Improving operations planning in a Metal Mechanical Industry

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Master's dissertation

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"The world as we have created it is a process of our thinking. It cannot be changed without changing our thinking."
Albert Einstein

Abstract

The current sample of the business world obligates companies to invest in the implementation of management systems focused on improving operational performance to obtain higher profit margins and market share by increasing productivity, reducing costs, and improving the quality of products or services. In this context, the company in which the project was developed produces metal parts with a job shop type of manufacturing system for big industries. As a result of stable growth in sales, it is intended to improve operations planning in order to strengthen customer service, reduce long lead times and manage finished product stock.

The project starts by assessing the initial situation of the operations by describing them and characterising the business with the auxiliar of process mapping, ABC analysis and indicators quantifications. The on-time delivery, on-time in full, the quantity of finished stock and the overall equipment efficiency were studied to state the starting point of the company. Based on this description it was possible to identify several problems.

The solution's design was then divided into phases for implementation. The phases involve the correct sizing of capacity, the definition of lead time objectives, the optimisation of production sequencing and the creation of material and information flow. These solutions are described at length and certain tools developed for the scope are introduced. In addition, the implementation of a pull by pushing planning system with both make-to-stock and make-to-order production is illustrated.

Melhorias nas operações de planeamento de uma Indústria Metalomecânica

Resumo

A atual amostra do mundo empresarial obriga as empresas a investir na implementação de sistemas de gestão centrados na melhoria do desempenho operacional para obter maiores margens de lucro e quota de mercado, aumentando a produtividade, reduzindo custos, e melhorando a qualidade dos produtos ou serviços. Neste contexto, a empresa em que o projeto foi desenvolvido produz peças metálicas para grandes indústrias com um sistema de fabrico do tipo *job shop*. Como resultado, a partir de um crescimento estável nas vendas, pretende-se melhorar o planeamento das operações de modo a reforçar o serviço ao cliente, reduzir os longos prazos de entrega e gerir o *stock* de produtos acabados.

O projeto começa por avaliar a situação inicial das operações, descrevendo-as e caracterizando o negócio com o auxílio do mapeamento de processos, análises ABC e quantificação de indicadores. A percentagem de entrega no prazo, a percentagem de entrega de encomenda total no prazo, a quantidade de stock acabado e a eficiência global dos equipamentos foram estudados para marcar o estado inicial da empresa. Baseada nesta descrição foi possível identificar vários problemas.

A conceção das soluções foi então dividida em fases para a implementação. As fases envolvem o correto dimensionamento da capacidade, a definição de objetivos de *lead time*, a otimização da sequência de produção e a criação de fluxos de material e informação. Estas soluções são descritas em pormenor e são introduzidas certas ferramentas desenvolvidas para o âmbito de aplicação. Além disso, é ilustrada a implementação de um sistema de planeamento *pull by pushing* com produção *make-to-stock* e produção make-to-order.

Foreword

At the Kaizen Institute, the company that received me, I recognize the professionalism of my supervisor José Miguel Freitas and the leadership of Pedro Peixoto, both of whom led me through this project. I also must thank all the consultants that welcomed me in and helped me to integrate for the first time into the business environment, namely Francisco Chaves.

Regarding the Faculty of Engineering of the University of Porto, I had the privilege of working with Professor Maria Pires and Professor Xavier Andrade who guided me closely in the development of this dissertation. I would also like to thank all the other professors that during my academic years provided me with the preparation needed for facing engineering challenges in the present day.

I sincerely thank my family, especially my parents and sister for the unconditional support and trust that made my journey possible. I would also like to acknowledge the impact and inspiration my grandparents' lives have on my values and expectations.

At last but not least, to my friends who carry life with lightness, reminding me of the importance of happiness and appreciation for the everyday.

Contents

Abbreviations

BOM - Bill Of Materials
FIFO - First In First Out,
KPI - Key Performance Indicator
OEE - Overall Equipment Efficiency
OTD - On-Time Delivery
OTIF - On-Time In Full
PDCA - Plan Do Check Act
SKU - Stock Keeping Unit
WIP -Work In Progress,
5S - Seiri, Seiton, Seiketsu, Seisou and Shitsuke

Glossary

BOM - List of components that make up the finished product
Bord of line - Location close to a production line where the materials necessary for the operation performed on the line are preferentially organized and accessible
Lean - Used to describe a production system with reduced waste
Gemba - Japanese word used in industry to describe the factory floor where value is added
Heijunka - Japanese word meaning Levelling
Kaizen - Japanese word meaning Continuous Improvement.
Kanban - Japanese word meaning card, which is commonly used as a means of information flow
Kobetsu Kaizen- Japanese word meaning Focused Improvement
Muda - Japanese word for waste.
Lead time - Time that a given product takes to go through the value chain from its origin to the customer.
Pull Flow - Production management system where all planning is pulled based on final orders from the next client.
WIP - Material that is between processes or being processed.
5S - Methodology for organising the workstation, originating from five Japanese words translated to sort, arrange, clean, standardise and discipline respectively

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1 Introduction

This document was elaborated as part of the curriculum of the Integrated Master in Mechanical Engineering of the Faculty of Engineering of the University of Porto. It is the result of a project developed by the Kaizen Institute Consulting Group to meet one client company's needs.
In this chapter, there will be a contextualization of the undertaking followed by a presentation of both companies' businesses, the objectives of the study, the methodology applied and the structure of this dissertation.

1.1 Context

In recent years there has been an exponential growth in market competitiveness that may be justified by the internationalization of most industries. The current sample of the business world obligates companies to invest in the implementation of management systems focused on improving operational performance to obtain higher profit margins and market share by increasing productivity, reducing costs, and improving the quality of products or services. The metal mechanical industry, where Company X (a fictitious name due to confidentiality) operates, is no exception.
Company X is a company that provides services in the metal mechanical industry. It integrates a corporate group, vertically organized, that has been a world leader in its area as exports 85% of its turnover to 80 countries on all continents and it is recognized as an innovative and technologically advanced company. With the cooperation of more than 500 collaborators, the company answers to top-tier clients.
To improve their operational performance and service, therefore customer satisfaction, Company X hired the *Kaizen* Institute. The *Kaizen* Institute is a worldwide consultancy firm established in Switzerland and founded in 1985 by Masaaki Imai. It is based on the continuous improvement culture and offers operational consulting services focused on increasing productivity, motivating employees and assisting executives with the implementation of structured methodologies across the whole organization. It is characterized by its vast global reach and sectorial, being present in over 60 countries, including industry, services transports, health, retail, IT, and finance, among others. There are 5 fundamental *Kaizen* principles: Creating customer value, Flow efficiency (zero waste), Going to *Gemba*, Empowering people and Being transparent/visual; this will be later presented in more detail.

"Improving the world with everyone, everywhere, every day". – The *Kaizen* Way

Figure 1- Kaizen's Institute Logo

Kaizen and Company X had been working together for the last few years, gradually integrating the *kaizen* principles within the teams. Before the present study, Daily *Kaizen* Meetings had already been integrated into the factory's routine however there was room for more improvements in *kaizen* culture.

1.2 Project Description

This project was a consequence of an increased number of delayed responses to costumer's orders. This change led to the need of reviewing the order processing as well as the production planning structure. During the characterization of the initial situation, the most critical cause of disturbance identified was planning for the wrong capacity sizing and counterproductive communication between the administrative teams. It was also identified the lack of rules for sequencing planning without the visibility of all the operations involved in the production process and consequently constant changes in the plans. To rectify the situation and facilitate the day-to-day life of the company's workers, as well as increase customer satisfaction several improvement actions were designed. These solutions were divided into four phases to ensure there is a phased implementation and with a prioritised order having into consideration the expected results versus the effort put into it.

The first phase focused on the correct dimensioning of the capacity of the factory, having into consideration the available hours, the OEE, reserved capacity for MTS and reserved capacity to catch up on delayed orders. The second phase addressed the poor communication between the administration teams and the necessity of confirming the order's due date. In this phase, lead times were also settled on for both the order processing and the production. These solutions will guarantee the date settle with the client is possible to attend to and therefore facilitate success. The third phase aimed to improve the producing sequencing by creating a set of rules that considered the need for optimization of material and resources. At last, the fourth phase attends to the operation flow. Multiple tools were introduced to enable the physical movement of information and material, as well as guarantee the factory is organised and clean.

1.3 Objectives

The purpose of the project was to guarantee the high customers demand was answered by the production without compromising lead times and for that reason, the following objectives were settled on by both companies:

- Improve service level and customer satisfaction
- Reduce long lead times
- Manage finished product stock

To achieve these goals, it was required deep analysis of the initial situation in the organization (AS IS). Justified by its importance, this was the phase that took the longest. Without a thorough understanding of the processes, it would not be possible to identify the problems and find their root causes. Subsequently, the solution was designed (TO BE) and actions were created to facilitate implementation.

To ensure detailed project management, a Mission Control Room was established where visual indicators such as the benefits tracking, progress of ongoing improvements and completion of deliverables were mirrored in the form of schedules and visual indicators. An example of this Mission Control Room can be observed in Appendix A.

1.4 Methodology

For the construction of this study, the methodology followed was a step-by-step focused improvement approach called *Kobetsu Kaizen*. This technique targets focused improvements to clarify and solve structured problems.

- Step 1 aims to define the scope of the work to be carried out by the team
- Step 2 is responsible for the definition of the current state by collecting real and live data from the machine/process and describing/analyzing the relationships between the different process steps
- Step 3 is where the objectives are decided on and specified
- Step 4 is responsible for identifying all the possible causes and prioritizing the strongest ones

- Step 5 focuses on designing a vision of improvement for the problem according to the root causes identified. It is also important to consider the solutions with the highest likelihood of preventing the problem from reoccurrence
- Step 6 the solutions are tested for viability
- Step 7 a list of the necessary actions is created and implemented
- Step 8 is reserved for results confirmation
- Step 9 should be the evaluation of the process and reflection on the next steps

Table 1- Timetable of the project development planning

	April		May				June				July			
	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29
Step 1: Problem														
Step 2: State														
Step 3: Objective														
Step 4: Causes														
Step 5: Solutions														
Step 6: Testing														
Step 7: Actions														
Step 8: Results														
Step 9: Evaluate														

Due to the complexity of the problem, a characterization of the current situation in detail was necessary and, consequently required a long period of time. Since the present study was carried out over 3 and a half months it was not possible to initiate steps 8 and 9. The project will be carried on further in time.

1.5 Document Structure

The dissertation paper is structured into five chapters.

The first, present one, has an introductory nature and delivers contextualization to the reader, as well as defines the entities involved in the project. The final objectives and the methodologies to achieve them are also here exposed.

The second chapter focuses on reviewing the state of the art of the subject in question by vouching that all the tools and methodologies employed are relevant and clearly described.

The third chapter is where the initial state of the organization (AS IS) is exposed and the problems are identified.

The fourth chapter is responsible for displaying the relevant discussed solutions and developments accomplished.

The fifth chapter presents the conclusions of the work developed, as well as potential future improvements/recommendations.

2 Theoretical Review

Following the introduction to the *Kaizen* Institute and the project developed this chapter presents a broad description of the *Kaizen* principles with a particular focus on the improvement methods and tools used in this case study. Firstly, the *kaizen* philosophy will be presented since these methods will serve as core values thought the project development. The 5 S tool and its benefits will be described. There will be a special focus on the total flow management theory that will be the fundamental pillar for the design of the solutions. Following the ABC analysis concept will be explained as well as the job-shop and bottleneck definitions. These notions will be later applied in the initial situation characterization. At last, the key performance indicators suitable for the theme in the study will be introduced.

2.1 *Kaizen* Philosophy

Kaizen is a term of Japanese origin meaning continuous improvement. This term is composed of Kai + Zen, which can be translated to change & better related to the search for perfection (Imai 1997). Figure 2 represents the meaning behind the company's logo. The flag attributes each level of innovation to the workforce it should involve.

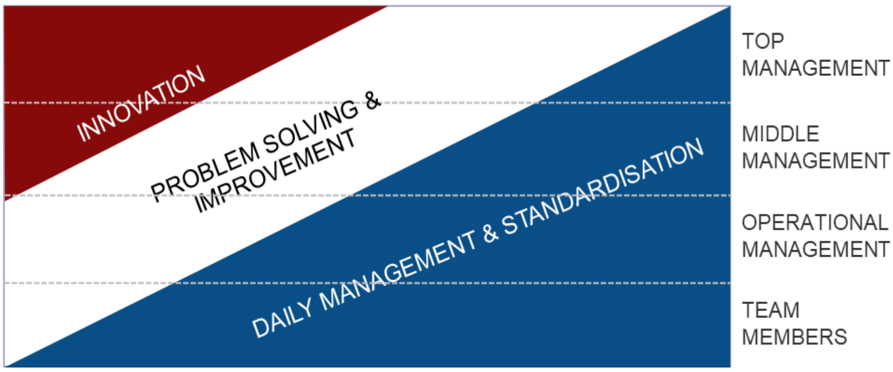


Figure 2- Representation of the levels of innovation on the logo

The basic concept of the philosophy is to try to implement a culture of continuous improvement in all elements and teams of the organisation. As previously mentioned, the *Kaizen* organisational development model is based on five principles, regardless of their domain: increasing productivity, shortening lead times, improving service level, or increasing quality indices:

<u>Create customer value</u>

In any organisation, the main goal should be to achieve the highest added value possible for its customer. Therefore, customer satisfaction must be assured by guaranteeing the best quality possible at a reasonable cost.

<u>Create flow (zero waste)</u>

Always look for creating flow in production/logistics, Planning must be made by Pull and *Muda* must be eliminated.

Muda is a Japanese word meaning waste. Taichi Ohno (one of the founders of Toyota Production System) believed all activities that did not add value to the client should be classified as waste and one should try to eliminate them.

These wastes were organised into seven types:

1. Waiting for people
2. Waiting for materials and information
3. Movement of people
4. Movement of material and information
5. Overproduction
6. Overprocessing
7. Errors

Go to Gemba

Gemba is the place where value is added and one of the key success factors in implementing the *kaizen* philosophy is focusing on working as close as possible to it. It is not feasible to run an organisation exclusively from within a control room, the improvement opportunities are not there, they are in the *Gemba*, therefore that is where we must act. Find the root causes of the problems and standardize the work done.

Empower people

The involvement and motivation of all employees from directors to operators are necessary to be effective in implementing the continuous improvement philosophy. Everyone must be in sync with the goals and strategies as well as no one should be blamed or judged.

Be transparent/visual

All arguments must be supported by data preferably with good visual management assuring the problem is visible and easily understood by everyone.

5 S

The 5S tool consists of a system to reduce waste and optimise productivity and quality. It is based on the principle that a good organisation of the work area guarantees more efficient management of the material and human resources of any team. The term originates from the five Japanese words *seiri*, *seiton*, *seiso*, *seiketsu*, shitsuke which can be translated to sort, arrange, clean, standardise and discipline respectively (Hiroyuki, 1995).
This exercise must follow the suggested order and starts with an exhaustive sorting in search of everything that is or is not necessary to be present at the workstation. As an auxiliary, a list of all the operations executed in said workstation may be helpful.
The next step is choosing the correct storage location according to the usage frequency. Table 2 exemplifies a logical solution for this question. One common affirmation to explain this step is "a place for everything, everything in its place".

Table 2- Exemplification of storage location according to usage frequency

Priority	Usage frequency	Storage location
Low	Equal or less than yearly	Central storage area
Average	Trimestral or monthly	Departamental storage area
High	Weekly, daily or hourly	By the point of use

Step three regards cleaning the workstation. The optimal goal would be to restore the initial conditions of the facilities/equipment and inspect to make problems visible. If it is necessary to repair any defect in the equipment, it is at this stage, as well as acquiring new tools to facilitate the execution of the tasks.

The standardization phase involves the creation of visual standards to ensure that the first three steps are explained thoroughly and can be implemented daily. There are a lot of possible suggestions for this phase to be successful in transmitting organizational values to the workers such as using colour codes as much as possible. Figure 3 shows an example of the difference between a factory before and after implementing 5S.

Figure 3- Before and after example of implementation of 5S

The final step is discipline, and it is essential to ensure compliance with all the standards previously created. Therefore, the success of a 5S initiative and the consequent results only are seen if this step is carefully addressed. The golden rules for succeeding are the involvement of all employees, as one of the *Kaizen* values explained, and the auditing of the compliance with the standards.

Total Flow Management

TFM was developed based on creating flow through all processes striving to reduce lead times, improve quality and shorten costs. This model stands on 3 pillars and incentives Pull Flow, allowing the organization to optimize resources by answering only to the needs of the clients (Coimbra, 2013). Contrary to push logic, where the production looks back and is planned based on previous consumption, pull logic looks ahead, meaning only known requirements must be produced (Vinelli, 1988).

Figure 4 is a representation of the mentioned 3 pillars which are: Production Flow, Internal Logistics Flow and External Logistics Flow; brought together by the elimination of Muda (waste), increase of added value operations percentage and reduction of the batch sizes and lead times. (Coimbra 2013).

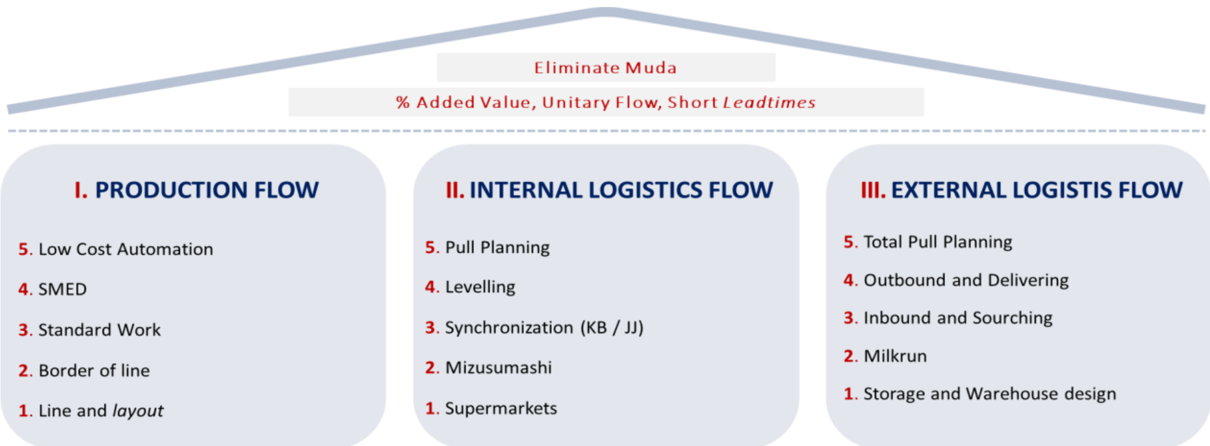


Figure 4- Representation of the pillars of Flow Improvement based on TFM

Production Flow is achieved by reducing Muda with the auxiliary of a functional line design and layout of the workstation and an accessible border of line. The purpose of creating flow is to establish an uninterrupted streamline from the begging to the end of the process, resulting in a reduction of stocks and intensification to the maximum of value-added. Any unnecessary stop or speed reduction in the production is considered a loss of flow efficiency impacting the lead time and costs. All operations should be standardized according to the easiest, fastest and safest way to be performed known to date. The fourth step is accountable for reducing set-up times through SMED (Single Minute Exchange of Dies). Shortening the unprofitable time in between the manufacturing of different SKUs will provide a more flexible production with easier portfolio rotation and levelling planning. It is a fundamental step towards eradicating the *Muda* of overproduction, the worst of all the *Muda*'s since it is known for camouflaging the others. At last, low-cost automation should be implemented to facilitate the execution of operations.

Internal Logistics Flow is a mechanism responsible for improving the efficiency of all the movements of material, WIP, people and information. This should be constituted by supermarkets, *Mizusumashi*, synchronization, levelling, and Pull Planning. The first is a small quantity stocking point with easy ground-level picking, restocking based on consumption and visual management. The second is the operator/equipment that transports the materials and information in "train station" mode, meaning there is a fixed route and expected time cycle. Synchronisation refers to how the Mizusumashi provides the border of line either in *Kanban* (continually) or in *Junjo* (sequentially). Finally, levelling guarantees the capacity of production is being respected by defining the production plan of each workstation and Pull Planning assures client requirements are being fulfilled.

External Logistics Flow relates to material loading and unloading operations. To be insured the warehouse design should minimize waste and maximize storage; external transportations must follow the Milk Run method; Inbound/Sourcing and Outbound/Delivering must be efficient; Total Pull Planning must, at last, be implemented.

Internal Logistics Flow

Due to the theme of the study, it is important to further explain the internal logistics flow pillar.

Supermarkets

Supermarkets are dynamic storage areas strategically located to provide a simplified supply of materials. The name was influenced by the comparison with a common supermarket where any customer can easily pick up the goods necessary and continue en route through the neatly aisles and shelves.

The several shelves can be found divided into small spaces that are filled with a single type of product with a fixed location with the aim of creating picking habits. Other characteristics are easy to access for picking (storage at floor level) and use of visual management (very important for stock management). The quantity and variety of materials to be placed in the supermarket depends on the proximity of the supplier, the consumption rate and the number of materials involved such as the value of the materials or components. These quantities must be calculated and scaled.

Its main objectives are to cancel out variations in demand so that each of the upstream processes can have a more even workload and create an internal flow between the various areas of the factory, namely between the material input area, the production area, the assembly area and the final storage area.

Mizusumashi

The second domain of improvement in logistic flow is the Japanese word *Mizusumashi* which stands for "water beetle". This references a logistics worker that transports items internally using a predetermined cycle path. This person is in charge of handling all information connected to production orders as well as container flow. By repeating the same movements in a predetermined cycle, the commonly called *Mizu* transports the flow containers between supermarkets and line borders. During this cycle, the worker will verify the availability of all the required materials at a specified number of stations along the way. They rely on a small train with sufficient load capacity to serve all the stations on its defined route and send information to many locations.

The pitch time is the nomination for the fixed cycle time. It would be equivalent to the cycle time if the *Mizusumashi* moved one piece at a time. However, this time should be designed to transport multiple small containers to many sites of usage within the boundary of several lines. An easier way to understand is almost as the production operators on the lines are the customers of the transporter. They have a logistics provider that visits every 20 to 60 minutes to check if any of the material is missing and eliminates any empty containers or waste created throughout the process (reverse logistics). Production can count on a consistent and timely supply (Coimbra, 2013).

Synchronisation

There are two possible ways to establish synchronisation in a pull supply chain, the *kanban* logistics cycle (continuous supply) and the *junjo* logistics cycle (sequential supply). The decision between continuous and sequential needs to be based on a compromise between the design of the supply process, the cycle time of the task and the amount of stock (Coimbra 2009).

In the *kanban* logistics cycle, the material is always available at the point of use and there is a continuous cycle of logistics replenishment. A *kanban* (which means "card") represents a replenishment order for material from a customer to a supplier and should contain as basic information the material ID, the customer ID, the supplier ID and the fixed quantity. In a *kanban* system, when the stock of a component in a supermarket reaches a certain level, there is an order for the restocking of material for the upstream process. The quantity for repositioning level must be dimensioned so that the supermarket does not run out of stock during the time it takes the *Mizusumashi* to make its route (pitch time). Besides this, a safety stock should be added to face the variability of the demand.

The ideal would be to have all parts on a continuous cycle of restocking on the line side next to the operators. However, keeping all references at the line side implies the use of a lot of space and therefore less ergonomics for operators and changes of movement. To circumvent this the use of sequenced supply for some parts is common. Typically, the references that are allocated to this type of synchronisation are those that have less rotation or those that take up more space. Through this synchronisation system, a sequence is established for the supply of these components to the line side according to the production plan.

When components are supplied in sequence, they are usually delivered to the line side as a *junjo* kit. The kit will have all the components required by the operators at each workstation on the line and will be delivered according to the sequence of the main product (Coimbra 2009).

Levelling

The fourth domain of improvement in logistic flow makes it possible to reduce the amplification effect of demand and to even out the workload. This tool allows to level the demand variability by sending a fixed value of products to production daily. This tool acts according to the real demand, with customer orders and replenishment orders being transformed into *kanbans* so that the production can be levelled later. The main elements that constitute the levelling are:

- Logistic box: allows the number of daily orders sent to production to be levelled according to the available capacity. This box is a physical device that enables the placement of *kanbans* according to the production start day, with each column corresponding to one day
- *Heijunka* or Levelling box: a physical device where the time in each column is equal to the complete standard cycle of the *Mizusumashi*. This respects the capacity of each line or workstation.

