TÉCNICO LISBOA

Process Improvement in Operations Management

The Case Study of SAS interior modules

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Abstract

The present dissertation focuses on SAS Palmela, an automotive industry's company responsible for the production and delivery of the cockpit and center console modules for Volkswagen Autoeuropa's T-ROC car model. This work arises in the context of continuous improvement and its main objective is to improve SAS's logistics and production processes, by making them more efficient.

A first literature review regarding Toyota Production System and Lean Thinking was conducted, and then regarding its flow mapping tools, Material and Information Flow Diagram and Value Stream Mapping, where it was decided to follow a methodology based on the former. Additionally, it was also conducted a literature review regarding In-house Logistics and the Storage Location Assignment Problem. This work's first step was to characterize and to map the current situation of the system in study. Based on the mapped diagram, improvement opportunities were identified, and then each one of them was studied in detail. After this step, each improvement opportunity was evaluated, weighing the obtained savings against the necessary investment and, considering this, the ones that would be accepted for implementation were selected. For the selected improvement opportunities, recommendations of actions to be taken for its implementation were developed.

Six improvement opportunities were accepted for implementation, such as the reduction of operator movements, the reduction of handling of materials and the digitalization of paper documents. A total investment of 124,500 € is estimated to allow for a reduction of 190,27% of operator time in total, increasing the efficiency of SAS's processes.

Keywords: Lean Thinking, Toyota Production System, Material and Information Flow Diagram, Value Stream Mapping, In-house Logistics, Storage Location Assignment Problem.

Resumo

A presente dissertação foca-se na SAS Palmela, uma empresa da indústria automóvel responsável pela produção e entrega dos módulos cockpit e consola central para os T-ROCs produzidos pela Volkswagen Autoeuropa. Este trabalho surge no contexto da melhoria contínua e o seu principal objetivo é a melhoria dos processos logísticos e produtivos da SAS, tornando-os mais eficientes.

Foi realizada uma primeira revisão bibliográfica acerca do Sistema de Produção Toyota e do Pensamento Lean, e depois relativamente às suas ferramentas de mapeamento de fluxo, Diagrama de Fluxo de Material e Informação e Mapeamento do Fluxo de Valor, onde se optou por seguir uma metodologia baseada na primeira. Além disso, foi também realizada uma revisão da literatura relativa a Logística Interna e ao Problema de Alocação do Local de Armazenamento. O primeiro passo deste trabalho consistiu na caracterização e mapeamento da situação atual do sistema em estudo. Com base no diagrama mapeado, realizou-se a identificação de oportunidades de melhoria, e para cada uma delas foi feito um estudo detalhado. Depois deste passo, cada oportunidade de melhoria foi avaliada, pesando o ganho potencial face ao investimento necessário e, tendo isso em conta, foram selecionadas as que seriam aceites para implementação. Por fim, foram feitas recomendações para a implementação das oportunidades de melhorias selecionadas.

Foram aceites seis oportunidades de melhoria para implementação, tais como a redução dos movimentos dos operadores, a redução do manuseamento de materiais e a digitalização de documentos em papel. Neste sentido, um investimento total de 124.500 € permitiria uma redução total de 190,27% em tempo de operador, aumentando a eficiência dos processos da SAS.

Palavras-chave: Pensamento *Lean*, Sistema de Produção Toyota, Diagrama de Fluxo de Material e de Informação, Mapeamento do Fluxo de Valor, Logística Interna, Problema de Alocação do Local de Armazenamento.

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List of Abbreviations and Acronyms

- **AE** – Autoeuropa
- **AFIA** – *Associação de Fabricantes para a Indústria Automóvel* (Portuguese Association of Automotive Manufacturers)
- **AGV** – Automated Guided Vehicle
- **BCM** – Body Control Module
- **CCB** – Cross Car Beam
- **CT** – Cycle Time
- **EDI** – Electronic Data Interchange
- **EDIFACT** – Electronic Data Interchange For Administration, Commerce & Transportation
- **ELV** – Extra Low Voltage
- **EOL** – End Of Line
- **FES** – Faurecia Excellence System
- **FTL** – Full Truck Load
- **GAMS** – General Algebraic Modeling System
- **IP** – Instrument Panel
- **I/O** – In/Out
- **JIS** – Just-in-Sequence
- **JIT** – Just-in-Time
- **KENN** – KEN Number, it corresponds to the car identification number
- **KESSY** – Keyless Entry, Start and exit System
- **LHD** – Left-Hand Drive
- **LTL** – Less than Truck Load
- **MIB** – Management Information Base
- **MIFD** – Material and Information Flow Diagram
- **MIKO** – *Mittelkonsole* (German word for Center Console)
- **MILP** – Mixed Integer Linear Programming
- **MPV** – Multi-Purpose Vehicle, it correspond to the Seat Alhambra or the Volkswagen Sharan car models
- **MRP** – Material Requirement Planning
- **NVA** – Non-Value-Added
- **OCU** – Online Connectivity Unit
- **PDC** – Parking Distance Control
- **PDP** – *Plan Directeur de Production* (French saying for Production Master Plan)
- **PIC** – *Plan Industriel & Commercial* (French saying for Industrial & Commercial Plan)
- **POF** – Point of Fit
- **RA** – Reception Area
- **RCM** – Radios, Clusters and *Manetes* (Portuguese word for Steering Switches)

- **RFID** – Radio Frequency Identification
- **RHD –** Right-Hand Drive
- **SKU** – Stock Keeping Unit
- **SLAP** – Storage Location Assignment Problem
- **TPA** – Truck Preparation Area
- **TPS** – Toyota Production System
- **TRA** – Truck Reception Area
- **TT** – Takt Time
- **VA** – Value-Added
- **VSM** – Value Stream Mapping
- **VW** – Volskwagen
- **WC** – Working Content
- **WIP** – Work In Process
- **WMS** – Warehouse Management Software

1 – Introduction

The present chapter intends to contextualize the Problem Background (1.1), to state the Objectives of the dissertation (1.2), to present the Research Methodology (1.3) and the Dissertation Structure (1.4).

1.1 Problem Background

The automotive industry has always been recognized as one of the most important industries worldwide, not only for being a reference in terms of technological development, but mainly due to the impact it has on the world economy (Klink *et al.*, 2013). Although the Portuguese automobile industry is not considered one of the largest in the world or even in Europe, this does not mean that this sector is not crucial to the country. According to AFIA (2021) (*Associação de Fabricantes para a Industria Automóvel*), only 0.9% of the Portuguese manufacturing companies manufacture components for the automotive industry. However, these companies are responsible for 9.1% of the employment in the manufacturing industry, totaling 62,000 jobs and contributing to 5.2% of the Portuguese national GDP, which corresponds to 11 billion euros. In addition to the great impact on the country's economy, the Portuguese automotive industry is also a major driver of technological development, accounting for 16.9% of manufacturing industry investment (5 billion euros) between 2015 and 2021. This industry is recognized for the great competitiveness that is associated with it, which can be observed by the growth in the number of competitors present in this market. While in 2016 there were 200 companies in Portugal, today the number has almost doubled, totaling 350 companies producing components for the automotive industry.

SAS is a multinational company that is a key player in complex interior module assembly and logistics. It currently has 22 factories around the globe and has a 5% market share in cockpit assembly worldwide. The company presents itself within the interior module assembly market as a leader in process and product engineering and also in Just-in-Time (JIT) delivery. For these reasons and the high competitiveness associated with the automotive industry, the company is focused on improving its logistics and production processes. It is in this context that the present dissertation arises, which is focused on the SAS plant in Palmela. SAS Palmela is responsible for assembling and delivering in Just-in-Sequence (JIS) and JIT the cockpit and center console modules for its main client, Volkswagen (VW) Autoeuropa for the production of the Volkswagen T-ROC (representing more than 90% of production volume), the Volkswagen Sharan and the Seat Alhambra car models.

1.2 Objectives

Considering that VW Autoeuropa is by far the largest car producer in Portugal and that SAS business depends on the ability to win new products from its customers, it is important for SAS to focus daily on improving its processes so that it never stops being competitive. This way, this work aims to improve the logistics and production processes of the SAS Pamela plant, having as main focus the identification of improvement opportunities for waste (Non-Value-Added tasks) elimination from the processes, making them more efficient and therefore, making the company more competitive.

To perform this analysis the Material and Information Flow Diagram (MIFD) flow mapping tool was chosen. This tool, whose origin goes back to the creation of the Toyota Production System (TPS), aims to visually describe the material and information flows that occur in the operations of the system under study, just like Lean's Value Stream Mapping (VSM) tool. The MIFD was chosen instead of the VSM because the former contains more detailed information regarding the different processes of the system, when compared to the latter tool. This way it is possible to have more information about the operation when identifying improvement opportunities and when suggesting improvements.

To conclude, this dissertation's main objective is to improve SAS's logistics and production processes by making them more efficient.

1.3 Research Methodology

In this section, the research methodology adopted in this master's thesis is presented. This research methodology is divided in 7 steps, which are individually explained:

Step 1 – The first step is to conduct a literature review concerning the Toyota Production System and Lean Thinking, and after concerning the MIFD and VSM tools. The objective of this first step is to review the state-of-art regarding the mentioned concepts with focus on the MIFD tool. The purpose of this step is to define concepts and to identify the most appropriate methodologies for the problem in hand. In this case, the MIFD was the methodology chosen to address the problem as it contains more detailed information, when compared to VSM.

Step 2 – In addition to the collection of necessary information, the second step is the construction of the MIFD relative to the current situation. This is followed by a first identification of opportunities for improvement which will later be included in the construction of the future MIFD.

Step 3 – The third step refers to validation and rectification by representatives from all departments regarding the current MIFD and regarding the identified opportunities for improvement, serving also as an input to the construction of the future MIFD. This step is essential to assure that the MIFD can mirror the various views of the different departments regarding the current situation of the plant.

Step 4 – After the validation and the collection of information provided by the different people, the next step is the construction of the future MIFD, where the improvement opportunities previously identified are applied. At the end of this stage, the author was named responsible of studying and analyzing an improvement opportunity (Improvement Opportunity #2). Here an external audit to the Palmela plant is made which serves to assess and validate the current and future MIFD.

Step 5 – Now focusing on Improvement Opportunity #2, a literature review regarding In-house Logistics, the Forward-Reserve Configuration and the Storage Location Assignment Problem (SLAP) is performed in order to obtain more knowledge and to identify the most appropriate methodologies.

Step 6 – After the literature review, the methodology for solving the problem is defined. This sixth step consists of the construction and description of the logic of all the steps developed to solve the problem.

Step 7 – In this final step and after the work developed, the results obtained are analyzed and discussed. After this, the results are presented and validated by the decision maker, and three solutions are suggested to the decision based on their efficiency. In the end the decision maker chooses one solution.

1.4 Dissertation's Structure

There are six chapters in this dissertation, each with its own purpose. The following is a summary of each chapter's main points:

- **Chapter 1** – *Introduction* – The present chapter intends to introduce the present dissertation. It starts with the contextualization of the problem's background and then it proceeds with the definition of the objectives. After this, it presents the research methodology applied in this dissertation and concludes with the explanation of the dissertation's structure.
- **Chapter 2** – *Case Study* – This chapter describes the company in detail. It starts by introducing SAS and its parent company. Then, and focusing on SAS Palmela plant, the production and logistics processes are characterized as well as the plant information.
- **Chapter 3** – *Literature Review* – In this chapter, a literature review was conducted on topics considered relevant to this dissertation. It started with a literature review on Toyota Production System and Lean Thinking philosophies, and then a comparison was made of the tools associated with each philosophy, the Material and Information Flow Analysis and Value Stream Mapping respectively. After this, a literature review was done regarding In-house Logistics in a production plant, the Forward-Reserve Configuration, and the Storage Location Assignment Problem.
- **Chapter 4** – *Methodology* – This chapter explains the logic used in the Material and Information Flow Analysis and the logic used to solve the subsequent SLAP Problem. Regarding the first problem, it explains the method used to collect the needed information for the diagram, then it explains the identification of improvement opportunities process. Regarding the second problem it explains the logic used when building the SLAP model.
- **Chapter 5** – *Results and Discussion* – In this chapter the results of both problems are presented and discussed. About the first problem, it starts by presenting the results obtained during the current state characterization and then the diagram (MIFD) built from there. Then, the opportunities for improvement are presented, as well as the results of the analysis of each of them, ending with the presentation of the future (MIFD) diagram. Finally, the results of the SLAP problem are presented, which is related to an improvement opportunity identified in the first problem.

- **Chapter 6** – *Conclusions and Future Work* – This chapter presents the main conclusions of the present master's thesis, as well as suggestions for future work.

2 – Case Study

This chapter introduces the company that will be the focus of this dissertation, SAS Palmela, presents its characteristics and describes the operations performed at the plant. Subchapter 2.1 is focused on SAS Palmela's parent company, Faurecia. Then, Subchapter 2.2 presents SAS and focuses on the Palmela plant, starting by describing the Plant Organization (2.2.1), the Production Operations (2.2.2), the Logistics Operations (2.2.3) and concluding with Plant Information (2.2.4).

2.1 Faurecia

Faurecia is a multinational company from the automotive industry with presence in 33 countries from multiple continents, namely Asia, Europe, North and South America. It presents itself as a multicultural company as it has approximately 111.000 employees from 146 different nationalities working across 257 plants and 39 research & development centers. Clean Mobility, Seating, Interiors, and Clarion Electronics are its four business groups, with a combined revenue of €15.6 billion in 2021 (Faurecia, 2022). Faurecia positions itself as a global leader in automotive technology, designing solutions for a safe, personalized, connected, and sustainable mobility (Faurecia, 2021a).

Bertrand Faure, the French company that would later originate Faurecia, was founded in 1914 with the goal of producing seats for the Paris tram and metro. Years later it would start to acquire important patents for seat comfort improvement and enter the light vehicles and trucks repair market. Peugeot creates ECIA as an independent equipment manufacturer in 1987, which ten years later would merge with Bertrand Faure. This way, Faurecia, a new leader in automotive seating industry, is created in 1998. Two years later, Faurecia bought Sommer Allibert (who owned 50% of SAS) and became the world's third largest manufacturer of automotive interiors, and in 2009 by acquiring EMCON Technologies, became the world leader in emissions control technologies. In 2016, a new strategy focusing on innovative technology was unveiled, with two fast-growing areas in mind: Sustainable Mobility – solutions for ultra-low & zero emissions – and Cockpit of the Future – solutions for personalized & connected experiences (Faurecia, 2021c). In 2019, to invest in the first area, it acquired Clarion and created Symbio, a joint venture with Michelin for hydrogen storage systems. And in 2020, with the second area in focus, it acquired the remaining 50% of SAS Interior Modules, expanding this way its system integrated expertise to all interior modules. Earlier this year, the company acquired Hella, combining the two companies to form the FORVIA group, the world's seventh largest automotive supplier group, with 1 in every 2 vehicles around the globe being equipped with its technology (Faurecia, 2021d).

Faurecia supplies the biggest automobile manufacturers worldwide, having many automotive groups as customers. Two of them can be identified as the most important, VW Group and Stellantis, which together account for more than 40% of the company’s sales in 2020 (Faurecia, 2021a). The distribution of sales’ percentage per customer can be seen in Figure 1.

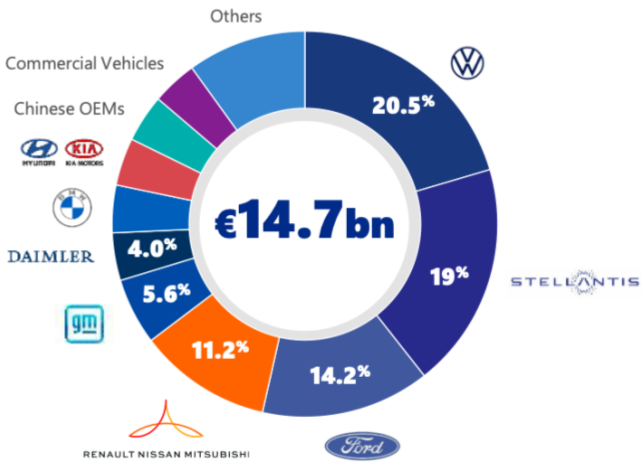


Figure 1: Faurecia's sales per customer from year 2020. Source: (Faurecia, 2021a)

2.2 SAS Interior Modules

SAS Interior Modules is a key player in the automotive industry's complex interior module assembly, logistics, and Just-in-Time delivery. The company was founded in 1996 by a joint venture between Sommer Allibert and Siemens, and has since been recognized for delivering high quality, innovative, and customer-specific modules precisely when and where they are needed. Since then, it has supplied some of the industry's most well-known manufacturers, including Volkswagen, Audi, PSA, Porsche, Tesla, BMW, Skoda, and others. Note that, SAS is a specialist in assembling interior modules and that currently 5% of passenger cars worldwide have an SAS's cockpit (Faurecia, 2021a). Despite SAS's specialization on cockpit assembly, with its innovative solutions and its perfectly coordinated logistics, the company has managed to grow into a skilled partner in other front-end modules, such as the center consoles.

In early 2020, Faurecia, who already owned 50% of SAS's shares (obtained with the acquisition of Sommer Allibert), completed the acquisition of the remaining 50% from Continental (which previously bought its shares from Siemens). Through this investment, Faurecia was able to accelerate its transformation, by becoming the number one supplier of interior modules worldwide, with a market share of 14% – leader in instrumental panels and door panels, and number 3 supplier in center consoles (Faurecia, 2021c).

Nowadays SAS employs 4.800 people throughout 22 plants and 35 assembly lines around the globe, with a total of €715 million in sales registered in 2020 (Faurecia, 2021a). Annually the company supplies more than 5,2 million cockpits, meaning that it is among the most important players in the global automotive industry.

2.2.1 Plant Organization

The current case study takes place at SAS Palmela assembly plant, present in the Industrial Park Autoeuropa. This plant was built in 2000 and currently employs around 200 people working on 19 shifts per week with 4 teams, 24 hours per day on week days, and 16 hours per day on the weekend days (SAS, 2022). SAS's plant only produces two types of products – cockpits and center consoles – for two production plants: Autoeuropa (Portugal) and Osnabrück (Germany), both from the VW Group. The Autoeuropa plant is the most significant client for SAS, given that it supplies the cockpit and center console modules for every vehicle produced by the client, which includes the Volkswagen T-ROC and Sharan models, as well as the Seat Alhambra model. For the Osnabrück plant, SAS only produces the center console module for the T-ROC Cabriolet model, which represents less than 10% of SAS's production in terms of volume.

Unlike most production plants, the SAS Palmela plant is an assembly plant with two different assembly lines, the Cockpit Module assembly line and the Center Console Module assembly line. Assembly plants usually are characterized by dealing with a high number and low volume of components. These components can be arranged in multiple combinations in order to obtain the exact combination required by the customer, resulting in a high number of different final products.

In the case of SAS, there are two major client requirements which make the operations more difficult: producing JIT and producing JIS. Producing JIT basically means that the right products are produced in the right quantities and at the right time (Monden, 2011), *i.e.*, without the need to build stocks of final or intermediate products, whilst still delivering the customer at the wanted time. Producing JIS means that, besides producing and delivering the right product in the quantity at the right time, the production must be synchronized with the customers' production in order to enable sequenced parts delivery (Wagner & Silveira-Camargos, 2012).

SAS Palmela plant accounts for a total area of 7.500m^2 (SAS, 2022). In this plant, additionally to the ground floor, there are two mezzanines, the MIKO Mezzanine (MIKO is the abbreviation for the German word *Mittelkonsole* which means Center Console) and the Welding Mezzanine. The MIKO Mezzanine is where the Center Console assembly line is present, besides a single workstation which is present in the Welding Mezzanine. It's worth mentioning that this workstation is the only one in the plant that uses Batch Production rather than JIS Production. In addition to this workstation, in the Welding Mezzanine there also exist two other workstations that produce frame panels which are automatically delivered to the Cockpit assembly line.

The Cockpit module assembly line requires almost 8 times more components than the center console's assembly line, making it the more labor-intensive assembly line in terms of production and logistics operations. As a result, this assembly line is located on the ground floor (apart from the two already mentioned workstations) in order to provide additional operating flexibility. Besides the cockpit assembly line, on the ground floor is where the plant's warehouse is located. This warehouse is composed of a bulk storage area, a rack storage area and an additional rack storage area, which is completely managed by an external company, DSV.

2.2.2 Production Operations

SAS Palmela plant has two assembly lines which account for 32 workstations in total which can be seen in the Annex 1. When describing the production operations is important to keep in mind that each workstation produces piece by piece, even the workstation that produces in Batch. One other aspect that is important to mention is that the workstations are exclusive to product types, *i.e.*, if one workstation is relative to the Cockpit Module Assembly Line, then it will not be a part of any process of the Center Console Module Assembly Line, and *vice-versa*. As previously mentioned, three different car models are produced on this assembly line, however the focus of this work is the production of the T-ROC model for the customer Autoeuropa, since it is the high runner (the product that accounts for the most part of production volume). In the subsections 2.2.2.1 (Cockpit Module Assembly Line) and 2.2.2.2 (Center Console Module Assembly Line), the assembly lines of the two products are presented in more detail.

2.2.2.1 Cockpit Module Assembly Line

The Cockpit Assembly Line consists of 24 workstations that work directly on the cockpit, plus 4 workstations working off-line that are intended to do pre-assembly operations or sequence components to be assembled at subsequent stations. On this assembly line all workstations operate in JIT and JIS. Thus, there is no creation of Work In Process (WIP) stock, except for the stations that work off-line. In these stations there is the creation of minimum intermediate stock in order to guarantee that the continuity of the assembly line production is never interrupted.

To enable cockpit assembly operations to occur as smoothly and safely as possible, the cockpit is assembled on a structure called a fixture. In turn, this fixture is fixed to another structure, the trolley, which follows the physical assembly line along an automatic rail. While the trolley always remains within the loop of the assembly line rail, the fixture always goes along with the cockpit, even within the customer's production line until the cockpit is assembled into the car. For a better understanding of the overview of this assembly line, a flowchart is presented in Figure 2. In this flowchart the workstations are represented by rectangles and the customer by an ellipse, the continuous arrows represent flow of the cockpit or cockpit components, and the dashed arrows represent the flow of the empty trolley back to the beginning of the line.

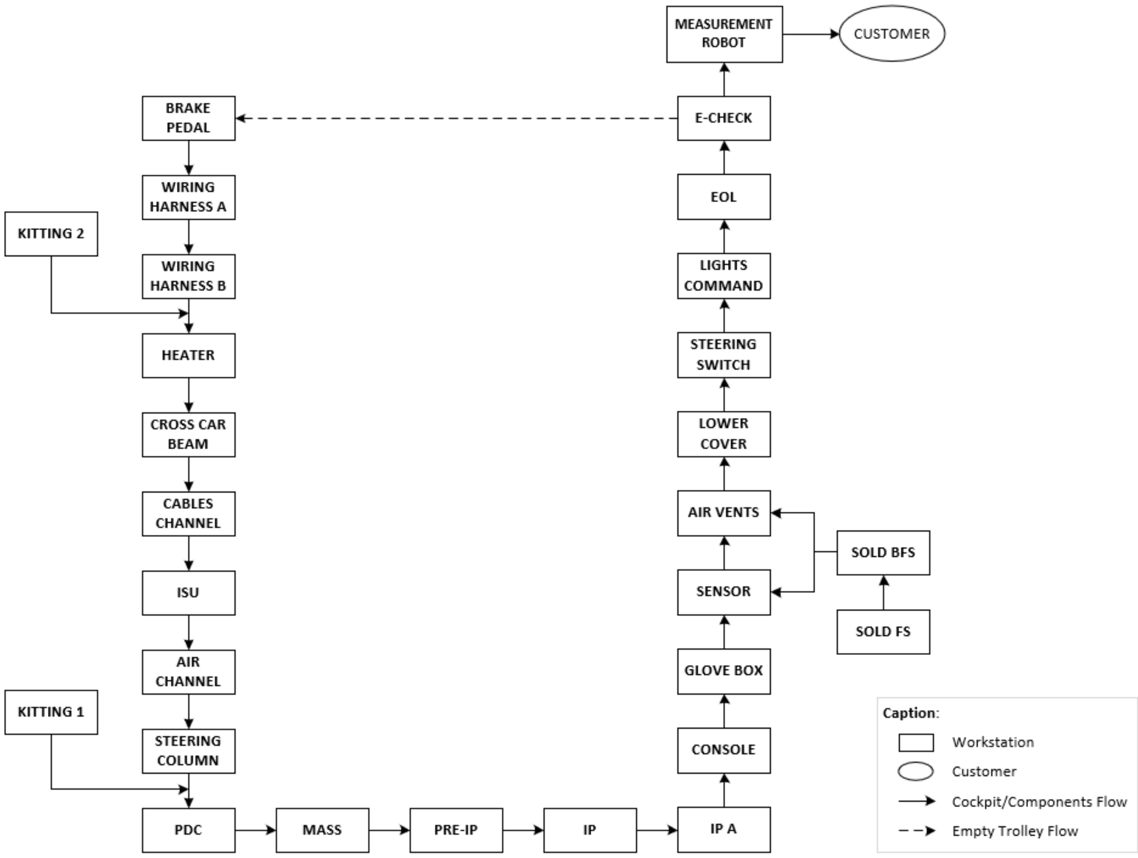


Figure 2: Flowchart of the Cockpit Module Assembly Line.

