2.1	Criar SW
					S3.2.2	Instruir o operador a tirar as dúvidas sempre com o chefe de secção
			C3.3	Operador queria falar com outro operador	S3.3.1	Sensibilizar operadores para a importância de não saírem do seu posto de trabalho
			C3.4	Outro operador não conseguia realizar tarefa sozinho	S3.4.1	Garantir condições para o operador conseguir realizar as tarefas sozinho
F4	Elevado número de peças não conformes (ex: roscagem)	Medição	C4.1	Operação não definida nas GO	S4.1.1	Definir na GO a operação de roscar e quais as referências que necessitam dessa operação
			C4.2	Displicência do operador	S4.2.1	Sensibilizar operadores para a importância das peças chegarem conformes à montagem
					S4.2.2	Criar método que impeça que o operador "adormeça"
			C4.3	Posto muito desorganizado e sem método	S4.3.1	Aplicar 5s no posto
					S4.3.2	Criar SW
			C4.4	Falta de poka-yokes e fixadores para algumas peças	S4.4.1	Criação de meios para fixar as peças durante a roscagem e criação de poka yokes que impeção erros na roscagem.
F5	Demasiado tempo investido em tarefas de pouco valor acrescentado	GEMBA/Medição	C5.1	Operações são repetidas ao longo do processo, nomeadamente a limpeza ou roscagem (ex: soprar uniões)	S5.1.1	Sensibilizar operadores para a importância de as operações estarem 100% bem-feitas antes de chegarem à montagem
					S5.1.2	Alterar gamas operatórias caso seja necessário ou esteja a ser a causa das repetições
					S5.1.3	Criar método de controlo (no caso do sopro)
			C5.2	O embalamento de algumas peças é muito demorado (ex: accionamento, troços retos 3m)	S5.2.1	Estudar alternativas ao embalamento actual
					S5.2.2	Garantir condições para que o uso da máquina de embalar (no caso dos troços) esteja sempre disponível quando necessário por apenas um operador
			C5.3	Retirar e limpar as chapas que vem do corte, por vezes é um processo demasiado demorado, em função do tipo de filme protector/chapa/fornecedor	S5.3.1	Verificar quais as chapas/fornecedores que causam problemas na limpeza e evitar a sua compra, caso seja vantajoso.
			C5.4	Alguns operadores deslocam-se e trocam de ferramentas em demasia.	S5.4.1	Criar SW que minimize estas perdas

F6	Demasiado tempo de espera pela inspecção (média 3 min)	Medição	C6.1	Chefe de secção não viu a luz	S6	Atribuir a tarefa de validação aos operadores
			C6.2	Chefe de secção está ocupado		
F7	Registo incorreto dos tempos no sistema	Medição	C7.1	Computador demorou demasiado a ligar	S7.1.1	Automatizar o arranque dos computadores de forma a estarem prontos a usar as 8:00
					S7.1.2	Verificar se existem problemas de SW
					S7.1.3	Substituir computadores
			C7.2	Operadores são interrompidos para fazer outras tarefas	S7.2.1	Garantir que o operador enquanto uma OF está aberta apenas realiza as operações das mesmas.
					S7.2.2	Criar mecanismo que permita ao operador “pausar” a OF quando vai fazer outras tarefas, permitindo assim registar quando este esteve ausente para efeitos de análise de tempos
			C7.3	Operador esqueceu-se de fechar OF	S7.3	Chamar a atenção dos operadores para a necessidade de fechar as OF’s
			C7.4	Operador abriu OF e não começou a montar imediatamente	S7.4	Garantir que a OF é aberta apenas quando se inicia efectivamente a montagem
			C7.5	Operador deslocou-se a outro posto para usar computador	S7.5.1	Colocar um computador em cada posto de trabalho
F8	Indisciplina e sentimento de desconexão/impotência com os problemas no chão de fábrica	GEMBA	C8.1	Sensação de que não há mudança mesmo estando os problemas visíveis	S8.1.1	Procurar resolver os problemas imediatamente, especialmente se forem “quick wins”
					S8.1.2	Divulgar e expor o trabalho que está a ser feito para mudar, procurando assim motivar e envolver os operadores
			C8.2	Sensação de que as sugestões que os operadores fazem não são ouvidas / tidas em conta	S8.2.1	Recolher feedback dos operadores e caso faça sentido procurar mudar, especialmente no caso de “quick wins”
					S8.2.2	Procurar envolver mais a gestão com os operadores
			C8.3	Sentimento de que “não faz a diferença/sentido” certas regras	S8.3.1	Procurar explicar/formar os operadores para a razão de ser de determinadas regras
F9	Demasiado tempo à espera do OL (média 4,5 min)	Medição	C9.1	OL não vê a sinalização	S9.1.1	Procurar alternativas de comunicação com o OL
					S9.1.2	Tornar o sistema actual mais visível
			C9.2	OL está ocupado	S9.2.1	Verificar se as tarefas que realiza são todas da sua competência
					S9.2.2	Redistribuir tarefas
					S9.2.3	Contratar outro OL
F10	Falta de método e standardização nos processos	Documentação	C10.1	Inexistência de SW	S10.1.1	Atualizar SW
					S10.1.2	Criar SW
F11	Grande variação de tempos de montagem entre operadores e em relação às GO	GEMBA/Medição	C11.1	Faltas de material	S11.1.1	Redimensionar BL
					S11.1.2	Garantir que todas os componentes estão disponíveis antes de iniciar a montagem
					S11.1.3	Instruir OL para precaverem as falhas de material e garantirem que não há paragens devido a isso
			C11.2	Diferença de método entre operadores	S11.2.1	F10
			C11.3	Não conformidades	S11.3.1	F4
			C11.4	“Vontade” do operador	S11.4.1	F8
			C11.5	Experiência do operador	S11.5.1	Formar os operadores para montar vários equipamentos todos da mesma maneira