- Sequencer: dictates the *kanbans* to be produced, ensuring the FIFO system, and showing the delay or advance of production, next to the production or assembly area.

Figure 5 shows an example for each element in order:

Figure 5- Examples of the main elements of levelling (logistic box; *heijunka*; sequencer)

Pull Planning

Pull planning purpose is to produce products in the most efficient way possible so that they can be pulled off the production line quickly and efficiently. This system differentiates from a push system since it will only rely on customer orders or consumption replenishment orders instead of on forecast approximations. Orders will need to be calculated and sent to the right places in the supply chain on a daily or even continuous basis to ensure the correct items are being delivered to customers. (Coimbra, 2013)

Table 3 simplifies the comparison between the main differences between both strategies.

Table 3- Comparison between push and pull strategies

Push	Pull
Production approximation	Actual consumption = Production precision
Large lots	Small lots
High inventories	Low inventories
Does not limit WIP	Limits WIP
On demand availability	Delayed availability

In addition, it is possible to follow a Pull by pushing model. Similarly to the pull model, a production order is introduced at the end of the line. In contrast, the last phase of the process does not communicate with the immediately preceding phase, but rather with the first phase of the process. After passing this information to the initial process phase, the system works as the push model, pushing the manufacturing orders through the various operations.

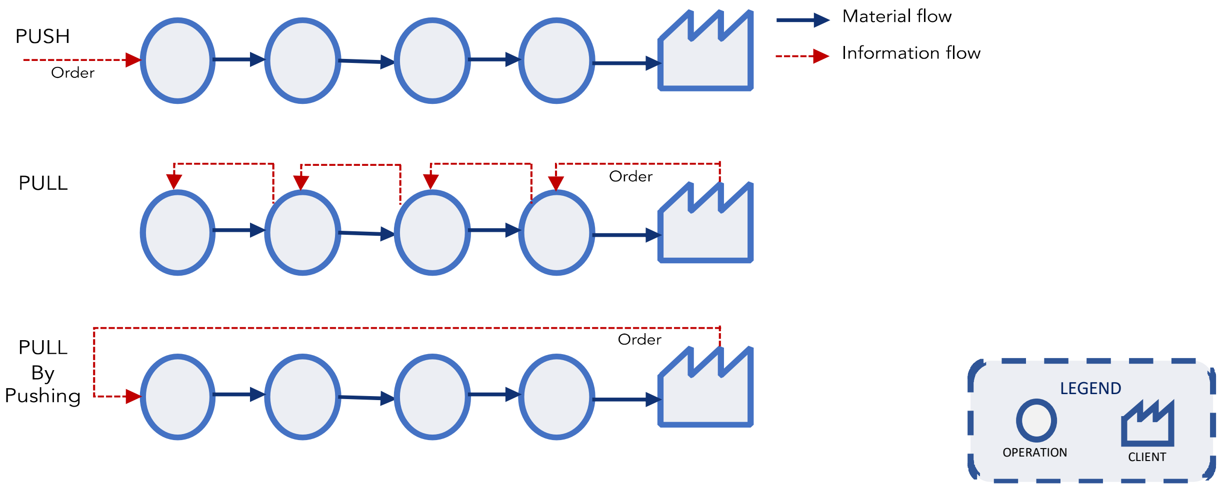


Figure 6- Exemplified Push, Pull and Pull by pushing models

The first step in implementing a Pull by pushing system is to decide which type of planning strategy will be best for the finished goods. There are two basic strategies: make-to-stock and make-to-order (Coimbra, 2013). This topic was already discussed by Popp (1965) who compared the cost of production to stock versus making it to answer an order. In Figure 7 it is possible to see the main differences between both strategies. The first creates a stock of finished products having the advantage of a short time to answer a client's request. However, this implicates a large inventory of finished products occupying space in the factory associated with high stocking costs. The second one does not show stock in any step of the process resulting in almost no costs associated, nevertheless with a slower response to customers.
In conclusion, in MTO the client's request is in control of the levelling and triggers the beginning of production as a mean to optimize resources and guarantee delivery due dates are obeyed. In MTS the client's request is answered in a shortened period of time and results in the order of production for replenishing the stock consumed.

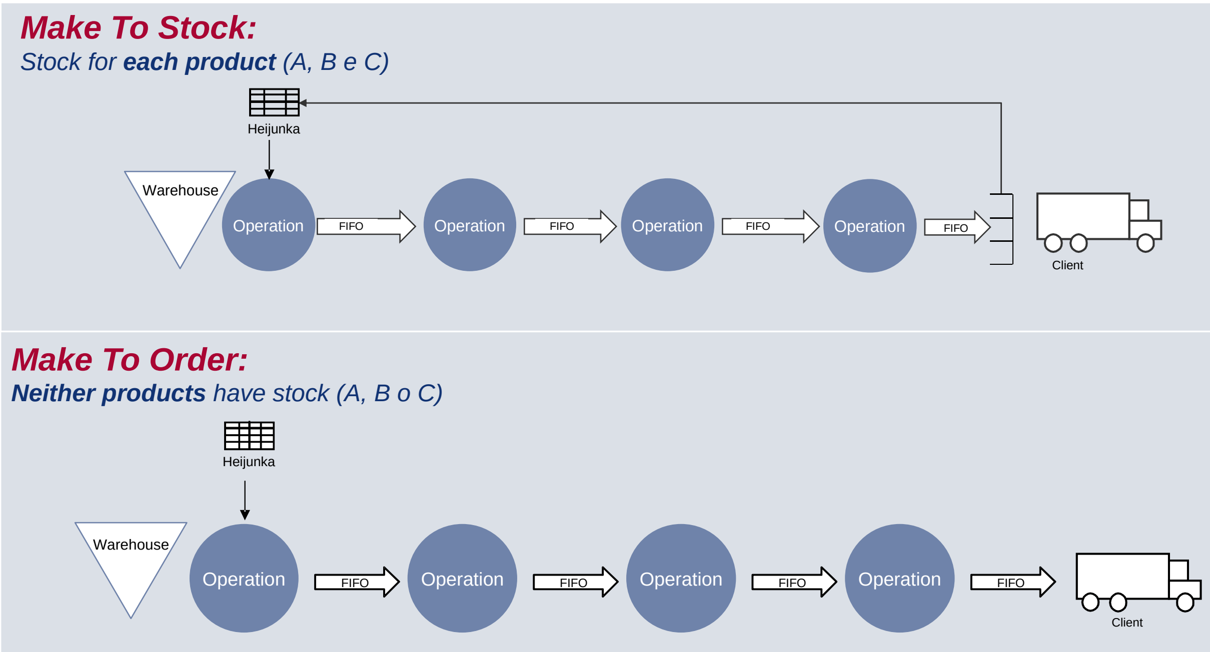


Figure 7- MTS and MTO overview diagram

Nowadays it is known a structured mix of the two strategies is a reasonable solution, making the decision on which part number in the portfolio should follow each strategy extremely delicate. To make an assertive decision it is common to conduct an ABC/XYZ analyse which will be posteriorly detailed. With this tool, it should be determined which SKUs represent the higher volume and frequency of production and therefore must follow the MTS strategy while the other SKUs the MTO.

2.2 ABC Analysis

The Pareto Principle on which the ABC analysis is based was established by Vilfredo Pareto, an Italian economist who studied the distribution of wealth in Italy. Pareto concluded that 80% of the country's wealth was concentrated in just 20% of the population and created the well-known 80/20 rule, stating that 80 per cent of consequences are the outcome of 20 per cent of causes. The most frequent application of this principle is in the analysis of sales, to demonstrate that in each business, 80 percent of sales are generated by 20 per cent of the references (SKU). This analysis can also be useful when characterising inventory control points having in consideration the money each SKU generates (Silver, Pyke, and Peterson, 1998). On the other hand, various authors withstand it is necessary to have in consideration more than one criterion when categorizing inventory, some characteristics debated are quantity stored/consumed, delivery time, criticality, cost, and durability (Soylu and Akyol, 2014).

The ABC analysis is especially helpful as an analytical method of analysing a large number of data such as long lists of references while categorizing stocks. This classification facilitates the separation of SKUs into three groups based on their importance (A being the most critical, B intermediate and C the least), either in terms of value in sales, space occupied or quantity. After the distribution, it becomes evident that group A should have a higher stock level when compared to groups B and C, as well as a greater management effort such as a more accessible location in the storage.

As discussed by Soylu and Akyol (2014), basing a categorization only on one criterion has proven insufficient and therefore it is possible to create multiple criteria ABC analyses with both quantitative and qualitative criteria.

The XYZ analysis distinguishes between items according to their consumption variations. Errasti (2010) summarizes the classes as follows:

- X: consumption is relatively consistent.
- Y: more volatile consumption, mainly due to trend-moderate or seasonal reasons.
- Z: erratic consumption.

Table 4 was constructure to clarify the structure of the analysis:

Table 4- ABC/XYZ analysis structure

		Volume		
		A	B	C
Fluctuation	X	High Volume, Stable		Low Volume, Stable
	Y		Average Volumes, Fluctuating	
	Z	High Volume, Very Fluctuating		Low Volume, Very Fluctuating

In this study, a variation of ABC and XYZ was created having into consideration the volume of sales of each reference (A<85%; 85%<B<95%; C>95%) as well as sales frequency (X= weekly; Y= monthly; Z=yearly), since the company reported that fluctuations were not relevant.

2.3 Job-Shop

A manufacturer specialized in custom-built or tailor-made parts is commonly called a job shop. When so, production is focused on creating specific products for each customer at a time. This is a typical scenery in the metal mechanical industry since it feeds other industries' personalized needs for production. This process structure is characterized by its layout, where similar equipment or functions are placed together, such as all drill presses in one area and grinding machines in another. Material handling, cost, and work-in-process inventories are all minimized by the layout.

There is a special discussion around the planning of factories that follow this strategy considering that they must comply with unique set-ups and sequencing of processing for each order. Various constraints should be contemplated for the projection (Falkenauer and Bouffoix, 1991).

- Capacity constraints: the most essential limitations, at any given time, only a limited number of resources of each sort are accessible. When more activities are scheduled on a type of resource than are available, the schedule becomes unworkable (e.g., it is not possible to execute three laser cutting operations simultaneously if there are only laser cutting machines available).
- Precedent constraints: operations that are members of the same task to complete partial or complete order. These are often known as technological restrictions since they frequently translate a required sequence of activities (for example, first drill a hole, then insert a screw).
- Temporal constraints: most time orders must start after a specific date (earliest starting time available) and end before a specific date (due date). These should account for the possibility of being jeopardized by lack of material (i.e., the job can't begin) or delays in operations that are subcontracted (e.g., transportations). Remember that the due date constraint is usually soft, meaning that it can be ignored for a higher cost (client dissatisfaction).
- Pre-emption constraints: enforce resources to be unavailable for non-production reasons during predetermined time intervals (e.g., maintenance or repair).

2.4 Bottleneck

The bottleneck has been a well-known concept amongst production management. The name refers to the narrowest point of a bottle, where the liquid flow is slowed down which can be analogic to being the step that defines the flow velocity of production. Its simplest definition might be a point of congestion in a process resulting in inefficiencies and delays. Bottlenecks could be a machine, an assembly line, or any other working station on a process. These are responsible to define the capacity of production since they are the slowest point therefore, they should be the first to be analysed when trying to increase the production daily output. (Jacob, 2018)

2.5 Key Performance Indicators (KPIs)

To analyse the impact of the project on the factory several key performance indicators (KPI) can be followed accordingly to the theme of the study:

- On-Time Delivery (OTD) = $\frac{\text{\#Orders delivered on planned time}}{\text{\# Total orders}}$
- On-Time in Full (OTIF) = $\frac{\text{\#Orders delivered on planned time in full}}{\text{\# Total orders}}$
- Quantity of finished product stock
- Number of complaints

These indicators are often used to measure the level of customer service and, consequently, customer satisfaction (Ishaq Bhatti, 2014). On-time delivery presents the ability, as a percentage, of the company to respond to the customer within the agreed timeframe. On-time in full differs only in that it also takes into account whether the delivery was in full or in part delivered to the customer. Having a stock of finished products is a known measure to assure fast answers to customers' requests and for that reason, its quantity is also a key performance indicator. The last one would be the number of complaints carried out.

- Planning compliance = $\frac{\#\text{Production orders on planned time}}{\#\text{Total orders}}$

Regarding the manageability of the production and employee satisfaction, planning compliance is a factor that should be taken into account. This percentage indicator conveys the ability of the production to follow the initial planning.

- Overall Equipment Efficiency

The overall equipment efficiency (OEE), as the name subjects monitor the performance of machines in production lines. This indicator takes into consideration three metrics: the amount of time equipment is available to perform its function; how long it takes to complete a process compared to the expected time and the number of units with acceptable quality (Pomorski,1997). The following formulas are used for its calculation:

$$OEE = Availability \times Performance \times Quality \tag{1}$$

$$Availability = \frac{Run\ Time}{Available\ Time} \tag{2}$$

$$Performance = \frac{Expected\ Cycle\ Time\ \times Total\ Count}{Run\ Time} \tag{3}$$

$$Quality = \frac{Good\ Count}{Total\ Count} \tag{4}$$

Since calculating each metric individually might not be possible it is possible to simplify the formula by annulling repeated values, which results as:

$$OEE = \frac{\sum^{SKU}(Good\ Count\ \times Expected\ Cycle\ Time)}{Available\ Time} \tag{5}$$

In short, if a machine has an OEE of 100% it means that it only produces quality parts, at the maximum rate and without any type of unplanned stoppage. This evaluation includes three criteria, which makes it very difficult to obtain high values.

3 Initial Situation Characterization

A thorough characterization of the present situation is the most critical step to ensuring the correct identification of the existing problems. For this reason, most of the project's time was devoted to this phase.

3.1 Process Description

3.1.1 Metal Mechanical Industry

As a metal mechanical industry player, Company X follows a job shop production strategy offering its clients the possibility of producing their designs with attention to detail and experienced technicians.
The skills mastered by the company are:

- Laser cutting with optical laser machines, special ones for tube cutting, fibre cutting and a combined machine it is possible to cut steel, stainless steel, aluminium, and other materials to answer simple or demanding projects
- Tube bending in a CNC machine with software to enable a variety of bend types, forms, and configurations
- Calendering with high precision
- Bending with sheet metal bending and panel bender allied to the usual expertise of the operators
- Machining with milling machines and metal lathes to make quick work of materials
- Welding with MIG, TIG, spot welding and welding robots
- Finishing and complimentary services: painting, polishing, laser engraving, Zinc plating, shot blasting and others
- Assembly with quality control enforced by an ISO 9001 certified team

These machines are organized in the company by 3 classifications: The first is the operation centre, the second is the task post and the last is the unity of the machine. For example, a laser cutting machine would have been described as: Center of operations LS2, task post CR, unit 1.

The mapping of the operations is presented in Figure 8 only as a simplification for a better understanding of the typical order and common processes.

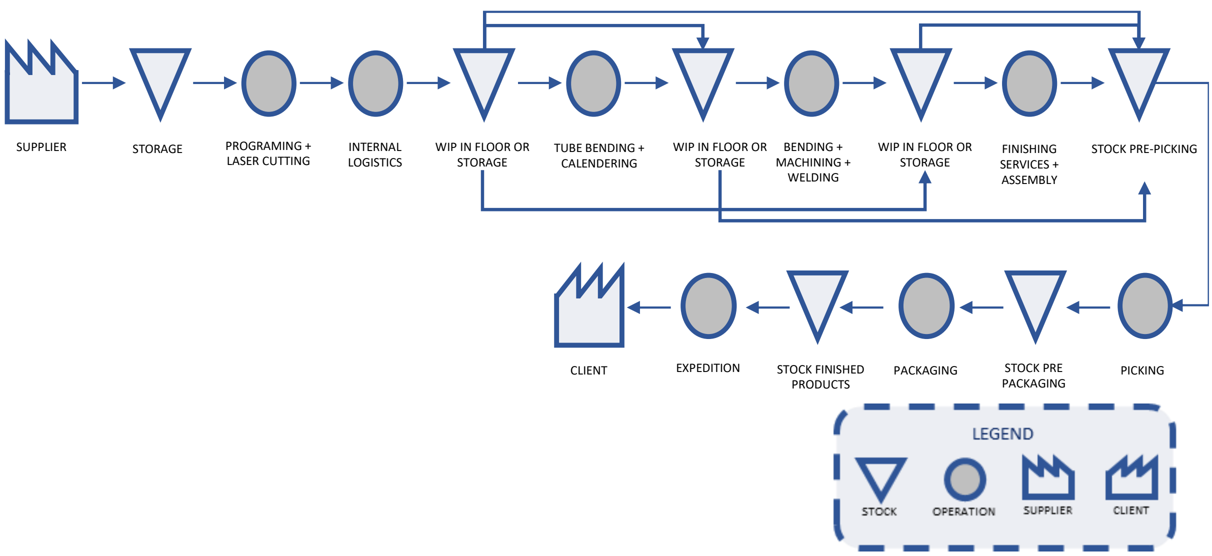


Figure 8- Simplified mapping of operations

3.1.2 Factory layout

For a better situation characterization, it was considered relevant to present the material movements through the factory to become a finished product for one of the most common trajectories, which is the laser cutting plus bending processes. The several steps represented in Figure 9 will be described in this paragraph, considering the flow represented by the red arrows. The initial phase is the reception and storage of the raw metal plate. The metal arrives at the factory (1) and is placed in a waiting zone (2). Next, it is stored (3) in the middle automatic warehouse that facilitates the movement of the plates through the factory to the several laser cutting machines. It is ready for the first operation, 2D laser cutting (4) unit 1 was randomly chosen for this example. After the machine has finished the program, it is necessary that an operator manually separates all the parts from the plate and stores them in designated containers. The parts need to wait for a bending machine to be available in an assigned zone (6) and the second operation follows, bending (7). The last few necessary movements take place, which are the loading (8) and unloading (9) from the elevator that transports the product to the upper-level floor to be packed (10) and finally sent to the expedition (11).

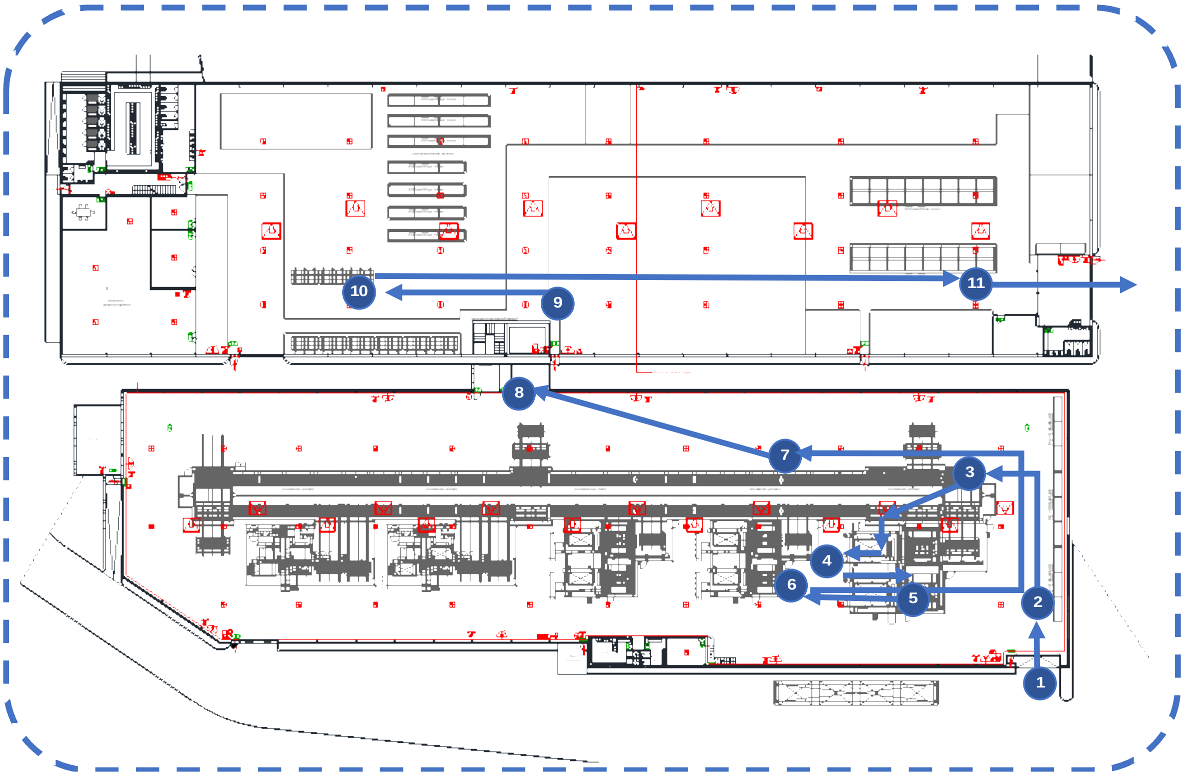


Figure 9- Factory's layout with the representation of a production process

As shown in Figure 9, eleven locations are required to complete the entire process. Since the parts in question are often heavy and difficult to transport, this number is higher than desired. In addition, there are long-distance moves and even floor changes that require special equipment. All in all, this process was considered complex and with room for improvement.

3.1.3 Order processing

The order processing required before the planning for production is executed was also documented. In Figure 10, a simplification of this process is represented, in the case of an order with parts never produced by the company. As observed, this is a complex procedure that was estimated to be taking around 5 days.

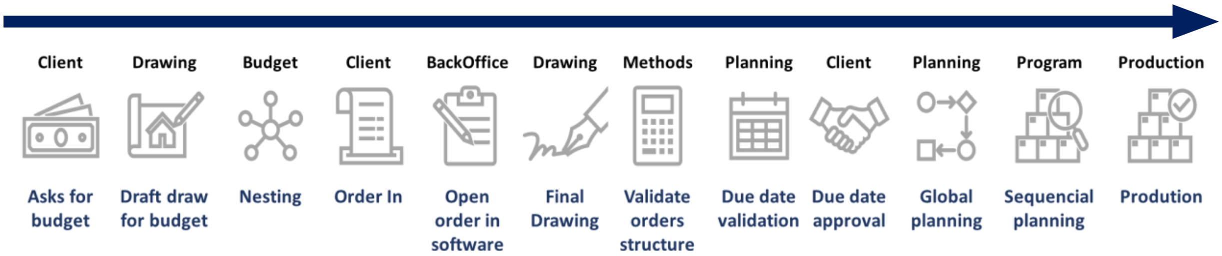


Figure 10- Simplification of the ordering process for new references

The action that initiates the sequence is the approach by a client that requests budgeting for one or more parts. This is directed to the Drawing team that drafts a simple draw that enables the creation of nesting for the plate by the Budget department. With the nesting created, the estimated price of production is sent to the client for approval. If approved, the order is registered by the BackOffice on the portal used for the management of the orders. Keep in notice that this portal differentiates from the planning software since it is not possible to insert orders with parts without the final structure.

Once the order is in the portal, the Drawing department starts working on the final drawings, with the necessary detail for production. It is then that the Methods department is able to determine which methods and machines will be needed for the manufacturing and how long each step will take. At this time the BackOffice has gathered all the necessary information to introduce in the software selected for production planning.

Based on the necessary time to produce the orders and with the know-how of the planning team a due date is discussed with the client and agreed to. After this, the planning team creates the fabrication orders with the date on which production should start, considering the due date negotiated with the client and the availability of capacity of each centre of operations. Finally, the order arrives at the programming department (responsible for programming the machines) and the detailed daily sequence of the production is defined. At last, production can start manufacturing the parts.

This process was identified as complex and long. In extension, this order of flux was not standardised, and multiple times wasn't followed as indicated. This resulted in disorganization and tension between the teams. It was also observed that the time needed to present a due date to the client was long, which didn't result in the loss of future sales but in client dissatisfaction. The members of the multidisciplinary team created to discuss the flow showed discontent with still using paper as a means of communication between departments.

The second possible situation, and more frequent, the parts required by the client have already been produced at least once in the factory. In this case, the process is reduced as shown in Figure 11.