The **Brake Pedal** is the first workstation of the assembly line, and its operator is responsible for the changeover of the fixture supports. If the fixture supports correspond to a Multi-Purpose Vehicle (MPV) car model, then it changes the left and right Cross Car Beam (CCB) supports and also the heater central support for the one's correspondent to the T-ROC car model. If the supports are already relative to the T-ROC model, then it does not change any support. Note that for the MPV model, this workstation has more operations which are not needed for the T-ROC and that case it still has some other operations which are not on the first workstation.

In the **Wiring Harness A** workstation, the operator obtains the KESSY module (abbreviation for Keyless Entry, Start and exit System), assembles it to the KESSY support and stores it in the sequencing box which is located in the trolley. Then, jointly with the Wiring Harness B operator, they obtain the wiring harness and place it properly on the fixture. To end its operations, puts protections in some specific wiring harness' antennas and electrical plugs.

In the **Wiring Harness B** workstation, the operator starts by transporting the wiring harness, as previously mentioned, and then obtains the BCM (Body Control Module), PDC (Parking Distance Control) and gateway modules and places them on top of the fixture. Assembles the BCM to the wiring harness' ISU and then the gateway module and its electric plug. Afterwards it performs a Pull Test to the gateway's plug; note that a Pull Test is performed when there is a need to assure that a connection is correctly done. To finalize, assembles the PDC module and its electric plug to the ISU.

While the Wiring Harness B operations are being done, the **Kitting 2** workstation operations occur outside the assembly line. In this station, the operator sequences and places some specific parts into the kitting box, which is introduced in the trolley after its completion. The parts sequenced in this station are: the front and rear air channels, the feet air channels, the anti-crash, the *frequenz* support and the heater feet cover. Additionally, it sequences and assembles the OCU (Online Connectivity Unit) module to its support and places it in the kitting box, completing the kitting box.

After these last two workstations is the **Heater** workstation. In here, the operator obtains and assembles the lower bracket in the heater, and after he positions the heater on top of the fixture's central support. Obtains, positions, and tightens the CCB to the fixture, and the heater to the CCB.

In the next workstation, **CCB**, the operator starts by positioning the ISU on the CCB and then tightens the OCU module and the ISU to the CCB. It takes the *frequenz* support from the kitting box and assembles it on the CCB. To finalize, it routes and clips the cables channel wires to the CCB, the airbag wires to the heater and the radio wires to the CCB.

In the **Cables Channel** workstation, the operator starts by connecting the BCM plugs to the BCM and performs a Pull Test to assure that it is correctly connected. Then, takes the KESSY module from the sequence box and assembles its support to the CCB. Connects the plug to the KESSY module and performs a Pull Test. To finalize, it routes the passenger airbag wires and packs the OCU module's plugs the left side's bag of the wiring harness.

The **ISU** workstation's operator only responsibility, when describing effective production processes and not considering the steps he performs to give inputs to the information systems, is to obtain the anti-crash bracket from the kitting box and to assemble and tighten it to the CCB.

After the ISU is the **Air Channel** workstation. Its operator starts by obtaining the front air channel from the kitting box and assembling it to the heater, then it does the same for the passenger feet air channels. Afterwards, it connects the heater plug to the heater and performs a Pull Test.

In the **Steering Column** workstation, the operator assembles and tightens the steering column to the CCB. Then assembles the column cables channel to the column and followingly the transceiver. It ends with a functionality check of the steering column.

In parallel with the Steering Column operations is the **Kitting 1** workstation, outside the assembly line. This workstation operations are similar to the Kitting 2 operations, as the operator is responsible for sequencing some parts and placing them in a kitting box, but in this workstation, he sequences the components for two cockpits at the same time by using a small cart to transport the kitting boxes. The parts sequenced in this workstation are the display support, the left and right cockpit lower covers, the central air vent, the display frame, the transceiver coil, the ELV (Extra Low Voltage) module, the feet LED light, the light sensor and the lights command.

After these last two workstations is the **PDC** workstation. Its operator starts by retrieving the last parts from the kitting box and placing them on top of the fixture. Then it takes the empty kitting box sequenced in the Kitting 2 station from the trolley and puts the new kitting box sequenced in the Kitting

1 station in the trolley. After this, assembles the driver feet air channel and the rear air channel to the heater. To end the workstation's operations, it routes the diagnose plug and the light command cables.

The **Mass** workstation's operator assembles the heater feet cover to the heater, then parks the loose wirings for the IP (Instrument Panel) assembly and routes the transceiver coil plug. To end its operations, marks the lower heater bracket in order to assure its presence.

In the **Pre-IP** workstation, its operator starts by obtaining the IP from the IP sequencing rail and transporting it to the pre-assembly table. Then assembles and tightens the airbag to the IP and marks the screws to assure their presence. Assembles the temperature sensors, and with the help of IP workstation's operator, it moves and positions the IP in the fixture. While the IP's operator continues its operations on the car, he connects the temperature sensor to the wirings and the airbag plug to the airbag and performs a Pull Test to both connections, ending its operations.

The **IP** workstation's operator starts by introducing the RCM (Radios, Clusters and *Manetes*) sequence box in the trolley. Then it helps the Pre-IP operator moving and positioning the IP in the fixture. Afterwards, routes different wirings relative to the cluster, to the steering switches, to the lights command and to the Climatronic module, throughout the IP. And ends its operations by tightening the sides of the IP to the CCB.

After this station is the **IP A** workstation. Its operator tightens the center of the IP to the CCB, connects the Cluster plug to its wirings and performs a Pull Test to this connection. Its operations end with the assembly of the cluster and of the central air vent to the IP.

In the **Console** workstation, its operator tightens the cluster to the IP, assembles the feet LED light and the driver lower cover to the IP, then connects the feet light to the wiring and performs a Pull Test. After this, obtains the glove box, assembles its light and places it in the glove box sequencing mat.

The **Glove Box** workstation's operator obtains the glove box from the sequencing mat and assembles it to the lower part of the IP. Connects the glove box light plug to the glove box and performs a Pull Test. Then assembles the glove box to the top part of the IP, routes the Management Information Base (MIB) module wiring through the IP's lights command space and to end its operations, tightens the glove box to the IP.

Outside this assembly line there are two workstations working in sequence, namely Sold FS and Sold BFS, which feed parts directly to the Solar Sensor and Air Vents workstations. The **Sold FS** operator assembles the top column cover to the FS cover and places this part in the sequencing box, and the box in the sequencing shelve in order to make this part available for the next workstation. Then, the **Sold BFS** operator obtains the FS cover, places it in its position on the pre-assembly table and assembles the FS air vent to it. Then obtains the BFS cover, places it in its position on the table and assembles the BFS air vent to it. After this, the color verification machine checks if the color of both FS and BFS covers match the order, and if correct, the operator positions both covers in a jig which, through two conveyor belts and a robot arm, is directly fed to the Solar Sensor and Air Vents workstations.

In the **Solar Sensor** workstation, the operator connects the solar sensor to its wiring, performs the Pull Test and after assembles the solar sensor to the IP. Assembles the passenger feet light to the glove box, connects it to its wiring and performs the Pull Test. Afterwards and to finalize its operations, assembles the FS cover to the IP.

After this workstation, the **Air Vents** operator tightens the driver lower cover to the IP and assembles the BFS cover to the IP. Routes the airbag plug and assembles the display support to the IP, ending its operations.

In the **Lower Cover** workstation, the operator tightens the display support to the IP, obtains the display, checks for any visual defect on the display and assembles it to the display support. After this checks again for any visual defect on the display and makes the display electric and antenna connections to the MIB. To finalize its operations, assembles the MIB to the glove box.

The **Steering Switches** workstation's operator starts by obtaining and assembling the ELV module to the steering switches, after this assembles the steering switches to the steering column. Connects the ELV module and the steering switches plugs to the wirings and performs a Pull Test for both plugs. Then assembles the transceiver coil to the driver lower cover and tightens the cover to the steering switches. Afterwards, assembles the display frame to the display support and prepares the lower wiring harness for the following electric tests.

Followingly, the **Lights Command** workstation's operator tightens the steering switches to the steering column and assembles the top column cover to the column. After this, it assembles the lights command to the IP and connects it to the wiring. Then assembles the left and right air vent grills and prepares the top wiring harness for the electric tests, ending this way the effective cockpit assembly process, as the next stations are totally composed of tests.

In the first tests workstation, **EOL** (End Of Line), the operator visually checks for any gaps between the FS and BFS covers and the IP and also with the cluster. Testes if the air vents are working properly. Checks if there exists any gap between the top and lower column covers. Checks if the assembled display frame matches with the ordered one, checks for any gaps between the display support and the IP, the display frame and the support, and the display frame and the display. Checks if the CCB is correctly tightened to the fixture. Checks if the glove box's switches, the glove box's light and the passenger feet light are connected, and if the glove box door is working properly. Checks if there is any gaps between the solar sensor or the light command cover to the IP and if the driver feet light is well connected.

The **E-Check** workstation, correspond to the electric tests' workstation in which the previously assembled modules and plugs are tested to assure they are functioning as they should before the cockpit enters the customer's assembly line. Its operator starts by securing the tester to the trolley, then makes all the different tester connections to the cockpit and after this the tests start. After the OK from the tester, the operator disconnects the different dummies and electric plugs and then stores the wiring harness, the airbag plug and other cables in order to assure that the cockpit is not damaged in the transportation process to the customer or even in future customer's assembly processes.

At last is the **Measurement Robot** workstation which has no operators. The operations of this workstation are completely done by a robot. This robot performs a series of measurements on the cockpit to ensure that it will physically fit in the car, in the customer assembly line. After this last workstation, the cockpit continues to follow the automated rail until it is automatically loaded in the delivery truck.

2.2.2.2 Center Console Module Assembly Line

The first important note relative to the center console module is that this product is delivered in three different parts, for an easier understanding, let them be called Part A, Part B and Part C. These parts are delivered in different racks which have each part stored in a specific space according to the customer sequence – each space is relative to a specific car. The different racks are all transported in the same truck and delivered at the same time to the customer. Note that the need for the center console being delivered in different parts and not altogether is due to the fact that, in the customer plant each part is being fed to the production line in different stages (Points of Fit). Once Parts B and C are fed to the customer's production line at Points of Fit (POF) close to each other (Workstations 97 and 101 respectively), then these products are produced and delivered to the customer in racks containing the same sequences. Since Part A is fed at a POF further down the line (Workstation 112) than the previous ones, then to avoid high intermediate stocks, it is sent to the customer in a staggered sequence with the other two parts. To illustrate this, in the same truck, while the racks of Parts B and C correspond to sequence i, the rack of Part A corresponds to sequence i - 1.

The Center Console Module Assembly Line is composed of only 4 workstations. Three of these workstations, namely MIKO 1, MIKO 2 and MIKO 3, are present in the MIKO Mezzanine and produce JIT and JIS, eliminating any need for WIP stock. Due to space restrictions in the MIKO Mezzanine, the other workstation, Blend MIKO, is located in the Welding Mezzanine. As both mezzanines are physically far apart, this pre-assembly workstation produces in batches and to stock, avoiding an overly complex logistics operation. In order to better understand the overall picture of this assembly line, a flowchart was drawn, and it can be seen in Figure 3.

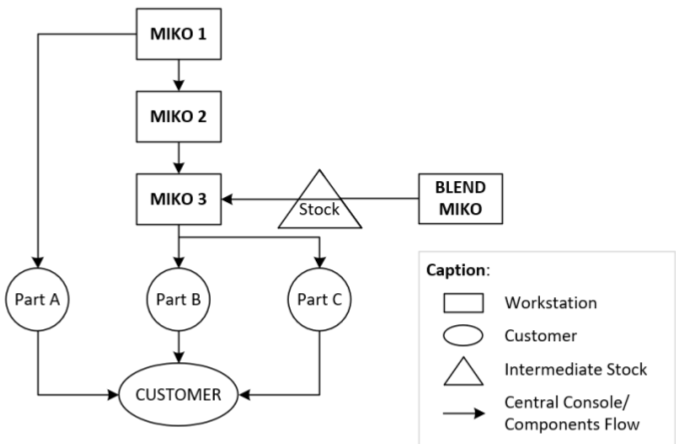


Figure 3: Flowchart of the Center Console Module Assembly Line.

In the **Blend MIKO** workstation, the operator feeds the automated welding machine by placing the frame and the blend in its respective positions on the jig in the conveyor belt. Then, the jig goes through the conveyor belt and the welding machine assembles 8 spring clips and 4 nuts to the blend and welds the frame to the blend, creating the MIKO cover. Afterwards, the operator checks if the cover has any visual defects and if the weld is properly done. After this, the operator puts the MIKO cover in the finished product box. When the pallet of finished product is complete, the pallet exits the workstation.

In the **MIKO 1** workstation, the operator obtains the central MIKO support and then assembles and tightens the arm rest to it, creating Part A which is stored in its specific rack space accordingly to customer's sequence. When the rack is full it exits the workstation. Periodically, this operator assembles USB plugs to the rear covers and stores them, accordingly to the sequence, in a supermarket to be available for the next workstation.

In the following workstation, **MIKO 2**, the operator starts by assembling the MIKO light and a USB plug to the MIKO lower cover and storing it in a box in the conveyor belt. Then, the operator assembles another USB plug, an antenna module and a switch to the KESSY cover and stores it in the box. To finalize, it takes the respective rear cover (pre-assembled in MIKO 1), puts it in the box and pushes a button in order to advance the box to the next workstation.

In the last workstation of the center console, **MIKO 3**, the operator obtains the handbrake switch and puts it in the box, finishing Part B. Then, through the conveyor belt, the box goes to a robot which stores it in its specific rack space, according to sequence. Then the operator starts the assembly of Part C by assembling the left, right and emergency switches as well as the climate module in the MIKO cover support. Afterwards assembles and tightens the MIKO cover support to the MIKO cover (pre-assembled in the Blend MIKO workstation), checks if there exist any visual defects and stores the top cover in its sequenced space on the Part C rack. When this rack is full it exits the workstation.

2.2.3 Logistics Operations

When it comes to Logistics Operations, these are focused on receiving different components, the flow of components within the factory, supplying the workstations with components and loading of trucks for the shipping of products to the customers.

The SAS Palmela plant has 4 different docks. One of them is used for the automatic loading of trucks with the cockpit module for the delivery to the VW Autoeuropa customer, a process that does not require any human intervention. One other dock is used to receive every component, except for the wiring harness, and to send the central console module to the Osnabrück customer, this being the dock with the most movement of components, SAS operators, and forklifts. The other two docks are not managed by SAS, their management having been outsourced to DSV. DSV uses one of the docks exclusively for loading trucks with the Cockpit Module racks for VW Autoeuropa. DSV uses the second dock for the unloading of the wiring harness component, being also fully responsible for the stock management of this component and for delivering it in sequence directly to the assembly line.

Since loading and unloading operations have already been briefly introduced, now the focus is on the material flow within the plant. After the unloading operations, the first operation is to check if the load is in accordance with the order sent to the supplier. If the unloaded material contains electronic components, these components also undergo a quality control. After these operations, warehouse labels are printed and attached to the containers, whose function is to identify each container and allocate it to its position in the warehouse. After the containers are identified and have their storage positions defined, then they are ready to be stored. These containers can be metal racks, when transporting large volume components, or pallets made up of different boxes of the same component, for smaller volume components. If they are metal racks then these are stored in the bulk area, in pre-established positions on the floor. If they are pallets, then they are stored on the warehouse racks on the third level or higher. After this, a pallet leaves the warehouse position it is occupying and moves to its dedicated picking position (first or second level on the racks) as soon as its picking position is empty.

The components can be supplied to the assembly lines being non-sequenced or sequenced *a priori*. When non-sequenced components are supplied, then multiple components of a single Part Number go in a box to a rack next to the station where they are needed, where they are stored. These racking areas next to the workstations, called Line-side presentations, are where the production operators pick up the component needed for a specific order they are working on. When it is necessary to supply the Line-side presentation area with components of a certain Part Number, the logistics operator responsible for supplying that rack takes the empty box from the rack and then goes to the picking position relative to that Part Number, picks up a box full of components, and delivers the box to its rack position. When it comes to components sequenced *a priori* means that instead of being delivered to the line in boxes with several elements of the same Part Number, the components are delivered in boxes where the components in that box (one or more Part Numbers) refer to a single order. Each box can contain a single type of component, such as the heaters which are delivered to the line already sequenced; or several types of components, such as the Radios, Clusters and *Manetes* which are delivered to the assembly line already sequenced in the same box.

2.2.4 Plant Information

One other topic of utter relevance when describing a factory is the information flow management. When describing the SAS Palmela plant information, it is first important to distinguish the two different types of information, namely Supply Chain Information and Internal Information. The Supply Chain Information is related with the exchange of information between different entities in the supply chain, *i.e.*, between SAS and its customers, and between SAS and its suppliers. While the Internal Information is related with the information exchanged within the plant, it can be information related to warehouse management, production management or quality control.

The Supply Chain Information is fully exchanged through a worldwide standard system called Electronic Data Interchange (EDI), short for Electronic Data Interchange For Administration Commerce & Transport (EDIFACT). The EDI standard was created by the United Nations in order to standardize the data exchange system between business partners and to integrate information from different systems. This system allows SAS to exchange information such as forecasts, orders, advanced shipping notifications, and invoices with its business partners.

Internal Information, as previously stated, is related to warehouse management, production management or quality control. For this, different information systems are used. SAP is the Warehouse Management Software (WMS) used by SAS, and its main objective is to control the movement of components in the plant in the most effective and efficient way possible. The software that SAS uses for production management and quality control is the Clever System. This software allows for the control of the parameters used in the production processes (such as the torque moment used in tightening process in the assembly line), it also ensures that the correct components are being assembled into each product and that the production is in accordance with the customer sequence. Besides these functionalities it also stores specific assembly information regarding each product in a data base, which is a requirement in the automotive industry due to legal regulation in case of any misfunction of critical parts experienced by the end customer. In addition to these two information systems, an internal system called JIS was created. This system has the function of integrating the communication between SAP and Clever. For example, JIS sends to Clever the information regarding the production sequence and the components list of each module. When a component is assembled, the information about what was assembled is registered in Clever, Clever sends a signal to JIS, which then sends a signal to SAP to remove this component from inventory.

3 – Literature Review

The purpose of this chapter is to provide a literature review within the scope of the case study presented previously and from there to define the methodologies that will be applied. Subchapter 3.1 (From Toyota Production System to Lean Thinking) is divided into three parts. The first one (3.1.1) focuses on the Toyota Production System, from its origin to its core fundamentals. The second one (3.1.2) focuses on the Western version of TPS, Lean Thinking. The last one (3.1.3) focuses on Flow Mapping tools, more specifically, on Material and Information Flow Analysis (from TPS), and on Value Stream Mapping (from Lean). Subchapter 3.2 (Logistics in a Production Plant) is associated with an improvement opportunity that emerged during the application of the Material and Information Flow Analysis, Improvement Opportunity #2. This subchapter is also divided into three parts. The first one (3.2.1) focuses on In-house Logistics and its different segments. The second (3.2.2) focuses on the strategic warehouse configuration which is referred to as the Forward-Reserve Configuration. And the third one (3.2.3) focuses on the Storage Location Assignment Problem. The last Subchapter (3.3) presents the Chapter Conclusions.

3.1 From Toyota Production System to Lean Thinking

3.1.1 Toyota Production System

The Toyota Production System, the first system referenced as a Lean production system by Krafcik (1988), was thought and built out of a need. The TPS's origin dates back to soon after the World War II. Japan lost the longest war on history and was left in a scenario of destruction after being hit with two atomic bombs, the country's manufacturing power was shut down and its consumers were struggling financially with almost no buying power. At the time, the leading Europe and United States automotive companies, such as General Motors and Ford, were following a production system based on mass production, which takes advantage of cost reduction through the exploitation of economies of scale – producing large volumes of few types of cars. Toyota was restarting its automotive production after the war, it did not have the same economic power as these American producers, thus it could not invest in the big equipment to produce as many parts as possible, and it even noticed that this system would not fit the small Japanese market (Liker, 2004). This was when Toyota realized that it had the need to search for a new system focused on flexibility and cost reduction through waste elimination, which would allow to produce many models of cars in small quantities (Ohno, 1988).

Toyota and TPS are directly linked to several generations of the Toyoda family. Even before Toyota existed, Sakichi Toyoda had already invented and implemented the first pillar of TPS (Liker, 2004). This pillar is called ***Jidoka*** and stands for autonomation, short for automation with a human touch. This pillar aims to equip machines or production lines with devices that automatically stop production as soon as they detect any abnormality (Monden, 2011). In case of a failure, if the machine is not equipped with an automatic stopping device, it will continue to produce defective products wasting time and raw materials that could otherwise be used efficiently. Another problem is associated with the safety of the operators, which is put at risk if machines are not stopped immediately after abnormalities are detected in their operation. This invention would also change the way companies were managing resources. At that time, mass production plants allocated one operator per machine, whether the machine was operating correctly or had a problem. By introducing the fault detection device, the operator is not needed if the machine is working correctly, but only needs to be present when the machine detects a fault. In this way it is possible for one operator to be allocated to more than one machine, reducing the number of operators and therefore increasing production efficiency (Ohno, 1988).

In 1950, Ejii Toyoda, Sakichi Toyoda's nephew and current president of Toyota, went on a tour to the United States in order to learn from the methods applied in American factories, namely the Ford factories (Womack *et al.*, 1990). Contrary to what he expected, what he found was a mass production system that had evolved little or not at all in the last 30 years. He was surprised to see several large machines producing large quantities, creating many interruptions in the process, mirrored by huge amounts of intermediate stocks between processes that hide the production problems (Liker, 2004). There was no concern with organization or leveling of the different production activities, because in the traditional production system what mattered was the lowest cost per piece and that was achieved through mass production. Ejii Toyoda clearly identified the need to improve this system, and when he returned to Japan, together with his plant manager Taiichi Ohno, they developed the solution to this problem, **Just-In-Time**, which would also be the second and final pillar of the Toyota Production System (Liker & Morgan, 2006). The main goal of applying Just-In-Time is to minimize inventory, ideally ending up with zero inventory. Just-In-Time means that throughout the production process, products from one station move to the next only when they are needed and only in the quantity required. This is the origin of the pull-flow concept, as opposed to the push-flow used by all factories to date. Despite the fact that implementing this system is a difficult task, all flaws are detected, rather than being disguised by intermediary stocks. And as stated by Ohno (1988), identifying flaws is an essential first step to solving them.

In addition to the two pillars mentioned above, Monden (1983) has identified three other elements that are essential in order to provide stability to the system, which are presented below:

- ***Heijunka*** – *Heijunka* is the Japanese word for Levelling. When producing JIT, a workstation takes the components it needs from the previous stations only when it needs it. Then the preceding stations must have the minimum stock to cover these components movements (Monden, 2011). If the variability of demand for the final product is very high, and *heijunka* is not applied, then the previous workstations must be prepared for peak demand, something that can be very rare, thus creating waste. When levelling is applied, the consumption of parts is distributed evenly throughout the days, allowing for a noticeable reduction in intermediate stock and for those intermediate stocks to have a higher turnover rate. The same thought can be applied to the idle time of people and equipment (Liker, 2004). As the workload is distributed throughout the days, instead of having the production of a given product concentrated in a short time period followed by a period of no production, the production follows a constant rate allowing for a higher utilization rate of machines and human resources.