F12	Elevado número de faltas de material	Medição	C12.1	Falha no BL	S12.2	Criar método para o OL preparar uma OF garantindo que não vão ocorrer falhas de material, e se forem, precavê-las
			C12.2	Armazém não separou o material	S12.2	Garantir que o armazém separa todo o material antes de ser iniciada a OF
			C12.3	Não foram impressas as etiquetas	S12.3	Garantir que as etiquetas estão todas impressas no inicio da OF
			C12.4	Não está indicado na OF	S12.4	Rever as GO's
			C12.5	Armazém não separou caixas do BL	S12.5	Garantir que o armazém separa as caixas do BL atempadamente de modo a não ocorrerem falhas
F13	Montagem de uma OF é interrompida para conclusão de outra	GEMBA	C13.1	Chefe de secção solícita o operador	S13.1.1	Criar opção do operador interromper a OF para fazer outras tarefas. Ou caso seja outra OF, mudar sempre.
			C13.2	Falta material (falta ou não conformidade)	S13.2.1	F12, F4
F14	Não são montadas as quantidades totais pedidas na OF	GEMBA	C14.1	São necessários produtos similares para outra OF com mais urgência	S14.1.1	Priorizar as OF's os produtos com mais atraso e abrir OF's para os mesmos
			C14.2	OF inicial tem a quantidade errada	S14.2.1	
F15	Quando inicia um processo de montagem o operador verifica que não estão todos os componentes necessários	GEMBA	C15.1	Componentes estão em paletes diferentes	S15.1.1	Colocar paletes com material para a mesma OF todas juntas
					S15.1.2	Implementar sistema de gestão visual que permita facilmente identificar a que OF pertence o material em cada palete
			C15.2	Componentes ainda não foram todos separados	S15.2.1	Colocar material na zona de entrada apenas quando todos os componentes estiverem separados
					S15.2.2	Sinalizar quais as paletes em que todos os componentes estão separados e quais aquelas em que a separação ainda está em curso
			C15.3	Falta de comunicação entre as secções de corte e fabrico	S51.3	Melhorar a coordenação entre as duas secções
			C15.3	Operador verificou mal		