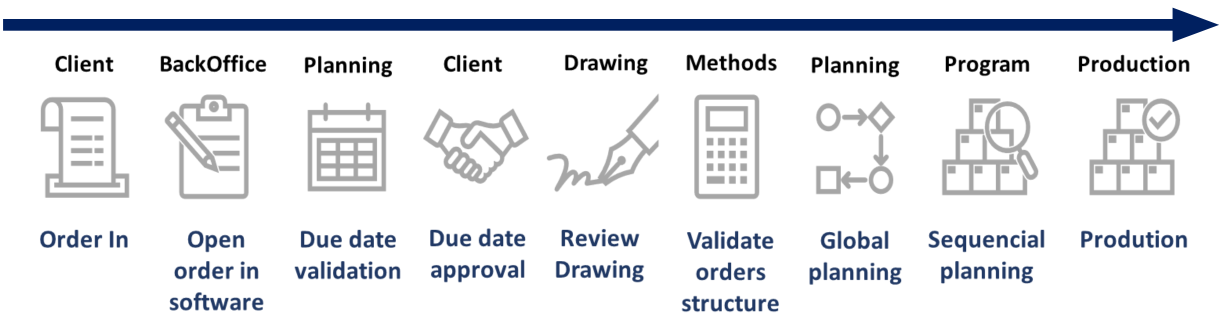


Figure 11- Simplification of the ordering process for references already produced in the factory

Even though this process seems simpler, it is in this flux that more delays occur. As we can see, since the parts are already inserted in the software as soon as the order gets registered planning can decide on an approximate date of the expedition to the client. However, global planning doesn't start immediately after this step as in the first process. Drawings and Methods departments need to review the drawings, either for quality assurance or because the client asked for small changes. This can cause a significant delay in the start of production and Planning can't predict the duration of the review, resulting in unreal due dates agreed with the client.

While in conference with the departments in question other issues were discussed. It was recognized as frequent that clients did not send all the necessary information regarding updating the drawings and took more than a day to answer when questioned by the Drawings team. This led to critical delays such as the order arriving at the global planning step already past its due date. Another frequent situation would be the client agreeing with a due date but then asking to anticipate the date for urgent reasons.

3.1.4 Problem identification

While examining the everyday of the factory 5 crucial difficulties were identified as urgent to correct. These issues were a result of the planning system situation that was submitted to an investigation to find the root causes of these straits.

1. **Overwork in some units and underwork in others**

   The first and most critical observation made was that the load attributed to the units exceeded capacity. Secondly, the distribution of work wasn't even, meaning some weeks a certain machine would work to its full capacity while other machines would be with low load and the week after the situation could be reversed. After carefully following and questioning the planning team it was shown that the global planning software was based on the Working Posts and didn´t have into consideration the machine unit and its specifications.

   For better understanding here is an example: In the laser cutting Operations Center (LS2), there were 3 working posts: Programing the machines (LS2PR), Cutting (LS2CR) and Logistics (LS2LI) which is the physical separation of the parts done manually by an operator. Included in the LS2CR are 5 units of 2D laser cutting machines: two for dimensions 4x2(m) and three for 3x1.5(m). If each machine worked 24 hours daily, it would have a daily total for the working post of 120 hours. If two orders of cutting a plate of 4x2 for 50 hours each have the same due date the planning software would recommend both those orders to be produced on the same day. This happens since the first constraint the software analyses is the due date and the second and last constraint is the amount of time it occupies from the working post (LS2CR). Since 50*2=100 hours which is less than 120 hours of capacity, the software approves the planning. In reality, those orders would only have a daily capacity of the two machines that have the 4x2 dimensions which are 48 hours. This situation would result in great stress in the factory since the other 3 machines would be unoccupied for 120-48=72 hours while it would be impossible for the two orders to be finished by the date agreed with the client. The example described although not based on true events reflected what happened weekly.

   Other possible causes identified in discussion with the machine operators were the frequent mistakenly cycle times. For example, a part that was described as taking 10 seconds to be laser cut would take about 20 seconds. This resulted in obvious delays in production.

2. **Constant changes in the planning do not allow the optimization of the production sequence and yield improvement**
   One of the keys to a more profitable metal mechanical business is the correct usage of the raw material. This topic is especially interesting in the laser cutting area where it is possible to combine more than one client's order in a metal plate nesting and program the machine to execute them together. However, for this to be possible there must be exact daily planning since combining the parts in the same nesting is not an easy job. In case there are a lot of changes in the planning, the material usage won't be optimized and there will be a loss of profit.

3. **Order deadlines without regard to production capacity, the capacity of administrative processes and the availability of starting materials**
   As mentioned before, the Planning department didn't have the correct visibility of the load/capacity of neither the administrative nor the production. As a result, the deadlines agreed upon with customers were only based on the worker's experience and the client's proposal. One prevalent circumstance would be the order only arriving at the production step passed its due date.

4. **Production sequence increases production lead times**
   After global planning, where orders are planned by the day, it's the sequential planning responsibility to define the order of production through the machines. After following this process, it was concluded that there were only taking into account two variables: the due date and the nesting for material saving in the laser cutting. Since the following operations were not considered there was visible WIP accumulated between machines as a result of the uneven levelling. Exaggerated set-up time at some stations such as bending was also an issue identified because of this sequencing. Whereas there is a division of the total quantity of parts in an order in the laser cutting machines in multiple days, for the benefit of metal plate utilization, there shouldn't be in the bending operations since these machines required long set-ups.

5. **The invisibility of the existence of bottlenecks and FIFO compliance in production**
   As previously explained, the planning sequence is based on the expedition date and the optimisation of the metal plates usage for the laser cutting process. The other processes are expected to follow the FIFO method since the sequence is already accordingly to the expected due date. Due to the disorganization on the factory floor, it wasn't possible to visualize just how much WIP there was in the factory. It should also be added that the information flow even on the shop floor is poor. Since it is not defined physically or informatically, the operators must search through the work guides papers the correct order for production. As a result, most time the FIFO (First In First Out) rule wasn't followed and some parts were forgotten or lost.

3.2 Descriptive analysis

3.2.1 Production flow quantification

The nature of a job shop manufacturing model results in an infinite number of production processes since each order might have its sequence of operations. To quantify the relevancy of each route a study was pursued taking into consideration the manufacturing orders from the last six months of the year 2021. In Appendix B the subject can be inspected with exhaustion however the main conclusions are presented in this chapter.

Figure 12 shows that 49,5% of parts that arrived at the expedition were sent directly from the Laser Cutting 2D machines and another 20% came from Bending. Sanding also presented a relevant value of 4,6%, as well as Combined Laser with 3,6%. At last, the Shot Blasting machine was the origin of 1% of the parts that arrived at the expedition. The remaining stations exhibited residual values.

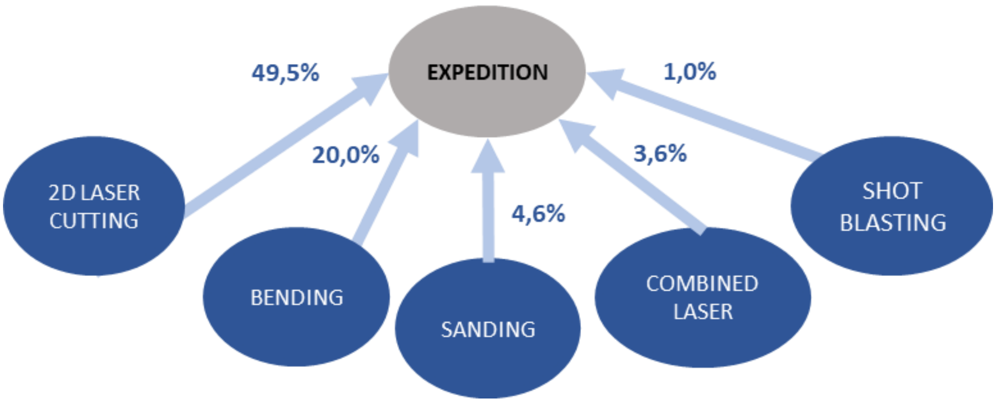


Figure 12- Representation of the origins processes before expedition

Following the first analysis, it was decided to study in more detail the relationship between the stations. To achieve this, the quantity of parts at each station was investigated with the upcoming operation in consideration. The main conclusions are shown in Figure 13.

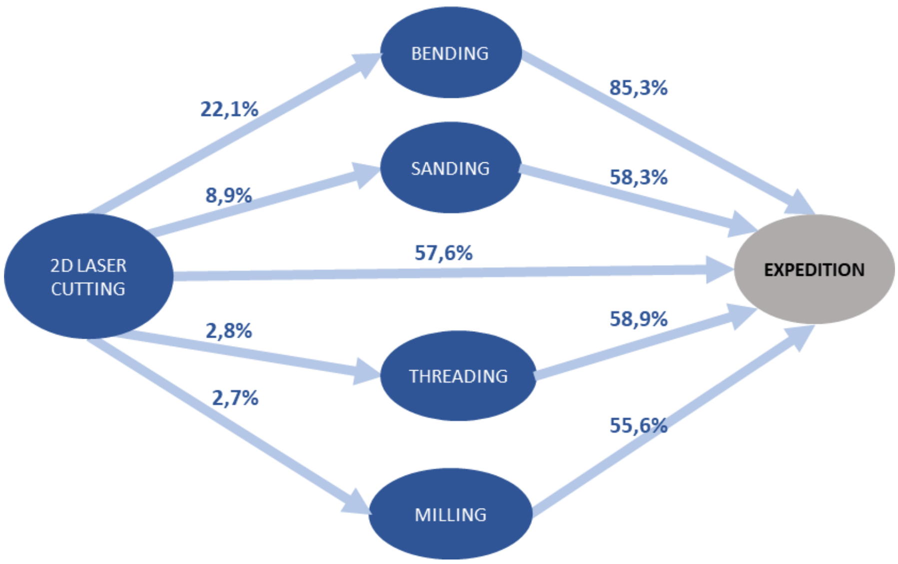


Figure 13- Detailed production flow starting in the 2D Laser Cutting

The map shows the main flows of the parts that feature sheet metal as raw material. The process therefore begins with the 2D laser cutting of the sheet, and while 57,5% of the parts go directly to packaging/shipping, the remaining 42,5% feature more complex flows. Of this remaining amount, 22,1% is known to go for bending, while 8,9% is known to be perfected in sanding. It was also concluded that 2.8% and 2.7% go on to threading and milling, respectively.

With this search, it was determined that from the production processes that start in the laser cutting 2D machines 57,6% were immediately concluded and 18,9% only went to bending. Leaving only about 23,5% of the parts with more complex processes.

3.2.2 Client's ABC/XYZ analysis

It was then decided to study the clients' relevancy to the company's business. For that reason, an ABC/XYZ analysis was developed regarding the quantities and the value of the orders for the full year of 2021. The classification used was A- 85% of volume, B- 85-95% volume, C- 95%-100% of volume, X- Ordered in over 48 distinct weeks, Y- Ordered in less than 48 distinct weeks but more than 11 months, Z- Less than monthly orders.

The quantities analysis results are presented in Table 5:

Table 5- Client's quantities ABC/XYZ analysis

Number of clients

	A	B	C
X	6 (2,0%)	0	0
Y	7 (2,3%)	16 (5,3%)	12 (4%)
Z	0	10 (3,3%)	249 (83,0%)

Units

	A	B	C
X	3 527 816 (57%)	0	0
Y	1 762 999 (28%)	359 913 (6%)	53 714 (1%)
Z	0	272 331 (4%)	260 438 (4%)

It is relevant to mention that 4 out of the 13 clients present in the most valuable classes (AX, AY, BX) are scrap buyers that acquire big quantities of metal scrap with low value. Therefore, from the 13 clients that buy 85% of all sales in quantities (units of parts) only 9 represent a finished product.

The value analysis results are presented in Table 6:

Table 6- Client's value ABC/XYZ analysis

Number of clients

	A	B	C
X	8 (2,7%)	2 (0,7%)	0
Y	9 (3,0%)	11 (3,7%)	4 (1,3%)
Z	7 (2,3%)	19 (6,3%)	219 (73%)

Value

	A	B	C
X	65%	1%	0
Y	13%	4%	0,4%
Z	7%	6%	5%

From the study, it was discovered that 8 clients represented 65% of the value in sales while 219 only represented 5%. This observation may also be useful for the analysis of the business structure and commercial strategy. The advantages of continuing to accept orders from customers falling into the lowest value classes of the analysis (BZ, CZ) were also reviewed. It was concluded that these included customers with possible scalability or relationships with the company. In contrast to the previous results, the scrap clients weren't present in the most

valuable classes of this analysis since the value of their orders isn't as significant as finished product clients.
Through this study, it was possible to identify the customers that are strategically of fundamental importance to the company.

3.2.3 References ABC/XYZ analysis

To follow the previous analysis where the strong impact of some clients in the business became clear, it was decided to put the references group through a similar analysis. The classification used was A- 85% of volume, B- 85-95% volume, C-95%-100% of volume, X- Ordered in less than 48 distinct weeks, Y- Ordered in less than 48 distinct weeks but more than 11 months, Z- Less than monthly orders.

The quantities analysis results are presented in Table 7:

Table 7- References quantities ABC/XYZ analysis

Number of SKU

	A	B	C
X	27 (0,1%)	22 (0,1%)	0
Y	555 (1,8%)	759 (2,4%)	497 (1,6%)
Z	751 (2,4%)	2 739 (8,8%)	25 864 (82,9%)

Units

	A	B	C
X	467 031 (10%)	3 261 (0,0%)	0
Y	2 492 311 (54,4%)	105 641 (2,3%)	14 719 (0,3%)
Z	931 822 (20,4%)	319 188 (7,6%)	214 239 (4,7%)

The study displayed that 2% of the references (104 SKUs) defined 64,4% of the total quantity sold. Nevertheless, the relevance of this analysis can be questioned since the quantity produced can be negligible parameter if the SKU in question involves an easy production or is small sized.
The value analysis results are presented in Table 8:

Table 8- References value ABC/XYZ analysis

Number of SKU

	A	B	C
X	60 (0,2%)	0	0
Y	1 031 (3,3%)	652 (2,1%)	354 (1,1%)
Z	1 841 (5,9%)	4 044 (13,0%)	23 232 (74,4%)

Value

	A	B	C
X	21,6%	0	0
Y	33,0%	1,5%	0,2%
Z	30,4%	8,5%	4,8%

These results were particularly interesting since they showed about 0,2% of the references (60 SKUs) were sold every week and represented almost 22% of the total value of sales. On the other hand, 74,4 % of references (23 232 SKUs) only resulted in 4,8% of the total order's price. In summary, 9,4% of the references sold in 2019 symbolized most of the company's income (85%) and the other 90,6% represented the remaining value (15%).

3.2.4 Raw Material ABC/XYZ analysis

The last ABC/XYZ analysis followed through was regarding the raw materials consumption of tube and metal plates. The classification used was A- 85% of volume, B- 85-95% volume, C- 95%-100% of volume, X- Ordered in less than 48 distinct weeks, Y- Ordered in less than 48 distinct weeks but more than 11 months, Z- Less than monthly orders.

The quantity analysis results are presented in Table 9:

Table 9- Raw material quantities ABC/XYZ analysis

Number of SKU

	A	B	C
X	10 (0,1%)	0	0
Y	91 (1,1%)	7 (0,1%)	0
Z	163 (1,9%)	2 359 (27,4%)	5 992 (69,5%)

Units

	A	B	C
X	12 210 (10,2%)	0	0
Y	39 311 (32,8%)	291 (0,2%)	0
Z	50 243 (42,0%)	11 724 (9,8%)	5 988 (5,0%)

The results showed that 1,2% of references (101 SKUs) of raw material covered 43% of the consumption of tubes and metal plates. It is important to explain that this analysis has into consideration the different occurrences of each type of material. This means a certain material for example “CC12345678” which would be a metal plate would have multiple SKUs because of the different dimensions it can be bought as, e.g. “3600x1250”; ”4000x2000”; “2100x1500”; etc.

The value analysis results are presented in Table 10:

Table 10- Raw material value ABC/XYZ analysis

Number of SKU

	A	B	C
X	10 (0,1%)	0	0
Y	94 (1,1%)	4 (0,0%)	0
Z	213 (2,5%)	1 271 (14,7%)	7 031 (81,5%)

Value

	A	B	C
X	15,6%	0	0
Y	34,9%	0,1%	0,0%
Z	34,5%	9,9%	5,0%

It can be concluded that 1,2% of references (104 SKUs) of raw material covered 50,5% of the value spent in the purchases of tubes and metal plates. It is also possible to see that the AY 94 SKUs make up for 34,9% when the 213 SKUs that are classified as AZ only correspond to 34,5%. This means that these references have a significantly lower price than the higher qualified. However, this analysis does not reflect any real strategy of the company since the values of the metal can variate consequently from worldwide factors.

3.2.5 KPIs

The last step to conclude the situation As-Is of the factory is to calculate the key indicators that were selected. The on-time delivery and on-time in full are distinguished for their objectiveness and straightforwardness and therefore were chosen to be studied. Since the company mentioned they were not able to reach their target of the quantity of finished product stock, this KPI was also found relevant to inspect. Regarding the number of complaints and planning compliance, these values were neither accounted for nor, for that reason, were not examined.

On-time delivery and On-time in full

Firstly, the on-time delivery, where completed orders were taken into account and studied having into consideration the temporal variable, as shown in Figure 14.

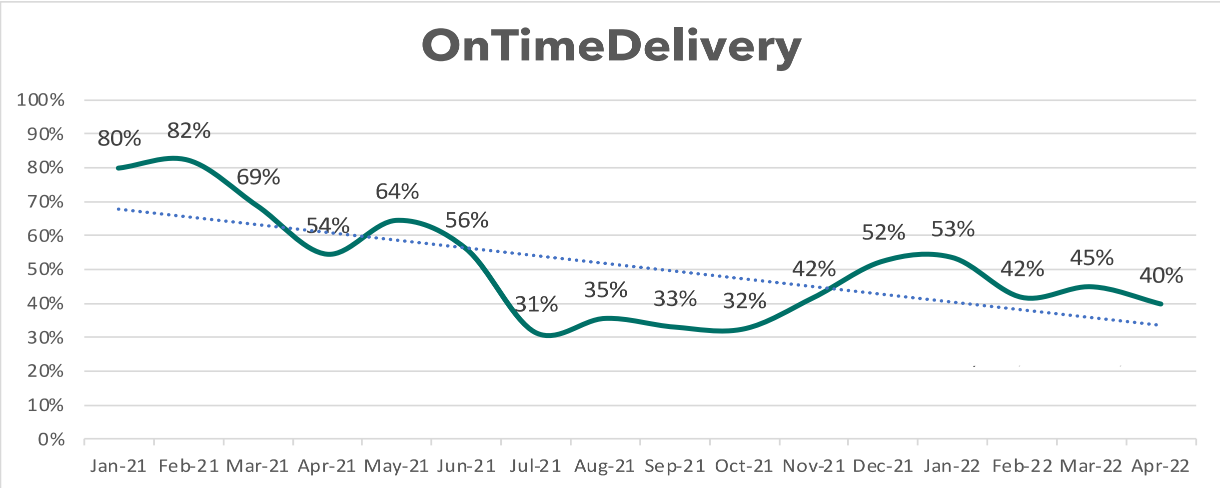


Figure 14- On-Time Delivery evolution and tendency

The decrease in time of the on-time delivery indicator may be justified by the increase in the number of orders by clients, resulting in a higher load of production work that without the most efficient planning was difficult to be concluded in time. For the validation of this hypothesis, the total sales value evolution was studied and shown in Figure 15.

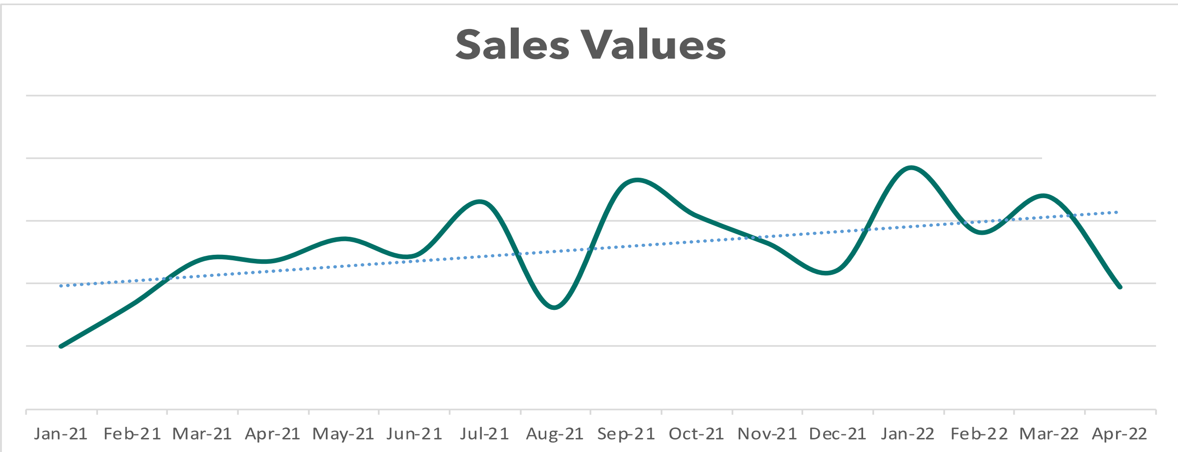


Figure 15- Value in sales evolution and tendency

As predicted the trend of the sales was the opposite of the on-time delivery. Even considering the trendline inclination the correlation is evident since the inverse of the inclination from the on-time delivery is approximately the sales values inclination.

The on-time in full percentage was also calculated, as presented in Figure 16, and the values are extremely close to the on-time delivery except for 3 months where the values were 1%

lower. This means almost every order is delivered late in full rather than on time but with only a part of the quantities expected.

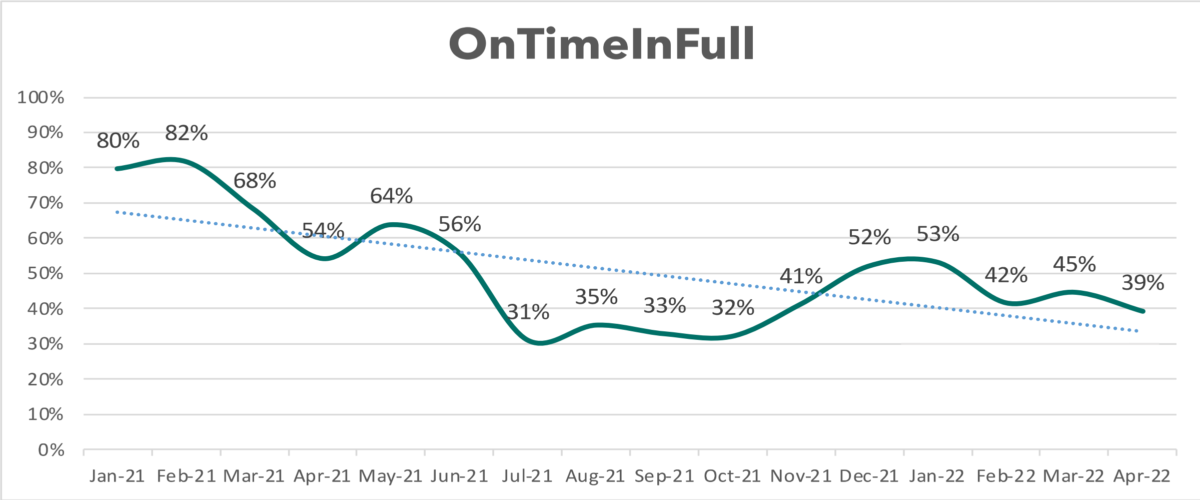


Figure 16- On-Time in Full evolution and tendency

Because the company in question delivers a heavy product and frequently to foreign countries the conclusion of this study seems logical. Due to the transportation costs, it is preferable to deliver in full rather than in more than one delivery.

Quantity of finished product stock:

The company already had a system where 1269 references that they established as frequently sold to the most relevant clients were dimensioned to have a stock of finished products. This included a defined safety stock and standard quantity of ideal production. However, it was concluded that 49% of references that were supposed to have safety stock were ruptured and that the solution wasn't effective in preventing late deliveries to the most valuable clients.

The process of creating the orders of production behind these references was investigated and the reason for the high percentage of rupture stock was found. Since production was consistently behind schedule, the replenishment of these safety stocks was considered secondary and irrelevant. Rather than creating manufacturing orders when the stock level reaches the replacement level, orders were only created when the customer placed a new order. The parts were therefore produced to fulfil the customer's order and not to create stock, which is the opposite of the objective of the solution implemented by the company. In addition, upon closer inspection it was noted that safety stocks were at values that did not meet current demand.