- **Standardized Work** – Imai (1986) referred to this element as the fundamental basis for continuous improvement to occur. This element aims to capture today's best practices, then allow the creativity and individual expression of workers to improve the standard, and finally incorporate those improvements into the standard so that the learnings can be passed from person to person (Liker, 2004). This element is composed of three sub-elements: takt time (the standard time each line must take to produce one unit, setting the pace of production), work sequence (order of operations according to which an operator processes an item), and standard inventory (minimum inventory between workstations).
- ***Kaizen*** – *Kaizen* is a Japanese expression which can be translated to "change for better" or simply "Continuous Improvement". In this context, Continuous Improvement is a philosophy which focuses on enhancing value-added activities for the customer and, on the other hand, on removing non-value-added activities. One of the most used tools when applying this philosophy is the PDCA Cycle, a never-ending cycle in which, in addition to planning (Plan) and executing the actions to achieve improvements (Do), the focus is on monitoring and assessing the results (Check) and, if the results are positive, on the consequent adjustments needed to ensure the standardization of processes (Act). At the end one should return to the search for new opportunities for improvement, starting a new iteration of the PDCA Cycle. A representation of this methodology can be seen in Figure 4.

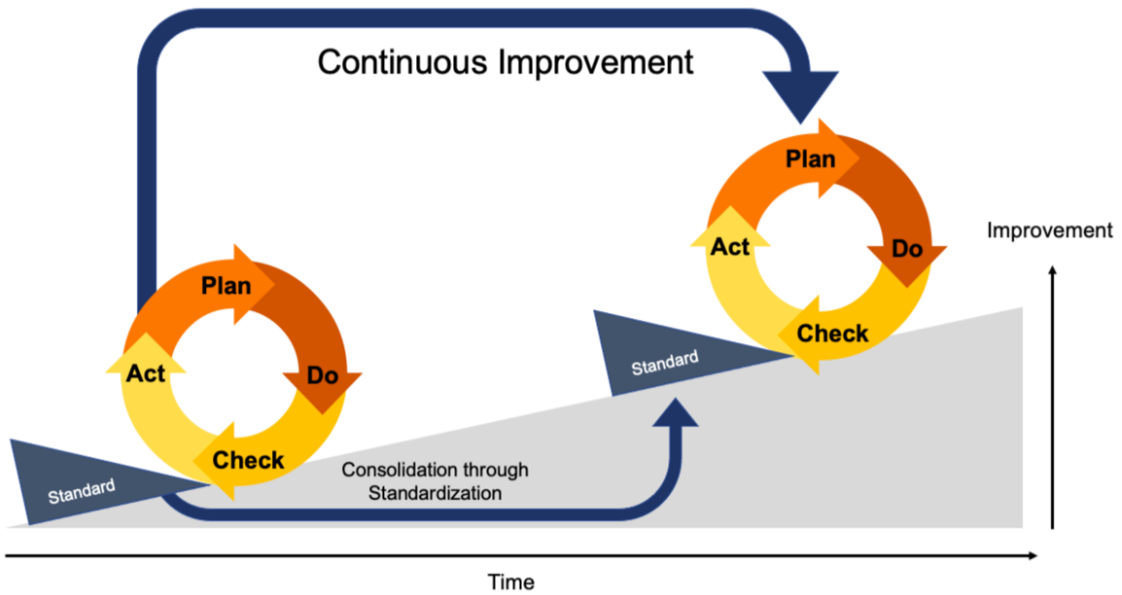


Figure 4: PDCA Cycle for Continuous Improvement. – Adapted from Chakraborty (2016)

One of the basic concepts of the Toyota Production System is that all workers should be involved, from top management to operators, therefore when a company is applying the TPS every worker must understand it. Since it is a complex system and to make the learning process easier, companies usually use a diagram named the Toyota Production System House to summarize the whole system. An example of the TPS House, adapted from Liker (2004), can be seen in Figure 5. The roof of the house corresponds to the final objectives of the system: to obtain products with the Best Quality, the Lowest Cost and the Shortest Lead Time, while providing the Best Safety and High Morale to the workers. The outer pillars correspond to the two TPS pillars: Just-In-Time and *Jidoka*. And the foundation of the house corresponds to the three additional elements which provide stability to the system: *Heijunka*, Standard Work and *Kaizen*. At the center of the house is Waste Elimination, being the underlying thought behind the pillars and the additional elements, according to which it is possible to reach the final objectives of the Toyota Production System.

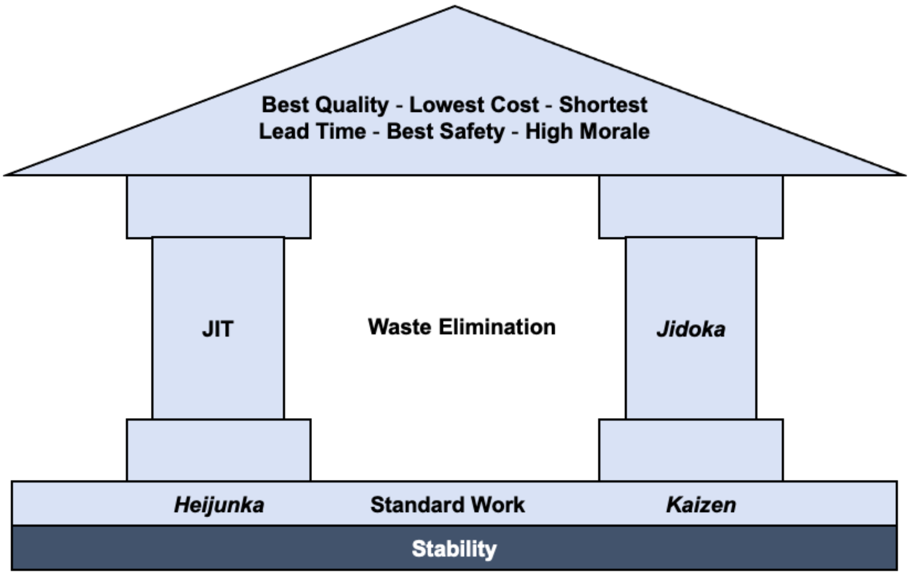


Figure 5: Toyota Production System House – Adapted from Liker (2004)

3.1.2 Lean Thinking

Krafcik (1988) was the first to use the term Lean to characterize a production system when referring to the Toyota Production System as the first Lean production system, highlighting its success. The concept emerged when this author was trying to break the myth that the performance of a factory was related to its geographical location. In this study, the author identifies two types of production systems: Lean and Buffered. The former would be associated with Japanese factories and the latter with Western factories. In his work, the term Lean is used to characterize a production system with higher productivity and improved quality performance. Beyond this he also states that this system has its associated risks, which must be managed with great discipline and skill associated with a well-trained and flexible workforce.

Nevertheless, the term Lean only gained visibility years later with the book "*The Machine that Changed The World*", where Womack *et al.* (1990) applied the term "Lean Production" to a production system inspired by the TPS, which is characterized by high efficiency and performance when compared to most systems traditionally used to date. The Lean Production was born with the same objectives as the TPS: to reduce its production costs while offering a high variety of products at the same time. This would only be possible by minimizing the waste ("fat") in the production processes (Waste Elimination), focusing this way on what the customer is willing to pay for. Only by cutting on its production “fats” a company would be able to become truly Lean (Melton, 2005).

Years later, Lean Production would be recognized as one of the most influential paradigms in automotive manufacturing, thus expanding its applicability from the shop floor to various industries from primary metals to the aerospace industry (Hines *et al.*, 2004), becoming a management philosophy called Lean Thinking. Lean Thinking argues that the focus should be on creating value for the customer and that therefore the elimination of waste should be associated not only with production processes, but with all processes from initial product development to the development of production processes and to the design of all facility operations (Melton, 2005). Womack & Jones (1997) referred to Lean Thinking as the antidote to waste, and that this philosophy is supported by 5 Lean Principles:

1. **Value**: The first principle is to Specify Value from the perspective of the end customer, *i.e.*, to identify what the customer actually values or what he is willing to pay for the specific product capabilities (Hicks, 2007). This step is critical for the application of Lean principles as it is the basis of the decision-making associated with the elimination of waste.
2. **Value Stream**: The second Lean principle is to Identify the Value Stream. Value Stream is the nomenclature for all the actions involved from the processing of raw materials to the delivery of the final product to the customer. After all activities have been identified, using the customer's values as reference, all activities that effectively contribute to value creation, called Value-Added (VA) activities, must be identified. The activities that do not directly contribute to value creation, called Non-Value-Added (NVA) activities, are considered waste, and can be subdivided into two types: NVA but necessary or NVA and unnecessary. While the former has a purpose and should be minimized, the latter is considered pure waste and should therefore be completely eliminated. By eliminating waste, it is possible to ensure that the customer gets exactly what he wants, while minimizing the lead time and the costs associated with producing the product (Ohno, 1988).
3. **Flow**: The third principle is to Ensure Continuous Flow. This means that after eliminating unnecessary activities, one must ensure that the flow runs continuously through the operations without any interruptions or delays. Melton (2005) noted that interruption of flow is directly linked with mass inventory and consequently with costs in larger than necessary warehouses or, in other words, with the creation of a high level of waste.
4. **Pull**: The fourth principle is to Establish a Pull-System. When a Pull-System is applied, the production order is given directly by the customer, allowing Just-In-Time delivery and manufacturing to be applied. In this way it is possible to minimize finished goods and WIP inventories, while ensuring a continuous flow and that the product is available for the customer when it is needed and in the required quantities.
5. **Perfection**: The last Lean principle is to Pursuit Perfection and is directly linked with *Kaizen*. It states that firstly there must be a vision of the ideal scenario for the operations, then in order to get to that stage, small gradual improvements must be followed, instead of one big disruptive improvement. Womack & Jones (1997) considered this principle to be the most important, and

that this continuous improvement mindset should be a part of the organizational culture of a company, with every employee cooperatively seeking perfection.

Muda, the Japanese word for waste, is defined as an activity that does not bring value to the customer, or alternatively, an activity for which the customer is not willing to pay. In a physical production environment, it is estimated that only 5% of the activities are Value-Added (VA) activities, contrasting with 60% unnecessary NVA activities and 35% NVA but necessary activities (Hines & Taylor, 2000). This is one reason why Waste Elimination is of utter importance to both TPS and Lean Thinking, and why it is considered the center of the philosophies behind these systems. Ohno (1988) argued that for better identification and subsequent elimination of waste that one should understand everything that could be considered waste, and for this he identified all types of waste, which became known as the 7 *muda*:

1. **Transportation**: Unnecessary movements of materials, such as movement of WIP between operations or locating materials far apart from where they are needed. The transportation of materials is a NVA activity for the product and should therefore be minimized.
2. **Inventory**: Inventory that is not essential to fulfill the current customer orders. These can be of raw materials, WIP or final product. Its presence can originate other types of waste such as motion or overprocessing.
3. **Motion**: Unnecessary movement of people. Can be originated due to inefficient layout, excess inventory, overproduction, or rework. As for the transportation *muda*, it is a NVA activity and therefore should be minimized.
4. **Waiting**: Refers to the idle times of people or machines. This type of waste can be related to delays in the delivery of parts by subsequent operations, delays in the production information, or changeover times.
5. **Overprocessing**: Extra operations such as rework, reprocessing, handling, or storage. These are usually linked to overproduction, defects, and excess inventory. This does not mean that rework or reprocessing should not be done, only that they are NVA activities and should therefore be minimized.
6. **Overproduction**: When more products are produced than the customer orders. This can result in excess inventory, overprocessing or even obsolete products.
7. **Defects**: Finished products that do not comply with customer specifications. This can be a great cause of customer satisfaction if the defect is not noticed before the delivery to the customer. Can lead to other types of *muda*, such as excess inventory or overproduction.

Years later, Womack & Jones (1997) identified a type of waste that had not been identified yet, adding the eighth type of muda:

8. **Underutilization of People**: This *muda* is related with wasting human potential, in particular people's improvement ideas for the operations and processes. This is one of the reasons why Lean argues that everyone should be involved from top management to operators.

3.1.3 Flow Mapping

When it comes to Flow Mapping, the most popular tool in Western countries and in the literature is undoubtedly VSM (Chavez *et al.*, 2018; Hines *et al.*, 1998). VSM is a Lean Thinking tool that allows to see and better understand the flow of information and material throughout the value stream. The mapping of the value stream refers to a visual representation of the products path, from the reception of raw materials from the suppliers, passing through various processes until the delivery of the final product to the customer (Rother & Shook, 1999). With this, there is a representation of all the organization’s activities, whether they are value added or non-value-added activities. By using the VSM it is possible to observe and analyze the macro picture of the entire organization, not looking at the processes individually and in detail. Thus, the VSM is not in itself the tool that improves and optimizes processes, but rather the tool that allows the identification of the weak and strong points of the value chain. With this it is possible for the organization to outline an improvement strategy for its business, focusing on the processes with the highest number of activities that do not add value or those that have the greatest potential for increased productivity.

Today, it is generally believed that Toyota uses and has always used VSM. However, according to Rother & Shook (1999), this tool is actually an adaptation of the tool invented by Toyota which is called Material and Information Flow Diagram (or alternatively Material and Information Flow Mapping). Thus, both tools have some differences, such as the difference of the level of detail contained in the diagram (Chavez *et al.*, 2018). While the VSM has a more restricted structure, using a simplified and non-extensive representation of the information flow which is basically restricted to the upper part of the diagram, the information flow in MIFD is represented with more detail, usually referring to more types of information and representing it throughout the whole diagram. Another difference is the symbology used in both tools with the MIFD recurring to a more diverse set of symbols when compared to the restricted standardized symbols used in VSM. Despite the differences between the two tools, they are similar and share the same purpose of mapping the material and information of an organization’s processes allowing the company to eliminate the waste identified in its processes and to establish an improvement strategy.

As for the VSM tool, for MIFD the first step is to obtain knowledge of the company's current situation. This is due to the simple fact that if you don't know the current situation then it is difficult to correctly identify which problems need to be addressed and thus enable a coherent path for improvement. An important aspect regarding this step, which is widely mentioned in the literature, is that the process of obtaining knowledge should be done through *Gemba* (Japanese word that means "on site") walks, observing the processes with one's own eyes, and also through interviews with the operators directly involved in them. This way it is assured that the map represents the reality of what actually happens, instead of what it is supposed to happen (Hines & Taylor, 2000).

Following the information gathering, the following step is to draw the current state diagram. According to the Faurecia standard (Faurecia, 2021b), the representation of information in the MIFD should be as detailed as possible and there should be represented specific information regarding each entity or flow:

- **Customer** – information regarding customer demand or volume, customer organization (such as shifts patterns), customer information transmission method and customer delivery method.
- **Manufacturing Process** – this varies according to the type of facility, but for an assembly plant this includes information regarding own organization, customer takt time, cycle time, work content and jobs per day for each workstation.
- **Stocks** – information regarding the type of storage (usually represented by different symbols), which parts are stored and in what quantities (if is dedicated storage represent the maximum and minimum number of parts and if not show the quantities registered in the *Gemba* walks).
- **Material Flow** – information regarding the type of transportation mode (usually represented by different symbols), and if the flow is external then also include transport time, distance travelled, and quantities transported or vehicle usage. If the flow is internal, then include the identification of the Automated Guided Vehicle (AGV) or operator responsible for the transportation, the quantities moved and if appliable the loop time.
- **Information Flow** – for internal flows this includes the identification of the type of information, if appliable the identification of the document and the hardware responsible for the information processing. For customer/supplier flows, this includes the type of order (forecast, real orders or production sequence), the frequency of the flow, the time of reception/sending of information, the transmission method and the horizon of the information.

After the mapping of the current state, there is the calculation of the lead time and its representation on the diagram. In the MIFD tool approach, the lead time has three possible origins: Stagnation Lead Time (associated with the stocks, represents the time a product stays in a location while it is not required), Transport Lead Time (associated with the transportation between location, represents the time it takes to transport a product from location A to location B) and Process Lead Time (associated with the production process, represents the time it takes to process a product). This distinction is made due to the fact that the first two are considered as waste, being the third one the only type of Lead Time associated with VA activities.

Followingly, the waste and the opportunities of improvement are identified and represented by what is called the *Kaizen* bursts in the current MIFD. The next step is to draw the future state MIFD as if the opportunities of improvement were already implemented. Then each opportunity is individually analyzed and is decided if it should be implemented or not. If it is decided that it should be implemented, then the action plant for this improvement is defined, ending this way the MIFD tool approach.

As both the MIFD and the VSM tools are several decades old, one would expect that there would be several cases of their application in the literature. However, at the time of the theorization of the Lean methodology, Lean and the VSM tool became much more popular in the Western world and also globally, leaving little recognition for the MIFD tool. Thus, it is noteworthy that there are numerous cases of application of the VSM tool in the literature and none concerning the implementation of the MIFD tool. Thus, and considering that these flow mapping tools have exactly the same objective, followingly it is presented some examples of the use of VSM found in the literature.

Singh *et al.* (2011) used the VSM tool to identify waste and possible opportunities for improvement in a small manufacturing plant in India which produces components for the maintenance of railway engines. When describing the current state of the company, the authors noted that the biggest waste was excessive inventories of raw materials, WIP, and finished product; and subsequently managed to reduce 83% of the total inventory mainly due to the implementation of a Kanban system. In addition to this waste, the authors were also able to reduce line cycle time by 4% and change over time by 7%. With these improvements, the authors were able to reduce manpower from 12 to 10 operators and, with the large inventory reduction, to reduce 83% of the total lead time.

The case study by McKenzie & Jayanthi (2007) took place at the American company Ball Aerospace which produces communication satellite antennas. This company used batch production in its production line and intended to implement a JIT production system. To facilitate this implementation the VSM tool was used. By analyzing the current state, they were able to detect all the points necessary for this implementation to occur, as well as analyze the batch size that would optimize the results. Thus, it was possible to implement a JIT system, although not using piece-by-piece production, through the use of a Kanban system. With this improvement, Ball Aerospace achieved a 21% reduction in their lead time, as well as ensuring an improvement in the quality of the products produced by reducing the inventory of intermediate and finished products.

Thiede *et al.* (2016) used the VSM tool for the analysis of opportunities to improve the efficiency of material and energy flow and consumption. This case study occurred at an Australian company that produces brake blocks and pads for trains and other railway vehicles. This study, contrary to the others presented, did not focus so much on the implementation of other Lean tools (such as Kanban), but rather on changes and improvements in the production processes used in the company. In this case study the authors identified improvements such as the implementation of automatic systems to stop the dust collector, improved insulation of the molding press during waiting times, increased recycling rate of certain flows, and others. With these improvements and with the possibility of implementing different scenarios, the authors estimated an average reduction of 5% for energy use per part, an average reduction of 1% for raw material consumption per part, and a 15% reduction for the longest lead time.

After analyzing the different case studies in the literature, it is possible to observe significant differences in the results obtained. This is mainly due to the discrepancies between the plants where the tool is implemented, taking into account for example the level of operations management for each the company. In addition to this, it should also be noted that flow mapping tools are not intended to improve the processes themselves, but to ensure a deeper knowledge regarding the current state of the plant and consequently facilitate the identification of improvement opportunities.

3.2 Logistics in a Production Plant

Logistics refers to a concept that has been used for more than a hundred years, which is also used in different contexts. It first emerged in the military context and only later was adapted for the business context. Thus, over time, Logistics has had different definitions, without a unique consensual definition (Lummus *et al.*, 2001). However, more recently the Council of Supply Chain Management Professionals (2019), an organization closely related to the logistics profession, defined Logistics Management as "that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements".

With the growing trend of mass-customization and the consequent increase in product variety, JIT logistics becomes an increasingly important topic for automotive producers. As assembly lines move at a constant pace, it is critical to ensure that logistics operations are carried out according to plan, ensuring that the right parts arrive at the right workstations and at the right time, under both JIT and JIS principles (Boysen *et al.*, 2009). If the parts are not available for the assembly line at the right time, then the final assembly line stops, creating high penalty costs. According to Thanou & Matopoulos (2021), for an automobile manufacturing company, an unplanned production stop of 1 minute duration can cost from $10,000 to $100,000, being one of the main reasons for the increasing criticality of the role of logistics in the automobile industry.

For the automotive industry context, logistics processes can be divided into three segments: External, In-house (or internal), and Reverse logistics (Boysen *et al.*, 2015). For a holistic understanding of the logistics processes, one can observe in Figure 6 the subdivisions of the three segments. The External Logistics segment can be subdivided into call order and transport logistics; the In-house Logistics segment into receiving, put away, picking, line feeding, line-side presentation, and shipping; and finally, the Reverse Logistics segment into internal return of empties and external return of empties.

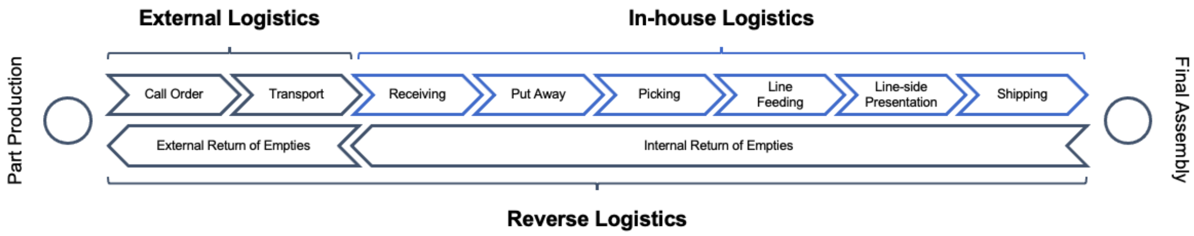


Figure 6: Logistics Segments – Adapted from Boysen *et al.* (2015)

Considering the objectives of this study, hereafter only the In-house Logistics segment and its subdivisions will be focused and addressed in more detail in the following subsection.

3.2.1 In-house Logistics in a Production Plant

3.2.1.1 Receiving

Receiving is considered as the interface of the materials' inbound flow in a warehouse. In this process, the trucks arrive, and the shipment is unloaded in a receiving dock. After this, the order arrival is registered in the WMS so that the ownership of the shipment is assumed. Then, the shipment is inspected to check for any damage and if the materials received match with what was ordered, ending this way the receiving process.

Nevertheless, according to Bartholdi & Hackman (2019), the Receiving process can start even before the truck arrives at the facility. This is made possible through a notification stating that the truck is arriving. With this, it is possible to plan the whole logistic process related to the reception of the truck, as well as the process of storing the materials before the truck arrival. This allows to allocate the truck to a dock, and also to plan and coordinate the resources (workforce and equipment) required for the subsequent logistics processes in advance (Gu *et al.*, 2007). To conclude, Receiving is not considered to be a labor-intensive process as it only accounts for 10% of the operating expenses of a traditional warehouse (Frazelle, 2002), and its main operational research problems in the automotive industry are the assignment of docks to trucks which is called the truck scheduling problem, and the respective time window assignment for the delivery (Boysen *et al.*, 2015).

3.2.1.2 Put Away

Put Away means placing materials in logistic areas to overcome the time gap between the receipt of materials and the delivery of those materials to the line. Due to market demands on increasing product variety and the consequent exponential increase on the number of parts, the idea suggested by Toyota of Just-In-Time, eliminating the need for any warehouse is not possible nowadays in the automotive industry (Boysen *et al.*, 2009). Storage plays a critical role in a warehouse, by organizing the materials in such a way that it optimizes the physical space utilization and at the same time the handling of materials. According to Gu *et al.* (2007), there are three major operational research problems that need to be addressed in the Put Away process: defining how much inventory to store in the warehouse for each Stock Keeping Unit (SKU), determining the frequency and when to replenish each SKU, and defining where to store each SKU in the warehouse and its movements between the different storage areas.