Figure I.1: Facts-Causes-Solutions analysis

Appendix J

Improvement Plan

Prob.	ID	Ação	Responsável	Data de Conclusão
1	**1.1**	Colocar um computador em todos os postos de trabalho	A	19/10/2019
1	**1.2**	Colocar softwares necessários nos computadores	F	12/05/2019
2	**2.1**	Verificar se as bancadas contêm todas as ferramentas necessárias à operação que estão destinadas	B	11/08/2019
2	**2.2**	Inquirir operadores sobre ferramentas em falta nas bancadas ou a necessitar de substituição	A	11/05/2019
2	**2.3**	Sensibilizar operadores/responsáveis para a importância de respeitarem a organização das ferramentas	A	09/05/2019
2	**2.4**	Adquirir/repor ferramentas em falta	H	21/11/2019
3	**3.1**	Criar ou adquirir suportes/meios de movimentação para peças de maiores dimensões	H	16/10/2019
3	**3.2**	Garantir as condições para o uso da máquina de embalar para peças de maior dimensão (ex: troço reto 3 m)	D	07/05/2019
3	**3.3**	Sensibilizar operadores para apenas serem auxiliados pelo responsável ou pelo operador logístico	A	12/11/2019
4	**4.1**	Criar standard work (roscar e escarear)	A	30/11/2019
4	**4.2**	Comprar matéria-prima de melhor qualidade	G	14/07/2019
4	**4.3**	Organizar e identificar postos de roscar e escarear (5s)	B	02/08/2019
4	**4.4**	Rever GO’s onde não estão incluídas todas as operações	G	28/10/2019
4	**4.5**	Garantir que perante a mudança de uma GO é comunicado aos operadores/responsáveis (ex: mudança de cotas)	G	27/10/2019
4	**4.6**	Agilizar o processo de alteração de GO’s	F	19/05/2019

5	**5.1**	Várias operações são repetidas ao longo do processo, nomeadamente a limpeza e roscagem das peças, sendo necessário definir claramente onde devem ser feitas	B	01/12/2019
5	**5.2**	O método de montagem de alguns operadores gera demasiadas perdas por movimentação, sendo necessário definir um SW que minimize esta situação.	G	08/08/2019
5	**5.3**	Garantir a conformidade das peças quando estas são produzidas	F	21/09/2019
5	**5.4**	Garantir que na montagem não é necessário fazer nenhuma verificação de conformidade das peças, sem que isso origine retrabalho	E	24/12/2019
6	**6.1**	Verificar se existem problemas de software	G	12/12/2019
6	**6.2**	Implementar sistema de registo de OF’s em curso mais rápido e eficaz	F	02/07/2019
6	**6.3**	Sensibilizar operadores para a necessidade de fazer registos correctos	E	13/07/2019
6	**6.4**	Garantir que os computadores arrancam até às 8:00	A	25/12/2019
6	**6.5**	Criar sistema de atalhos que permita ao operador indicar operações que faz ou paragens durante a OF (limpeza, sair do posto, espera por validação, fazer outra tarefa etc.)	G	24/11/2019
6	**6.6**	Automatizar o lançamento de OF's	A	01/12/2019
7	**7.1**	Alertar os operadores para a importância de serem disciplinados com as regras do chão de fábrica, mesmo que isso implique perdas de eficiência a curto-prazo	A	30/10/2019
7	**7.2**	Sensibilizar operadores logísticos para serem disciplinados na reposição dos bordos de linha e na organização do material no chão de fábrica	H	15/06/2019
7	**7.3**	Ouvir genuinamente as opiniões dos operadores relativamente aos problemas recorrentes no chão de fábrica, procurando motivá-los com pequenas mudanças sugerias pelos mesmos	G	28/07/2019
7	**7.4**	Procurar eliminar o sentimento de impotência e desconexão dos operadores perante os problemas no chão de fábrica	C	20/07/2019
7	**7.5**	Procurar resolver os problemas imediatamente, especialmente os que envolvem pouco esforço, mesmo que signifiquem melhorias aparentemente insignificantes	B	11/10/2019
7	**7.6**	Envolver a gestão de topo nas principais melhorias e alterações, de modo a demonstrar a seriedade das mesmas perante os operadores	B	27/06/2019

8	**8.1**	Criar Standard Work	E	12/05/2019
8	**8.2**	Atualizar Standard Work já existente	C	03/09/2019
8	**8.3**	Envolver operadores na criação de SW	H	28/05/2019
8	**8.4**	Explicar aos operadores o conceito de SW e sensibilizá-los para a sua utilidade	A	19/05/2019
8	**8.5**	Formar operadores de acordo com o SW	G	11/06/2019
8	**8.6**	Sensibilizar responsáveis para a importância do SW e da garantia da sua sustentabilidade	G	15/11/2019
9	**9.1**	Rever e alterar tempos das GO's	E	05/06/2019
9	**9.2**	Garantir que os operadores seguem todos o mesmo método de montagem (SW)	B	06/09/2019
9	**9.3**	Dar formação adequada aos operadores, especialmente aos que costumam realizar trabalho de exterior	E	22/08/2019
9	**9.4**	Implementar sistema de recompensas de acordo com os tempos de produção	F	19/08/2019
9	**9.5**	Formar os operadores para vários produtos, de forma a colmatar as ausências ou saídas de outros.	D	02/08/2019
10	**10.1**	Estudar alternativas ao sistema de sinalização actual (tempo médio de espera 4,5 min)	H	13/06/2019
10	**10.2**	Criar novas rotas para os OL	C	13/06/2019
10	**10.3**	Adquirir mais paletes	G	18/09/2019
10	**10.4**	Criar método para os OL preverem as ocorrências invés de reagirem às mesmas	C	26/07/2019
10	**10.5**	Estudar a hipótese de contratar outro operador logístico	C	01/10/2019