Overall Equipment Efficiency

To conclude the characterisation of the current situation of the plant and the identification of problems, an estimated OEE of the machines in question was obtained using the formula (5) already presented in the literature review.

$$OEE = \frac{\sum^{SKU}(Good\ Count\ \times Ideal\ Cycle\ Time)}{Available\ Time} \tag{5}$$

It was not possible to develop this calculation with the precision that was intended since there were no records of the previous exact available times. It is known that the machines can work in two shifts, three shifts daily or even overtime extraordinary hours depending on the necessity. However, there was no data regarding this parameter for each machine. For that reason, the typical tendency of the workstation was followed and as a result, the laser cutting workstation was estimated to be available for 2 daily shifts while the bending workstation was for 3 daily shifts.

The first machines to be put in perspective were the 2D laser cutting machines, since these are the bottleneck in the majority of processes, and the average results from Jan-21 until Apr-22 are disclosed in Table 11. Appendix C demonstrates with more detail the values calculated.

Table 11- Average value of the OEE for the 2D Laser Cutting Units

Unit	1	2	3	4	5	6	7
OEE	76,23%	59,54%	47,88%	65,49%	69,26%	23,08%	55,28%

The evidently low-value OEE of unit 6 was questioned and it was identified as a machine rarely used that would soon be discarded. Successively the OEE was estimated having into consideration the temporal aspect, as presented in Figure 17.

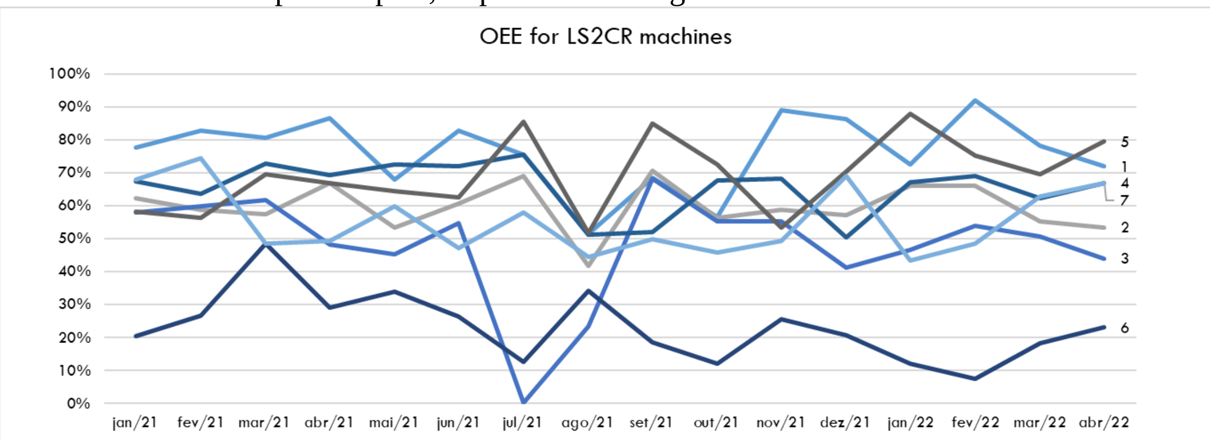


Figure 17- OEE evolution for the 2D laser cutting machines

The values were within expectations with a slight decline during August, which is common due to it being the holiday period for most employees. It is also possible to identify that unit 3 did not produce during the month of July, which was a measure to compensate for the employees on vacation. Regarding the variability between machines, there are reasonable values of 30% variance, which can be justified by the aforementioned poor load levelling or by the different performance of the operators in charge of each unit.

The second machines to be put in perspective were the bending machines and the average results from Jan-21 until Apr-22 are disclosed in Table 12:

Table 12- Average value of the OEE for the Bending Units

Unit	1	2	3	4	5	6	7
OEE	47,07%	43,48%	52,25%	53,01%	55,78%	59,07%	28,57%

Here there was once again an abnormality in unit 7. When questioned the answer found that justified the situation was that the newness of the machine made it harder for operating since the operators weren't as familiar.
Similarly, to the first case, the temporal behavior was introduced in Figure 18 and once again there was a sharp decline in August as a result of reduction of employees. In this workstation the variation between the units OEE is noticeably smaller than on the previously presented. A potential justification for the situation described could be the fact that the planning defines the production of the laser machines, since they are the bottleneck, and the other machines follow the FIFO law. Consequently, the levelling of the bending units is more effective.

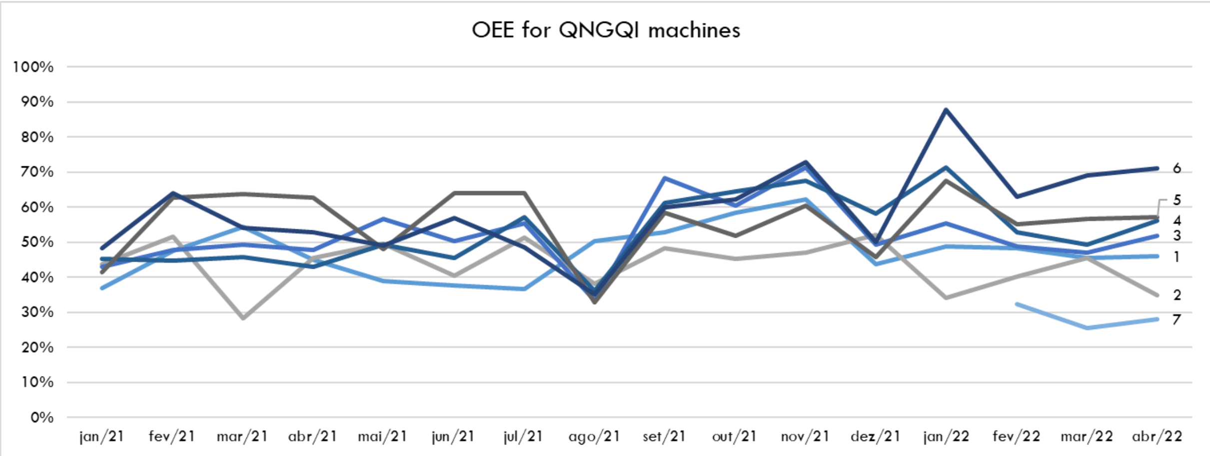


Figure 18- OEE evolution for the bending machines

4 Proposed Solutions

After careful characterisation of the plant's flows and identification of problems, it was then possible to start the process of designing solutions. Four steps have been created for sequenced implementation taking into account the level of priority, where each step includes several necessary measures. The action plans explain these measures, which are later developed and tested.

4.1 Capacity / Load Sizing

The correct dimensioning of each workstation's production capacity should be the starting point, which will deliver more immediate results. This will have the goal of rectifying the lack of load-levelling between them and removing planning for posts that do not meet the standards of the parts. To accomplish this, changes to the current system will be required, as well as the addition of additional elements to be considered. As 2D laser cutting is the bottleneck in most production flows this should be the first workstation to be reviewed. Next should be bending, as these machines can also be responsible for delimiting the output.

4.1.1 Action plan

Split planning from operation centres into workstations

As explained in section 3.5.1, the planning by the operation centre proved to be inefficient and faulty, with serious consequences on the company's ability to deliver. The most efficient way to correct these occurrences would be to separate the working stations into smaller groups of machine units with similar characteristics. In this way, it will be possible to plan accurately without having to go into the detail of the machine unit, as this would make the planning work excessively difficult.

For example, looking once more at the case of the 5 laser machines. If within this centre we have two machines for cutting 4x2 sheet metal and three for 3x1.5, then the most efficient way is to divide this post into two for planning. Once the necessary groups have been defined internally, the computer system company can easily insert this load division into the platform.

Consider Operational Efficiencies

Regarding the capacity of each workstation, it should not only be taken into account the opening working hours but also the efficiency of the machine. Therefore, it will be advisable to calculate the OEE of each machine every month and apply an average of the last 4 months to the capacity. Thus, ensuring that the analysis is factoring in the latest average performance of the equipment while also absorbing variations.

This will ensure that the planning is considering each machine's performance, unplanned stops and quality defects.

Consider Planned Maintenance

Each machine requires long-term maintenance (1-4 days) annually or every 6 months depending on the manufacturer. Therefore, since these maintenance jobs are scheduled in advance, they must be communicated to the planning team with enough time to cancel the capacity for the defined days. The easiest way to ensure that this communication is clear is to enter a manufacturing order for the maintenance as if it were a customer's order and plan it for the defined days, thus blocking the load. At the factory, this procedure was verified as possible and will be implemented when planned maintenance is booked.

Reserve Capacity for Kanban Replenishment

For strategic customers, based on the order history, the references that should be kept in stock of finished products should be defined or the safety stock should be resized. After that, the time required to produce the monthly consumption of these references can be calculated and deduced on capacity. This solution will significantly improve the response time to the needs of major customers.

Characterize Theoretical Cycle Times

As +30,000 different references are produced per year, it would not be feasible to review all production times for all of them at once. However, using these erroneous cycle times repetitively has a huge disadvantage because it discredits production planning. Thus, the advice would be whenever a cycle time error is identified during production the operator should report it in the system. In this way, the methods and time department will know to rectify the reference production sheet.

4.1.2 Developments and testing

For the implementation of the first cycle of solutions the correct capacity of the machinery working posts was calculated using the following formula:

$$\textbf{Capacity (h)} = \sum^{units}\left([\text{Available Hours (h)} * \text{OEE (\%)}] - [\text{Production for } Kanban \text{ (h)}] - [\text{Production of delayed Orders (h)}] \right) \quad (6)$$

The results are exposed in Table 13 and Table 14 for laser cutting and bending as an example since they are the machine responsible for the most critical delays.

Table 13- Capacity study for the LS2 Centre

<table>
<tr><th>Operations Centre</th><th>Work Post</th><th>Unit</th><th>Available Hours</th><th>OEE</th><th>Load for Kanban</th><th>Load for delays</th><th>Daily Capacity</th></tr>
<tr><td rowspan="6">LS2</td><td rowspan="2">C1 (4x2)</td><td>1</td><td>22,5h</td><td>82%</td><td rowspan="2">17h</td><td>4,5h</td><td rowspan="2">6,4 h</td></tr>
<tr><td>2</td><td>22,5h</td><td>62%</td><td>4,5h</td></tr>
<tr><td rowspan="3">C2 (3x1,5)</td><td>3</td><td>22,5h</td><td>50%</td><td rowspan="3">24h</td><td>4,5h</td><td rowspan="3">6,15 h</td></tr>
<tr><td>4</td><td>22,5h</td><td>66%</td><td>4,5h</td></tr>
<tr><td>5</td><td>22,5h</td><td>78%</td><td>4,5h</td></tr>
<tr><td>C3 (templates)</td><td>7</td><td>22,5h</td><td>51%</td><td>3h</td><td>4,5h</td><td>3,975 h</td></tr>
</table>

Table 14- Capacity study for the QNG Centre

Operations Centre	Work Post	Unit	Available Hours	OEE	Load for Kanban	Load for delays	Daily Capacity
QNG	**Q1**	**1**	22,5h	48%	3h	4,5h	**3,3h**
	Q2	**2**	22,5h	40%	3h	4,5h	**1,5h**
	Q3	**3**	22,5h	50%	4h	4,5h	**2,75h**
	Q4	**4**	22,5h	58%	4h	4,5h	**4,55h**
	Q5	**5**	22,5h	60%	4h	4,5h	**5h**
	Q6	**6**	22,5h	73%	5h	4,5h	**6,925h**
	Q7	**7**	22,5h	23%	1h	2h	**2,175h**

This development started by grouping the units considering their specifications. It was necessary to gather a focus group with members of the production team to discuss each machine's characteristics. During this session there were various possibilities presented however, the main conclusion was that the dimensions were the most important parameter. For instance, the LS2CR work post was divided into 3: LS2C1 for the 2 units that fit 4x2 metal sheets, LS2C2 for the 2 units that fit 3x1,5 metal sheets and LS2C3 for the unit that needs templates.

Following that, the references to be produced for *Kanban* reposition were selected based on the ABC/XYZ analysis previously made. All references that fell in the AX and AY categories were reviewed with the production team and the list was reduced having into consideration the size and the frangibility of the parts. A SKU that oxidizes easily or is difficult to move will not be suitable for production for stock. It was then presented to the production team the possible formulas to dimension the stocks created for this SKUs.

To educate the production team about stock sizing, four models were created for an interactive engagement with this theory and explained, as can be consulted in Appendix D. The models differentiated from each other in the level of liability by applying different formulas for the safety stock. These included a fictional consumption of a product and by introducing a production lead time and a lot size the optimized security stock and reposition level is calculated considering the liability chosen. The models also show the service level, which represents the percentage of weeks that there was not a rupture of stock, as well as a graph with the evolution of various parameters.

After guaranteeing everyone understood the topic clearly the most appropriate formulas were agreed to, as shown in Appendix E, and the values were calculated, as shown in Appendix F. Company X was provided with this data and will make a final decision on which references would be kept in stock having into consideration the space available and the maximum value worth of the finished product imposed. To conclude this action the chosen references necessary weekly production time was estimated and divided by the 5 working days. This load was subtracted from each work post capacity to ensure there is time available for maintaining finished product stock.

At last, since the factory had a significant number of late orders to answer to, it was agreed to save 20% of the opening hours (22,5*0,2=4,5) for keeping up with delayed production, this value should be reviewed and reduced when possible. Another possible approach to this problem could be to not take any orders for 15 days and eliminate all the delays at once.

However, this solution did not fit the strategy of the company, and for that reason was not considered.
In addition, a dashboard in Power BI was created to demonstrate with more detail the availability component of the OEE evolution. It was reported by employees that there were many machine stoppages and that the reasons behind these were not studied. Therefore, from the dashboard, it is possible to calculate availability for any operation centre, workstation or unit and have the temporal factor into account. It also shows a Pareto chart with the causes of the stoppages. A second page was added for sharing the observations made by operators in the field for each occurrence. This dashboard is shown in Figures 17 and 18 as well as in Appendix G.

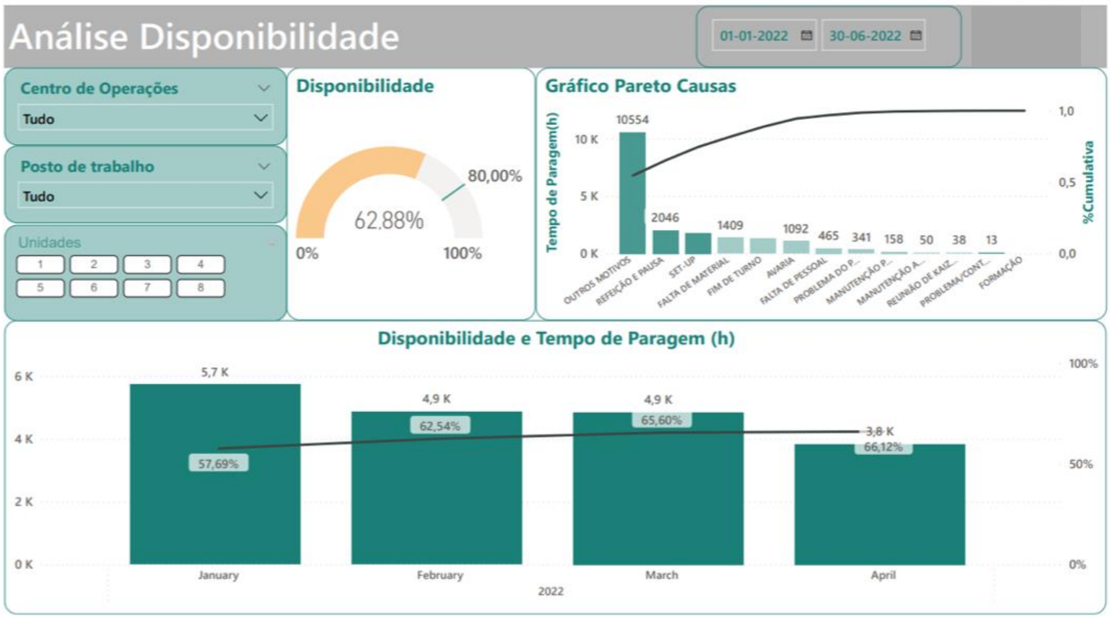


Figure 19- First page of the availability dashboard

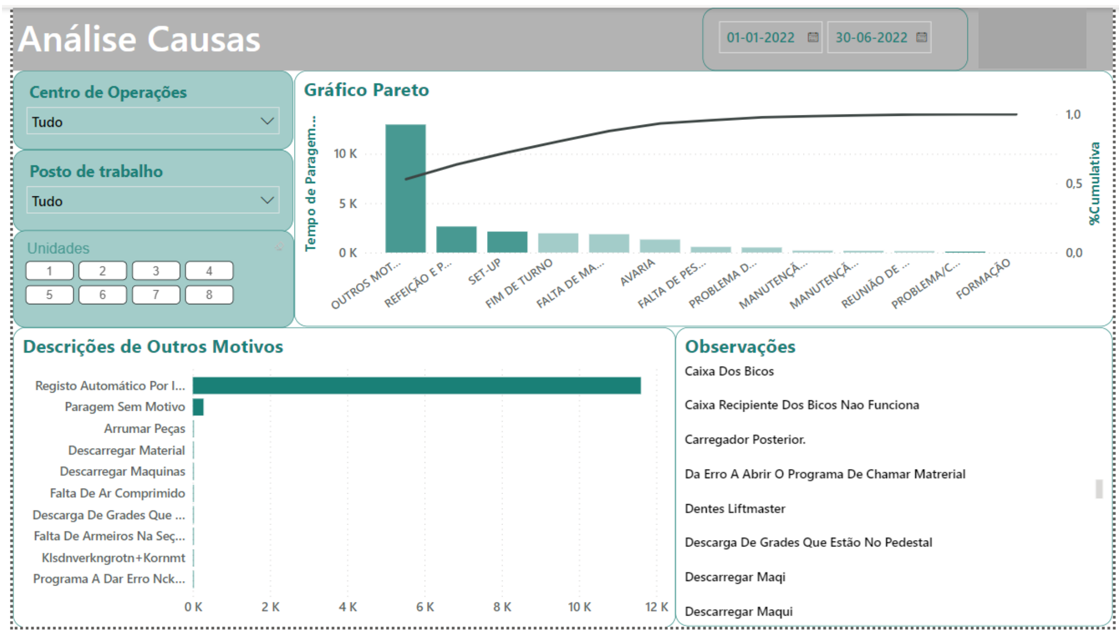


Figure 20- Second page of the availability dashboard

A board was also posted in the factory, in the aisle of the laser cutting machines in order to follow the evolution of OEE with daily update frequency. Tracking the oscillations of this KPI and involving the operators is intended to make more visible the reasons that result in increases or decreases in this value. In Appendix H there is a picture of said board.
Furthermore, the operators were sensitized to the wrong theoretical cycle times problem and asked to report each occurrence rather than disregarding it when observed.

4.2 Defining Order Validation Rules and Setting Deadlines

The second solution design session focused on the importance of defining deadlines for each step of the process in order to provide clients with the expected expedition date in a reasonable time.

4.2.1 Action plan

Define Information Flow Lead Time

As previously explained, the information flow during the order processing did not have a standard process. This meant the departments did not have a defined goal time to complete their tasks nor a defined flow. This lead time should therefore be attributed to each department as well as the ideal flow of information. It would also be advantageous to create a contractualisation for the communication with the client since the time it takes them to answer also has an impact on the lead time of the order.

Define Production Lead Time

Similarly to the situation in the order processing, there weren’t defined expected lead times for the different production processes. For this reason, it was imperative that targets for these times were established. Based on these assumptions, the delivery date to the client will be estimated, and it is therefore essential that what is defined is ambitious yet achievable.

Create Raw Material Stock Visibility

The raw stock material is another factor that if taken into consideration will improve customer satisfaction. Since the factory is not able to keep stock of all raw materials in all the possible sizes the creation of a list with the most common raw materials and sizes is necessary. These materials should be considered as always in stock and differentiated from exotic materials. The exotic ones should have an additional parameter in the due date calculations for the client. This parameter is the lead time to acquire the raw material and should be defined by the Purchase team.

4.2.2 Developments and testing

This implementation phase began with the development of the new process flow and the time expected for each department, represented in Figure 21.

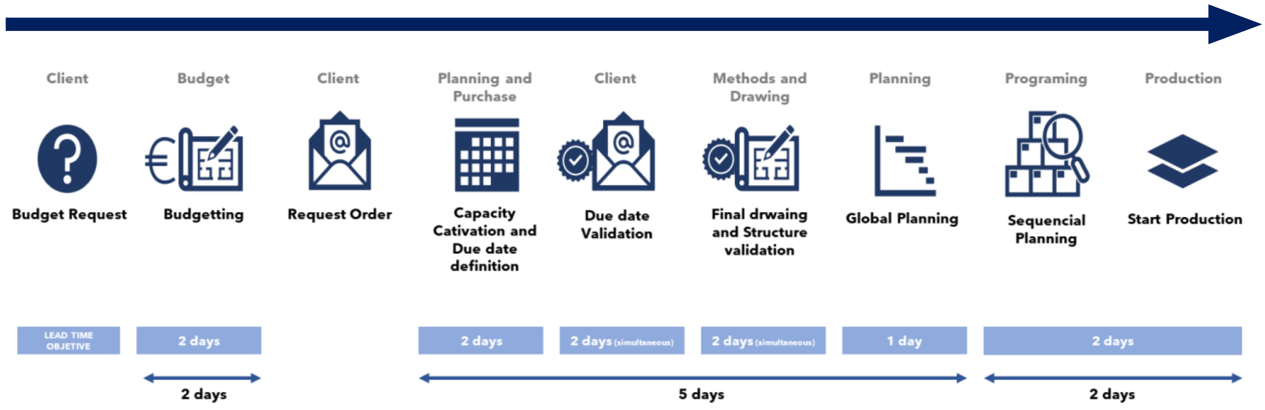


Figure 21- Designed order processing flow

The first difference is the more standardization of the two possible processes, which now follow the same flow, only differentiating on where they start. The second main difference is in how the planning defines the due date, which before was based on know-how.

The intention would be that when an order is entered in the back office it should be planned globally immediately to give a quick and accurate answer to the customer about the expected expedition date. The planning team will consider that the confirmation from the customer plus the administrative part will take up to 5 days. After that, it would verify if the raw material needed is common or exotic, in case it is the second option, a ticket will be created and sent to the purchasing team to know the estimated time of delivery of the material. Having in consideration the material first available date and the load/capacity tool, by resourcing to ghost production orders, the planning team can captivate the capacity of the machines to produce the order. This captivation will play a fundamental role so that when waiting for the approval of dates proposed to multiple clients, there is no overlapping of load. The additional two days before the start of production will be explained in the next solution phase. Finally, the expected lead time of each productive operation can be added, and the final due date is concluded.

In case the calculated due date is later than what the client suggested when requesting the order, this date will be communicated to the client which should have 48 hours to confirm or deny the proposition. If these 2 days are outdated the captivation of the capacity will expire, a new due date will need to be calculated and the client will be informed.

Since high rates of approval are expected it was decided that simultaneously with the client's confirmation, the drawing and methods team could start working on the projects, therefore, speeding the process. At last, the planning team meets all the requirements to plan the production by replacing the ghost production orders with the real ones. This process is schematised in more detail in Appendix I.

Secondly, the production lead times for the more common processes were established based on the company's goals as presented in Table 15:

Table 15- Expected Lead time for each operation

Operation	Lead Time (days)
Laser 2D	2
Laser 3D	2
Bending	2
Subcontracting	10
Welding MIG	8
Welding TIG	4
Combined Laser	2
Sanding	0.5
Threading	0.5
Milling	0.5
Moulder	0.5
Finishings	4

It is important to emphasize once again the importance of creating lead time targets for these flows. Not only to speed up the calculation of due dates proposed to clients but for both cases, it will also then be possible to work with an improvement purpose and develop solutions to ensure that these objectives are met. After a correct analysis of the jobs' performance, if these lead times are not being met, the need to acquire new resources (people or machines) can be questioned. However, these investments should never be questioned without first defining clear objectives and looking for low investment solutions.
To finalize this implementation cycle, with the assistance of the ABC/XYZ analyses the most valuable and frequently used raw materials were identified. The quantity analysis was later filtered to only references AX, AY or with a delivery lead time longer than 15 days. With a similar approach to what has been developed for SKUs ordered by customers the safety level of stock, the optimal level for buying, the average stock and the maximum stock were calculated for the raw material. The results from these calculations were submitted to the Purchases Team. It is now on the team’s hands to review the study followed and implement the resizing of safety stocks level in the company’s software.