For the automotive industry, parts usually are stored in two different logistic storage areas, the centralized storage area, and the decentralized storage area. The centralized storage area is characterized by being far away from the line. This distance, in turn, if one were to feed the line directly from this area, would result in an inflexible delivery of large batches and consequently large inventories at the workstations (Boysen *et al.*, 2009). On the other hand, the decentralized storage (for instance, Lineside Presentation or Supermarket) is an area close to the line that allows for smaller and frequent deliveries, which are delivered to the line just as they are needed. By using the supermarket strategy, it is possible to make small pre-assemblies and prepare just-in-sequence kitting boxes (also referred to as kits) before delivering to the workstations (Battini *et al.*, 2013). This strategy allows for an increase in the flexibility of the deliveries to the line and to save space in the workstations, at the cost of an additional handling step (Coelho *et al.*, 2018).

Lastly, the Put Away process, like Receiving, is not considered as being labor-intensive, and according to Frazelle (2002) typically accounts for 15% of a warehouse operating expense.

3.2.1.3 Picking

Picking is a process in which the goods ordered by the customer are retrieved from storage and can either be done manually – picker-to-parts system – or in an automated way – parts-to-picker. Picking accounts for over 55% of warehouse operating costs, and many authors believe it to be the most important area to study in order to increase productivity (de Koster *et al.*, 2007; Frazelle, 2002).

The parts-to-picker system includes an automated storage and retrieval system that automatically collects a unit load (e.g., a pallet) of the wanted part and brings it to a pick position. In this position, the picker takes the number of parts he requires, and the remaining parts left in the unit load are automatically stored. According to Boysen *et al.* (2009), in the automotive industry this system is only used for small and low-valued parts, and when applying this system, the sequencing of automated storage and retrieval machines is the most important operational decisions problem (Lee & Schaefer, 1996).

The most common system employed in the automotive industry (and also in most traditional warehouses), is the picker-to-parts system which consists in the pickers walking or driving through the warehouse to pick the required parts. According to Boysen *et al.* (2009), this system is typically associated with larger and valuable parts, and when applying it, the main operational decisions are the batching and the routing problems. The batching problem refers to assigning groups of parts to be picked simultaneously in one trip by each picker (Gu *et al.*, 2010b). The routing problem refers to finding the sequence of part retrieval performed by each picker trip. As Tompkins *et al.* (2010) stated, travelling is a large portion of the total picking effort, which justifies the objective of the two problems – to minimize the total travel distance.

3.2.1.4 Line Feeding

When compared to a traditional warehouse, the logistics in a production plant have two additional logistics processes, the Line Feeding (also called Delivery to Line) and the Line-side Presentation. Both processes arise with the need of supplying components to the production lines.

The main objective related to Line Feeding is how to transport the components from the central warehouse to each of the workstations (Battini *et al.*, 2009). Far from being the only solutions to this problem, many authors refer to three types of transportation to the lines (Battini *et al.*, 2009, 2013; Boysen *et al.*, 2015): forklifts, tow trains and conveyor system. A forklift is a versatile lifting and transport vehicle that can lift heavy pallets or containers, and that, when compared to the other two modes of transportation, lacks carrying capacity. According to Boysen *et al.* (2015), this type of transport is directly associated with two types of operational research problems: which transport jobs to allocate to each forklift, and the sequence of jobs that should be performed by each forklift. These authors also refer that both problems are interdependent and similar to the parallel machine scheduling problem. A tow train is a motor-driven vehicle that pulls unpowered wagons carrying material bins. The tow train can be guided by a human operator, or automatically by an AGV. With a higher load capacity when compared to a forklift, it transports materials from the warehouse to multiple stations in a single trip (milk-run). The operational research problems related with the tow train are (Boysen *et al.*, 2015): the determination of the routes for each tow train, the timing or frequency that each route is to be taken, and also which parts and in what quantities must be served by each tow train. A conveyor system can also be used to deliver parts or subassemblies from a central warehouse, supermarket, or directly from feeder lines to the production line. Conveyor belt and overhead conveyor are examples of conveyor systems, but even the production line itself can work as a part delivery system. In this case, the kitting boxes, which are sequenced in supermarket areas, travel down with the production line and the workstations' operators remove the parts they require directly from the kitting box until. Boysen *et al.* (2015) referred the selection of which parts to be included in a kit as the main problem related with conveyor systems. This problem is considered as critical since production lines have restricted space, and if a kit is composed of large volume parts it can obstruct production process, resulting in significant inefficiencies (Battini *et al.*, 2013).

3.2.1.5 Line-side Presentation

The last logistics process before the usage of parts in the production line is the Line-side Presentation. This process consists of the placement of the parts delivered by the line feeding systems in dedicated storage space at the production line, which can be placed on simple ground space or on dedicated racks. While the simple ground storage is used for unit-loads, the dedicated racks are used for smaller bins, which in the optics of the production workers is advantageous since the parts can be handled in a more ergonomic way (Finnsgård *et al.*, 2011). Given that in a modern assembly line, a vehicle spends between 60 to 90 seconds on each workstation and that walking can occupy a significant portion of the cycle time, the minimization of the travelling distances become of utter importance. For these reasons, Boysen *et al.* (2015) identified the parts placement problem either on the ground or in a dedicated rack's specific position as the most important operations research problem related with the Line-side Presentation logistics process.

3.2.1.6 Shipping

Shipping operations consist of loading the customer orders into the transport vehicles. Its related tasks are quite similar to the tasks involved in the Receiving process. Before starting loading operations, the reception of each truck must be planned, specifically with the allocation of trucks to loading docks and also with the allocation of resources necessary for the loading of each truck (Gu *et al.*, 2007; Rouwenhorst *et al.*, 2000). This is considered as a fairly simple process, and it estimated that shipping operations on average account for 15% of a warehouse operating expense (Frazelle, 2002).

3.2.2 Forward-Reserve Configuration

Several studies highlight the importance of the picking operation, by stating that, within the various logistics operations that take place in a warehouse, picking requires the most attention (de Koster *et al.*, 2007) and that this operation alone represents more than half of the operating costs of a warehouse (Frazelle, 2002). In traditional warehouses often is inefficient to pick the materials directly from the central storage area, which accommodates the whole inventory of every SKU, due to two main reasons (Gu *et al.*, 2010a). One reason is that to increase space utilization, the storage area may use high-density storage equipment such as high-stacking deep-lane pallet racks, which do not allow for convenient or quick item access and extraction. The second reason is that, as this area accommodates all SKUs, the picking operators must travel large distances between the picking locations, making it an excessive unproductive operation. With this in mind, and to counteract the effort involved in the picking process, many warehouses employ the Forward-Reserve Configuration (Figure 7), by dividing the storage area into a Forward Area and a Reserve Area (Gu *et al.*, 2010a; van den Berg *et al.*, 1998). The former is an area that serves as a "warehouse within a warehouse" by storing the SKUs in easy-to-access locations for an efficient picking operation (Walter *et al.*, 2013). The latter is an area where materials are stored in the most economical way (bulk storage area) and is used to replenish the forward area (Rouwenhorst *et al.*, 2000). van den Berg *et al.* (1998) mentioned another possibility when applying this configuration, where instead of having two physically distinct areas, to have the forward and reserve area on the same pallet rack. While the lower levels of the pallet rack are utilized as picking locations and correspond to the forward area, the upper levels are used to replenish the lower levels and correspond to the reserve area.

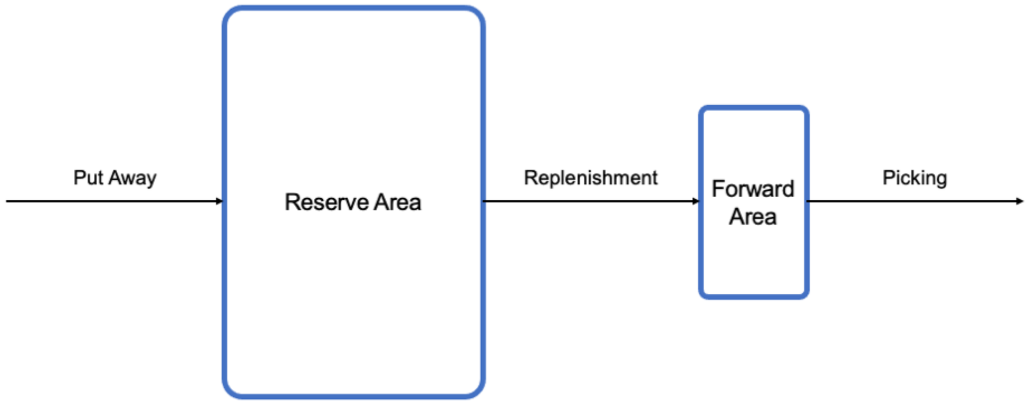


Figure 7: Forward-Reserve Configuration – Adapted from Bartholdi & Hackman (2008)

To ensure travel efficiency of the picking operators, the storage capacity of the forward area must be limited, otherwise it would become an excessively low-density area and the picking operations would become inefficient. Also, as the number of SKUs assigned to the forward area grows, less space may be assigned to each SKU, causing more frequent replenishment. As a result, it is of utter importance to carefully consider which SKUs should be assigned to the forward area and in what quantities, in order to balance the trade-off between picking and replenishment operations and maximize the forward area's benefits. The decisions concerning this trade-off are referred in the literature as the Forward-Reserve Problem, which has already been addressed by several authors.

The problem of determining which SKUs to assign to the forward area and how to allocate space among the selected SKUs, while considering the forward area with a fixed capacity, was firstly addressed by Hackman *et al.* (1990). The authors proposed a heuristic with the objective of minimizing the material handling costs involved in the picking and replenishment operations. Later, Frazelle *et al.* (1994) extended the first model by considering the capacity of the forward area as a decision variable, instead of having a fixed capacity. While the two previous models assume that the replenishment of a SKU can always be instantly done in a single trip, van den Berg *et al.* (1998) proposed a model that optimized unit-load replenishments which has into consideration the busy and idle periods of a warehouse. Lastly, Gu *et al.* (2010a) formulated a branch-and-bound algorithm which addressed jointly both the assignment and the allocation problems. Even though it required more computational effort than the previously mentioned heuristics, according to the authors it provided the optimal solution in fast enough time for practical application.

3.2.3 Storage Location Assignment Problem

As mentioned when addressing the forward-reserve problem, a SKU can be stored in more than one warehouse department (e.g., in the reserve area and in the forward area). And in turn, these departments tend to have differences between them, in terms of storage capacity and the way materials are handled in different operations. For this reason, it is essential for each department to have its own strategy to allocate SKUs to storage spaces, *i.e.*, for each department to select the most appropriate storage assignment policy for their own operations (Rouwenhorst *et al.*, 2000).

A storage assignment policy is a set of rules that are used for assigning SKUs to storage locations. According to Brynzér & Johansson (1996), SKUs have several characteristics that can be considered when selecting a storage assignment policy for a warehouse or a department, and when assigning a SKU to a location. Frequency of movement (inbound or outbound), volume, weight, part number and supplier are examples of such characteristics. de Koster *et al.* (2007) stated that the five most frequently used storage assignment policies are: random storage, closest open location storage, dedicated storage, full turnover storage, and class-based storage.

In the random storage policy, each incoming pallet (or group of similar products) is assigned a location at random from all available empty locations in the warehouse (or warehouse department) with an equal probability. This random selection is only possible in a computer-controlled environment, and it is usually performed by a WMS. According to Choe & Sharp (1991), the random storage policy results in high space utilization, or in low space requirement, at the expense of increased travel time.

When the position is chosen by humans, instead of using a WMS, the system would probably be the closest open location storage policy. Using this policy, for an incoming pallet, the put away operator stores the pallet in the first empty location he encounters. This usually results in a warehouse with full racks around the depot and gradually emptier towards the back. According to Hausman *et al.* (1976), the random storage and the closest open location storage policies result in similar performance if the SKUs are only moved in full pallets.

Another possibility, quite distinct from the previous ones, is the dedicated storage policy. Using this method, all SKUs have fixed and dedicated positions for their storage. Thus, each product must always have enough positions for the warehouse to be able to accommodate its maximum inventory level. This is the main disadvantage of this policy, because even for products that are out of stock, some number of locations will be empty. One advantage of is that the employees responsible for the picking operations become familiar with the product locations. Other possible consideration is that this policy can be advantageous if the products have different weights. This way, the heavier products will be stored in the lower locations and the lighter products in the top locations, enabling a better ergonomics in the picking operations. Choe & Sharp (1991) referred that the dedicated storage policy yields the largest savings in travel times, but at the cost of substantial under-utilization of space.

The fourth policy is the full turnover storage, which some authors referred to as a specific case of the dedicated storage policy (Yu & de Koster, 2013). This policy assigns the products in the warehouse (or warehouse department) according to their turnover, or popularity. The products with the higher turnover are usually stored near the depot (most convenient positions), and the slow movers (products with low popularity) are stored towards the back of the warehouse. One of the most used versions of this policy is the Cube-per-Order Index (COI) policy, which was proposed by Heskett (1963). In this policy, instead of distributing the products according to their turnover, the products are distributed according to their cube-per-order indexes. The COI of an item is defined as the ratio of the item's total required space to the number of trips required to meet its demand per unit time. This policy places the items with lowest COI near the depot and the items with highest COI towards the back. Gu *et al.* (2007) noted that if each unit load occupies the same amount of storage space, then the popularity policy based on the apportioned demand (*i.e.*, the ratio of the unit demand to the number of units transported on each picking trip) is essentially the same as the COI policy.

The class-based storage policy combines some of the methods used in the other policies. Firstly, the SKUs are divided into classes accordingly to predefined criteria such as the COI, popularity, or volume, in which the products with similar characteristics of the chosen criteria belong to the same class. Then, each class is assigned to a specific warehouse area, which is a dedicated and fixed decision. To finalize, inside of each class, the locations of the respective area are random. Muppani & Adil (2008) stated that the random and dedicated storage policies are extreme cases of the class-based storage policy. While the random storage is considered the class-based storage policy with a single class, the dedicated policy considers one class for each SKU (Chan & Chan, 2011). According to Fontana & Cavalcante (2013) the class-based storage policy can be a good alternative to making a warehouse more efficient by combining the random and dedicated storage policies for achieving a better use of space utilization while at the same time increasing the efficiency of the order picking operation.

In the literature, the Storage Location Assignment Problem concerns the allocation of incoming products to storage locations in warehouse departments, with the objective of reducing material handling cost and/or reducing space utilization. Logically, different departments of a warehouse can use different SLAP problems depending on the storage assignment policy utilized in that department, on the specific characteristics of the SKUs stored in the department, and even on the available storage technology. Gu *et al.* (2007) defined SLAP as a problem that has into account: the physical configuration of the storage area and storage layout; the availability, physical dimensions, and locations of the warehouse department locations; as well as the physical dimensions, demand, quantity, arrival and departure times of the products to be stored. With this information, the optimization model determines the locations where the incoming products will be stored. The authors also suggest that storage assignment might be influenced by several performance factors and constraints, such as storage capacity, picker capacity, compatibility between storage locations and SKUs, and item retrieval policy (e.g., first-in-first-out, last-in-first-out, and others).

Remembering that the two SLAP objectives are to minimize material handling cost and to minimize space utilization and that these objectives may be conflicting to each other, here arises the need to balance this trade-off. Given that picking operations account for more than 55% of a warehouse's operational costs (Frazelle, 2002), this is the operation that must be optimized to have a significant impact on total costs. According to Chan & Chan (2011) , picking efficiency is related to minimizing the total time for the administrative process, component picking, documentation, and travel time between picking locations. However, the authors emphasize that the primary goal of picking is to reduce travel times. Having said that and given that the material handling cost is frequently represented as a linear function of picking travel times (or equivalently picking travel distances) (de Koster *et al.*, 2007), a literature review on SLAP will be addressed from now on, with a focus on studies that addressed the minimization of the material handling cost.

Daniels *et al.* (1998) proposed a model with the objective of minimizing the total material handling cost which simultaneously determines the allocation of inventory to positions and the picking sequence. In this model, the inventory of an item may be stored in more than one bin, and when an item arrives at the warehouse it is allocated a free position and simultaneously the picking sequence by which that position will be visited is computed. According to the authors, the problem of determining of the sequence resembles a traveling salesman problem, and they addressed several heuristics to solve this problem.

Due to the growth of e-commerce, Pan & Wu (2009) studied the pick-and-pass system. In this study, the authors proposed three algorithms that optimally allocate products to storage in a pick-and-pass system for a single picking zone, for a picking line with zones of different dimensions, and for a picking line with zones of equal dimensions. These algorithms have the same objective of minimizing picking travel distances for each of the different scenarios.

Chan & Chan (2011) proposed a simulation model that measures the impact of using different storage assignment policies and different routing policies. In this study the authors performed 27 different experiments in which they combine assignment and routing rules using scenarios with different pick densities. This study was performed for a warehouse with manual picking and multi-level racks, and the results of the experiments were measured in terms of picking travel distances and also order retrieval time.

Kovács (2011) addressed the storage assignment problem in a warehouse served with milk-run picking, being therefore a special case designated correlated storage assignment problem. In order to solve this problem, the author proposed a mixed integer programming model that using the class-based storage policy aims to minimize the order cycle time as well as the total picking effort (retrieval and travel times). The author also mentioned that, in comparison with the COI strategy, by having into account the correlation between items, his model can achieve improvements up to 38% for the considered objectives.

Later, Ene & Öztürk (2012) developed a storage assignment and order picking system in an automotive industry real case scenario using a mathematical model and a stochastic evolutionary optimization approach. The solution for this problem is obtained in two steps. First a mixed integer linear programming model is modeled to solve the class-based storage assignment problem with the objective of minimizing the total travel distances. Then, in the second step, the authors proposed an integer programming formulation to achieve the optimal solution for the batching and routing problems. However due to long computational time, they additionally proposed a genetic algorithm for near-optimal results with low computational effort which is more suited for real world application.

3.3 Chapter Conclusions

In this chapter the concepts and methodologies that will serve as a basis for the dissertation were presented and explored. Concerning the first subchapter (3.1), two flow mapping methodologies were analyzed: the MIFD and the VSM. These methodologies would serve as a basis for the improvement of the logistic and productive processes of the SAS Palmela plant. After the analysis of both methodologies, it was concluded that, due to the fact that the MIFD contains greater detail in what concerns the representation of the flows when compared to the VSM, it could be more advantageous for the identification of improvement opportunities and therefore for the effective improvement of the processes. Thus, it was decided that the methodology followed in this thesis would be based on the MIFD. Regarding the second subchapter (3.2), due to the specificity of the problem at hand, it was found that a methodology based on the SLAP problem would be the most appropriate to follow.

4 – Methodology

This chapter aims to explain the logic used in the Material and Information Flow Analysis and the logic used to solve the subsequent SLAP Problem. Regarding the Material and Information Flow Analysis, subchapter 4.1.1 (Current State Characterization) explains which method was used to gather information about the current state of the plant. Subchapter 4.1.2 (Current State Mapping) explains the symbology and codes used in the MIFDs. And subchapter 4.1.3 (Improvement Opportunities & Future State) explains how the identification of improvement opportunities and the validation of the current and future MIFDs was done.

During the identification of improvement opportunities, the author identified that there was potential to reduce the distances traveled by logistics operators during picking activities by creating and optimizing a Storage Location Assignment Problem model. After the identification of the improvement opportunities, the author was named responsible for developing the studies and solving the SLAP model. Thus, this study is presented in more detail in subchapter 4.2 (Storage Location Assignment Problem) which explains the logic used to build the SLAP model.

4.1 Material and Information Flow Analysis

The Material and Information Flow Diagram is intended to represent the information flows throughout the plant as well as the material flows, particularly with regard to inventories, transportation, and material processing operations. Taking into account that a factory normally works with a large number of products and components, it is not possible to represent every material in a single diagram. Thus, before the representation of the diagram, or even the collection of information regarding the current state, one must choose which end products will be the focus of the diagram, as well as which materials are most significant for the construction of that end product. This choice of the most significant materials can be made according to different criteria such as materials from a given product family, materials from a particular supplier, materials with higher value in inventory and others. Thus, before entering the collection of information, in a meeting with the FES (Faurecia Excellence System) Director the final products in focus were selected, and also the most significant materials for the construction of that product.

4.1.1 Current State Characterization

After selecting the materials in focus, the next step was to collect information regarding the current situation of the plant. As previously mentioned, the characterization of the current state is relative to the flow of information and the flow of material within the factory. The information regarding the current conditions was collected in two ways, either through *Gemba* walks, or through unstructured interviews with different people in the plant that have in-depth knowledge about the processes in question. In order to correctly characterize the flow of information, some key points had to be characterized. With that in mind, Table 1 was created, which summarizes the key questions to characterize the current state, as well as the means (Methodological Approach) used to obtain the information needed to answer them.

Table 1: Key questions regarding the characterization of the information flow.

Question:	**Methodological Approach:**
1) Regarding customer orders, what type of information is sent by the customer?	Unstructured interview with the Logistics Director.
2) How is the information regarding customer orders transmitted?	Unstructured interview with the Information Technology Technician.
3) How is this information processed internally?	Unstructured interview with the FES Director.
4) How is production information passed on to the workstations? Are there any documents needed for this process? If so, which ones?	Unstructured interview with the Information Technology Technician + *Gemba* Walks + Unstructured interview with the Logistics Supervisor.
5) What type of information regarding material orders is sent to suppliers?	Unstructured interview with the Logistics Director.
6) How does one know when to move material inside the factory?	*Gemba* Walks + Unstructured interview with the Logistics Team Leader.
7) When receiving material, how is the information processed?	Unstructured interview with the Logistics Operator (Gate Clerk).
8) Are there documents that follow along with the finished products to the customer?	*Gemba* Walks + Unstructured interview with the Production Supervisor.

In the same way that the information flow was characterized, the material flow was characterized using key questions. Thus, Table 2 was created containing the key questions to characterize the material flow in the current state, and the respective means (Methodological Approach) used to obtain the information to answer them.

Table 2: Key questions regarding the characterization of the material flow.

Question:	**Methodological Approach:**
9) How is the centralized storage zone organized?	Unstructured interview with Logistics Team Leader.
10) Are there decentralized material storage zones (Supermarkets or Lineside presentations)?	*Gemba* Walks + Unstructured Interview with Logistics Team Leader.
11) Within the selected materials, how does the material flow within the factory through the various inventories and workstations?	*Gemba* Walks.
12) What are the means of transport from the suppliers to the factory? What is the frequency? Are transports exclusive (Full Truck Load [FTL]) or shared (Less than Truck Load [LTL])?	Unstructured interview with Logistics Technician.

Question:	Methodological Approach:
13) Are there any operations taken inside the plant that are operationalized by an external company? If so, which ones?	Unstructured interview with Engineering Technician.
14) How many Production Operators (MOD) are required per workstation?	*Gemba* Walks.
15) How many Cockpits are produced per day? And how many Center Consoles are produced per day?	Calculation based on information provided by the customer.
16) How is the organization of the SAS factory? (Working days, number of shifts and hours per shift)	Unstructured interview with Production Supervisor.
17) What is the pace (Takt Time [TT]) required to deliver Cockpits to the customer? What about the TT of Center Consoles?	Calculation based on information provided by the customer.
18) What is the pace (Cycle Time [CT]) of the Cockpit production line? What about the Center Console production line?	Calculation based on information provided by the customer and on information provided by the Production Supervisor.
19) What is the Working Content (WC) of each workstation?	Times recorded in the daily audits to the operators working in different workstations that are performed by the Production Team Leaders.
20) How is the final product transportation to the customer? What is the frequency? Are transports exclusive (FTL) or shared (LTL)?	Unstructured interview with Production Director.

Both the material flow and the information flow can be accurately characterized by answering these 20 key questions. Thus, after obtaining answers to all questions, it was possible to calculate the Lead Time. As previously said and according to Faurecia (2021b), the Lead Time may have different origins, and can therefore be divided in three types: Stagnation Lead Time, Transport Lead Time and Process Lead Time. Each one of these types is calculated differently. The Stagnation Lead Time is related with the time a given material spends on a given point of stock, and for a regular inventory point it can be calculated using the Equation 1:

$$Stagnation\ Lead\ Time = \frac{Quantity\ of\ inventory}{Consumption\ rate} \tag{1}$$

The Transport Lead Time can be subdivided in external transports and internal transports. If it is related with an inbound of material, the Transport Lead Time is accounted as the frequency of transport. For instance, if a given material is ordered once per month, then it means that in one transport, the vehicle must transport the equivalent of one month of consumption of that material, and the

Transport Lead Time is one month. If it is related with an internal movement of material, the Transport Lead Time is accounted as the time it takes to transport the materials from point A to B.