11	**11.1**	Melhorar coordenação entre departamento supply chain e produção	F	17/09/2019
11	**11.2**	Otimizar reabastecimento dos bordos de linha	C	06/10/2019
11	**11.3**	Melhorar coordenação entre armazém e produção	B	27/08/2019
11	**11.4**	Criar método para o operador logístico preparar as bancadas para montagem (ex: rever BL, garantir todo o material, verificar consumíveis, verificar ferramentas)	B	19/12/2019
11	**11.5**	Incentivar Operadores logísticos e criar métodos para estes preverem as faltas invés de reagirem a estas	A	17/08/2019
11	**11.6**	Especificação correta das GO's, para diminuir aprovisionamentos	A	08/05/2019
11	**11.7**	Sensibilizar OL's para a importância de respeitarem o funcionamento do bordo de linha, em vista a reduzir os abastecimentos recorrendo a BL de outras bancadas	D	19/06/2019
11	**11.8**	Sensibilizar o armazém para a importância de reabastecer as caixas bordos de linha	F	30/06/2019
11	**11.9**	Rever organização dos BL, visto que não cabem todas as peças necessárias em algumas bancadas (necessário um BL no meio)	F	26/07/2019

Figure J.1: Improvement plan

Appendix K

A3 in the Threading Section

A3 - Relatório de resolução de problemas | **Titulo:** Implementação dos 5'S e do Standard Work na Zona de Roscagem | **Data:** 10/06/2019

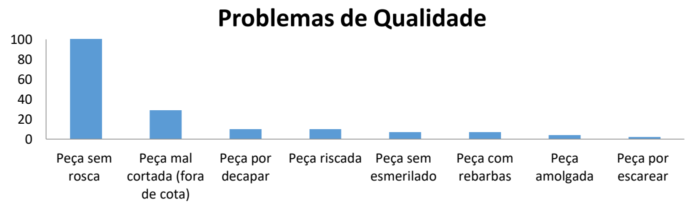
Desafio / Problema:

1 - Posto de trabalho desorganizado e sem identificação das ferramentas

2 - Ausência de forma standard de efetuar as operações

3 - Ausência de condições para o trabalho ser feito com qualidade

4 - Elevado número de não conformidades derivadas da roscagem



Objectivo:

1 - Reduzir o número de não conformidades derivadas deste posto

2 - Criar um método standard de efetuar as operações de roscagem e

3 - Garantir a limpeza e organização do posto

4 - Melhorar o conforto dos operadores a efetuar as operações

Ações:

ID	Ação		Responsáveis	Status
1	**Organizar e identificar postos de roscar e escarear (5s)**		**FS/ BS/ JGF/ DR**	**100%**
	111	Definir equipa para remodelação do posto	FS/ BS	100%
	112	Analisar posto e estudar quais as ferramentas necessárias e, se necessário, adquiri-las	FS/ BS/ JGF/ DR	100%
	113	Definir locais para as ferramentas e identifica-los	FS/ BS/ DR	100%
	114	Limpar e organizar o posto	FS/ BS	100%
	115	Agendar auditorias 5S	FS/ BS/ JGF	100%

ID	Ação		Responsáveis	Status
2	**Atualizar/ Criar SW (roscar e escarear)**		**FS/ BS/ JGF/ DR**	**40%**
	2.11	Sensibilizar responsáveis para a importância do SW e da garantia da sua sustentabilidade	FS/ BS	0%
	2.12	Envolver operadores na criação de SW		100%
	2.13	Criar SW	FS/ BS	100%
	2.14	Formar operadores de acordo com SW	FS/ BS/ JGF	0%
	2.15	Criar auditoria mensal para garantir sustentabilidade do SW e recolher feedback com possibilidades de melhoria	JGF	0%