4.3 Production Sequencing

In the Metal Mechanical Industry, one of the biggest factors in the profit margin results in yield optimization. Therefore, the third phase of solutions sought to find all the areas where there could be exploitation to be pursued.

4.3.1 Action plan

Define Planning Freeze Time

The first step for optimizing the production sequencing would be to freeze the production plan within a few days. This means no changes should be allowed to the plan after that period.
It was observed that often, to optimize the use of the metal plate, parts are combined and "steal" time from other planned orders. For example, during the sequencial planning order X parts and

Y parts are included in the same setup to optimize the use of the plate. However, the X parts were globally planned for production today while the Y parts were only planned for production in 4 days. This results in an extended cycle time of the cutting program from 6 to 10 hours. With the added time for cutting the Y pieces, the capacity reserved for other pieces that were globally planned to be cut today is taken away.
By defining that global planning should plan 2 days in advance it is also possible to delimit the programming to only optimize production for the same interval.

Define Sequence Optimization Rules

The second step would be to decide and clarify the main production sequencing rules that were pinpointed as necessary. Some of the said rules were already being followed by production however without a settled prioritization.

4.3.2 Developments and testing

Regarding the planning freeze time, the Planning team was advised to establish a 2-day rule.
The higher this value is the easier it is to reduce the usage of the metal plate and the greater the impact on the order lead time. This means that by defining a mandatory time interval between planning and production this value is added to the lead time in all orders. Thus, it was discussed with the company's management what would be the optimal value with an ideal impact on lead time and plate optimization ratio.
The result is the planning team on this day can only modify the days following the first two, as these are already blocked. For example:

- On Mondays at 9 am production planning for Tuesdays and Wednesdays is concluded
- On Wednesdays at 9 am production planning for Thursdays and Fridays is concluded
- On Friday at 9 am production planning for Saturdays and Mondays is concluded

Since the administrative shifts start at 8 am there would still be a small window of 1 hour to make any extremely urgent changes to the global planning, giving some important flexibility to the department. Regarding the programming, it leaves them 7 hours plus 8 hours for them to execute the sequential planning for these said days. For example:

- From 9 am Mondays to 5 pm Tuesdays create the sequence for Tuesdays and Wednesdays
- From 9 am Wednesdays to 5 pm Thursdays create the sequence for Thursdays and Fridays
- From 9 am to 5 pm Fridays create the sequence for Saturdays and Mondays

After collecting the most critical parameters in the production process, the following sequence of rules was prioritized:

1. **Respect the planned delivery date**

The first rule regards the defined production lead time. Answering the client at the contractual date must be the most important factor since improving customer service is the main goal of the project.

2. **Nesting optimization**

The second rule attends to the company’s profit margin. This parameter is at a high level of importance since its factor is quite powerful. The scrap value is significantly lower than the finished product value, therefore it is beneficial to include the most possible parts in each metal plate laser cutting program. Planning already takes this aspect into account with the auxiliary of a program developed by the laser cutting machines manufacturers.

3. **Optimization of plate change setups in laser cutting**

The third rule considers the automatic storage machine that is responsible for delivering the metal plates in the laser cutting machines. Since the storage can only move one plate at a time the process may be time-consuming if not efficiently coordinated. For example, it was observed that at the start of the morning shift several machines would wait for the delivery of metal plates in the other machines, losing availability.

4. **Optimize routing occupancy**

The fourth rule addresses the correct levelling of the load between the centres that follow the first operation, which is the one that is planned, in the present case the Laser cutting. To facilitate implementation, an additional page was added to the platform used for planning, created by the IT team. This page, shown in Appendix J, returns the calculated total time of bending for each nesting of laser cutting. It also includes a graph with the comparison between each assigned time of cutting and bending for each laser machine. Having this visibility presents a great advantage relative to the current situation, as it lets the planning team know if they are overloading the bending stations while planning for the bottleneck, which is the laser cutting. The remaining operations are expected to follow the FIFO rule.

5. **Optimization of bending setups**

The fifth rule aims to prevent excessive time spent on setting up the bending machines. On these machines, the tools are changed manually, which is not a very time-consuming task. However, the more set-ups that are performed, the more the sum of these times increases, which results in a high loss of productivity. One should therefore try to produce parts that require the same tools sequentially.

6. **Adhere to WIP size limits**

The sixth rule conveys the relevance of complying with the defined lead time and not exceeding these values in the sum of WIP working hours. As long as these limits are respected in between all the operations the first rule is almost certainly being complied with.

4.4 Operational Flow

The last phase of solution design regards the physical movement of information and material, as well as the rules for synchronizing posts.

4.4.1 Action plan

Defining Information Flow Rules

As mentioned in the characterization of the initial situation, there was no visibility of the load and capacity of the administration teams (Back office, Drawings, Methods, Planning). In addition, the orders were passed from one team to the next using printed paper with the information. Therefore, the development of an information flow control platform could be a possible solution for the difficulties the employees encountered. Creating this platform would allow the accounting of information flow time to ensure the defined deadlines are being respected as well as ensure the FIFO rule is being followed.

Set Station Synchronization Rules

One additional advantage to having the defined expected time for each process of production is the possibility to manage the WIP working hours (material waiting to enter a workstation). It is important to calculate the maximum time each part can wait in between workstations by subtracting the cycle time from the operation expected Lead Time.

Define Material Flow Rules

For the definition of material flow, there are several measures to be taken. The first is the introduction of a *Mizusumashi*, an employee only responsible for moving the material between workstations, with a pre-defined route and timetable. The most appropriate means of movement for the type of pieces in this industry should also be decided on. Note that there are both very

small parts inside boxes as well as long spacious tubes. For this reason, the best method must be a train where different trailers can be attached.
Finally, it would be advisable to create an interface for consulting FIFO by workstation, so that operators do not have to consult paper guides to know the order for production.

Implementing 5S

5S rules should be implemented in the factory, to reduce efforts, problems with hygiene, cleanliness and low productivity. Allowing the workplace to become an environment conducive to productivity. The factory floor should be delimited in such a way that no material is obstructing the *Mizusumashi's* train passage and the areas of storage of WIP are identified.

4.4.2 Developments and testing

The development of a platform's main goal was to facilitate communication between the departments and the accountability of the number of orders each department has in process simultaneously. During the requirements gathering phase, several possible functionalities were identified, and a proposal was drawn up with the following requirements:

- Traceability of the order's route through the various posts until it enters execution;
- Insertion in the database the history of each order with the following details: Number of new and revised drawings; Time in each post; Observations; Time limit; Date created; Client; Employees who moved the order; Time stopped at each post (time after arrival at the new post while there is no record of work); Time in pause at each workstation; Time in progress at each workstation; Split work execution by drawings
- Visibility of the work hours load on each post;
- Visibility of the total number of new/revised drawings assigned to each workstation;
- Visibility of the number of urgencies at each workstation;
- Limitation of expected time in each post, with visibility by a colour system, to facilitate priority management;
- Assignment of urgency parameter;
- Confirmation of receipt of the order in the post;
- Include attachments such as drawings/emails from the customer;
- Access restriction to posts not assigned to certain users
- Creation of superuser, with full permissions

The IT team of the company was presented with this proposal and took charge of building the necessary programming. The platform is not yet finished as some functionalities have not yet been implemented however, Appendix K shows the current state
This new data collection will present various advantages both to the teams and the leaders. The team leaders will be able to identify which departments are overworked and when teams may need to be resized temporarily. It also shows the time spend in each step of the process so that the causes of delays can be easily identified and questioned. The teams will have an easier communication system and will no longer be required to deliver the information about each order by paper. It is also planned to implement an automatic analysis page for this data, similar to an interactive report with the following information:

- Average Lead Time per post
- Lead Time per order
- Time stopped per order
- Time in pause per order
- Time in progress per order
- Average time necessary for each new/review order in the drawing department

This information will have the possibility to be filtered accordingly to client name, order number, date or post to facilitate analysis.

At last, a summary illustration of material and information flow was developed to exemplify the solutions created, as shown in Figure 22.

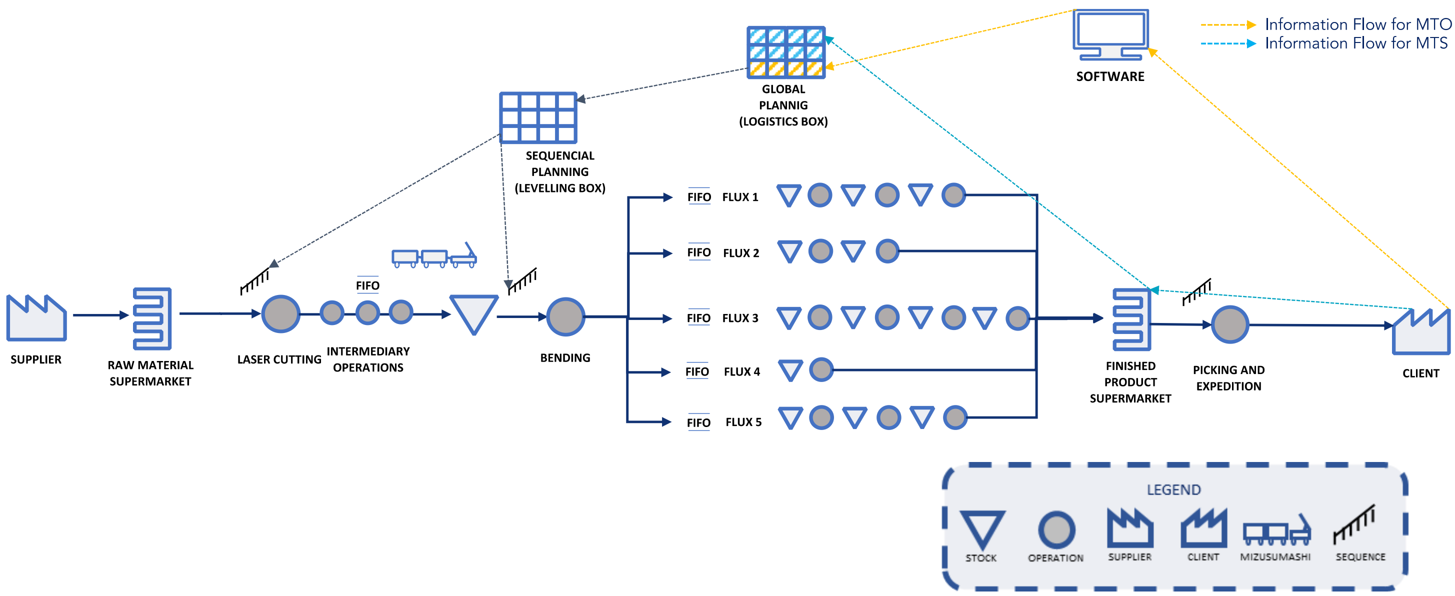


Figure 22- Simplified illustration of the information and material flow

This chart is a good summary of pull by pushing planning for both make-to-order and make-to-stock orders. The material flow is represented in a solid line and the information flow is in a dashed line.

Regarding the movement of information, two possible flows converge. The first is a client ordering an SKU that has been identified as relevant for producing to stock. In this case, as soon as the client puts in the order, a picking request from the supermarket is created. This output from the supermarket disputes a manufacturing order suggestion in the planning platform, i.e. in the logistics box. On the other hand, if the SKU orders by the client are categorized as make-to-order, the backlog inserts the order in the software to be processed and later sent to the planning team. From that point on, the processes are equivalent for both models. Following the global planning is the sequential planning in two distinct points: The first for the laser cutting, to continue to make maximum use of sheet metal and thus ensure optimal material utilisation. The second is before the bending operation which acts as a distributor for the following operations. This re-sequence allows preventing the bending of SKUs where the buffers are already full, meaning that the following operations have already met their full capacity.

Regarding the movement of material, the process begins with the delivery of the raw material by the supplier and the respective storage in the supermarket. Then, when a manufacturing order is created, the material is removed from the supermarket by the automatic elevator and inserted in the sequential planning of the laser cut. After the laser-cut, several intermediate operations can occur that must be managed taking into account the FIFO rule and transported internally by the *Mizusumashi*. Then another stock point is located prior to bending to re-sequence. Once again, the intermediate operations take place following the FIFO rule and stocking the supermarket of finished products, with the help of the *Mizushumashi*. Finally, on the shipping date, the items are picked and packed ready to be delivered to the external transport for the customer.

5 Conclusions and Future Developments

The purpose of this study was to help Company X improve customer service and manageability of the production. Due to the extensive problem identification and consequently long list of solutions this implementation is projected to take several months. Nevertheless, the current situation can be described:

- All the capacity/load sizing actions are in progress, except the splitting of the work posts since the software does not allow its implementation. However, it is anticipated that the rest of the actions followed will present a big impact. The sizing of the finished product supermarket has been concluded and an easy way to update the levels of security stock and replenishment in the program is being examined.
- The new order acceptance rules and deadlines have been approved by the company's board and should start to be complied with. The raw material supermarket is in the same state as the finished product.
- Regarding the production sequencing, the two-day freeze of planning has also been approved. The sequencing rules have been defined and are being applied by the programming team. There are still improvements to be made to facilitate this team's decision-making.
- At last, the operational flow actions are yet to be implemented. The information flow platform is still in development by the IT team, and therefore the administrative teams have not yet started to use it. Finally, the *Mizushumashi* route is still to be designed, but this will be the upcoming focus.

Since the solutions were developed in detail and tested it is expected that a positive outcome will be the result of the project. According to the experts in the company, when all the actions take place, an increase of up to +30% in on-time delivery, and consequently on-time in full, may be observed. It is also likely that relations between departments will benefit since with less occurrence of conflicts there will be fewer tensions generated. Even so, it is still possible to summarise some conclusions that the development of this thesis has shown.

The first was that a factory with a job-shop model is indeed a challenge to plan and therefore requires a lot of rigour and detail. For this reason, this type of model must feature two characteristics: Flexibility of production which has an accentuated influence on the speed of response to customers. This adjustability is a result of reduced set-up times and the ability to quickly signal loss of flow when bottlenecks appear; and Flow, to reduce the amount of WIP. To achieve such, it is necessary to have an organised synchronisation between posts and a clear tactic of how to react to the variations of routes for production that characterizes a job-shop model. The Pull by pushing method is trusted to be the best solution for this situation, as it allows multiple sequencing to buffer these variations and prevent the appearance of multiple bottlenecks. This statement is in alignment with advocated Kaizen's philosophy, since creating flow is one of its core values.

It was also possible to relate the growth of a company, namely the increase in sales, with the increasing delay in delivery to customers. In other words, the on-time delivery was decreasing, given that, with a higher load pressure, all small defects in planning become relevant and with increased consequences. This means that even if a company has faulty planning, it may not feel the impact of these defects if the load does not exceed this level of inefficiency. However, when a company is looking to grow and gain market share it will be necessary to correct these situations or it will not keep up with the increase in sales. The fall of the Roman Empire is an excellent example of how one should first study the viability of rapid growth in any organism.

As noted, the company already had solutions designed for finished product stock. However, due to the outdated dimensioning of these reserves and even the irrelevance of some of the references, these replacement levels were not being respected. From this example, it is possible to prove the importance of the correct sizing of supermarket levels as well as its constant re-evaluation. We can also refer to the fact that the stress present in the factory resulted in employees searching for solutions with immediate impact instead of following the previously developed solutions, which would not have such prompt results. The occurrence should not be identified as a mistake on the part of the employees but rather as a flaw in the company culture and an opportunity for further education. For this reason, training sessions were conducted on supermarket sizing to ensure that everyone was informed about the process and its impact on customer service. Although the traditional view is that the people at the top of the chain should create the long-term actions and the people at the bottom of the chain only the quick ones, both should work in agreement.

Finally, ABC/XYZ analyses were also carried out taking into account three agents, each with two parameters. In all of them, the Pareto Principle was confirmed: 80% of the value was always generated by less than 20% of the individuals. Awareness of this phenomenon should facilitate the company's strategy building, as well as validate whether the creation of urgencies is necessary.

Future Developments

As evidenced in chapter 4, the proposed solutions have yet to be implemented in the factory so that an analysis of the results can be led through, and the company can collect the benefits. For that reason, the project will continue until the goals defined are met. Simultaneously to the implementation, the on-time delivery, on-time in full and OEE will be closely observed to identify the relations between the proposed solutions with possible evolutions on these KPIs.

In addition, it would also be advantageous to create a proposal for changing the factory layout with the aim of decreasing the number of movements and complexity of expediting an order. As it was clarified in 3.2.1 at the date, an order of a part that only requires 2D laser cutting, which is 49% of the orders, needs to change floor level to be packed and arrive at the expedition.

Another area with the potential to be analyzed in more detail would be the commercial strategy. As was demonstrated in 3.2.2, a small number of customers has a greater weight than the majority of the customers' portfolios. Therefore, it may be advantageous to create explicit criteria for customer acceptance. Another approach to the issue might be instead of responding to individual orders and trying to allocate each individual part to production, to sell machine capacity to the larger customers. With this, strategic clients would be assured that they had exclusive production time and that whatever was needed would be manufactured within these contractual intervals.

The last suggestion for future projects will be the development of tools for implementing the rules created for optimising production sequencing. This area will bring many economic advantages to the company if well-executed since it optimizes several resources. It is suggested the conception of an algorithm that considers the automatic setup of the laser cutting tools and the plate change of the machines for the first production sequencing. For the second sequencing, an algorithm for the reduction of the manual setups of the bending tools would be indicated

References

De Toni, A., M. Caputo, and A. Vinelli. 1988. “Production Management Techniques: Push-Pull Classification and Application Conditions.” International Journal of Operations & Production Management 8 (2): 35–51. https://doi.org/10.1108/eb054818.

Coimbra, Euclides A. 2013. Kaizen in Logistics and Supply Chain. New York: Mcgraw-Hill Education.

Coimbra, Euclides A, and Kaizen Institute. 2009. Total Management Flow: Achieving Excellence with Kaizen and Lean Supply Chains. Howick, N.Z.: Kaizen Institute.

Errasti, A, C. Chackelson, and R. Poler. 2010. Review of An Expert System for Inventory Replenishment Optimization. In Balanced Automation Systems for Future Manufacturing Networks, edited by A Cortiz and P Gasquet Gomez. Berlin: Springer.

Falkenauer, E, and S. Bouffoix. 1991. Review of A Genetic Algorithm for Job Shop. In International Conference on Robotics and Automation, 824–29.

Hirano, H. 1995. 5 Pillars of the Visual Workplace: The Sourcebook for 5S Implementation. Productivity Press.

Imai, M. 1997. Gemba Kaizen: A Commonsense Low-Cost Approach to Management. New York: McGraw-Hill.

Ishaq Bhatti, M., H. M. Awan, and Z. Razaq. 2013. “The Key Performance Indicators (KPIs) and Their Impact on Overall Organizational Performance.” Quality & Quantity 48 (6): 3127–43. https://doi.org/10.1007/s11135-013-9945-y.

Jacobs, F. Robert, and R. B. Chase. 2018. Operations and supply chain management.

Vilfredo Pareto, Ann S Schwier, and Alfred N Page. 1971. Manual of Political Economy:
Transl. By Ann S. Schwier. New York: Kelley.

Popp, W. 1965. “Simple and Combined Inventory Policies, Production to Stock or to Order?” Management Science 11 (9): 868–73. https://doi.org/10.1287/mnsc.11.9.868.

Pomorski, T. 1997. Review of Managing Overall Equipment Effectiveness [OEE] to Optimize Factory Performance. In 1997 IEEE International Symposium on Semiconductor Manufacturing Conference, A33–36.

Silver, E A, D F Pyke, and R Peterson. 1998. Inventory Management and Production Planning and Scheduling. New York: Wiley.

Soylu, B. and B. Akyol. 2014. “Multi-Criteria Inventory Classification with Reference Items.” Computers & Industrial Engineering Vol. 69 (March): 12–20. https://doi.org/10.1016/j.cie.2013.12.011.