The Process Lead Time, on the other hand, corresponds to the time that the material spends on the production line, in the different workstations. This can be calculated by multiplying the maximum number of Standard In Process Stock (SIPS) – number of cockpits (or MIKOs) in the assembly line carrousel counting since the material entry workstation – by the Cycle Time (CT), as can be seen in Equation 2:

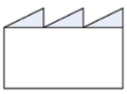
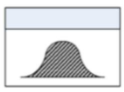
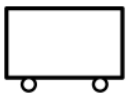
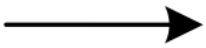
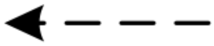
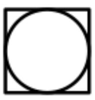
$$Process\ Lead\ Time = \ Max\ SIPS\ \times CT \qquad (2)$$

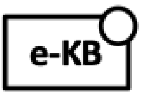
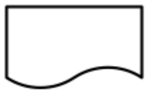
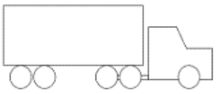
4.1.2 Current State Mapping

After collecting information for the characterization of the plant's current state, the representation of the current situation follows. This representation was done by mapping the plant's material and information flows in the diagram. The MIFD was drawn using various symbols, many of them being standard and used by different organizations, and other non-standard ones that are used on a case-by-case basis, depending on each company for the best representation of its reality.

For a better understanding of the diagrams in question, one can observe in Table 3 the symbols used in both the current and future MIFDs and their respective meaning.

Table 3: Material and Information Flow Diagram symbols and their meaning.

Symbol	Meaning	Symbol	Meaning
	Customer/ Supplier		External Warehouse
	Workstation		Stock
	Logistics Operator		AGV
	Logistics Operator with Hand Pallet Truck		Logistics Operator with Forklift
	Material Flow		Information Flow
	Orders Forecast		Real Orders/ Production Sequence

Symbol	Meaning	Symbol	Meaning
	Electronic (Withdrawal) Kanban		Paper Document/ Tag
	Documents Printer/ Tags Printer		E-ink
	Visual Control of Stock		Sequencing of Parts
	Automatic Transportation System		Elevator
	Transportation by Truck		Transportation by Boat

Another important aspect for understanding the diagram has to do with the representation of the frequency of external transports. For the characterization of the frequency of each transport, an **X-Y-Z** code is used. This code uses the three input fields in the following way:

- **X** – represents the period;
- **Y** – represents the number of shipments per period X;
- **Z** – represents the maximum number of vehicles in transit at any given moment.

4.1.3 Improvement Opportunities & Future State

Following the representation of the current state in the diagram, a multidisciplinary team was established to validate and, if necessary, to make rectifications to the MIFD. This team was composed of members from various departments within the company, including engineering, logistics, production, FES, and quality, to ensure that the MIFD accurately reflects the company's reality. Aside from validating and rectifying the diagram, this team would be in charge of identifying opportunities to improve the factory's information or material flows. Hence, a *kaizen* meeting was scheduled for the discussion of the mentioned points, which would consist of three steps:

1. Presentation of the current MIFD to all team members
2. Rectification and final validation of the current MIFD by the team members
3. Identification of improvement opportunities

For each improvement opportunity identified, it was assigned a person responsible for the in-depth study of the improvement in question as well as for the definition of an action plan for it. This in-depth study would be later analyzed by the team in order to decide if it should be implemented or not.

After the *kaizen* meeting, the future MIFD was created in accordance with the identified improvement opportunities, thus finishing the methodology associated with the MIFD tool. It should also be noted that months later there was an audit by the Faurecia Group to the SAS plant, where the MIFD methodology was assessed and validated.

4.2 Storage Location Assignment Problem

This study arises in the context of Improvement Opportunity #2 and its ultimate goal is the minimization of the distances traveled by logistics operators during picking operations. To make this possible, a mathematical SLAP model was developed which considers all available picking positions (*i.e.*, positions that currently are, or can be, allocated to picking operations), all decentralized stock positions (stock in supermarkets or in line-side presentation areas), all materials that need picking positions, as well as the average number of transportations required for each material per day. Note that, by using the number of transportations required for each material (apportioned demand) it can be considered that this SLAP model follows a popularity storage policy but given that each picking position occupies the same amount of volume, this is essentially the same as the COI policy (Gu *et al.*, 2007). With this data as input, the SLAP model returns the optimal allocation of material – picking position, so that operators walk the shortest possible distance (NVA activity).

Firstly, it is important to mention that the picking positions are in the racks that make up the Racks zone (Figure 10). In these racks, the Forward Reserve Configuration is applied, *i.e.*, the lower levels of the racks are used as a Forward Area (picking positions) to have a fast response time to the necessary replenishments, and the upper levels are used as Reserve Area (warehouse positions) to have better space utilization in the warehouse. As de Koster *et al.* (2007) mentioned, by using this configuration it is possible to have the advantages of having dedicated positions, while having the disadvantages minimized because the total number of dedicated positions is limited.

Since the decentralized positions (line-side presentation or supermarket) contain the stock for the producing operations, these are concentrated in zones that have to accommodate multiple positions close together. With this in mind, the decentralized positions were grouped, depending on their physical location, into 10 points, which from now on will be referred to as In/Out (I/O) points. Each of these I/O points corresponds to a stock area near the assembly line where specific materials are delivered according to the needs of the workstations that depend on that stock area. For instance, the supermarket at workstation Kitting 2 (Figure 11) corresponds to one of these I/O points which contain the decentralized positions for the materials needed in this workstation. In Figure 8, the I/O points are identified with a cross. The green cross identifies the I/O point that corresponds to the material input to the MIKO Mezzanine, which is fully supplied by a dedicated operator. The orange crosses identify different I/O points on the ground floor, which are totally supplied by a dedicated operator. The purple crosses identify I/O points also on the ground floor, but which are supplied by another dedicated operator. Finally, the red cross corresponds to the input of material for the Welding Mezzanine, which does not have a dedicated operator and therefore the movements of this material can be performed by the three picking operators, according to their availability at the time.

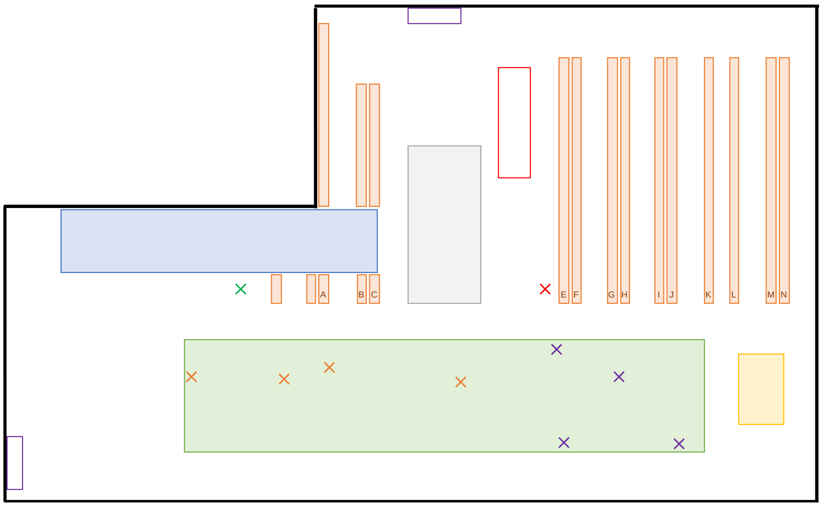


Figure 8: Identification of the I/O points in the ground floor Layout.

The picking positions, on the other hand, as they are physically distributed throughout the warehouse, were not grouped together, and were instead considered individually. For the computation of the SLAP model, first it is necessary to calculate the distances between the I/O points and the picking positions. As far as movement of the pickers is concerned, for each replenishment, they start at the I/O point (by observing that there is a need to replenish a box of a material), move to the respective Picking Position (represented by a circle in Figure 9) and return to the I/O point. Due to the orthogonal nature of the plant layout, which has long aisles in both horizontal and vertical directions, the Manhattan Distance was used as the basis for calculating the distances traveled by these pickers, while having into account that the pickers travel through the center of the aisles and not through the racks (as it is physically impossible). Equation 3 describes the standard calculation of the Manhattan Distance between point 1, with coordinates (a,b), and point 2, with coordinates (c,d).

$$Manhattan\ Distance = |a - c| + |b - d| \tag{3}$$

However, there are some replenishments (identified with circled I/O points in Figure 9) which have some particularities that cause the standard Manhattan Distance not to resemble the picker movements and will now be presented. In order to replenish the mezzanines, the pickers have to lift the materials, and therefore they must use a forklift. To minimize the number of crossings between forklifts and pickers who are on foot, it was defined that forklifts can only enter and exit the vertical aisles of the Racks area by using the upper horizontal aisle, due to safety reasons. Thus, for the calculation of the distances from these I/O points to those picking positions, this additional distance traveled was accounted for, while keeping the assumption that there are only horizontal or vertical moves (Manhattan Distance). Two examples of such movements can be seen in Figure 9, namely through the green dashed line and the red dashed line. Another special case is the replenishment of the two circled purple I/O points. When an operator is replenishing one of these points, in order for him to go to the picking positions, he cannot pass through the production zone (green rectangle) nor passing between this zone and the IP zone (yellow rectangle), due to the operations that take place in these zones. So, the logistics operator has to pass around the IP zone, as can be seen by the purple dashed line in Figure 9. For this, a fictitious I/O point (represented by the black square) was added, and the Manhattan Distance was calculated starting from that fictitious I/O point to the picking position and having the remaining trip count as constant for all materials from the two circled purple I/O points. To conclude, it is important to note that the I/O points that are not circled are associated with the cases where the calculation of the traveled distances follows the standard Manhattan Distance.

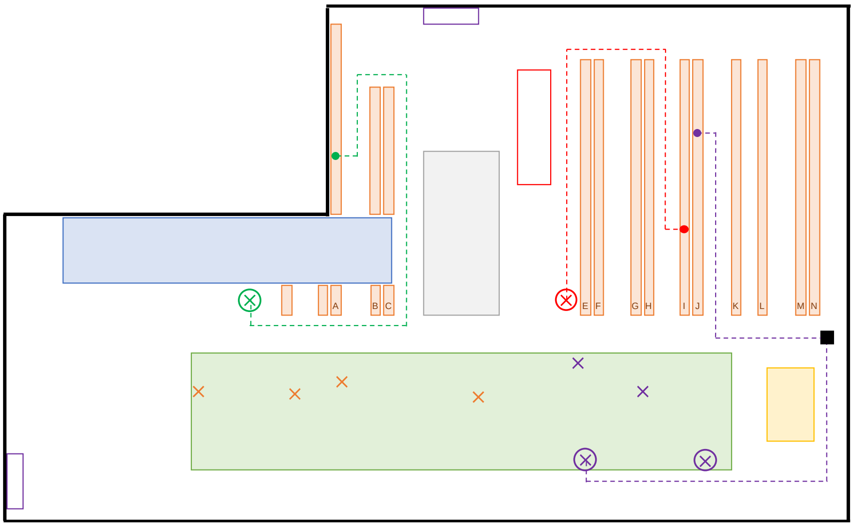


Figure 9: Examples of routes for the special cases I/O points.

One other important factor to consider is that a picking position can be on one of two levels of a rack (level 1 or level 2), and that it is ergonomically beneficial to operators for a material to be on level 1 rather than level 2. For this, a height factor (HF) was created in order to "penalize" the allocation of materials to level 2 positions. This factor can be described as the maximum additional distance an operator is willing to travel for a material to be on level 1 instead of level 2. Besides this, it was also taken into account that there are some materials that, must be stored in a picking position on level 1 due to the weight of its pallet or due to the configuration of the boxes that make up a pallet. Thus, another factor (r_m) that characterizes the need (or lack thereof) for a material to be stored on level 1 of the rack was created.

Taking all this into account, the mathematical model for the SLAP problem was created. Followingly there is a characterization of the sets, parameters and decision variables used in this model, as well as the mathematical formulation.

Sets:

- $l \in \{1,2,\dots,L\}$ representing the set of L I/O points considered;
- $m \in \{1,2,\dots,M\}$ representing the set of M materials that require a picking position;
- $p \in \{1,2,\dots,P\}$ representing the set of P picking positions;

$i \in \{1,2,\dots,M\}$ representing the set of the initial M picking positions (which currently store the M materials).

Parameters:

- $HF \in \mathbb{R}_+$ maximum distance that an operator is willing to additionally travel for a part to be stored on level 1, instead of on the rack's level 2;
- $t_m \in \mathbb{R}_+$ average number of transportations of material m per day;
- $h_p \in \{0,1\}$ height level of picking position p (h_p=0 if picking position p is on level 1, and h_p=1 if position p is on level 2 of the rack);
- $r_m \in \{0,1\}$ height restriction of material m (r_m=0 if material m must be stored on level 1, and r_m=1 if material m can be stored on either level);
- $d_{l,p} \in \mathbb{R}_+$ distance between I/O point l and picking position p;
- $a_{l,m} \in \{0,1\}$ allocation between I/O point l and material m ($a_{l,m}$=1 if material m has to be supplied in I/O point l, $a_{l,m}$=0 otherwise).

Decision Variables:

- $x_{m,p} \in \{0,1\}$ $x_{m,p}$=1 if material m is allocated to position p, $x_{m,p}$=0 otherwise.

Mathematical Formulation:

$$\min z = \sum_l \sum_m \sum_p a_{l,m} \times t_m \times \left(d_{l,p} + HF \times h_p\right) \times x_{m,p} \qquad (4)$$

Subject to:

$$\left(r_m - h_p\right) \times x_{m,p} \geq 0, \quad \forall (m,p) \qquad (5)$$

$$\sum_p x_{m,p} = 1, \quad \forall m \qquad (6)$$

$$\sum_m x_{m,p} \leq 1, \quad \forall p \qquad (7)$$

$$x_{m,p} \in \{0,1\}, \quad \forall (m,p) \qquad (8)$$

The first equation (Equation 4) represents the objective function of the SLAP model that aims to minimize the total traveled distance in picking operations per day while penalizing the allocation of materials to level 2 positions for ergonomic reasons (HF). Equation 5 assures that if a given material cannot be allocated to a level 2 positions, then that it is allocated to a level 1 position. Equation 6 ensures that each material must, and can only, be allocated to one picking position. Equation 7 guarantees that each picking position can only be empty or allocated to a single material. The last equation (Equation 8) defines the domain of the decision variables.

Considering that changing a high number of picking positions is a complex process, and that it can generate several problems when it comes to the SAP material movements, a sensitivity analysis was performed with the objective of observing the changes in the optimization results when varying the number of allocations (pair material–picking position) that can change, when compared to the current allocations. To make this sensitivity analysis possible, the set of p picking positions ($\{1,2,\ldots,P\}$) and the set of m materials ($\{1,2,\ldots,M\}$) were defined so that $x_{i,i} = 1,\ \forall i \in \{1,2,\ldots,M\}$. In addition to this, a new parameter $n \in \mathbb{Z}_+$ was created representing the minimum number of allocations (material-picking position) that should be kept as they are today, that is, the minimum number of picking positions that should remain allocated to the same material they accommodate today. Then, a new constraint (Equation 9) was added to ensure that at least n allocations remain as they currently are:

$$\sum_{m} \sum_{p \mid p=i} x_{m,p} \geq n \qquad (9)$$

That said, the Mixed Integer Linear Programming (MILP) model was formulated through the General Algebraic Modeling System (GAMS) Studio 34 software, using IBM CPLEX Optimizer, in a 2x Intel Xeon X5660, 2.8GHz computer with 64GB of RAM, to obtain the results of the SLAP model. The results are shown and discussed in subchapter 5.2 (Picking Locations Management).

5 – Results and Discussion

This chapter aims to present the results obtained and discuss them for the Material and Information Flow Analysis and for the Storage Location Assignment Problem. Subchapter 5.1.1 (Current State Characterization and Mapping) begins by presenting the answers to the Key Questions that were identified as fundamental to building the MIFD. After obtaining these answers, through observations in the shopfloor (*Gemba Walks*) and through interviews with the people responsible for the different processes, the current MIFD is then presented. In the subchapter 5.1.2 (Improvement Opportunities) the improvement opportunities identified at the kaizen meeting as well as the impacts of each of them are presented. After this, the future MIFD is presented, which represents the flow of information and material if all improvement opportunities were implemented. Subchapter 5.2 (Storage Location Assignment Problem) presents the detailed results of Improvement Opportunity #2 as it was identified and explored autonomously by the author. At the end three possible suggestions are identified and proposed to the decision maker (Logistics Director).

5.1 Material and Information Flow Analysis

The implementation of the MIFD tool began by deciding which end products and their constituent components to focus on. This choice was made in a meeting with the FES Director, where it was established that the final products in focus would be the cockpit and the center console of the T-ROC model, since this model represents more than 90% of the plant's production. The criterion established for the selection of components was the ten components with the highest value in inventory: one Climatronic module (reference number 2GA 907 044 A XBT), one OCU module (5WA 035 284 E), one Cluster (17A 920 320 B), one Display (5NN 919 605 B), three MIB modules (3G5 035 820 H, 3G5 035 820 J, and 3G5 035 832 E), one BCM module (5Q0 937 084 EB), one Steering Column (5Q1 419 512 K) and one Heater (5WB 816 005 F).

However, the components that are supplied by Faurecia, the Wiring Harnesses, and the MIKO Covers’ high runners (reference numbers 2GA 863 042 B ZAR, 2GA 863 042 B 041, and 2GA 863 042 B ICB) were also focused on the diagram. This decision was taken due to the fact that the flow of these components is significantly different from the flow of the other represented components, and therefore only with their presence the diagram would represent the factory’s reality. The components supplied by Faurecia for the T-ROC model are four glove boxes (reference numbers 2GA 857 097 A 82V, 2GB 857 097 A 82V, 2GA 857 097 82V, and 2GB 857 097 B 82V), two IPs (2GA 857 002 RA3, and 2GB 857 002 A RA3), and two cockpit covers (2GA 858 365 82V, and 2GB 858 365 82V). The Wiring Harness component, on the other hand, does not have a reference number, as each Wiring Harness is different from each other and corresponds to a specific car, therefore these components are identified by their TAB number (016_622_K, and 016_623_J), depending on if they are Left-Hand Drive (LHD) or Right-Hand Drive (RHD), respectively.

5.1.1 Current State Characterization and Mapping

After the *Gemba* walks and the unstructured interviews, the answers to the key questions that were stated on subsection 4.1.1 (Current State Characterization) were obtained, and are presented:

1) **Regarding customer orders, what type of information is sent by the customer?** Currently there are three types of information regarding customer orders, namely Forecasts with a view horizon of one year, Real Orders (concrete orders for cockpits but not knowing in advance exactly when each cockpit will be produced) with a view horizon of four weeks, and the Production Sequence (order in which the cockpits are to be produced immediately) which does not have a specific view horizon. Forecasts and Real Orders are received with the same cadence (weekly) since they are share the same document, where the first four weeks refer to Real Orders and from the beginning of the fifth week until the end of the year refer to Forecasts. On the other hand, the Production Sequence is continuously updated by the customer and has no fix view horizon. When it comes to specific customers, usually VW Autoeuropa (AE) sends the information regarding Forecasts and Real Orders once per day between 05:00 and 06:00, while VW Osnabruck sends that information on each Monday at 16:00.
2) **How is the information regarding customer orders transmitted?** Given the difference between the types of information shared, there is also a difference between the transmission methods for sharing it. The document containing the Forecasts and the Real Orders is transmitted using EDI, a worldwide standard system created by the United Nations with the objective of facilitating a means of sharing information in a standardized way between different business partners. As for the Production Sequence, it is sent by the customers to a company called T-Systems, that is also physically present in the industrial park. This company processes the information sent and sends it directly to JIS, which is SAS's information management system.
3) **How is this information processed internally?** As just mentioned, the information regarding the Production Sequence is not processed internally but is in fact processed externally by T-Systems and then sent directly to the JIS. However, this process is quite different from what happens with Forecasts and Real Orders. The information regarding Forecasts is focused on the monthly meeting *Plan Industriel & Commercial* (PIC, it is the French saying for Industrial & Commercial Plan). In this meeting, the forecasts of the customer orders with a view horizon of one year are analyzed, the leveling (*heijunka*) is done, and then the resources needed to satisfy these orders are planned, as well as the plant's major changes that will take place in the next 6 to 12 months. The information regarding Real Orders, on the other hand, is focused on the weekly meeting *Plan Directeur de Production* (PDP, it is the French saying for Production Master Plan). With the Real Orders information as well as with the plan defined in the *Plan Industriel & Commercial* (PIC, it is the French saying for Industrial and Commercial Plan) meeting, a detailed production plan is defined by adjusting the forecasted volumes and respective resources for a period of 5 to 12 weeks.
4) **How is production information passed on to the workstations? Are there any documents needed for this process? If so, which ones?** The vast majority of workstations have a Clever

station, which consists of a computer, a screen, and a scanner. This station's function is to control the production at each station and receives information directly from the JIS, which was previously fed with the Production Sequence supplied by the customer. In addition to these screens that are fed from the JIS, the operators can also consult information about the production on paper documents such as the T-100 sheet, the Kitting 1 sheet or the MIKO sheet, which refer only to a specific product and that always go along with that product, informing the various stations along the assembly line. These sheets are printed on printers that are located in the workstations and are also fed directly from the JIS with information. Note that the Clever stations only have information regarding some components, and that the ones that are present in the paper documents are the components that are not controlled at the Clever stations. This is the method of communicating information to all workstations, with the exception of the Blend MIKO workstation since it is the only workstation that works in Batch. For this station there is no Clever station, and the daily production planning is defined based on the consumptions established in the PDP meeting and the inventory at the time.

5) **What type of information regarding material orders is sent to the suppliers?** After the weekly production plan is defined in the PDP meeting, the defined production is passed to the WMS used, SAP. Within SAP, this information is processed by Material Requirement Planning (MRP) and orders are automatically issued to suppliers using the EDI system. The format of the documents containing these orders is the same as the one used by the customer, the first four weeks are Real Orders and from the fifth week until the end of the year are Forecasts. Regarding the frequency with which the orders are sent to suppliers, for suppliers geographically closer to the SAS plant, which tend to have more frequent deliveries, there is a sharing of information 3 times a week, while for suppliers further away, which tend to have less frequent deliveries, the sharing of information is done weekly.

6) **How does one know when to move material inside the factory?** As already mentioned, the movement of components within the plant is done either by logistic operators or by AGVs. Usually, the logistic operators are responsible for the movement of non-sequenced materials, while the AGVs are responsible for the movement of already sequenced materials. In the case of AGVs, the materials are sequenced by operators with a Clever station that is informed directly by the JIS. When the Clever station confirms that the materials are all correctly sequenced, then the operator gives the order to the AGV to go ahead and supply the line. For non-sequenced materials, the logistics operators visually check the material racks that are next to the production workstations. When a box of a component is placed on the top shelf, this is a signal that this component should be replenished. So, the logistics operator scans the barcode on the box, and an e-Kanban (material movement order) is created, and the operator is informed of which position he should pick up a box. When he arrives at that position he scans the barcode from that position, informing SAP that the e-Kanban has been satisfied, picks up a box of that component and transports it to the assembly line rack. To feed picking positions it works in the same way. When a picking position is empty, the operator scans that position, an e-Kanban is created and the operator is informed of which

warehouse position he should pick a pallet from, he goes to that position, scans it to inform SAP that the e-Kanban was satisfied and transports the pallet to his picking position.

7) **When receiving material, how is the information processed?** When a shipment from the suppliers is received, the order is checked by the Gate Clerk operator to confirm that the components received are in accordance with the ones ordered. After this, if there are electronic components in the shipment, then these are put aside so that they can be checked by the quality department. After the electronic components quality check or, in case of non-electronic components, the components are registered into SAP and for each pallet a label is automatically generated and printed. This label is then sticked to the pallet with the objective of informing the quantity of components it contains and where it should be stored. After this material receiving process, the pallets can then be stored by the logistics operator assigned to the put-away workstation.