Figure K.1: A3 of the problem in the threading section

Appendix L

Standard Work for the Threading Process

Instrução de Trabalho
=União Transportador=

Secção: Roscagem		**Data:** 20/08/2019
Referência: 8011044444		
Descrição: União Transportador		

OPERAÇÃO		INSTRUÇÃO		
Nº	**Designação**	**Quem**	**O quê**	**Como**
1	Abrir OF	Operador	Abir a OF no Manufactor	MANUFACTOR
2	Preparar material	Operador	Pegar na caixa com peças para roscar na palete de entrada (figura à esquerda) e colocar no lado esquerdo da parte de baixo da bancada de roscagem (figura à direita)	 
3	Colocar macho	Operador	Colocar macho adequado à roscagem da peça na máquina de roscar.	 
4	Lubrificar	Operador	Lubrificar o macho.	

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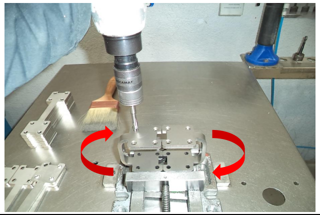
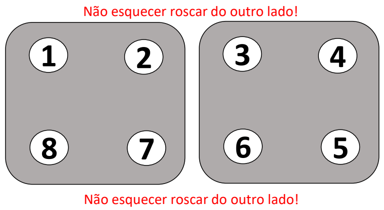
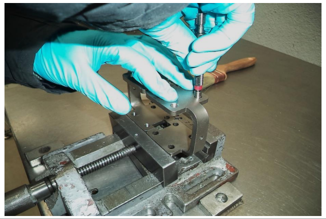
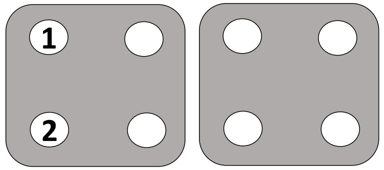
5	Roscar	Operador	Colocar 2 uniões no torno conforme a figura à esquerda e roscar conforme a ordem da figura à direita. Inverter a peça e roscar igualmente do outro lado. Depois, colocar a peça final no caixote debaixo da bancada, conforme a figura em baixo. Repetir este passo 5 vezes.	  
6	Controlo de qualidade	Operador	Com o passa-não passa testar as roscas identificadas na figura. Caso falhe o teste, verificar se o macho está conforme. Caso não esteja, trocar o macho por um novo. Regressar ao ponto 4 até não haver peças por roscar.	 
7	Limpar e colocar material na saída	Operador	Soprar todas as roscas de todas as uniões e colocar na caixa do ponto 2. Colocar a caixa com as peças finais na zona indicada na figura do lado direito.	 
8	Fechar OF	Operador	Por fim, fazer o fecho da OF indicando a quantidade produzida.	MANUFACTOR

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Figure L.1: Standard work for the threading section

Appendix M

5s Audit Sheet

Auditoria 5's

Data: ______________________ **Área Auditada:** ______________________

Auditor: ______________________ **Responsável da Área:** ______________________

Categoria	Item	Classificação					
	Distinguir entre o que é necessário e não é	N/A	1	2	3	4	5
Organizar	Estão presentes equipamentos ou ferramentas que não são neces						
	As ferramentas presentes estão no local indicado?						
	Os locais para as ferramentas são apropriados?						
	Um sítio para tudo e tudo no seu sítio						
Simplificar	Os caminhos e postos de trabalho estão claramente marcados e						
	Os gabaris, ferramentas e equipamentos estão identificados corretamente e nos locais corretos?						
	Os items são guardados depois do uso?						
	Limpar e procurar formas de manter o posto organizado						
Limpar	Os equipamentos de limpeza estão facilmente acessíveis?						
	Os equipamentos e o posto de trabalho estão limpos e livres de óleo, lixo e detritos?						
	As linhas, rótulos e sinais estão limpos e em bom estado?						
	Manter e monitorizar as 3 primeiras categorias						
Standardizar	O quadro de gestão visual é usado, organizado e atual?						
	Os operadores estão vestidos adequadamente?						
	As operações de limpeza foram devidamente atribuidas?						
	O lixo e os recipientes de sucata são esvaziados regularmente?						
	Garantir que são mantidas as melhorias						
Sustentar	O programa 5S é discutido nas reuniões e como uma métrica de performance?						
	As ferramentas estão conformes para sustentar o programa 5S?						
	No geral, a área mantém as regras e disciplinas 5S?						
	Sub-Total						
	Total	**/80**					