APPENDIX A: Mission Control Room photos

APPENDIX B: Production Routes Study Results

	Quantidade	Seguinte												
	Operação Inicial	Expedição	Quinagem	Lixadeira	Balancé	Roscar	Fresadora	SubContratos	Granalhadora 1	Ret. Rebarbas \ Limpar \ Medir	Boleadora	Laser Gravação	Rebarbar / Polir	Soldadura
	Laser 2D	49,54%	68,61%	94,18%	4,09%	56,49%	62,55%	19,78%	33,98%	74,63%	96,66%	6,26%	0,00%	2,53%
	Quinagem	20,04%	1,50%	0,52%	0,58%	8,54%	3,06%	24,52%	15,08%	13,43%	1,66%	2,51%	0,92%	36,94%
	Laser Combinada	3,63%	8,47%	3,39%	94,74%	5,56%	8,77%	1,80%	0,00%	8,59%	1,04%	29,93%	0,00%	0,05%
	Lixadeira	4,66%	8,26%	0,17%	0,00%	7,92%	8,65%	5,97%	0,95%	0,39%	0,00%	1,28%	0,00%	0,07%
	Acabamentos 1_Expedição	2,56%	0,00%	0,31%	0,00%	6,58%	0,00%	11,08%	8,72%	0,10%	0,00%	26,17%	0,00%	0,00%
95%	Balancé	4,62%	0,06%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	14,70%	2,16%	0,00%
	Roscar	2,40%	4,96%	0,18%	0,23%	0,04%	0,32%	5,11%	0,16%	0,63%	0,00%	2,55%	0,00%	0,80%
	SubContratos	3,20%	0,08%	0,05%	0,00%	1,11%	1,29%	0,00%	0,03%	0,13%	0,00%	11,94%	1,10%	0,55%
	Fresadora	1,80%	0,93%	0,41%	0,00%	7,57%	3,05%	6,73%	16,28%	0,74%	0,00%	2,96%	0,61%	0,30%
	Laser Tubo	1,77%	0,69%	0,01%	0,00%	0,18%	0,19%	0,00%	0,81%	0,00%	0,00%	0,00%	0,21%	0,01%
	Granalhadora 1	1,00%	1,41%	0,00%	0,00%	1,51%	0,00%	5,32%	8,90%	0,00%	0,00%	1,30%	0,00%	0,49%
	Soldadura	0,35%	0,04%	0,09%	0,00%	0,01%	0,20%	2,16%	0,99%	0,14%	0,00%	0,00%	55,17%	16,23%
	Ret. Rebarbas \ Limpar \ Medir	0,98%	0,36%	0,05%	0,00%	0,32%	0,75%	6,17%	7,10%	0,94%	0,00%	0,00%	0,00%	0,01%
	Boleadora	0,17%	1,86%	0,00%	0,00%	3,04%	4,82%	1,34%	1,73%	0,03%	0,15%	0,23%	0,00%	3,79%
	Laser Gravação	0,57%	0,72%	0,00%	0,00%	0,00%	0,00%	0,09%	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%
	Rebarbar / Polir	0,43%	0,00%	0,00%	0,00%	0,19%	1,61%	2,04%	1,45%	0,07%	0,00%	0,00%	0,51%	8,34%
	Controlo	0,67%	0,00%	0,02%	0,00%	0,00%	0,00%	1,40%	0,00%	0,00%	0,00%	0,17%	3,36%	0,80%
	Calandra	0,25%	1,01%	0,00%	0,00%	0,03%	1,23%	0,00%	0,02%	0,00%	0,00%	0,00%	0,00%	0,00%
	Máq.Sld.Pernos (Condensadores)	0,29%	0,06%	0,01%	0,00%	0,00%	0,00%	0,04%	0,01%	0,00%	0,00%	0,01%	2,60%	3,18%
	ROBOT	0,01%	0,00%	0,00%	0,00%	0,00%	0,02%	0,43%	0,00%	0,00%	0,00%	0,00%	27,02%	3,63%
	Desempeno / Esquadria	0,18%	0,06%	0,00%	0,00%	0,13%	0,03%	0,33%	2,34%	0,00%	0,00%	0,00%	3,48%	2,03%
	Acabamentos	0,14%	0,02%	0,59%	0,00%	0,02%	0,44%	0,78%	0,03%	0,08%	0,00%	0,00%	0,51%	0,55%
	Máq. Soldar (Resistência)	0,10%	0,23%	0,00%	0,00%	0,56%	0,00%	0,35%	0,00%	0,00%	0,00%	0,00%	0,43%	3,41%
	Limpeza da Peça	0,08%	0,00%	0,00%	0,00%	0,01%	0,00%	0,53%	0,23%	0,00%	0,00%	0,00%	0,00%	3,16%
	Retirar PVC	0,06%	0,22%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	4,79%
5%	Máq. Prensa (PEM)	0,12%	0,01%	0,00%	0,00%	0,00%	0,00%	0,49%	0,01%	0,07%	0,00%	0,00%	0,00%	0,92%
	Serrote Fita	0,02%	0,02%	0,00%	0,00%	0,00%	2,95%	0,00%	0,31%	0,00%	0,00%	0,00%	0,00%	0,00%
	Máq. Rebitar	0,08%	0,01%	0,00%	0,00%	0,01%	0,00%	1,67%	0,06%	0,02%	0,00%	0,00%	0,00%	0,01%
	Prensa	0,04%	0,30%	0,00%	0,00%	0,00%	0,05%	0,00%	0,00%	0,00%	0,49%	0,00%	1,39%	0,00%
	Acabamento p/ PIntura	0,02%	0,00%	0,00%	0,00%	0,01%	0,00%	1,38%	0,26%	0,00%	0,00%	0,00%	0,00%	4,96%
	Montagem	0,09%	0,00%	0,00%	0,00%	0,02%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,34%	2,18%
	Maq. Pernos	0,05%	0,07%	0,00%	0,00%	0,00%	0,00%	0,48%	0,00%	0,00%	0,00%	0,00%	0,00%	0,24%
	Curvar Tubo	0,02%	0,02%	0,00%	0,36%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Limpeza	0,04%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Quebrar Quina (Máq.Trumph Man)	0,03%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Jacto de Vidro	0,00%	0,01%	0,00%	0,00%	0,15%	0,00%	0,00%	0,48%	0,00%	0,00%	0,00%	0,17%	0,00%
	Granalhadora 2	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Rosca	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Inspecção	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Serralharia 1	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,06%	0,00%	0,00%	0,00%	0,00%	0,00%
	Sr3 Acabamentos	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Quantidade	seguinte												
Operação inical	Expedição	Quinagem	Lixadeira	Balancé	Roscar	Fresadora	SubContratos	Granalhadora 1	Ret. Rebarbas \ Limpar \ Medir	Boleadora	Laser Gravação	Rebarbar / Polir	Soldadura
Laser 2D	57.61%	22.11%	8.89%	0.32%	2.77%	2.65%	0.68%	0.72%	1.40%	1.60%	0.08%	0.00%	0.03%
Quinagem	85.25%	1.77%	0.18%	0.17%	1.53%	0.47%	3.07%	1.17%	0.92%	0.10%	0.12%	0.04%	1.51%
Laser Combinada	26.13%	16.91%	1.98%	46.36%	1.69%	2.31%	0.38%	0.00%	1.00%	0.11%	2.39%	0.00%	0.00%
Lixadeira	58.37%	28.69%	0.18%	0.00%	4.19%	3.96%	2.20%	0.22%	0.08%	0.00%	0.18%	0.00%	0.01%
Acabamentos 1_Expedição	48.37%	0.00%	0.47%	0.00%	5.26%	0.00%	6.17%	3.01%	0.03%	0.00%	5.50%	0.00%	0.00%
Balancé	93.12%	0.35%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.29%	0.48%	0.00%
Roscar	58.93%	33.77%	0.36%	0.38%	0.04%	0.28%	3.69%	0.07%	0.25%	0.00%	0.69%	0.00%	0.19%
SubContratos	89.86%	0.60%	0.12%	0.00%	1.32%	1.33%	0.00%	0.02%	0.06%	0.00%	3.73%	0.34%	0.15%
Fresadora	55.64%	7.99%	1.03%	0.00%	9.86%	3.43%	6.11%	9.16%	0.37%	0.00%	1.01%	0.21%	0.09%
Laser Tubo	85.00%	9.11%	0.03%	0.00%	0.37%	0.33%	0.00%	0.71%	0.00%	0.00%	0.00%	0.11%	0.01%
Granalhadora 1	54.92%	21.54%	0.00%	0.00%	3.51%	0.01%	8.63%	8.95%	0.00%	0.00%	0.80%	0.00%	0.26%
Soldadura	20.32%	0.70%	0.45%	0.00%	0.03%	0.43%	3.72%	1.05%	0.13%	0.00%	0.00%	35.81%	9.14%
Ret. Rebarbas \ Limpar \ Medir	67.44%	6.81%	0.28%	0.00%	0.92%	1.89%	12.47%	8.92%	1.05%	0.00%	0.00%	0.00%	0.00%
Boleadora	14.95%	45.25%	0.00%	0.00%	11.27%	15.45%	3.47%	2.77%	0.05%	0.18%	0.22%	0.00%	3.21%
Laser Gravação	62.20%	21.85%	0.00%	0.00%	0.00%	0.01%	0.28%	0.00%	0.00%	0.00%	0.00%	0.01%	0.00%
Rebarbar / Polir	47.78%	0.00%	0.03%	0.00%	0.87%	6.45%	6.59%	2.91%	0.12%	0.00%	0.00%	0.62%	8.82%
Controlo	86.57%	0.03%	0.19%	0.00%	0.00%	0.00%	5.33%	0.00%	0.00%	0.00%	0.24%	4.82%	1.00%
Calandra	42.72%	48.62%	0.00%	0.00%	0.24%	7.80%	0.00%	0.05%	0.00%	0.00%	0.00%	0.00%	0.00%
Máq.Sld.Pernos (Condensadores)	66.25%	4.03%	0.27%	0.00%	0.03%	0.00%	0.30%	0.03%	0.01%	0.00%	0.03%	6.56%	6.97%
ROBOT	2.42%	0.00%	0.00%	0.00%	0.00%	0.22%	3.32%	0.00%	0.00%	0.00%	0.00%	79.44%	9.27%
Desempeno / Esquadria	48.92%	4.55%	0.00%	0.00%	1.55%	0.26%	2.68%	11.63%	0.00%	0.00%	0.00%	10.50%	5.32%
Acabamentos	44.80%	1.40%	15.57%	0.00%	0.31%	5.21%	7.37%	0.19%	0.44%	0.00%	0.00%	1.84%	1.72%
Máq. Soldar (Resistência)	33.56%	20.56%	0.06%	0.00%	7.73%	0.00%	3.40%	0.02%	0.00%	0.00%	0.00%	1.57%	10.77%
Limpeza da Peça	40.73%	0.00%	0.00%	0.00%	0.23%	0.00%	8.40%	2.25%	0.00%	0.00%	0.00%	0.00%	16.51%
Retirar PVC	33.31%	34.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	26.41%
Máq. Prensa (PEM)	69.96%	1.06%	0.00%	0.00%	0.00%	0.04%	8.55%	0.14%	0.71%	0.00%	0.00%	0.00%	5.28%
Serrote Fita	16.91%	4.30%	0.00%	0.00%	0.00%	72.97%	0.00%	3.78%	0.00%	0.00%	0.00%	0.00%	0.00%
Máq. Rebitar	53.22%	1.88%	0.00%	0.00%	0.16%	0.00%	33.88%	0.82%	0.24%	0.00%	0.00%	0.00%	0.08%
Prensa	24.60%	58.37%	0.00%	0.00%	0.00%	1.29%	0.00%	0.00%	0.00%	4.91%	0.00%	10.82%	0.00%
Acabamento p/ PIntura	12.68%	0.08%	0.00%	0.00%	0.21%	0.00%	28.87%	3.33%	0.00%	0.00%	0.00%	0.00%	33.92%
Montagem	65.58%	0.00%	0.00%	0.00%	0.55%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.72%	15.04%
Maq. Pernos	49.39%	21.28%	0.00%	0.00%	0.00%	0.00%	14.51%	0.00%	0.00%	0.00%	0.00%	0.00%	2.38%
Curvar Tubo	29.68%	8.06%	0.00%	33.83%	0.00%	0.00%	0.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Limpeza	89.57%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Quebrar Quina (Máq.Trumph Man)	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Jacto de Vidro	2.69%	13.44%	0.00%	0.00%	29.57%	0.00%	0.00%	40.05%	0.00%	0.00%	0.00%	8.60%	0.00%
Granalhadora 2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Rosca	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Inspecção	74.36%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Serralharia 1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sr3 Acabamentos	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

APPENDIX C: Example of the calculations sheet used for defining the OEE of the Laser cutting 2D machines

LS2CR: Corte 2D

unidade 1	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	315	330	345	315	405	375	450	345	450	405	390	405	405	345	420	375	
Tempo Previsto	244,1	272,8	277,9	272,2	275,4	310,1	339,2	177,9	308,5	228,9	347,2	349,4	293,9	317,3	328,4	269,4	
OEE(%)	77,50%	82,66%	80,55%	86,42%	68,01%	82,68%	75,37%	51,57%	68,56%	56,53%	89,03%	86,27%	72,57%	91,97%	78,19%	71,83%	76,23%

unidade 2	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	315	330	375	345	405	375	405	345	435	405	405	375	390	345	390	405	
Tempo Previsto	195,9	193,9	214,7	230,6	216,1	227,2	279,6	143,8	306,6	227,7	237,9	213,7	257,0	227,4	215,8	216,2	
OEE(%)	62,18%	58,76%	57,26%	66,85%	53,35%	60,58%	69,05%	41,69%	70,48%	56,21%	58,73%	57,00%	65,88%	65,91%	55,32%	53,38%	59,54%

unidade 3	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	270	330	375	195	270	180	15	165	450	420	405	345	375	345	375	240	
Tempo Previsto	156,4	197,5	231,7	94,2	121,9	98,5	0,0	38,4	307,1	232,4	223,6	142,2	174,4	185,9	190,0	105,3	
OEE(%)	57,93%	59,86%	61,78%	48,29%	45,16%	54,72%	0,16%	23,28%	68,24%	55,34%	55,22%	41,22%	46,51%	53,88%	50,67%	43,87%	47,88%

unidade 4	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	270	345	390	315	405	375	375	330	240	405	375	390	405	345	405	450	
Tempo Previsto	182,2	219,3	284,2	218,0	294,1	270,3	282,6	168,8	124,5	274,1	255,5	196,4	272,2	238,4	252,2	301,2	
OEE(%)	67,48%	63,56%	72,88%	69,22%	72,61%	72,08%	75,36%	51,14%	51,89%	67,67%	68,13%	50,36%	67,22%	69,11%	62,27%	66,93%	65,49%

unidade 5	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	345	345	360	330	345	360	420	330	420	435	375	390	390	360	435	390	
Tempo Previsto	200,4	194,4	250,4	220,9	222,2	224,9	359,2	170,7	357,1	314,8	200,4	274,2	342,5	270,5	302,8	309,7	
OEE(%)	58,09%	56,35%	69,56%	66,94%	64,40%	62,49%	85,52%	51,74%	85,03%	72,36%	53,44%	70,30%	87,82%	75,13%	69,62%	79,40%	69,26%

unidade 6	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	105	60	82,5	37,5	150	90	120	105	97,5	105	142,5	127,5	225	165	270	210	
Tempo Previsto	43,0	32,1	79,9	21,8	102,0	47,3	30,2	71,6	36,3	25,1	72,9	52,5	27,3	12,3	49,5	48,3	
OEE(%)	40,99%	53,52%	96,82%	58,03%	68,01%	52,55%	25,18%	68,17%	37,18%	23,93%	51,13%	41,16%	12,11%	7,46%	18,34%	23,02%	42,35%

unidade 7	jan/21	fev/21	mar/21	abr/21	mai/21	jun/21	jul/21	ago/21	set/21	out/21	nov/21	dez/21	jan/22	fev/22	mar/22	abr/22	Média
Abertura(horas)	315	315	300	315	360	345	375	300	375	360	390	315	300	330	360	315	
Tempo Previsto	214,3	234,2	145,6	155,4	215,1	162,8	217,4	133,6	186,4	165,1	191,8	216,9	129,7	159,8	225,6	210,4	
OEE(%)	68,02%	74,36%	48,52%	49,34%	59,74%	47,17%	57,98%	44,55%	49,71%	45,85%	49,19%	68,85%	43,24%	48,44%	62,68%	66,80%	55,28%

Unidade	1	2	3	4	5	6	7
OEE	76,23%	59,54%	47,88%	65,49%	69,26%	42,35%	55,28%

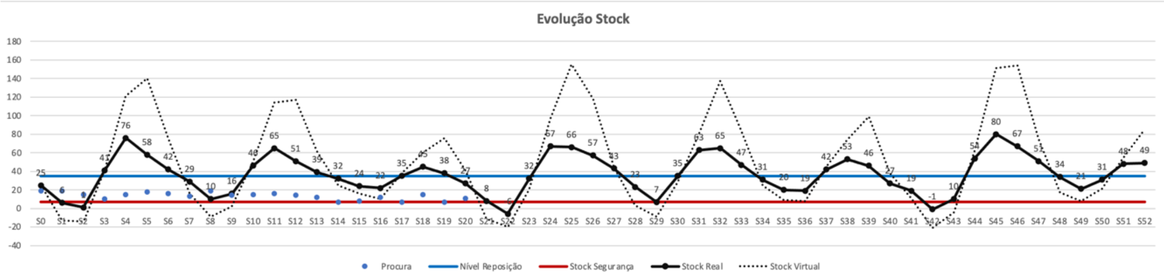
APPENDIX D: Simulation models created to demonstrate the theory of supermarket dimensioning, having into consideration risky, normal or conservative calculations

Modelo Com base na produção histórica do período anterior - Arriscado

Lead Time Reposição (Semanas) LT	2	**Stock Segurança (SS)**	7,0	**SS: Desvio Padrão do Cons no LT**		**Média Stock Real**	36,5
Procura Média Semanal (Média Histórico)	13,8	**Nível Reposição (NR)**	35	**NR:** Procura Média Diária x LT +SS		**Média Stock em Semanas**	2,7
Desvio Padrão Procura (Histórico)	6,5	**Média Stock Esperado**	24,5	**Média Stock:** SS+0,5 x Tamanho Lote		**Nivel serviço**	96,2%
Tamanho de Lote	5	**Média Stock em semanas**	1,8	SV = SR - Procura periodo + Encomendas a chegar		**Procura Média**	13,8
				Encomenda = Roundup[(NR-SV)/Lote]*Lote			

Semana	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Consumo	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12
Procura no LT	0	19	38	34	25	25	33	34	29	32	33	29	31	30	26	19	15

Semana	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Procura	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12	7
Nível Reposição	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Stock Segurança	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Stock Real	25	6	1	41	76	58	42	29	10	16	46	65	51	39	32	24	22	35
Rupturas	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Encomenda a Realizar	10	50	50	0	0	0	0	20	45	35	0	0	0	0	10	20	25	0
Receção de Material	0	0	10	50	50	0	0	0	0	20	45	35	0	0	0	0	10	20
Stock Virtual	25	-13	-14	41	121	140	76	16	-9	2	51	114	117	62	25	16	10	38

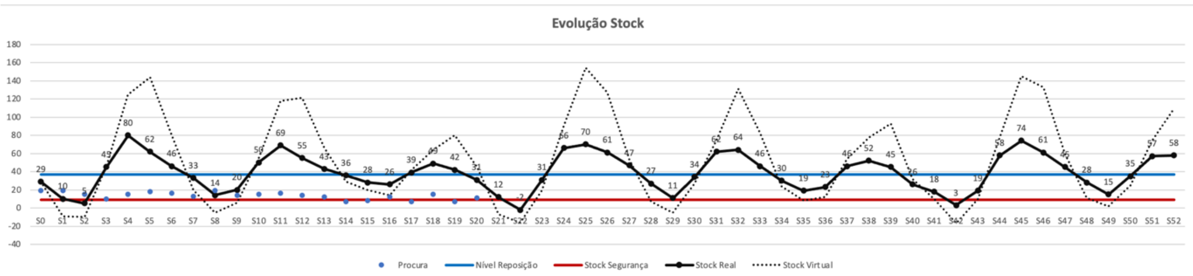


Modelo Com base na produção histórica do período anterior - Normal

Lead Time Reposição (Semanas) LT	2	**Stock Segurança (SS)**	9	**SS: Desvio Padrão Cons Semanal**		**Média Stock Real**	38,7
Procura Média Semanal (Média Histórico)	13,8	**Nível Reposição (NR)**	37	**NR:** Procura Média Diária x LT +SS		**Média Stock em Semanas**	2,8
Desvio Padrão Procura (Histórico)	4,0	**Média Stock Esperado**	29	**Média Stock:** SS+0,5 x Tamanho Lote		**Nivel serviço**	98,1%
Tamanho de Lote	5	**Média Stock em semanas**	2,1	SV = SR - Procura periodo + Encomendas a chegar		**Procura Média**	13,8
				Encomenda = Roundup[(NR-SV)/Lote]*Lote			

Semana	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Consumo	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12
Procura no LT	0	19	38	34	25	25	33	34	29	32	33	29	31	30	26	19	15

Semana	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Procura	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12	7
Nível Reposição	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
Stock Segurança	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Stock Real	29	10	5	45	80	62	46	33	14	20	50	69	55	43	36	28	26	39
Rupturas	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Encomenda a Realizar	10	50	50	0	0	0	0	20	45	35	0	0	0	0	10	20	25	0
Receção de Material	0	0	10	50	50	0	0	0	0	20	45	35	0	0	0	0	10	20
Stock Virtual	29	-9	-10	45	125	144	80	20	-5	6	55	118	121	66	29	20	14	42



Modelo Com base na produção histórica do período anterior - Médio Conservador

Lead Time Reposição (Semanas) LT	2
Procura Média Semanal (Média Histórico)	13,8
Desvio Padrão Procura (Histórico)	4,0
Tamanho de Lote	5

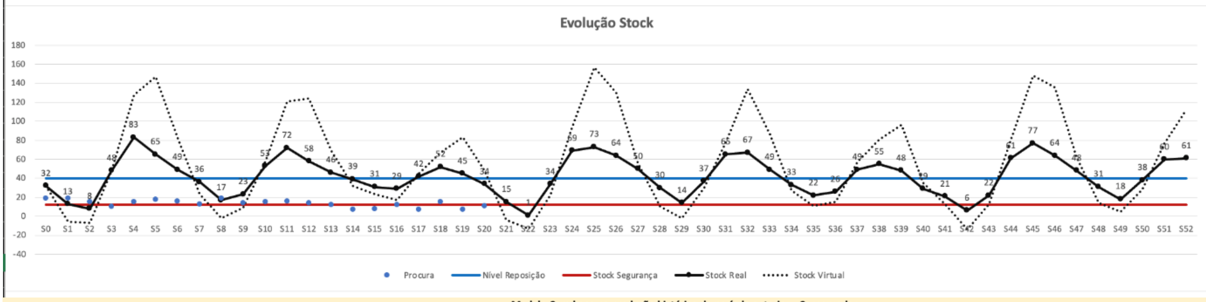
Stock Segurança (SS)	12
Nível Reposição (NR)	40
Média Stock Esperado	32
Média Stock em semanas	2,3

SS: Max Cons LT - Avg Cons LT
NR:Procura Média Diária x LT +SS
Média Stock: SS+0,5 x Tamanho Lote
SV = SR - Procura periodo - Encomendas a chegar
Encomenda = Roundup[(NR-SV)/Lote]*Lote

Média Stock Real	41,7
Média Stock em Semanas	3,0
Nivel serviço	100,0%
Procura Média	13,8

Semana	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Procura	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12
Procura no LT	0	19	38	34	25	25	33	34	29	32	33	29	31	30	26	19	15

Semana	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Procura	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12	7
Nível Reposição	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Stock Segurança	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Stock Real	32	13	8	48	83	65	49	36	17	23	53	72	58	46	39	31	29	42
Rupturas	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Encomenda a Realizar	10	50	50	0	0	0	0	20	45	35	0	0	0	0	10	20	25	0
Receção de Material	0	0	10	50	50	0	0	0	0	20	45	35	0	0	0	0	10	20
Stock Virtual	32	-6	-7	48	128	147	83	23	-2	9	58	121	124	69	32	23	17	45



Modelo Com base na produção histórica do período anterior - Conservador

Lead Time Reposição (Semanas) LT	2
Procura Média Semanal (Média Histórico)	13,8
Desvio Padrão Procura (Histórico)	4,0
Tamanho de Lote	5

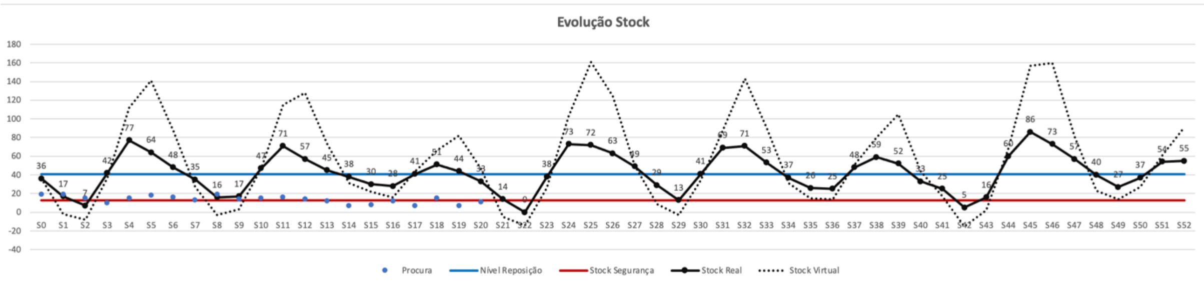
Stock Segurança (SS)	13
Nível Reposição (NR)	41
Média Stock Esperado	35,5
Média Stock em semanas	2,6

SS: (Max Consumo Sem - Média Consumo Sem) * LT
NR:Procura Média Diária x LT +SS
Média Stock: SS+0,5 x Tamanho Lote
SV = SR - Procura periodo - Encomendas a chegar
Encomenda = Roundup[(NR-SV)/Lote]*Lote

Média Stock Real	42,3
Média Stock em Semanas	3,1
Nivel serviço	100,0%
Procura Média	13,8

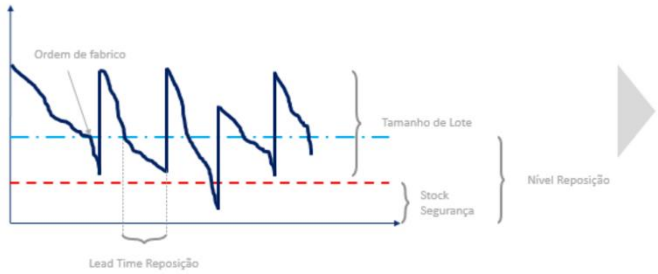
Semana	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Consumo	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12

Semana	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17
Procura	19	19	15	10	15	18	16	13	19	14	15	16	14	12	7	8	12	7
Nível Reposição	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
Stock Segurança	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Stock Real	36	17	7	42	77	64	48	35	16	17	47	71	57	45	38	30	28	41
Rupturas	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Encomenda a Realizar	5	45	50	5	0	0	0	15	45	40	0	0	0	0	10	20	25	0
Receção de Material	0	0	5	45	50	5	0	0	0	15	45	40	0	0	0	0	10	20
Stock Virtual	36	-2	-8	37	112	141	87	27	-3	3	47	115	128	73	31	22	16	44



APPENDIX E: One Point Lessons created to explain to the teams the formulas used to calculate the supermarket's dimensions

Conceito



Níveis de stock controlados, com níveis de reposição,
Tamanhos de lote definidos,
Stocks de segurança definidos

A ordem de fabrico deve ser imitida quando o stock atinge o nível de reposição

Cálculos Auxiliares

$$\boldsymbol{Stock\ Segurança} = \boldsymbol{\sigma_{Consumo}} + \boldsymbol{\sigma_{LeadTime}} \times \boldsymbol{Consumo}$$