8) **Are there documents that follow along with the finished products to the customer?** The cockpit modules sent to the customer do not require any box or rack with multiple products to transport them, therefore there is no need of using any documents to organize or inform the customer. But, in case of the center console module, the parts are transported to the customer using racks. The center console Parts B and C are produced at MIKO 2 and MIKO 3 workstations in sequence and are then stored in a rack. When this rack is full, a paper Load List is printed and sticked to the rack to inform the customer which center console parts correspond to each KEN Number (KENN, it corresponds to the car identification number) and where they are located in the rack. With the same purpose, for the center console Part A, which is produced at MIKO 1 workstation, there is also a paper Load List that follows along with the rack.

9) **How is the centralized storage zone organized?** Currently in the plant there are four main centralized storage zones, namely Racks zone, Bulk zone, IPs zone and Wiring Harnesses zone (DSV has full responsibility for this zone and therefore will not be addressed hereafter). In Figure 10 one can observe these zones by the orange, gray, yellow and blue rectangles respectively. The Bulk and IP zones store large volume components, and so that their inventories do not take up excessive space, the metal containers that carry the components are stored container upon container, without the need for shelving. The Racks zone, on the other hand, has the characteristic of being dispersed and not condensed like the previous ones because it is a component storage zone in racks with shelves. Another particularity of this zone is that it is sub-divided into two, the positions of the first level of shelves and some positions of the second are defined as Picking positions (Forward Area); the remaining positions of the second level and the upper levels are defined as Warehouse positions (Reserve Area). In addition to these zones, Figure 10 also shows the zone of empty containers (red rectangle), the two docks used by SAS (purple rectangles) and the ground floor production area (green rectangle).

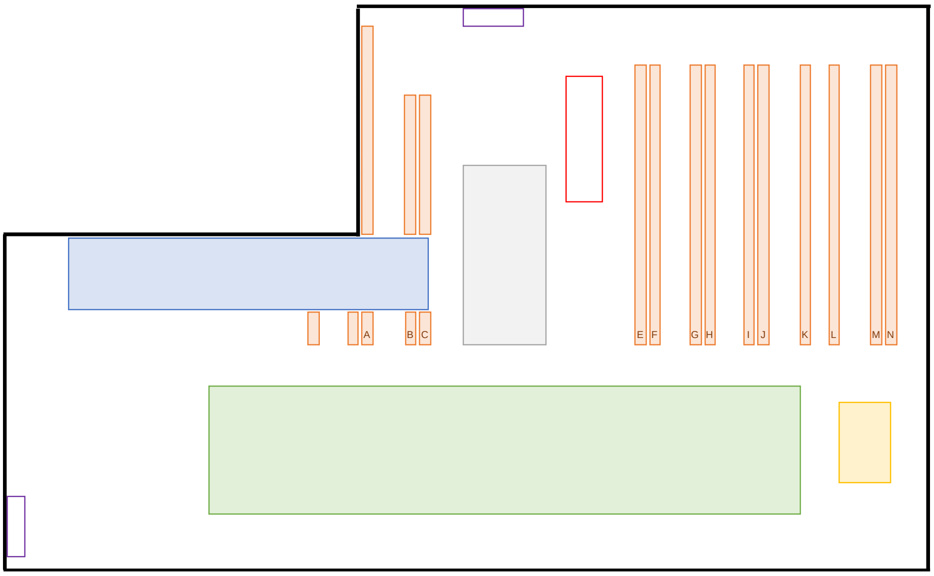


Figure 10: SAS Palmela Plant ground floor Layout.

10) Are there decentralized material storage zones (Supermarkets or Lineside presentations)? In the factory, regarding the types of decentralized storage zones, there are Supermarkets and Lineside Presentations, and both are located next to the production workstations. The Supermarket areas that exist in the factory are only on the ground floor and correspond to the storage areas of Kitting 1 and Kitting 2 workstations. They are considered Supermarket areas because the operations in these stations are only for sequencing the components that will be assembled in subsequent stations and not for assembly itself. As an example, one can see in Figure 11 the Supermarket area of Kitting 2 workstation. On the other hand, the Lineside Presentation areas take place both on the ground floor near each of the stations and in the two mezzanines and these stocks are intended to directly supply the operators who will assemble them.

Figure 11: Kitting 2 workstation's Supermarket area.

11) Within the selected materials, how does the material flow within the factory through the various inventories and workstations? The flows of the selected materials can be quite different from one component to another. Therefore, 5 groups of material flows will be explained. Flow 1: The most common flow is for the material to arrive at the receiving dock on a pallet and then be stored in a warehouse position. When its picking position becomes empty, the pallet is moved from the warehouse position to its dedicated picking position, and from there the components are transported box by box to the decentralized stock at the assembly line. Flow 2: The flow is the similar to the previous, except that in this case the material does not pass through the picking positions, either the components are sequenced in the warehouse positions and go directly to the line (heater component), or after the warehouse position, the pallet is moved to decentralized stocks and the components are sequenced from that position (steering column component). Flow 3: The components are transported from Faurecia by AGV and arrive to SAS's AGV Reception Area, then they are removed from the top of the AGV and stored in dedicated picking positions, after this the components either proceed box by box to a decentralized stock area (cockpit cover components) or are sequenced in their picking positions and supply the line from those positions (glove box and IP components). Flow 4: This flow only applies to the wiring harnesses, since DSV is responsible for this component. The materials arrive to DSV's dock in individual boxes and are stored in the Wiring Harnesses zone. The components are sequenced by DSV operators in this area and fed to the workstation directly by AGV. Flow 5: This flow only applies to the MIKO covers since this component is an intermediate product produced in batch. This component is produced in the Blend MIKO workstation, in the Welding Mezzanine, pallet by pallet. When a full pallet is produced, it is moved to a warehouse position and after this, when its dedicated picking position is empty, it is moved to this position. When there is the need to replenish this component in the MIKO 3 racks, it is transported from the picking position to the MIKO Mezzanine. Note that, from the selected materials (in subchapter 5.1 Material and Information Flow Analysis), if a given material was not referred in any of these descriptions of the 5 groups of material flows, it is possible to assume that it follows the Flow 1, which is the most common one.

12) **What are the means of transport from the suppliers to the factory? What is the frequency? Are transports exclusive (FTL) or shared (LTL)?** With the exception of materials supplied by Faurecia and the Wiring Harnesses which are transported by AGV, all materials are transported to the plant by truck, and in less frequent cases the cargo may have been transported by sea or air. To better understand the supply chain of the selected components, information about their supplier, transportation distance, method and time, delivery frequency, and whether transportation is dedicated (Full Truckload [FTL]) or shared (Less than Truckload [LTL]) was gathered for each of them and can be seen in Table 4. For the materials which are delivered to SAS by AGV, the information is characterized by the time it takes for an AGV to travel the complete loop, the frequency of delivery and how much material it transports per loop. The Wiring Harnesses AGV is characterized by having a loop time of 6 minutes, with a frequency of delivery of 239 times per day and transporting 4 sequenced wiring harnesses to the assembly line and then taking the empty boxes back. The Faurecia AGVs are characterized by having a loop time of 30 minutes, with a frequency of delivery of 172 times per day (considering that there are multiple AGVs in this loop) and transporting one rack of 6 IPs, or alternatively four pallets of a combination of glove boxes and cockpit covers pallets.

Table 4: Transport and supplier information regarding the selected materials.

Material Reference Number	Supplier Name	Supplier Country	Number of Materials Supplied	Distance	Transport Method	Transport Time	Delivery Frequency	FTL or LTL?
2GA 907 044 A XBT	Behr-Hella	Bulgaria	37	3.600 km	Truck	8 days	once a week	LTL
5WA 035 284 E	LG Electronics	Vietnam	33	8.176 km	Boat (+ Truck)	60 days	twice a month	LTL
17A 920 320 B	Continental	Czech Republic	16	2.833 km	Truck	4 days	twice a week	LTL
5NN 919 605 B								
3G5 035 820 H	Joynext	Poland	71	3.073 km	Truck	5 days	twice a week	LTL
3G5 035 820 J								
3G5 035 832 E								
5Q0 937 084 EB	Continental	Germany	56	2.353 km	Truck	4 days	once a week	LTL
5Q1 419 512 K	Thyssenkrupp	France	8	2.302 km	Truck	3 days	twice a week	LTL
5WB 816 005 F	Valeo Termico	Spain	19	906 km	Truck	1 day	twice a day	FTL

13) **Are there any operations taken inside the plant that are operationalized by an external company? If so, which ones?** As previously mentioned, there are certain operations within the plant that are performed by an external company, DSV. Those already mentioned is the handling of the wiring harnesses, from the unloading of the truck to the DSV Truck Reception Area (TRA), to their storage and subsequent sequencing of components to be delivered to the assembly line via AGV. Other operations that DSV performs, are the movement of the racks that transport the center consoles, in their final state, to the MIKO Truck Preparation Area (TPA), and subsequently DSV is also responsible for loading the center consoles onto trucks (only for the customer VW Autoeuropa).

14) **How many Production Operations (MOD) are required per workstation?** While performing *Gemba* walks, it was possible to observe that there is one production operator per workstation, with the exception of the Sold FS and Blend MIKO workstations and the E-Check workstation. The Sold FS and Blend MIKO workstations share a single operator, the operator has to distribute his work between the two stations so that the Blend MIKO station's welding machine loop is always running and also that the Sold BFS workstation operator has the pre-assembled components whenever he needs them. On the other hand, the E-Check workstation works with 3 operators, with all of them working independently from one another as they are working on different cockpits at each time.

15) **How many Cockpits are produced per day? And how many Center Consoles are produced per day?** SAS's main customer, VW Autoeuropa, currently places orders for both Cockpit and MIKO modules. And each of the products can be either T-ROC or MPV (VW Sharan or Seat Alhambra). The customer VW Osnabrück, on the other hand, only receives the MIKO module from SAS, and always for the T-ROC model. The number of daily orders can be seen in Table 5.

Table 5: Customers' daily orders per product.

Customer	Product	Car Model	**Daily Demand** (units/day)
VW Autoeuropa	Cockpit	T-ROC + MPV	845 + 60
VW Autoeuropa	MIKO	T-ROC + MPV	845 + 60
VW Osnabrück	MIKO	T-ROC	56

16) **How is the organization of the SAS factory? (Working days, number of shifts and hours per shift)** Since SAS produces JIT, its organization is defined based on the organization of the main customer, VW Autoeuropa. That is, the plant works in 19 shifts per week (3 shifts per weekday and 2 shifts per weekend day). The morning and afternoon shifts have 7.48h per shift and the night shift has 6.48h per shift, accounting for 21.44h of production time per day. For this the company has 4 teams so that every day during the week one team takes a day off while the other three work. Each team has 32 production operators and 10 logistics operators.

17) **What is the pace (TT) required to deliver Cockpits to the customer? What about the TT of Center Consoles?** Takt time is defined as the pace required to produce and supply customers' orders. The Takt Time for each product can be calculated using Equation 10, and its results can be seen in Table 6.

$$Takt\ Time = \frac{Daily\ Available\ Time}{Daily\ Demand} \quad (10)$$

18) **What is the pace (CT) of the Cockpit production line? What about the Center Console production line?** Cycle Time is defined as the time between consecutive parts that a given system of operations can produce, and in the case of the system uses a carousel, it is the time that a unit spends at a workstation. To calculate the Cycle Time, it is necessary to take into account the efficiency of the assembly line, and in this case an efficiency of 97% was considered. Thus, the Cycle Time was calculated for the assembly line of each of the modules as can be seen in Equation 11. Furthermore, the Takt Time (TT) and Cycle Time (CT) results for each module can be seen in Table 6.

$$Cycle\ Time = Takt\ Time \times Efficiency \quad (11)$$

Table 6: Takt Time and Cycle Time per product assembly line.

Product	**Daily Production** (units/day)	**Takt Time** (seconds)	**Cycle Time** (seconds)
Cockpit	905	85	82
MIKO	961	80	77

19) **What is the Working Content (WC) of each workstation?** Currently, and according to Faurecia fundamentals, every day each Team Leader chooses an operator at a particular workstation to audit. In this audit, in addition to checking compliance with safety and quality key points, the Team Leaders chronometer 5 work cycles. In order to obtain the Working Content (WC) of each workstation, the last 30 clocked times were obtained, and the arithmetic mean was applied to them. Each workstation's WC can be seen later in the current MIFD (Figure 13).

20) **How is the final product transportation to the customer? What is the frequency? Are transports exclusive (FTL) or shared (LTL)?** As far as transportation to the customer is concerned, Table 7 contains information about the customer and his location, the number of products shipped per transport, the fill rate on each trip, the distance traveled, how often the transport takes place, and whether the transport is dedicated (FTL) or shared (LTL). Furthermore, it is important to note that all these transports are exclusively done by truck. While for the client VW Osnabruck the transport is shared with other suppliers, for the client VW Autoeuropa this is exclusive and therefore the trucks make successive loops throughout the day. For the transport of Cockpits there are two trucks doing the loop all the time, while for the loop of MIKOs, this is only done by one truck. Note that the Transport Time refers to the time since the truck exits SAS's plant, until the cargo is unloaded in the customer's plant and the truck starts returning to SAS's plant.

Table 7: Information regarding transportation to customer.

Product Shipped	Customer	Customer Country	Products Shipped per Transport	Fill Rate	Distance	Transport Time	Delivery Frequency	FTL or LTL?
Cockpit	VW Autoeuropa	Portugal	12 cockpits	50%	2 km	12 min.	75 times a day	FTL
MIKO	VW Autoeuropa	Portugal	36 MIKOs	67%	2 km	25 min.	25 times a day	FTL
MIKO	VW Osnabrück	Germany	56 MIKOs	55%	2.524 km	4 days	once a day	LTL

After collecting information about the operations and with special focus on the selected components, it was possible to proceed to the Lead Time analysis. The lead time was calculated for the selected components, according to the methods described in subsection 4.1.1 (Current State Characterization), and it was found that the component with the longest lead time is the OCU module (5WA 035 284 E). For the representation of the diagram, it was necessary to know the Lead Time, as well as its origin, for the component with the longest lead time. Thus, the entire flow of this material was firstly segmented into 11 activities as it can be seen in the flowchart present in Figure 12.

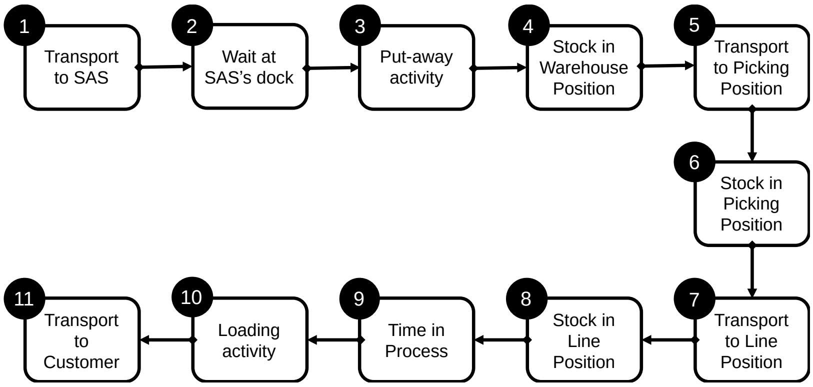


Figure 12: Flowchart of OCU module flow and segmentation in activities.

Then, each segment was evaluated according to its impact on Lead Time, as it can be seen in Table 8. In addition to the data in the table, the following data were used as input to calculate lead time: daily material consumption of 769 units/day, a pallet contains 660 units (15 boxes), and a box contains 44 units. It is also important to refer that when a stagnation activity does not correspond to a position intended for stock storage (e.g., wait at SAS's dock), it is not calculated according to the Equation 1 (subchapter 4.1.1 Current State Characterization), but instead by the average stagnation time at that point.

Table 8: Activity observations and respective Lead Time impacts for the OCU module (5WA 035 284 E).

Activity Observation	**Lead Time Type**	**Lead Time** (days)
1) 15 days between arrivals of this material	Transport	15
2) The material stays in the dock for 1 hour for computer processing and quality control activities	Stagnation	0,04
3) Material is stored in the Warehouse positions in 15 minutes	Transport	0,01
4) 10 pallets were observed in Warehouse Positions	Stagnation	8,58
5) To transport a pallet of material from a Warehouse Position to its dedicated Picking Position takes approximately 1 min	Transport	0
6) The Picking Position accommodates a maximum of 15 boxes (1 pallet)	Stagnation	0,86
7) To transport a box of material from its Picking Position to its Line Position (Kitting 2 supermarket) takes 20 seconds	Transport	0
8) The Line Position accommodates a maximum of 3 boxes	Stagnation	0,17
9) 32 SIPS were observed from the moment the material is moving with the trolley until the cockpit leaves the last workstation	Process	0,03
10) It takes 2 minutes for the automatic transportation system to load the truck	Transport	0
11) It takes 12 minutes from the moment the truck leaves SAS, until the cargo is unloaded at the customer	Transport	0,01
	TOTAL	**24,7**

After answering the 20 key questions, it was possible to draw the Current MIFD, which can be seen in Figure 13. Note that the lines and symbols marked in blue refer to the path of the component with the longest lead time, the OCU module (5WA 035 284 E).

Once the diagram was finished, it was presented at the *kaizen* meeting and validated by the selected team. Thus, it was possible for the team to analyze the diagram, and from there the team began the identification of improvement opportunities, which will be characterized in subchapter 5.1.2 (Improvement Opportunities).

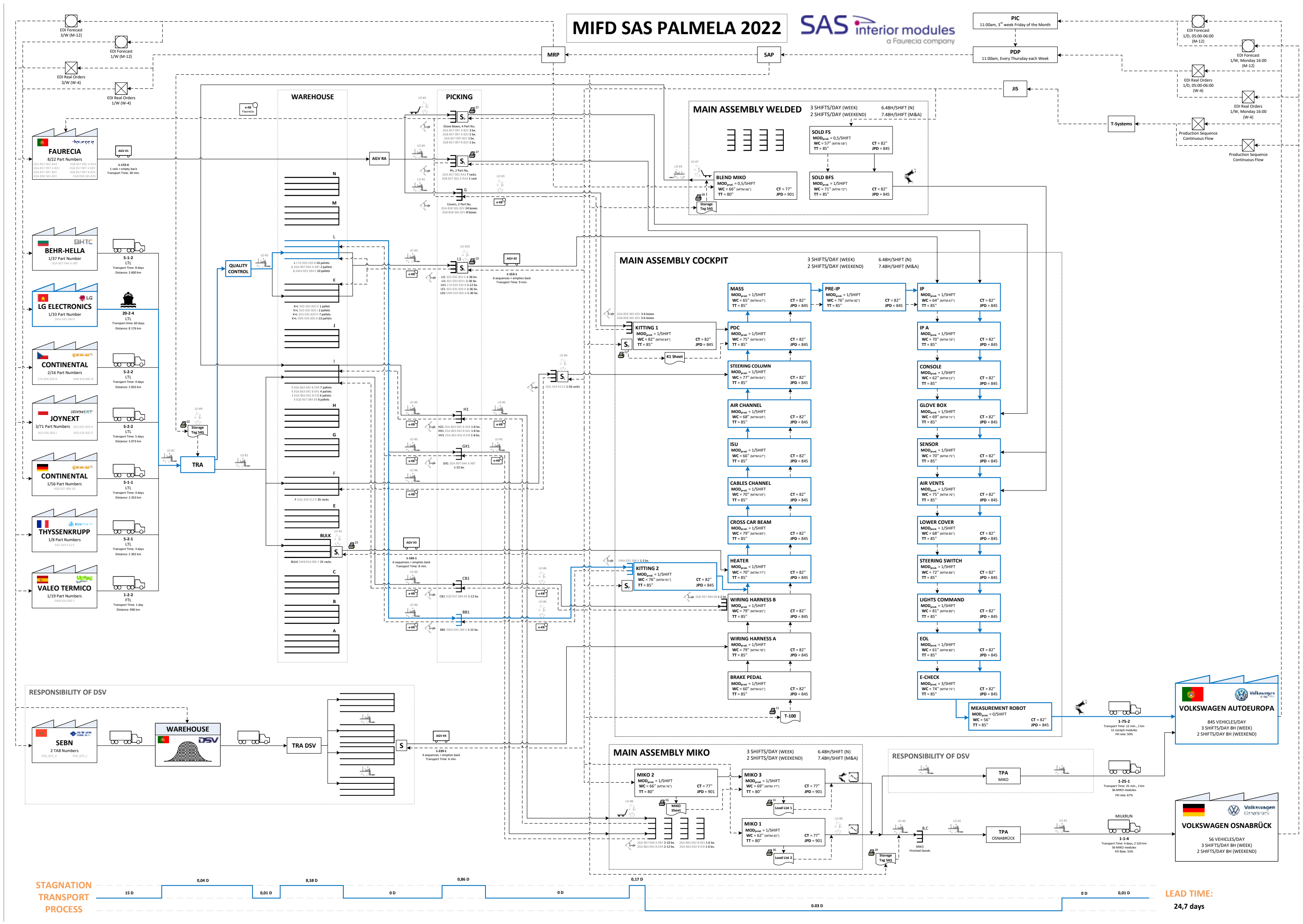


Figure 13: Current Material and Information Flow Diagram (Current MIFD).

5.1.2 Improvement Opportunities

The decision of whether to implement an improvement, or not, is based on a cost-benefit analysis, that is, whether the investment required is worth the benefits obtained. For this, the Payback Period was used, which consists in the time required to recover the investment costs. In Equation 12 one can observe the formula used to calculate the Payback Period:

$$Payback\ Period = \frac{Investment\ Costs}{Annual\ Benefits} \tag{12}$$

Following an in-depth analysis of each Improvement Opportunity, the kaizen meeting team determined that for an improvement to be implemented, it must have a Payback Period of less than or equal to 2 years. If an Improvement Opportunity has no significant investment costs, then the criterion is to have associated benefits to the plant.

It is important to refer that the different improvement opportunities have specific time periods when they can be implemented, which is during the factory shutdowns when the customer, and therefore the SAS plant, are not producing. Thus, the author was not able to observe the implementation of any improvement opportunity, because the internship ended before the plant shutdown.

An important aspect to mention is that the benefits associated with certain improvements refer to the elimination or reduction of NVA tasks. These benefits, although they are not direct gains, should be accounted for, as the Kaizen philosophy suggests that one should focus on several small improvements rather than just looking for big improvements. One final note that is important to mention is that, for confidentiality reasons, the cost of an operator can not be shared, and therefore the savings of each improvement opportunity will be presented in terms of operator occupancy percentage (the time saved of an operator divided by the total time of an operator, using the same time period).

5.1.2.1 Improvement Opportunity #1

Improvement Opportunity #1 was thought of with the intent of reducing the lead time of the component that has the longest lead time, the OCU Module (reference number 5WA 035 284 E). In this way, it would be possible to reduce the money invested in large stocks for a component that has a higher cost than the average component and to ensure greater flexibility to adapt to any change in the market.

The supplier of this component has its facilities in Vietnam and the deliveries of this component are mostly made by boat, having a transportation time of 60 days. Considering the long distance it travels and also that the cargo has to go through customs, sometimes there are deliveries that arrive late and therefore there is a need to use extraordinary air transportation, with transport costs approximately 5 times higher when compared to sea.

Currently this component is received twice a month, *i.e.*, every 15 days, and this opportunity for improvement aims to study what the optimal frequency of delivery is. Considering that this boat coming from Vietnam, has at maximum a frequency of one week, the only possible increase in frequency would be to double it, *i.e.*, every 7 days. To be able to answer what the optimal frequency is, it is necessary to resort to inventory management, namely to the model of periodic review with variable ordered quantities, since the deliveries can only be made with a certain periodicity. This model states that the optimal frequency of deliveries (T) can be calculated according to Equation (13):

$$T = \sqrt{\frac{2 * C}{\mu_D * I * c}} \tag{13}$$

In which, C represents the cost of transportation, μ_D represents the average daily demand (consumption) of the OCU Module, I represents the rate of the cost of keeping inventory and c the unitary cost of the OCU Module.

By using a cost of transportation of 5.960 €/transportation, an average daily demand of 665 units/day, a cost of keeping inventory of 0,2% of the unitary cost per day, a unitary cost of 79,11 €/unit and the equation (13), it was possible to conclude that the optimal frequency is approximately every 11 days. However, since the transportation cannot be done every 11 days, but rather every 7 days (Option A) or every 15 days (Option B), then the costs of these two possible alternatives had to be calculated using the same values for the parameters, and these results can be seen in Table 9. Note that the units ordered must complete full pallets (660 units/pallet).