Comentários:

Preocupações	*Pontos Positivos*	*Sugestões*

Figure M.1: 5s Audit sheet

Appendix N

A3 of 5s Implementation

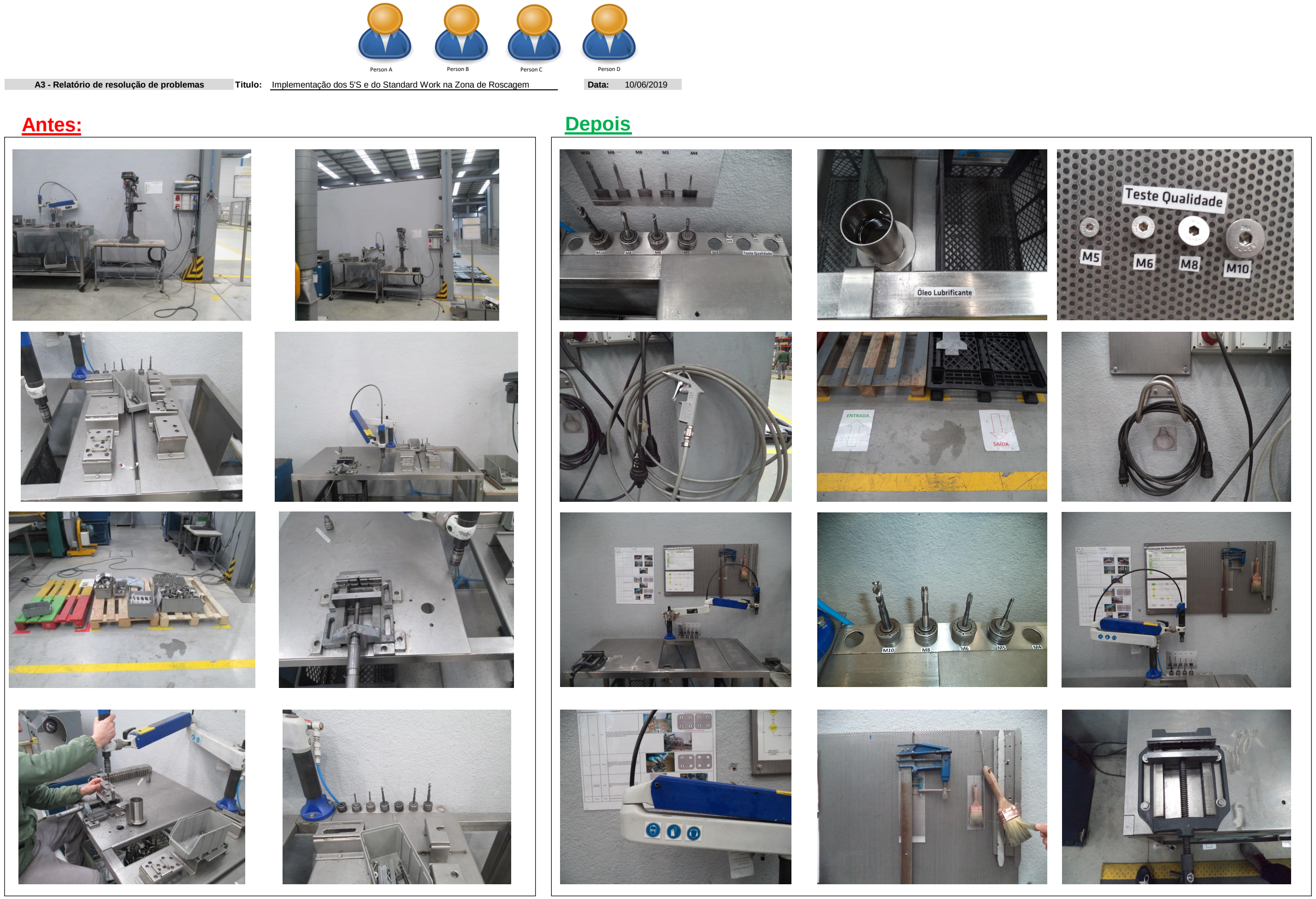

Figure N.1: Before and after 5s implementation