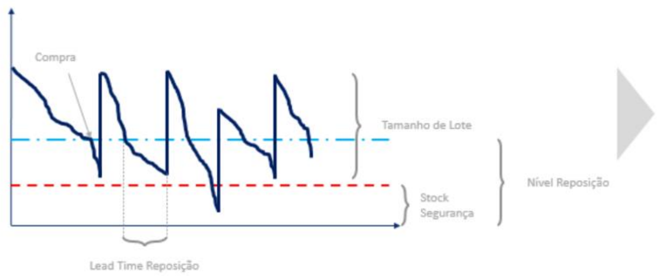
$$\boldsymbol{Nível\ de\ Reposição} = \boldsymbol{Consumo} \times \boldsymbol{LeadTime_{Reposição}} + \boldsymbol{StockSegurança})$$

$$\boldsymbol{Qtd\ a\ Encomendar} = \boldsymbol{Nível\ Reposição} - (\boldsymbol{Stock_{atual}} - \boldsymbol{QtdEncomendada} + \boldsymbol{WIP})$$

$$\boldsymbol{Stock\ Médio} = \boldsymbol{Stock\ Segurança} + \boldsymbol{0,5} \times \boldsymbol{Tamanho\ de\ Encomenda}$$

$$\boldsymbol{Stock\ Máximo} = \boldsymbol{Nível\ Reposição} + \boldsymbol{MOQ}$$

Conceito



Níveis de stock controlados, com níveis de reposição,
Tamanhos de lote definidos,
Stocks de segurança definidos

A compra deve ser realizada quando o stock atinge o nível de reposição

Cálculos Auxiliares

$$\boldsymbol{Stock\ Segurança} = \boldsymbol{MAXConsumo_{LeadTime}} - \boldsymbol{ConsumoMédio_{LeadTime}}$$

$$\boldsymbol{Nível\ de\ Reposição} = \boldsymbol{Consumo} \times \boldsymbol{LeadTime_{Reposição}} + \boldsymbol{StockSegurança})$$

$$\boldsymbol{Qtd\ a\ Encomendar} = \boldsymbol{Nível\ Reposição} - (\boldsymbol{Stock_{atual}} - \boldsymbol{QtdEncomendada} + \boldsymbol{WIP})$$

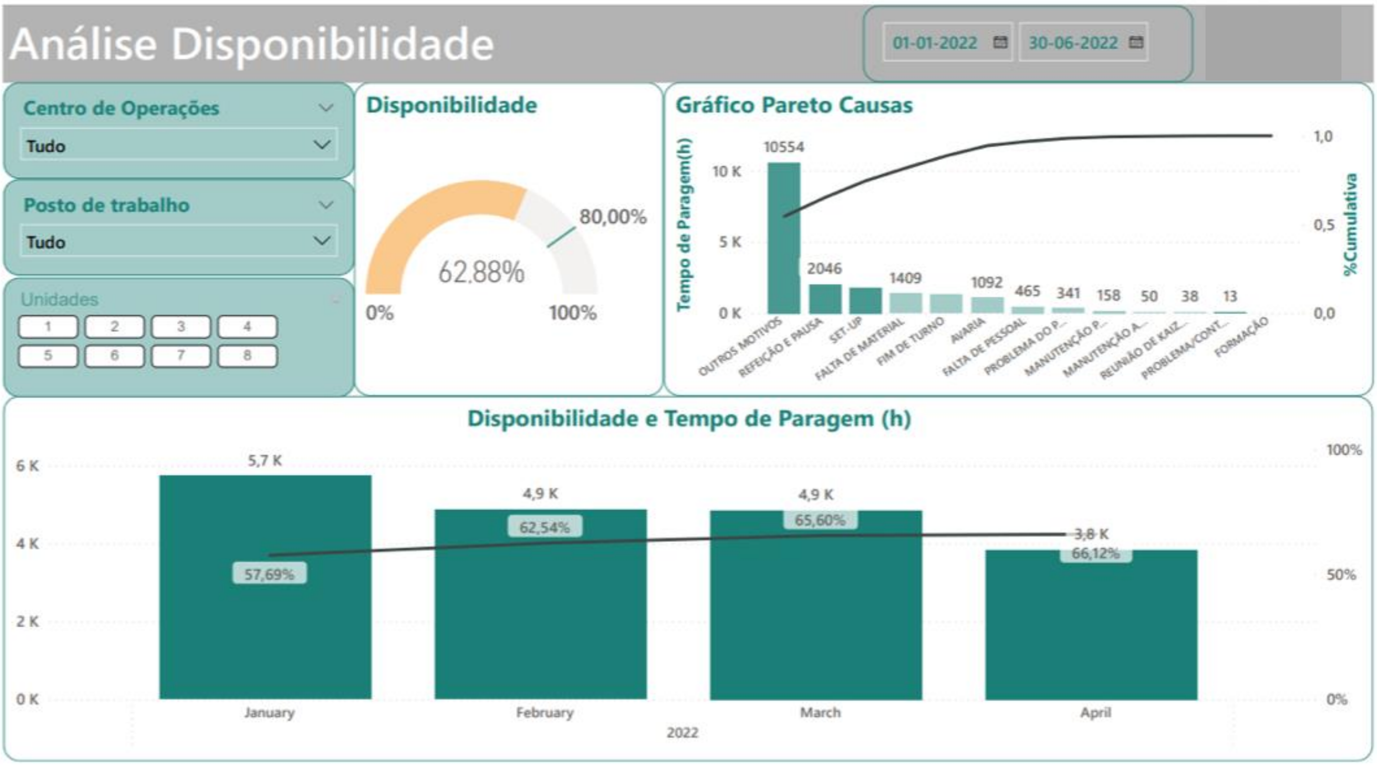
$$\boldsymbol{Stock\ Médio} = \boldsymbol{Stock\ Segurança} + \boldsymbol{0,5} \times \boldsymbol{Tamanho\ de\ Encomenda}$$

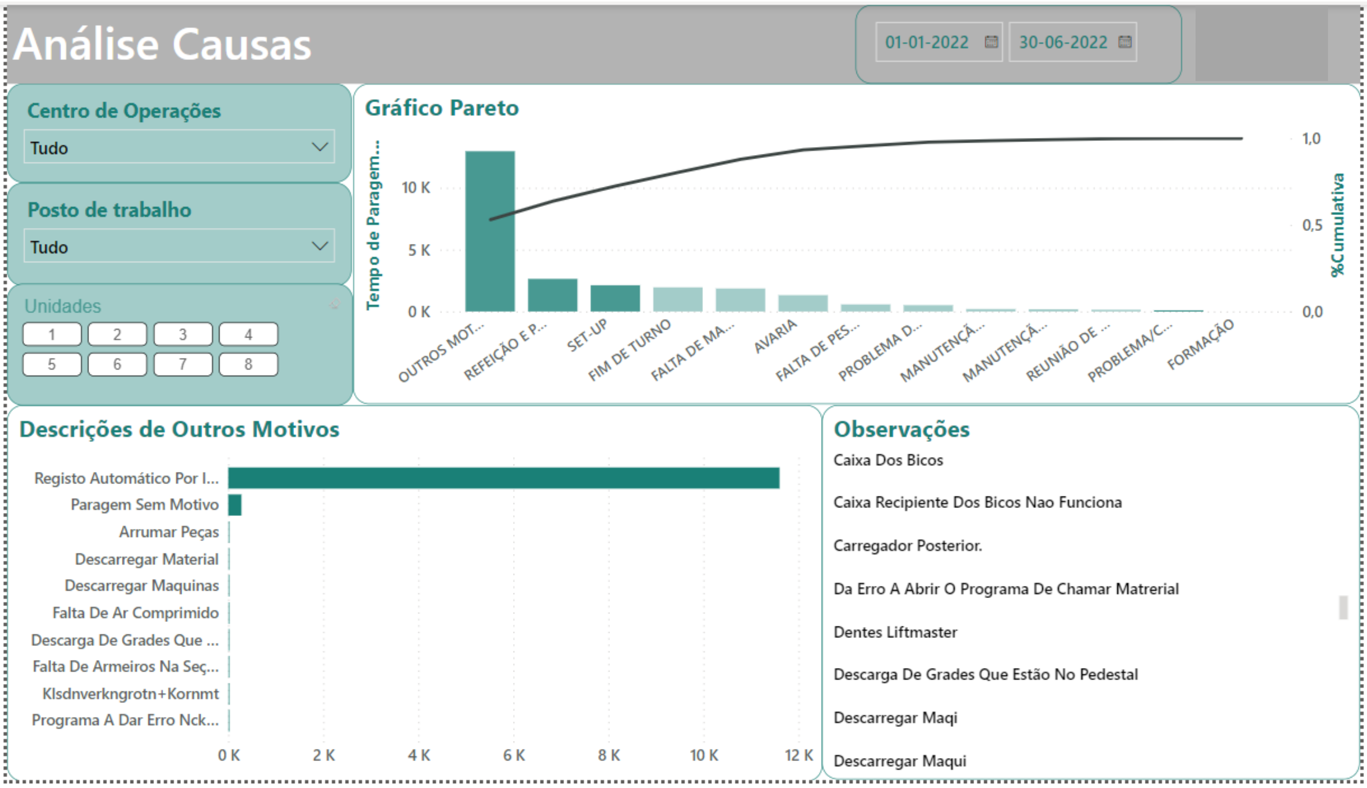
$$\boldsymbol{Stock\ Máximo} = \boldsymbol{Nível\ Reposição} + \boldsymbol{MOQ}$$

APPENDIX F: Example of the calculations sheet used for dimensioning stock levels

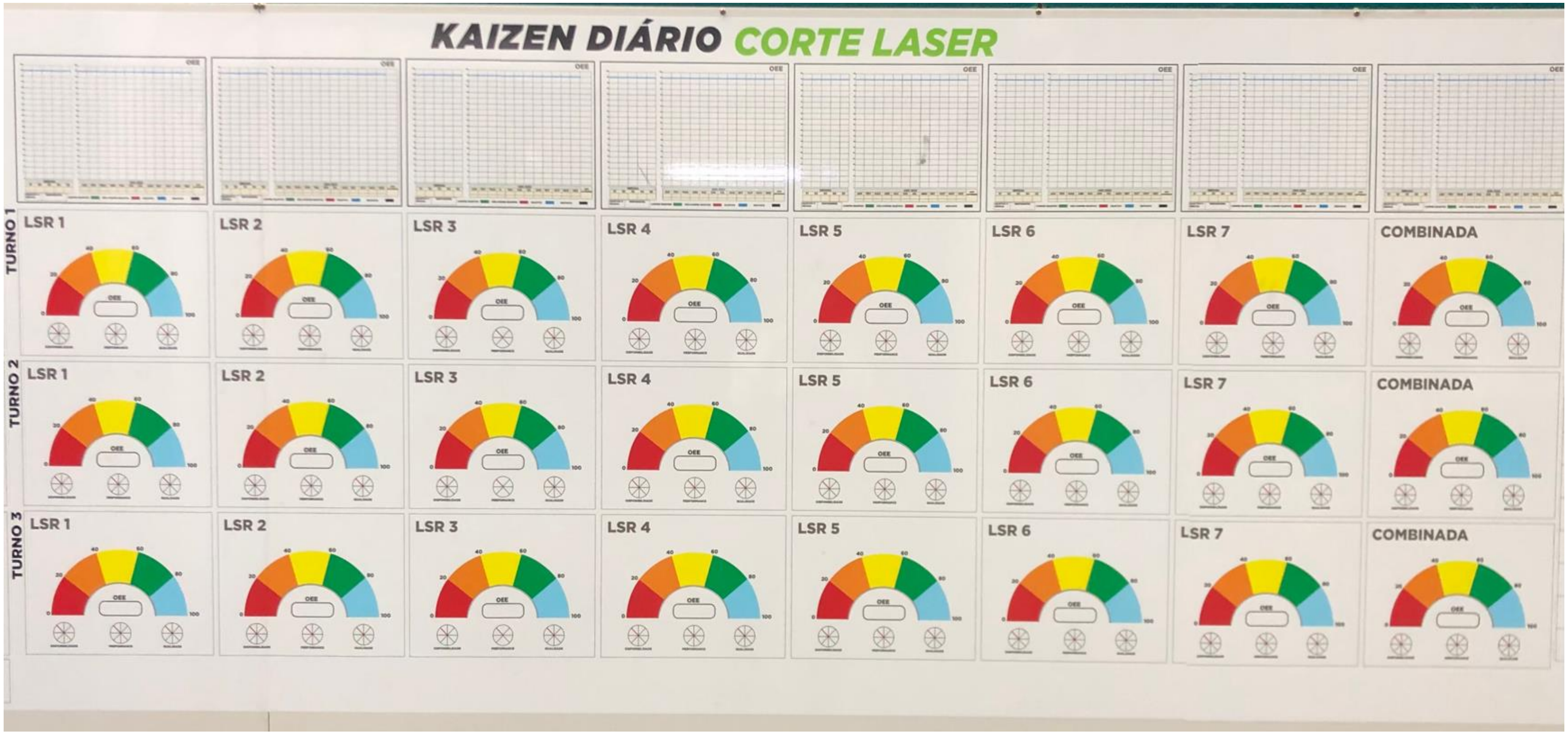
cod_art	num_cliente	Custo Unitário	Kanban?	LT Reposição (semanas)	Variabilidade LT	Consumo Semanal	Variabilidade Consumo	Stock Segurança	Nível Reposição	MOQ	Simulação Encomenda Semanal	Stock Max	Stock Médio	Custo Stock
AC0000000170001	100157	7,35 €	Sim	2	0,25	28	15	22	71	1	28	99	36	264,62 €
AC0000000397704	100132	446,95 €	Sim	2	0,25	10	5	8	25	1	10	35	13	5 810,36 €
AC0000000433802	100132	652,56 €	Sim	2	0,25	2	1	2	5	1	2	7	3	1 957,67 €
AC0000000868802	100285	663,88 €	Sim	2	0,25	2	1	2	5	1	2	7	3	1 991,65 €
AC0000000869602	100285	762,46 €	Sim	2	0,25	3	1	2	7	1	3	10	4	3 049,82 €
AC0000000869802	100285	823,73 €	Sim	2	0,25	3	2	3	8	1	3	11	5	4 118,66 €
AC0000000870802	100285	832,00 €	Sim	2	0,25	3	1	2	7	1	3	10	4	3 327,99 €
AC0000001123303	100132	326,06 €	Sim	2	0,25	8	4	6	20	1	8	28	10	3 260,65 €
AC0000001123403	100132	5,88 €	Sim	2	0,25	217	38	93	472	1	217	689	202	1 187,46 €
AC0000001123603	100132	790,40 €	Sim	2	0,25	4	0	1	8	1	4	12	3	2 371,21 €
AC0000001123703	100132	1 544,27 €	Sim	2	0,25	6	2	4	14	1	6	20	7	10 809,86 €
AC0000001191702	100132	82,22 €	Sim	2	0,25	14	9	13	37	1	14	51	20	1 644,45 €
AC0000001192101	100183	155,66 €	Sim	2	0,25	18	9	14	45	1	18	63	23	3 580,22 €
AC0000001192302	100183	104,06 €	Sim	2	0,25	15	4	8	34	1	15	49	16	1 664,91 €
AC0000001193902	100183	347,88 €	Sim	2	0,25	16	5	9	37	1	16	53	17	5 914,02 €
AC0000001228302	100132	8,17 €	Sim	2	0,25	19	7	12	45	1	19	64	22	179,82 €
AC0000001323401	100132	140,57 €	Sim	2	0,25	10	5	8	25	1	10	35	13	1 827,41 €
AC0000001323501	100132	166,93 €	Sim	2	0,25	9	4	7	22	1	9	31	12	2 003,18 €
AC0000001323601	100132	161,93 €	Sim	2	0,25	4	3	4	11	1	4	15	6	971,58 €
AC0000001323801	100132	160,29 €	Sim	2	0,25	2	1	2	5	1	2	7	3	480,86 €
AC0000001323901	100132	124,24 €	Sim	2	0,25	4	3	4	11	1	4	15	6	745,41 €
AC0000001324001	100132	145,85 €	Sim	2	0,25	10	5	8	25	1	10	35	13	1 895,99 €
AC0000001324101	100132	139,09 €	Sim	2	0,25	16	6	10	38	1	16	54	18	2 503,69 €
AC0000001324301	100132	152,04 €	Sim	2	0,25	10	5	8	25	1	10	35	13	1 976,51 €

APPENDIX G: Dashboard for availability analysis of each machine and the causes for downtime

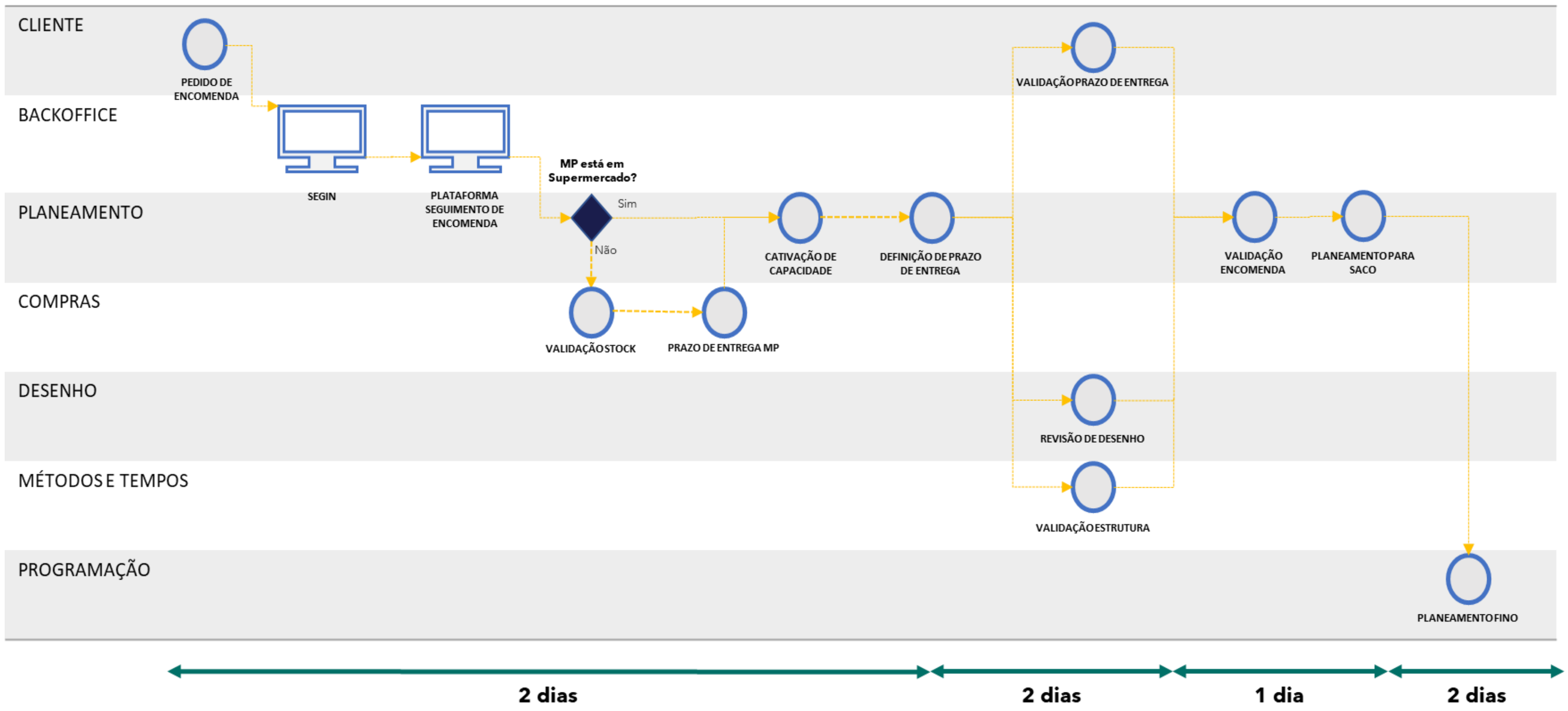




APPENDIX H: Board implemented on the factory floor for visual management of the machine's OEE



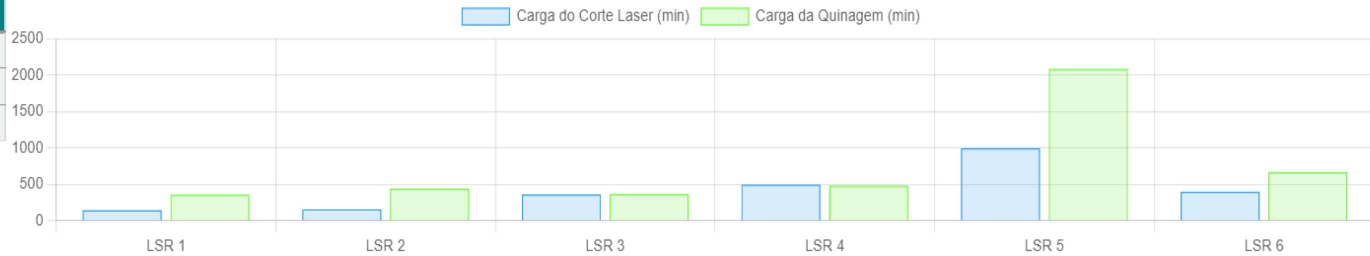
APPENDIX I: Designed administrative flow in more detail



APPENDIX J: Page added to the platform to create visibility of the levelling between Laser cutting 2D and Bending

Buffer Quinagem

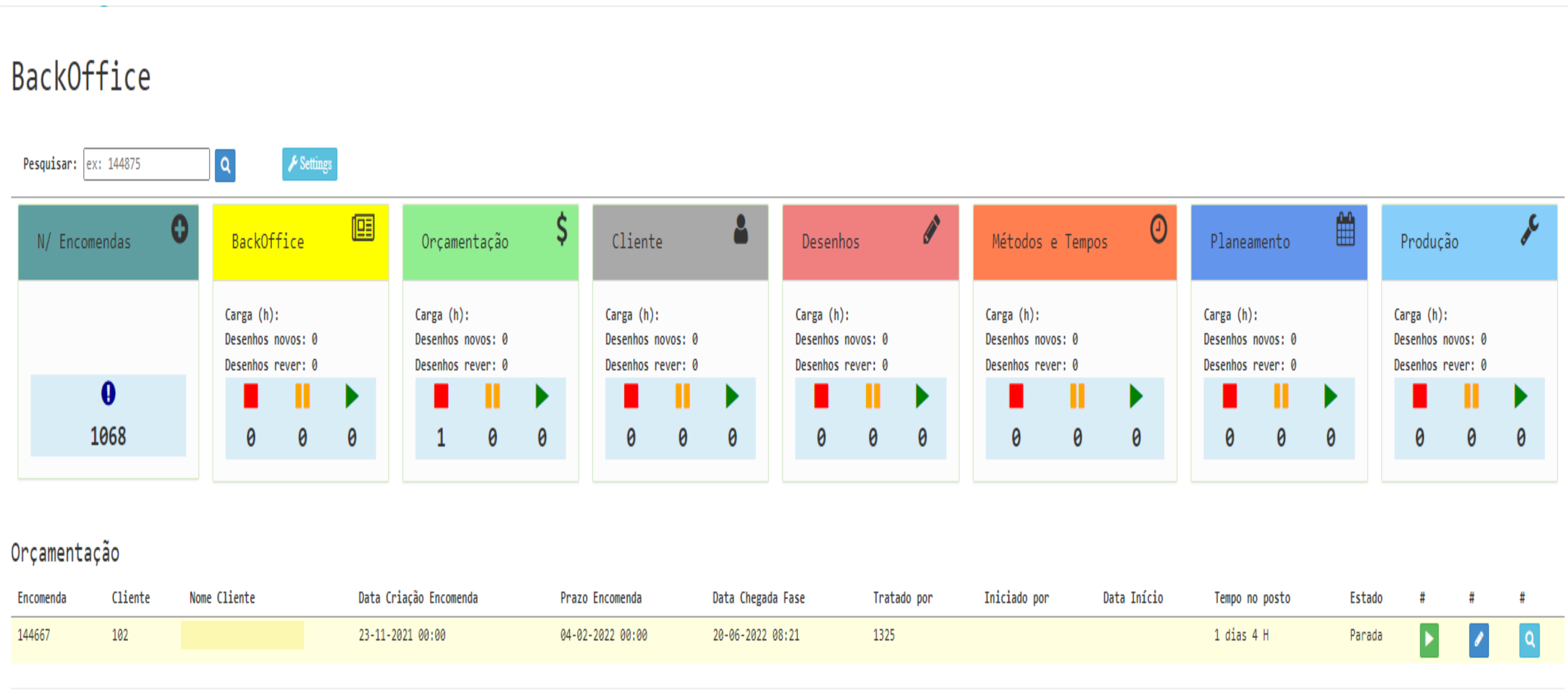
Carga	Tempo Corte (min)	Tempo Quinagem (min)
Carga em atraso	16213.93	23962.65
Carga para hoje	734.86	1065.68
Carga futura	1203.16	1352.36