Table 9: Annual Costs Comparison between Option A and Option B.

	Option A	Option B
Period between deliveries	7 days	15 days
Quantity ordered	8 pallets	16 pallets
Average Stock	2.640 units	5.280 units
Annual Transportation Cost	310.771,43 €/year	145.026,67 €/year
Annual Inventory Cost	152.460,79 €/year	304.921,58 €/year
Total Annual Cost	**463.232,22 €/year**	**449.948,25 €/year**

By comparing these results, it is possible to conclude that Option A is 13.283,97 €/year more expensive than Option B. This indicates that even while ordering every 15 days does not shorten the lead time for the OCU Module, it is still more cost-effective to do so, given the restriction on delivery complying with a periodicity of at least 7 days and the consequent inability of ordering every 11 days. Thus, the Improvement Opportunity #1 would not be accepted.

5.1.2.2 Improvement Opportunity #2

Improvement Opportunity #2 consists in the reorganization of the components' Picking locations so that the logistics operators travel less during the picking operations. Currently, the logistics operators that do the picking operations are responsible for supplying specific areas of the assembly line depending on the workstation they are operating. When there is a need to replenish a box of a component, the logistics operator scans the barcode referring to that component (creating an e-Kanban), thus knowing where to pick that component, moves to the location, scans the barcode present in the location (signaling that he is picking that component), picks the component and transports it to the assembly line. That said, it is possible to conclude that much of the operator's time is spent moving between locations, that is, in an NVA activity. Thus, this improvement opportunity arises with the objective of minimizing the time spent on logistics operators' movements in the Picking operations.

As can be seen in more detail on subchapter 5.2 (Storage Location Assignment Problem), this was studied using a MILP model with the objective of minimizing the travelling distances, while having into account the number of allocations (material – picking position) that are changing. From this, three solutions were suggested to the decision maker (SAS Logistics Director) which chose to change 114 allocations. This solution resulted in a reduction of 26.151 meters per day on average in the distances traveled in the picking activities.

From the 114 allocations, 60 correspond to positions that are visited by foot (replenishment of ground floor production workstations) and 54 are visited using a forklift (replenishment of mezzanines production workstations). Considering this proportion of foot-visited locations and forklift-visited locations, and by considering that a person of foot walks at a speed of 1 meter per second and that a forklift travels at a speed of 1,67 meters per second (equivalent to the speed limit of 6 kilometers per hour), it was concluded that the logistics operators in the picking activities travel on average at a speed of 1,32 meters per second. This means that the implementation of this Improvement Opportunity would save approximately 331 minutes per day in Picking activities. Having into account that in a day there are two shifts of 7,48 hours (morning and afternoon shifts) and one shift of 6,48 hours (night shift), it can be concluded that the Improvement Opportunity #2 results in a saving of 25,75% of operator time, which can now be allocated to VA activities. As this solution has no significant investment costs (the only cost is the time invested for changing the positions) but brings significant savings to the plant's operations, this Improvement Opportunity would be accepted to be implemented.

5.1.2.3 Improvement Opportunity #3

Improvement Opportunity #3 consists in the reorganization of the layout of the Kitting 1 supermarket. Currently, the Kitting 1 operator, using a small cart to transport the kitting boxes, goes to the different shelves and collects the needed components for two different cockpit orders at the same time. For a better understanding of the operations, the current layout of the Kitting 1 supermarket can be seen in Figure 14. The operator starts in the bottom position (Position 0), then he visits the different shelves (Positions 1, 2, 3 and 4) in a clockwise sequence and returns to the bottom position (Position 0) with the kitting boxes complete for both orders.

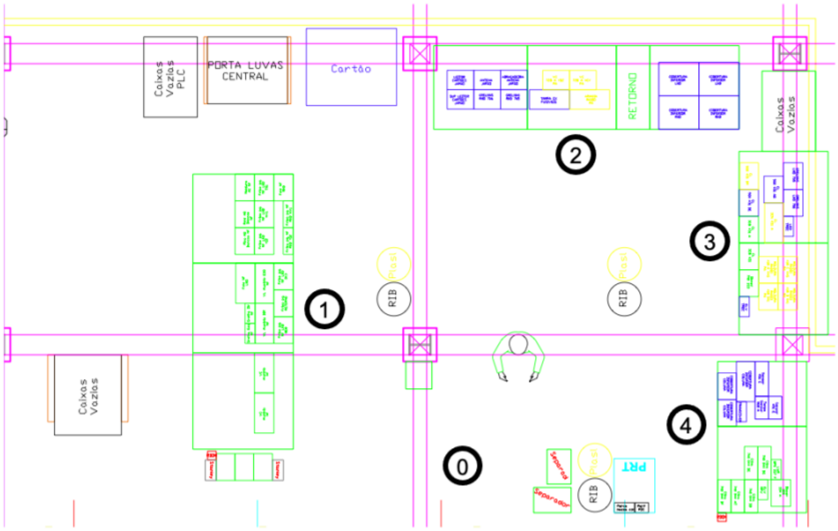


Figure 14: Current Layout of the Kitting 1 supermarket.

By observing the operator of this workstation, it was possible to recognize that he spent a significant amount of time moving between the different shelves. Considering that motion is a NVA activity, and one of the 7 *muda* identified by Ohno (1988), it became clear that an opportunity for improvement would be to eliminate this waste activity, or at least minimize it.

That said, studies were made to the layout of this supermarket, resulting in the solution presented in Figure 15. By using this layout, and due to the reduced travelled distance, the operator would be able to sequence the components for each cockpit order individually and would no longer use the small cart. Instead of using the small cart, he would sequence the kitting boxes and place them in a sequencing mat (Position X), waiting for being introduced in the cockpit trolley. This would allow to have the components of the T-ROC (high runner with more than 90% of the orders) available together in the most desirable positions (Area 1), while the MPV car models' components being available together but in less desirable positions (Area 2). This way, in more than 90% of the cycles the operator would only work in Area 1, reducing its working time, and only when sequencing parts for the MPV car models he would have to visit Area 2, minimizing its motion.

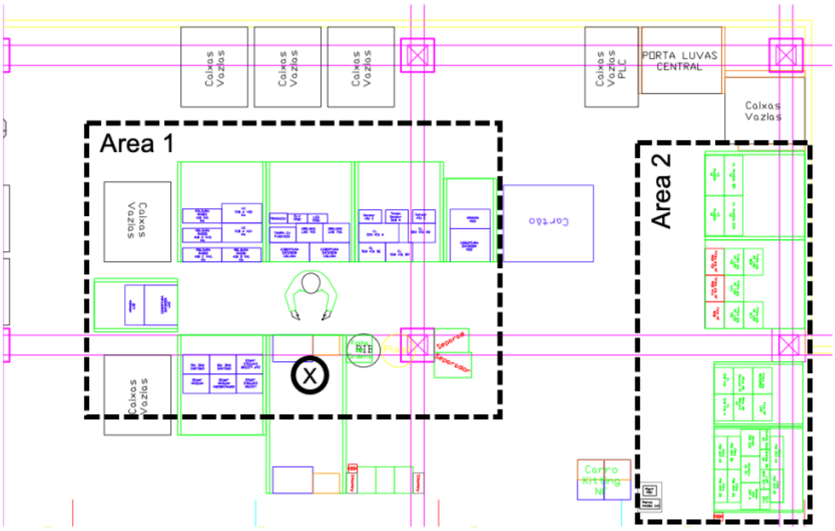


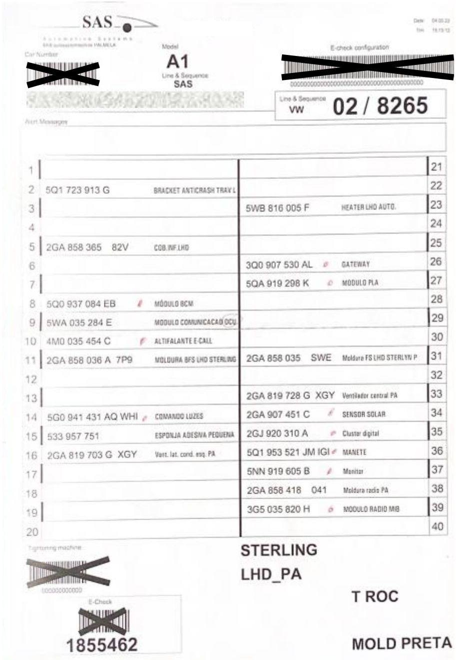
Figure 15: Future Layout of the Kitting 1 supermarket.

Since the implementation did not occur during the internship period, it was not possible to physically observe the impact of this improvement. However, to estimate what the impact of the layout change was, the Methods-Time Measurement (MTM) was used individually for the T-ROC and MPV models. With this method, it was possible to estimate a reduction of 19,6 seconds per cockpit for the T-ROC and an increase of 3,6 seconds per cockpit for the MPV. By using the ponderation of cockpits models produced, it was concluded that on average there is a reduction of 18 seconds per cycle.

Currently the plant produces 905 cockpits per day and by multiplying this number to the 18 seconds saved per cockpit, it was possible to conclude that this improvement results in a saving of 275 minutes per day. Given that for each day, there are two shifts of 7,48 hours each and one shift of 6,48 hours, this reduction corresponds to 21,40% of operator time. As the only investment for the Improvement Opportunity #3 was the time to physically change the layout, and given that it brings significant savings to the plant's operations, this Improvement Opportunity would be accepted to be implemented.

5.1.2.4 Improvement Opportunity #4

Improvement Opportunity #4 consists in the digitization of the T-100 sheet. Each T-100 sheet (example in Figure 16) corresponds to an order for a single cockpit. On this sheet there is information such as the KENN of the car (blurred rectangle due to confidentiality reasons), which components have been ordered by the end customer and are to be assembled in that cockpit, and a barcode to enable a computer record of which components have been assembled in each car (crossed barcode on the top left corner due to confidentiality reasons). That said, it is possible to conclude that this is an essential document for production operations to take place.


SAS
Automotive Systems
Car Number
Model
A1
Line & Sequence
SAS
E-check configuration
Line & Sequence VW 02 / 8265
Alert Messages

1						21
2	5Q1 723 913 G	BRACKET ANTICRASH TRAV L				22
3				5WB 816 005 F	HEATER LHD AUTO.	23
4						24
5	2GA 858 365 82V	COB.INF.LHD				25
6				3Q0 907 530 AL	GATEWAY	26
7				5QA 919 298 K	MODULO PLA	27
8	5Q0 937 084 EB	MÓDULO BCM				28
9	5WA 035 284 E	MODULO COMUNICACAO OCU				29
10	4M0 035 454 C	ALTIFALANTE E-CALL				30
11	2GA 858 036 A 7P9	MOLDURA BFS LHD STERLING		2GA 858 035 SWE	Moldura FS LHD STERLYN P	31
12						32
13				2GA 819 728 G XGY	Ventilador central PA	33
14	5G0 941 431 AQ WHI	COMANDO LUZES		2GA 907 451 C	SENSOR SOLAR	34
15	533 957 751	ESPONJA ADESIVA PEQUENA		2GJ 920 310 A	Cluster digital	35
16	2GA 819 703 G XGY	Vent. lat. cond. esq. PA		5Q1 953 521 JM IGI	MANETE	36
17				5NN 919 605 B	Monitor	37
18				2GA 858 418 041	Moldura radio PA	38
19				3G5 035 820 H	MODULO RADIO MIB	39
20						40

Tightening machine
STERLING
LHD_PA
T ROC
E-Check
1855462
MOLD PRETA

Figure 16: Example of T-100 sheet document.

Currently, whenever a customer order arrives, a T-100 sheet is printed on the printer #21. Before the production of that order begins, the corresponding T-100 sheet is manually inserted into its holder on the trolley, to ensure that the information regarding that cockpit always follows along with it. After the cockpit assembly is complete, this paper document is no longer needed and is deposited in a paper garbage can.

Given that 905 cockpits are produced per day and therefore 905 T-100 sheets are printed, it was concluded that one opportunity for improvement would be to digitize this document, avoiding this way the consumption of approximately 1,4 tons of paper per year. For the digitalization to be possible, the proposed solution was to invest in e-ink tablets to display the T-100 information. With this system, the e-inks would be statically attached to the trolleys, and in the beginning of the assembly line, by using an RFID (Radio Frequency Identification) system, the e-ink would automatically update and receive the new information regarding that trolley's cockpit order. Thus, the operators would no longer need to handle the paper sheet, a NVA activity, saving time which could be allocated to other VA activities.

This Improvement Opportunity requires an investment in the e-inks and their trolley supports, in an information management system and in an RFID system. These investments were estimated to cost approximately 10.500 €, with an additional cost of 100 €/year in batteries. On the other hand, it allowed for cutting the costs of the paper itself as well as the costs of the printing process which account for 3.016,80 €/year. Additionally, as the operator no longer needed to handle the paper document, it would allow for a reduction of 7,2 seconds per cycle (MTM estimation), which results in a reduction of 109 minutes per day of operator time, or equivalently 8,49% of operator time. Taking the investment and the savings generated into account, the payback period was calculated and as its result was less than 2 years, Improvement Opportunity #4 would get the approval to be implemented.

5.1.2.5 Improvement Opportunity #5

Improvement Opportunity #5 consists in the elimination of the IP Stock, before the sequencing operation of this component. To better understand the whole process, in Figure 17 there is a representation of the layout of the IP stock area and POF to the assembly line.

Currently, the IPs are transported in racks (metal containers which transport 6 IPs) and delivered from the supplier to SAS directly through an AGV. When the AGV, transporting one rack arrives, it waits in the AGV Reception Area ([RA], represented by Point Y) for the logistics operator to transport the rack using a forklift from the top of the AGV to the IP stock area (Stock IP). Then, the logistics operator takes an empty rack and places it on top of the AGV, which then follows back to the supplier. This concludes the explanation of how the logistics operator feeds the IP stock area with IPs, but he has other responsibilities such as sequencing the IP for each order. When sequencing an order, he goes to the Stock IP area, takes the demanded IP, and places it in the IP carrousel in Point X. This carrousel allows the logistics operator to sequence a set of IP orders, and then to have a periodic task of managing the racks in the Stock IP area. At Point Z is where the IPs are retrieved from the carrousel by the Pre-IP workstation's operator, he assembles the Airbag to the IP and with the help of the IP workstation's operator transport the IP to the corresponding trolley.

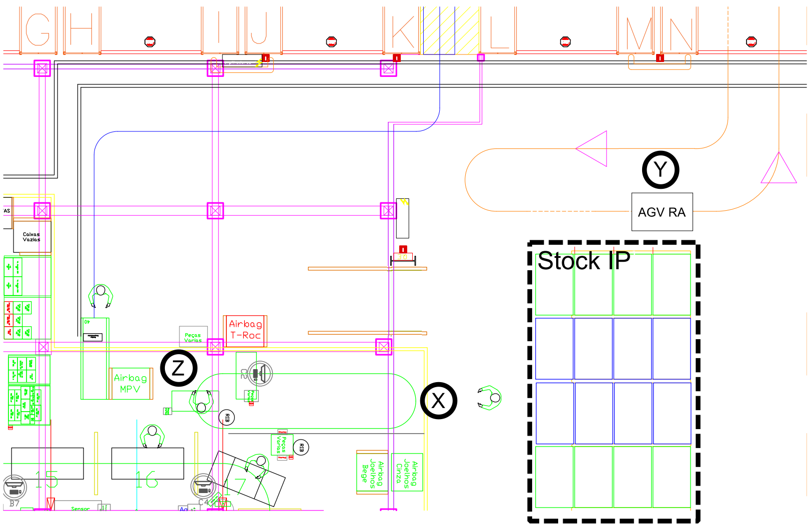


Figure 17: Current Layout of the IP Stock and POF to the assembly line.

When observing all these operations, it is concluded that the management of the stock is a NVA activity and besides that, that it occupies almost the entire time of the logistics operator. Thus, this activity should be eliminated, or at least minimized.

That said, this whole process and layout were studied, and resulted in a proposed solution which can be seen in Figure 18. Note that this solution could only be implemented after the end of production of the MPV models, when there would only exist two distinct IPs, the LHD and the RHD for the T-ROC car model. In this solution, instead of all AGVs going to the same RA, they go to one of two RA, depending on what type of IPs they are transporting in the rack; if the rack corresponds to the LHD IP, then the AGV goes to the Point L; if the rack corresponds to the RHD IP, then the AGV goes to the Point

R. With this layout, there is no longer the need for a logistics operator. Instead, the Pre-IP operator, who is on top of a platform due to ergonomic reasons, retrieves the needed IP directly from the rack which is still on top of the AGV. After this, the operator places the IP on top of a conveyor belt and assembles and tightens the Airbag to the IP, ending its operations. On the other side of the conveyor belt, the IP workstation's operator with the help of the Mass workstation's operator transport the IP to the corresponding trolley.

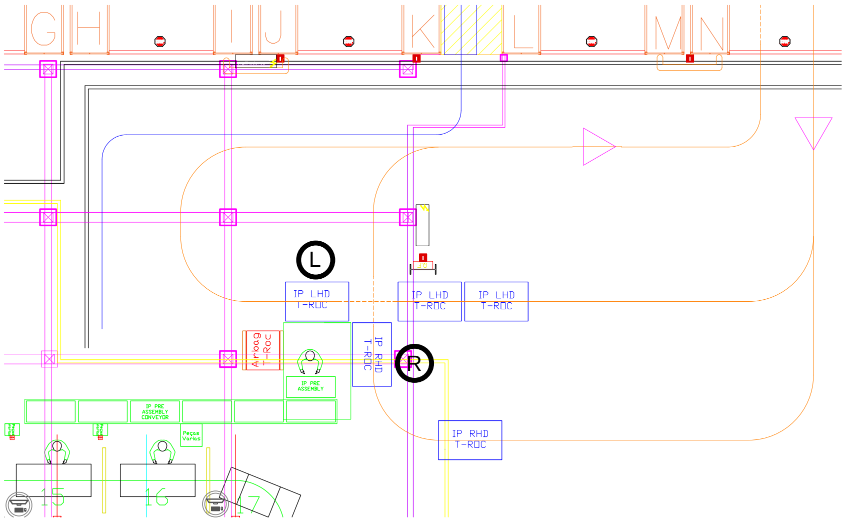


Figure 18: Future Layout of the IP stock and POF to the assembly line.

The investment for Improvement Opportunity #5 is composed of the acquisition of a conveyor belt for the IPs, of a platform for the Pre-IP operator and of two additional AGVs to assure that there is always a rack available for the operator to pick IPs from. The cost of these acquisitions was estimated as 68.000 €. One other additional cost is the time that the Mass workstation's operator will have occupied, due to the additional work of having to transport the IP from the conveyor belt to the trolley, this represents approximately 11 seconds per cycle (MTM estimation) which correspond to 12,90% of operator time. The time that the Pre-IP operator would have saved from not transporting the IP would now be used in the task of retrieving the IP from the rack and placing it on the conveyor belt and therefore would have no monetary impact. On the other hand, this improvement opportunity would lead to a reduction of one operator (100% of operator time), the logistics operator that was in charge of moving the IP racks. Having all this into account, the payback period of the Improvement Opportunity #5 was calculated and as it was less than 2 years, this improvement opportunity would be approved to be implemented, once the production of the MPV car models end.

5.1.2.6 Improvement Opportunity #6

Improvement Opportunity #6 arises to counteract the root cause of the largest number of assembly line stoppages that currently occur, *i.e.*, the delay in receiving orders from the customer. On the customer's assembly line, the POF of cockpits occurs in one of the first workstations. This means that there is little time from when a particular car starts to be produced by the customer until the respective cockpit is inserted into the line. Thus, for the SAS plant, the number of customer orders waiting to start being produced is always low and can even reach 0 if the customer is late in sending information regarding the production sequence. When this happens, it means that there is no information for the production at SAS's assembly line and therefore the production line stops. One other problem associated with when the line stops due to lack of customer orders is that in order for the AGV #4, the one which transports the wiring harnesses, to start moving towards the assembly line, it must be full with 4 wiring harnesses. So, when the line restarts, as the sequencing operation could not be done in advance, due to the customer delay of information, the AGV may cause the line to stop again due to delays in sequencing those 4 wiring harnesses. The main reason for this to happen is that the wiring harnesses are the first sequenced components that are be introduced in the assembly line, giving little response time to the sequencing activity.

The SAS assembly line carousel has capacity for 35 trolleys (or equivalently, cockpits) at any one time, however, since there are only 28 workstations on the carousel this means that in each cycle there are 7 trolleys along the carousel that are not being worked on. Currently, the first workstation that effectively starts to assemble the cockpit is the CAB A workstation, in the first physical position (Position 1) of the assembly line carousel, as it can be seen if Figure 19. The next physical position (Position 2) is the CAB B workstation, then in Position 3 is the Brake Pedal workstation (but only if it is an MPV cockpit, if it is a T-ROC cockpit then there are no assembly tasks in this workstation), in Position 4 is the Kitting 2 workstation. In the Position 5 there is an empty position, with a trolley that is not being worked on, and in the following position is the Heater workstation.

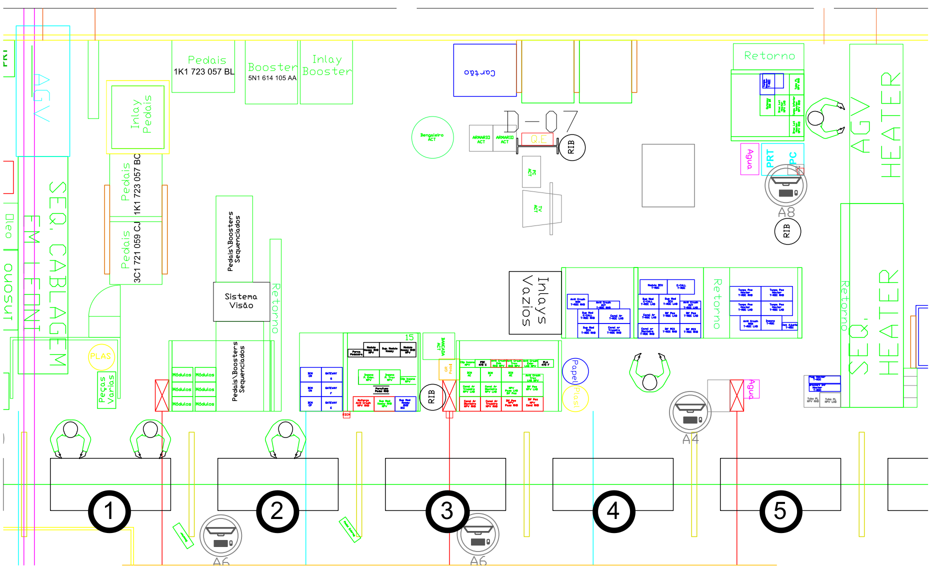


Figure 19: Current Layout of the carousel's first physical positions.

The Improvement Opportunity that was identified for the delay of information problem, was to advance the first workstation in the carousel. Note that this solution could only be implemented after the end of production of the MPV models, when the Brake Pedal workstation would be extinct as it does not perform any assembly operation for the T-ROC model, and the changeover currently performed by this workstation of the fixture supports would no longer be required. In this solution, instead of the first workstation to be in the Position 1, it would be in the Position 3, as it can be seen in Figure 20. This way the lack of customer orders would not stop the line once the trolley gets to Position 1, but instead only when it gets to Position 3, which corresponds to a delay of 2 cycle times, in which the customer meanwhile could send the information and therefore the assembly line would not stop at all. Besides this advance in the carousel, the first workstation in the line would be the Kitting 2 workstation instead of CAB A, this way, when the line stops due to delay of customer information, the wiring harness AGV would have one more cycle time of margin to sequence and deliver the wiring harnesses. By using this layout, Position 1 and 2 would have empty trolleys, with no assembly tasks, in Position 3 there would be the Kitting 2 workstation, where the kitting boxes would be sequenced for the next workstations, in Position 4 there would be the CAB A workstation were the AGV would deliver the sequenced wiring harness, in Position 5 there would be the CAB B workstation and in the following position it would still be the Heater workstation.