Pesquisar

Nº Agrupamento	Nº de Ord. a Quinar	Tempo Quinagem (min)	Situação Agrupamento	U.Posto LS2	Data início Corte	Qtd. Agrupamento	Tempo Corte (min)
2022200271	6	3,73	Firme		2022-05-10 09:59	6,00	1,35
2022200428	12	188,80	Firme		2022-05-11 09:49	53,00	421,56
2022210323	10	169,60	Firme		2022-05-18 09:57	33,00	41,97
2022220525	2	444,45	Firme		2022-05-31 05:54	1000,00	66,66
2022220599	11	359,10	Firme	1	2022-06-01 09:59	634,00	146,39
2022220723	2	74,67	Firme	5	2022-06-07 08:50	105,00	79,80
2022220729	3	141,86	Firme		2022-06-06 08:23	266,00	607,37
2022220784	14	132,98	Firme	5	2022-06-14 09:51	136,00	15,59
2022230159	2	42,67	Firme		2022-06-15 09:58	4,00	12,93

APPENDIX K: Backoffice application created for following the orders



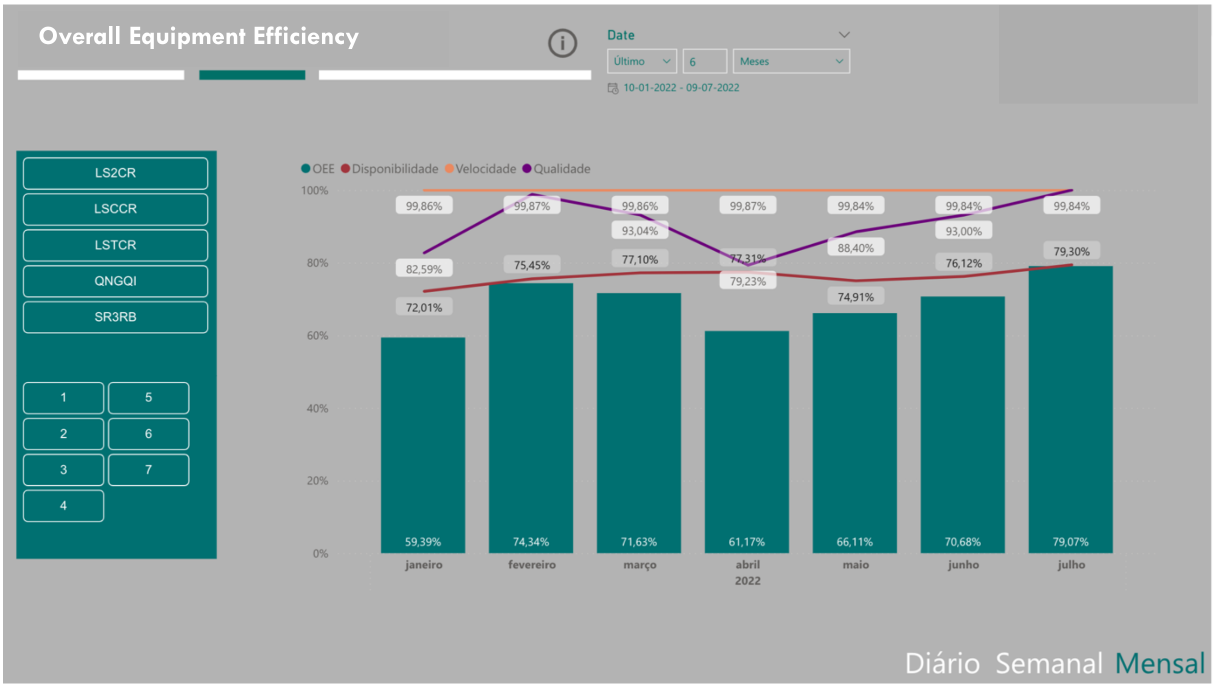
APPENDIX L: Dashboard developed in Power BI for following the key indicators

Since this project is expected to extend in a longer period of time and to combat the difficulty of updating the data for the calculation of indicators in Excel and improving their visibility, a production management dashboard was created. To this end, a survey of requirements was carried out and the analyses to be demonstrated were structured.
It is important to clarify that this new detail in the OEE calculation was only possible because the first study led to the understanding that the inputs of downtime in the software should change. To correct the lack of information about the daily number of shifts in each machine, it is now considered an open time of 24 hours for all posts and the team leaders need to categorise end of shift time as a machine downtime. Subsequently, the necessary data was collected, and an ODBC Driver was created that allows the automatic update of the data from the company X database.

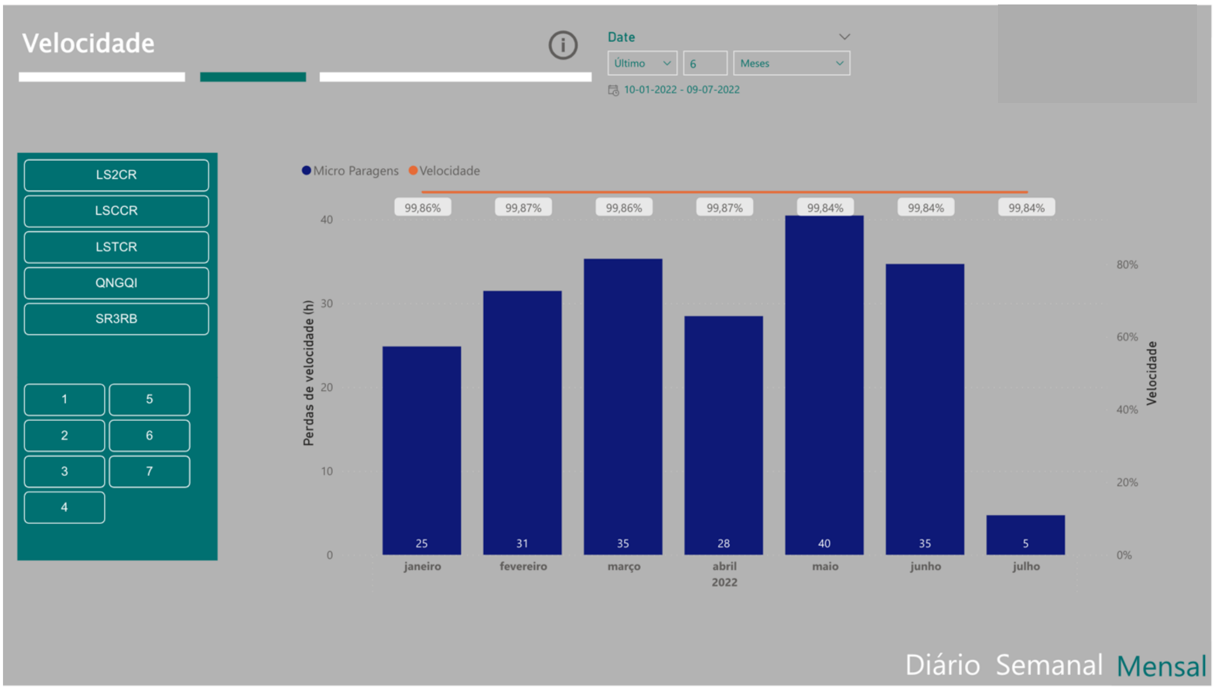
The result is reflected in the following images:

1. Home page showing last month's data for the posts identified as significant

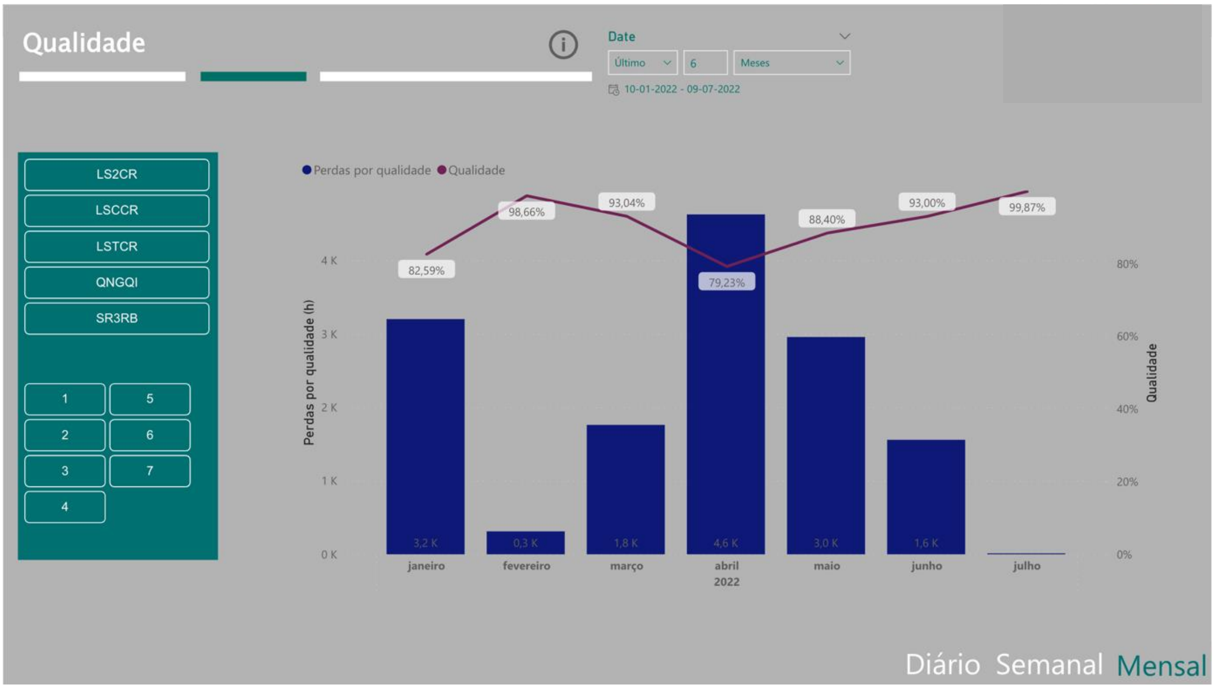
2. Overall Equipment Efficiency analysis, with the possibility to filter through work post and unit. Visibility of the impact of each parameter (availability, velocity and quality)



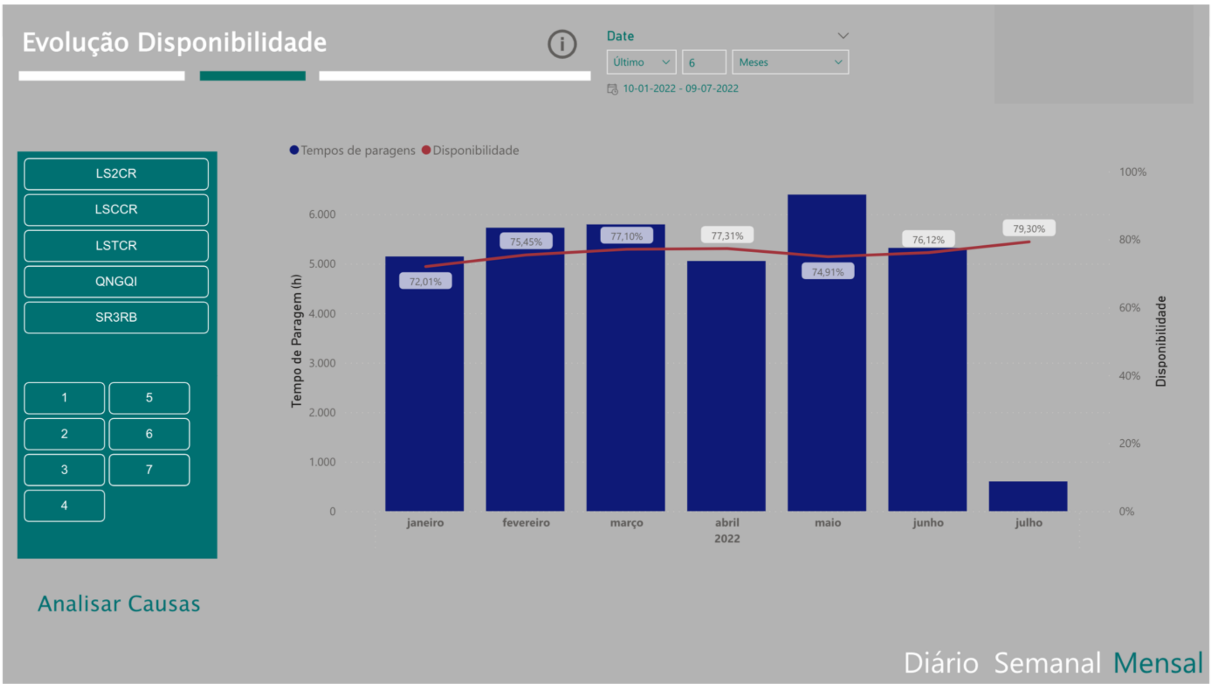
3. Velocity analysis, with the possibility to filter through work posts and units.



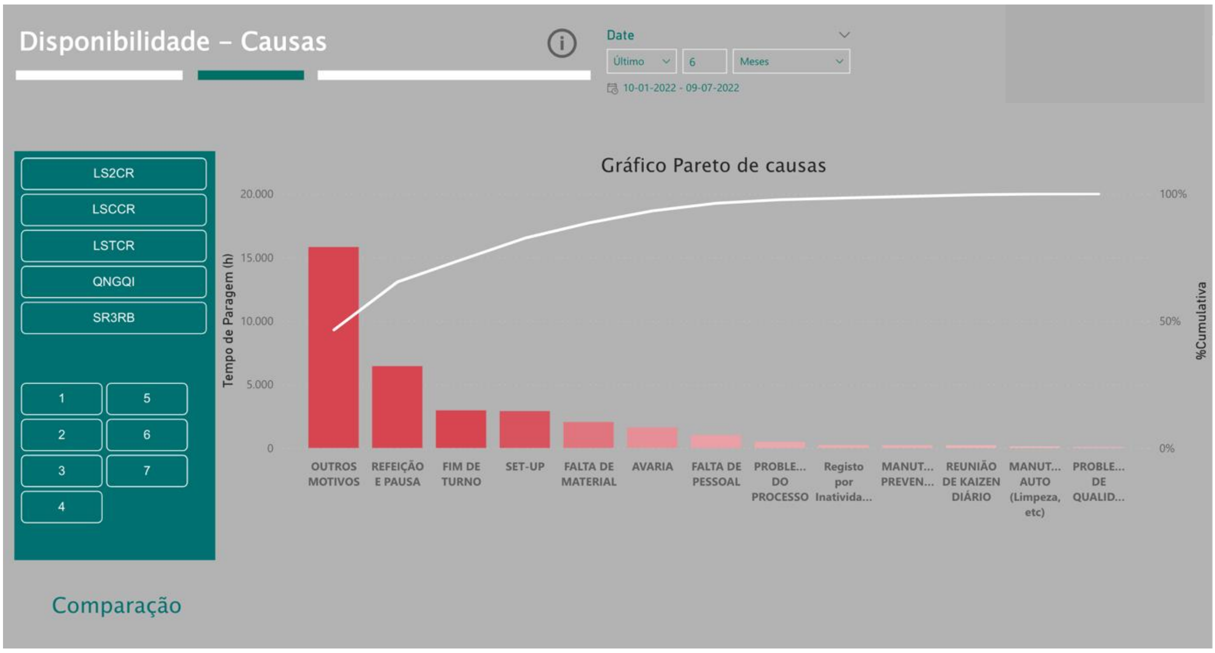
4. Quality analysis, with the possibility to filter through work posts and units



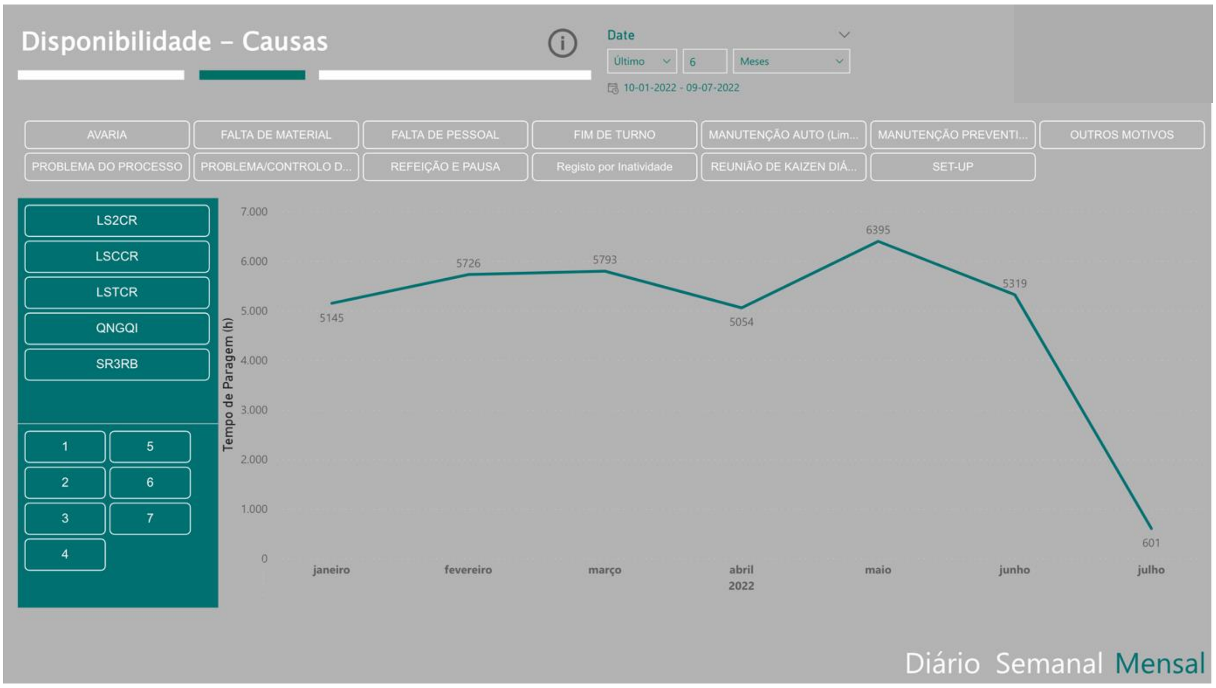
5. Availability analysis, with the possibility to filter through work posts and units.



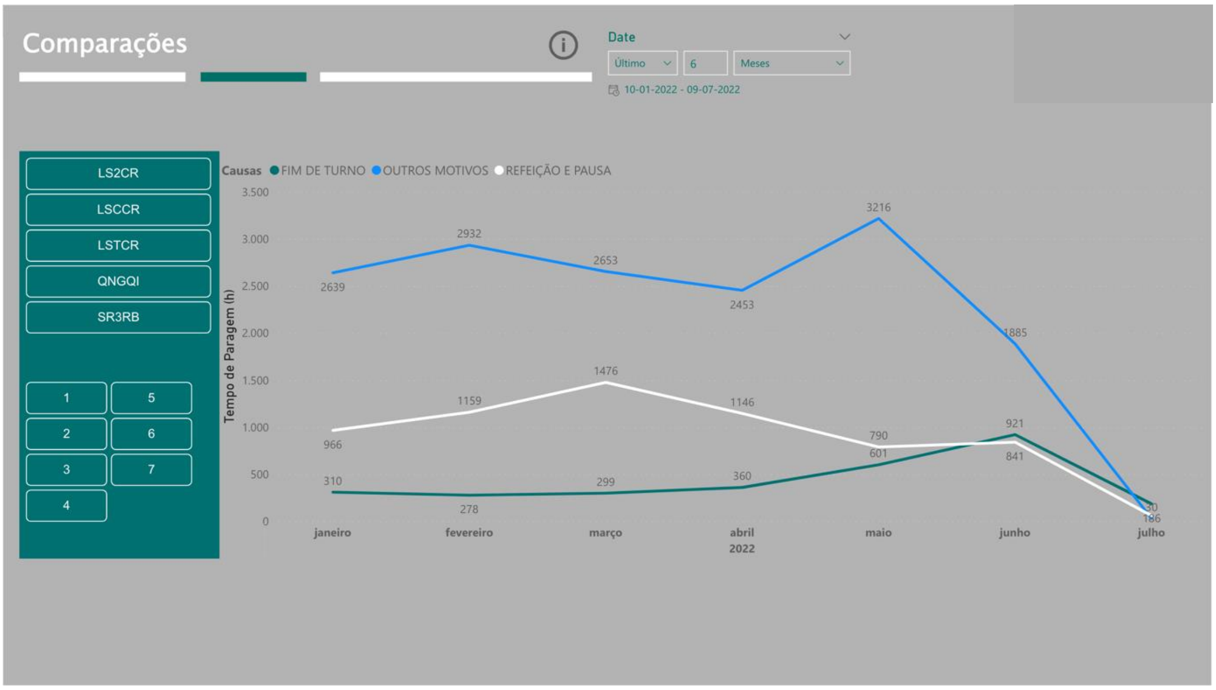
6. Causes of downtime Pareto analysis, with the possibility to filter through work posts and units.



7. Causes of downtime analysis, with the possibility to filter through work post, unit and cause.

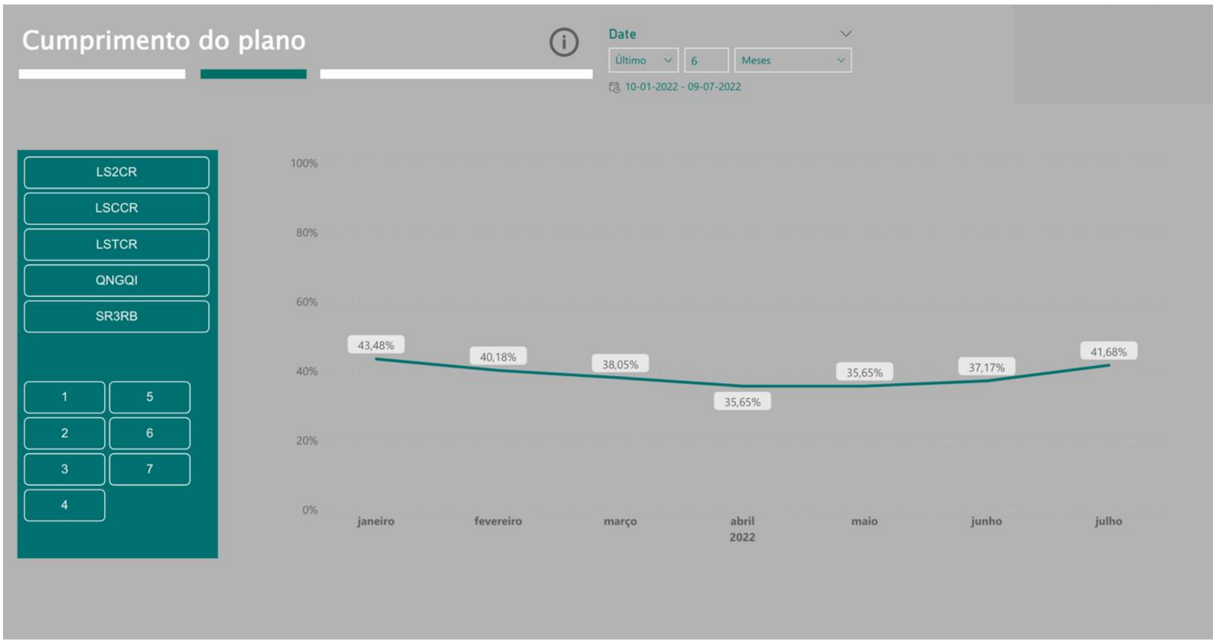


8. Comparison of the evolution of 3 principal downtime causes, with the possibility to filter through work posts and units.



This analysis is especially important to verify the team leaders are complying with the new input goals. It is possible to observe that the end-of-shift downtime has had a relevant growth in June, as expected.

9. Planning compliance analysis, with the possibility to filter through work posts and units. It is assumed the plan has been followed if production initiates within 8 hours of the planned hour.



10. On-time delivery and on-time in full analysis, with the possibility to filter through clients.