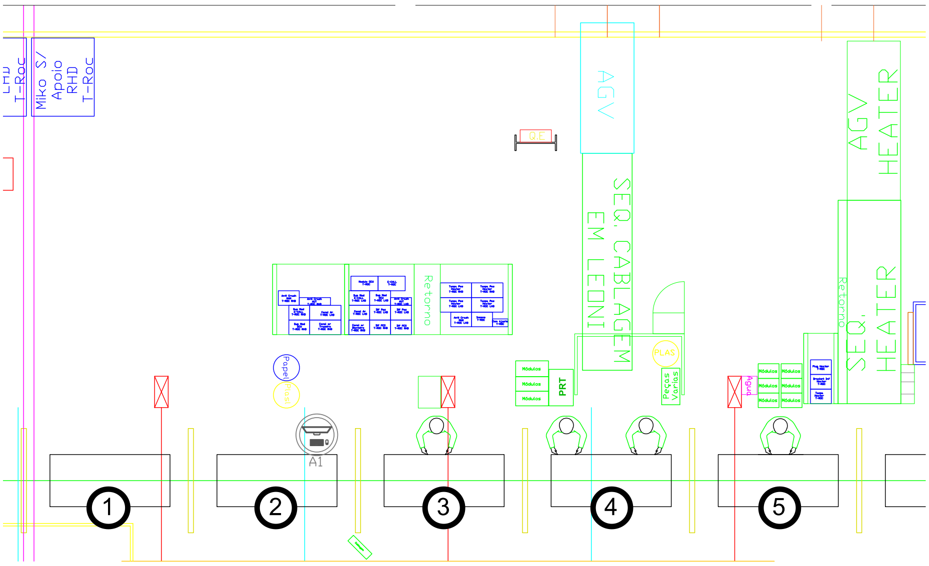


Figure 20: Future Layout of the carousel's first physical positions.

In six months, SAS's assembly line stopped 672 times due to delays of customer information, which accounted for 4420 minutes of no work in total. By analyzing the data base of line stops, and by cutting 2 cycle times (164 seconds) each the time the line stopped more than 164 seconds and by completely eliminating the stops that were shorter than 164 seconds, this would lead to a reduction of 224 line stops and to a reduction of 1888 minutes of the total time the line stopped. In a year this means that there would be approximately more 3776 minutes of production time per year for each operator on the assembly line, which corresponds to 0,92% of additional operator time per operator. By having into account that there are 27 operators on the assembly line, this means that there is an additional 24,84% of operator time in total.

Currently, the operator of the Kitting 2 workstation has a periodical task, when the AGV #3, which transports the heaters, arrives to the line, this operator must move the heaters from the top of the AGV to the heaters table, in order for them to be available to the Heater workstation. With this solution, and using the future layout, the Kitting 2 operator would be in Position 3, and therefore he would not be able to perform this task anymore. This way, the Improvement Opportunity #6 would require an investment in a *Karakuri* system to automatically move the sequenced heaters to the heaters table once the AGV arrives. This investment was estimated to have a cost of 40.000 €. As the Kitting 2 operator would have saved the time of performing this task, he would have saved approximately 1 second per cycle (MTM estimation) that could be allocated to other tasks, which corresponds to a saving of 1,17% of operator time.

By considering all the savings (26,02% of operator time) and the investment required, the payback period was calculated and as its result was less than 2 years, Improvement Opportunity #6 would be approved to be implemented once the production of the MPV models ends.

5.1.2.7 Improvement Opportunity #7

Improvement Opportunity #7 consists in the minimization of transport of materials. Currently, the MIKO 1 workstation is physically present in the MIKO Mezzanine, as it can be seen in Figure 21. Even though the operations that occur in this workstation are basic, *i.e.*, the assembly of the arm support to the MIKO, the transport of components to this workstation is time intensive due to two factors: the big dimension of the components means that there are few units per container and therefore that these have to be transported with high frequency; and the long time it takes to transport this containers, as they have to be transported up from the ground floor to the Mezzanine with a forklift (clocked time of 1 minute per transportation) and then transported in the mezzanine with a hand pallet truck (clocked time of 1,5 minute per transportation). Also, other factor to have in mind is that the Central Console part that is produced in this workstation (Part A) is assembled independently from the other MIKO workstations, as the finished products are stored in the rack that is always on the elevator (red rectangle), which means that, with the current configuration, this elevator must be always available for this workstation.

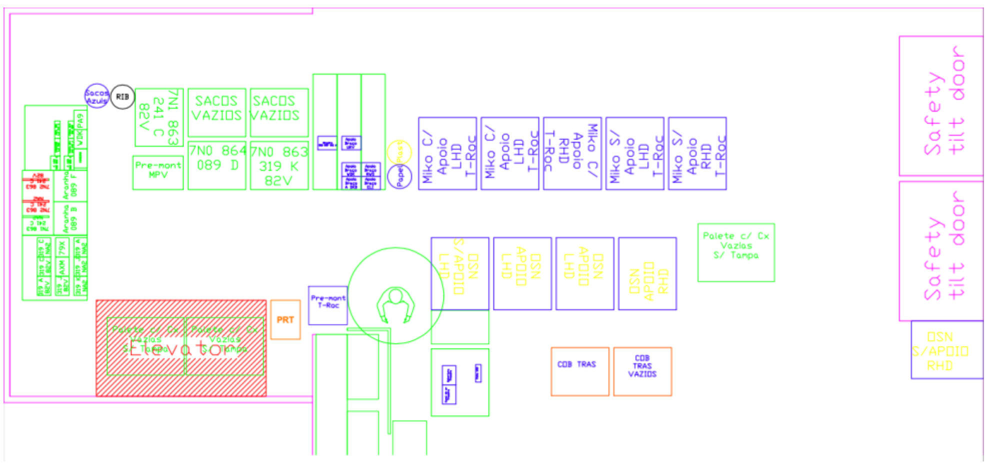


Figure 21: Current Layout of the MIKO 1 workstation.

Currently, on the ground floor there is an area that is being used for the Brake Pedal workstation operations, which only occur when the cockpit being produced is a MPV model cockpit, as it can be seen in Figure 22. Once the production of the MPV models end, this area will be empty. Thus, the idea of this Improvement Opportunity is to occupy this area for the MIKO 1 workstation, when producing for the VW Autoeuropa customer. Note that for the Osnabrück customer this would not be possible, since the three parts of the central console are shipped in the same box.

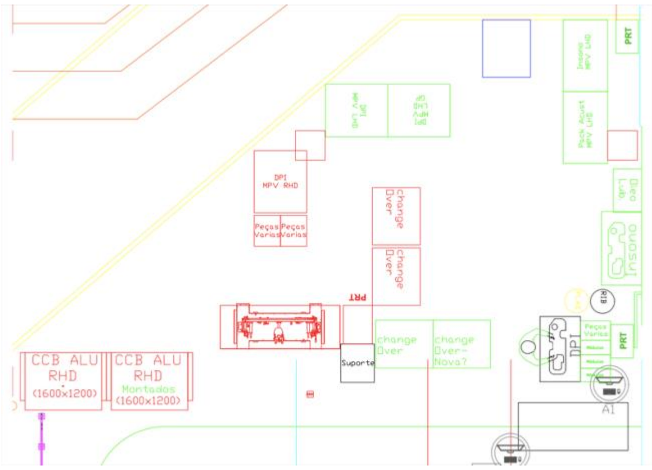


Figure 22: Current Layout of the Brake Pedal workstation.

So, the solution for this is for the MIKO 1 workstation to physically work on the ground floor when it is producing for the Autoeuropa customer (approximately 95% of the day) and to physically work on the MIKO Mezzanine only when it is producing for the Osnabrück customer (approximately 5% of the day). The future layout for the ground floor MIKO 1 workstation can be seen in Figure 23, and the future layout for the mezzanine MIKO 1 workstation in Figure 24.

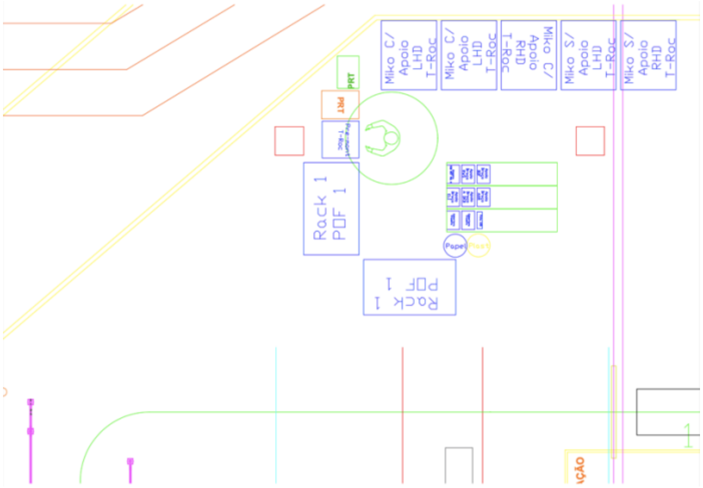


Figure 23: Future Layout of the ground floor MIKO 1 workstation.

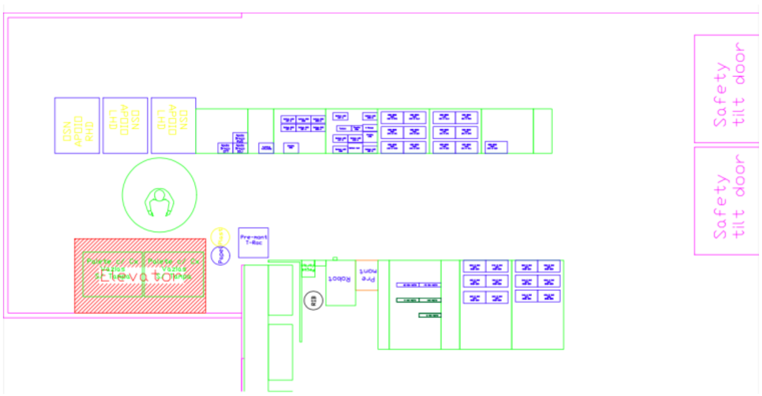


Figure 24: Future Layout of the mezzanine MIKO 1 workstation.

By having into account the movements frequency for the arm rest and MIKO components and the clocked time it takes to lift a pallet to the mezzanine, and to transport the pallet in the mezzanine, it was possible to estimate that if this solution would be implemented, it meant that the logistics operator that lifts the pallets up to the mezzanine would save 110 minutes per day (8,60% of operator time), and the logistics operator that moves the materials in the mezzanine would save 166 minutes per day (12,91% of operator time). Both of these saved times accumulate to a total of 21,51% of operator time.

Besides moving the physical stock near the line, which has no significant costs, the only investment required for the implementation of the Improvement Opportunity #7 is a Clever station, which is the information system that assists the operator in its production activities. This would cost approximately 6.000 €. By considering this cost and the total savings of this solution (21,51% of operator time), the payback period was calculated and as it was less than 2 years, Improvement Opportunity #7 would be approved to be implemented, once the production of the MPV models ends.

5.1.2.8 Improvement Opportunity #8

Currently in SAS's factory, the only WIP stock in existence is related to MIKO covers. At the Blend MIKO workstation in the Welding Mezzanine, 8 spring clips and 4 nuts are assembled on the blend and then the frame is welded to the blend, creating the MIKO cover. This station is the only one that works in Batch, completing a full pallet of covers of the same SKU and then moving on to the next SKU. Thus, when a pallet of these covers is finished, the pallet leaves this workstation and is stored in the warehouse. When the supermarket at MIKO station 3 needs to be replenished with one of these covers then a pallet is taken from the warehouse and the supermarket is replenished. To complete all these movements, first a logistics operator must transport the pallet with a hand pallet truck from the workstation to the door of the Welding Mezzanine, then another logistics operator must lower the pallet from the mezzanine and store it in the warehouse, then when needed another logistics operator has to pick up the pallet from the warehouse and lift it to the MIKO Mezzanine, when it arrives at this mezzanine a fourth logistics operator has to transport the pallet from the mezzanine door to the supermarket using a hand pallet truck.

This way, the Improvement Opportunity #8 arises to counteract this complex material flow, with the possibility of installing an automatic transport system that would allow for this movement of material to be easier and cheaper. The idea that was thought of was to install a gravity ramp with an individual lane for each of the three most requested references (high-runners) which would directly link both mezzanines. This way, instead of the stock travelling from the Welding Mezzanine to the warehouse (clocked time of 180 seconds per transportation), and then from the warehouse to the MIKO Mezzanine (clocked time of 200 seconds per transportation), these references would always have their stock at the gravity ramp. Note that, one other possibility would be to have this workstation to work piece by piece and eliminate the stock completely, but this is not possible as the customer demands for a safety stock of at least 5 days, as this component is a result of a welding process.

By having into account the movements frequency for this component and the clocked time it takes to lower a pallet from the Welding Mezzanine and to store it, and to take a pallet from the warehouse and to lift it to the MIKO mezzanine, it was possible to estimate that if this solution would be implemented, it meant that the logistics operator that lifts the pallets up to the mezzanine would save approximately 11 minutes per day (0,84% of operator time), and the logistics operator that moves the materials in the mezzanine would save approximately 12 minutes per day (0,93% of operator time). The saved time for this is due to the fact that, when compared to per example the MIKO components mentioned in the previous improvement opportunity, this cover has small dimensions, meaning that this transportation has a much lower frequency. Nonetheless, the times saved for both operators would be occupied with other required activities, and therefore there would be an associated saving of 1,77% of operator time.

However, when estimating the cost associated with implementing a gravity ramp between the two mezzanines, it was concluded that this solution has a cost of €40,000, which is too heavy when compared to the total savings associated with this solution (1,77% of operator time). Since the calculated payback period was greater than 2 years, Improvement Opportunity #8 would not be accepted.

A summary of the results of each improvement opportunity can be seen in Table 10. This table shows for each improvement opportunity the needed Investment, the Savings, and also if it was accepted to be implemented or not. Considering only the six Improvement Opportunities that were accepted, it can be concluded that, through a total investment of 124.500,00 €, it is possible to reduce the operational costs by 2.916,80 €/year and to reduce 190,27% of operator time. Although this does not mean that the factory can directly reduce two operators per shift, this means that a significant amount of time that is used for NVA activities (waste) can, with the implementation of these improvements, be allocated to other VA activities.

Table 10: Summary of the Improvement Opportunities results.

Improvement Opportunity	**Investment (€)**	**Savings** (% of operator time)	**Operational Costs Variation** (€/year)	**Accepted?**
~~**1**~~	---	~~Not Applicable~~	~~+13.283,97~~	No
2	---	25,75%	Not Applicable	Yes
3	---	21,40%	Not Applicable	Yes
4	10.500,00	8,49%	-2.916,80	Yes
5	68.000,00	87,10%	Not Applicable	Yes
6	40.000,00	26,02%	Not Applicable	Yes
7	6.000,00	21,51%	Not Applicable	Yes
~~**8**~~	~~40.000,00~~	~~1,77%~~	~~Not Applicable~~	No

5.1.3 Future State

After identifying all the improvement opportunities, the future MIFD was drawn and can be seen in Figure 25. This future state diagram aims to show how the flow of material and information within the factory would be, if the improvement opportunities were implemented, and to demonstrate the impact of these changes in the lead time of the component with higher lead time. It is important to highlight that regardless of the decision about the implementation of an improvement opportunity, all improvement opportunities must be included in the future MIFD (Faurecia, 2021b).

It should also be noted that after the current and future MIFD were mapped, there was an external audit of the plant by the Faurecia group, with the aim of evaluating specific points of the plant management, one of them being flow mapping. In this audit, the auditors sought to verify if the material and information flows were represented in detail, and mainly if the plant had a strategic vision for its future, by checking the opportunities for improvement. At the end of this audit, the plant's flow mapping was evaluated, and received the maximum score.

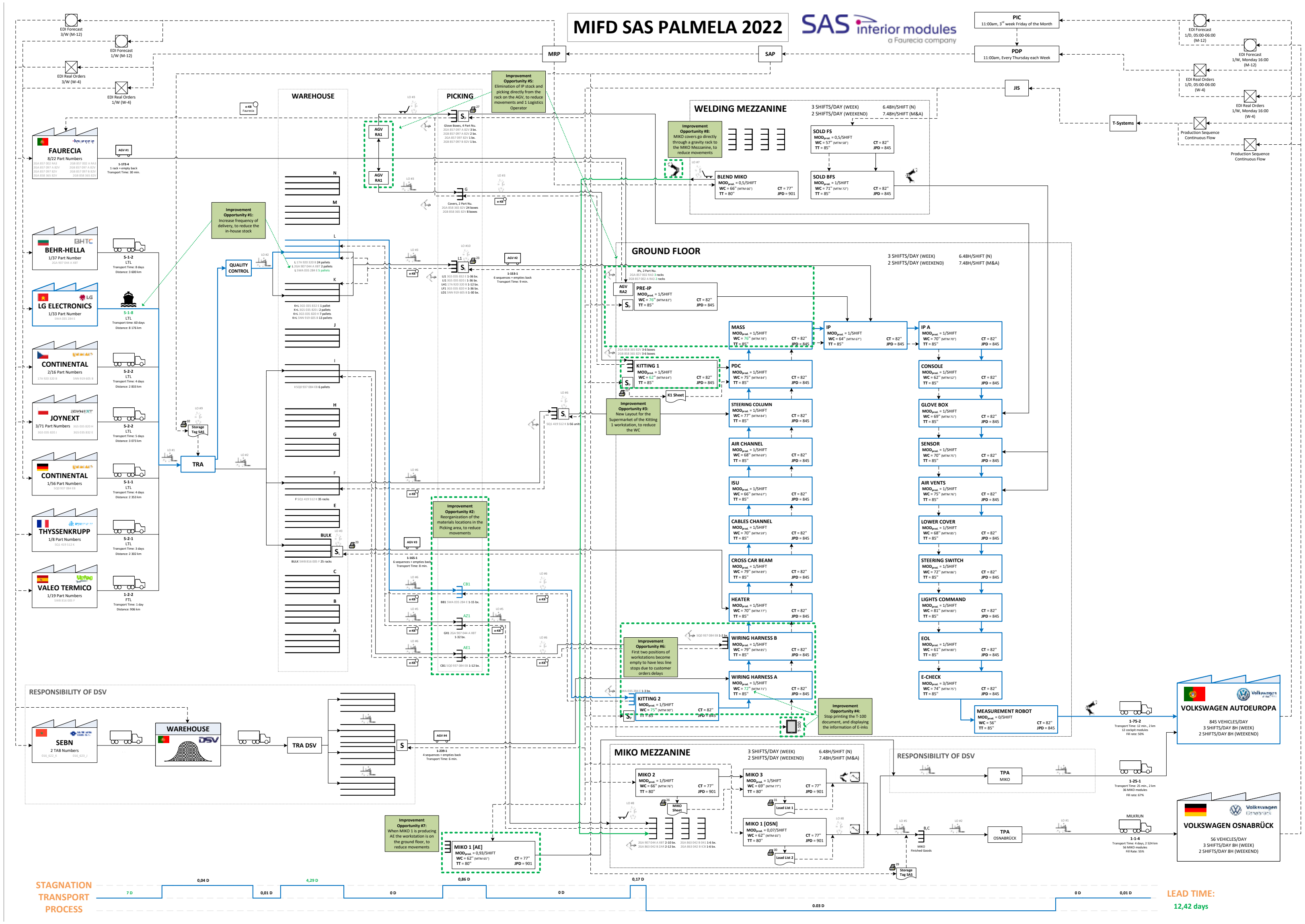


Figure 25: Future situation Material and Information Flow Diagram (Future MIFD).

5.2 Storage Location Assignment Problem

After modelling the SLAP mathematical model, it was computed using GAMS. For the sensitivity analysis of parameter n (number of allocations that should remain as the current situation) the model was computed for different values of n. First the model was computed using n=0, which corresponds to the Optimum Result because for this case it is possible to vary all allocations without any restriction. Next, n is increased by 10 units and the model is computed again. This process is repeated until n=224 was reached, which corresponds to the Current Scenario as no allocations can change. From this sensitivity analysis it was possible to plot the graph of the reduction in travelling distances (in picking operations) as a function of the number of allocations that cannot be changed (n), which can be seen in Figure 26.

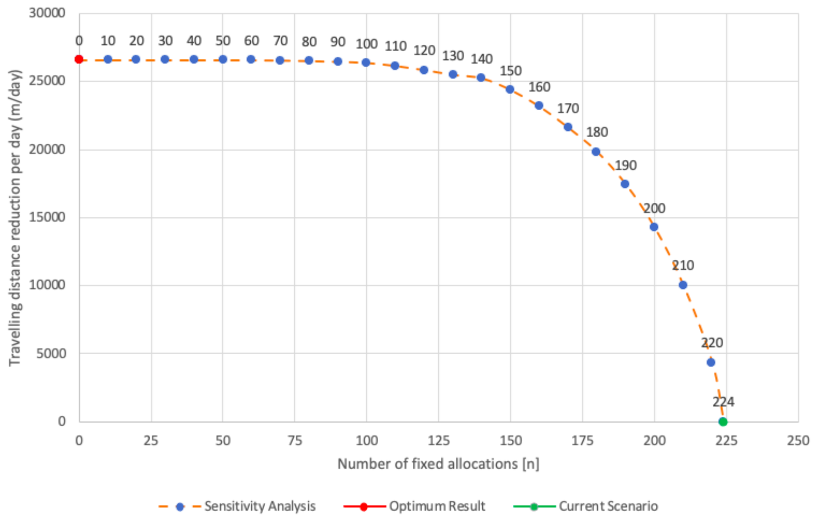


Figure 26: Sensitivity analysis of parameter n.

Since it is not known how many changes in the warehouse the decision maker (SAS Logistics Director) is willing to make, or how much distance reduction she wants to achieve, the author decided that his suggestion to the decision maker would be made based on efficiency (*i.e.*, how much distance can be reduced per allocation that can be changed). That said, to facilitate the interpretation of the results, the graph representing the total reduction of distance travelled during picking operations as a function of the number of allocations that can vary (the total number of allocations [224] minus the number of allocations that cannot vary [parameter n]) was plotted, which can be seen in Figure 27. The graph has been divided into three distinct ranges based on efficiency:

- **Range A**: Points whose efficiency (slope) is greater than or equal to 175 m/day per varying allocation – green rectangle in Figure 27;
- **Range B**: Points whose efficiency is less than 175 m/day per allocation to vary and greater than or equal to 25 m/day per varying allocation – yellow rectangle in Figure 27;
- **Range C**: Points whose efficiency is less than 25 m/day per varying allocation – red rectangle in Figure 27.

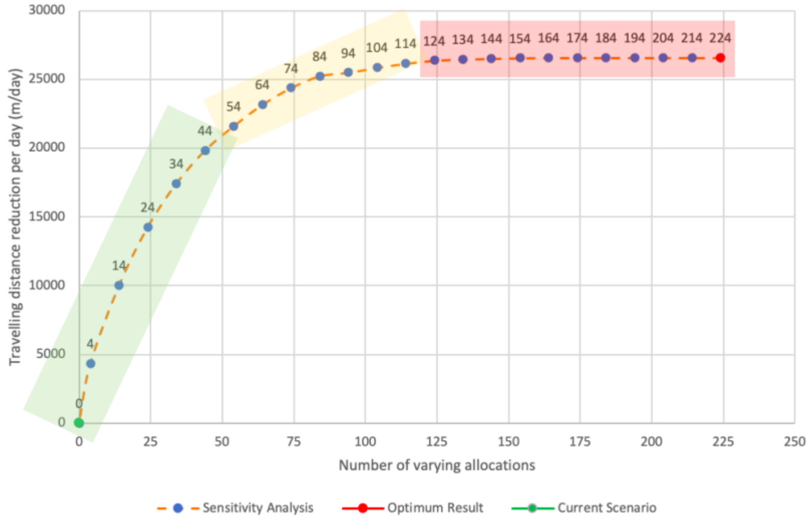


Figure 27: Total reduction of distance travelled during picking operations as a function of the number of allocations that can vary.

Thus, even if the decision maker's decision about how many allocations to vary, or how much distance reduction she wants to achieve, is not known, three suggestions can be made which are presented in decreasing order of efficiency (slope between two adjacent points):

1. Variate as many allocations as possible until the efficiency is less than 175 m/day per allocation to vary. This corresponds to varying 44 allocations (or alternatively n=180), resulting in a total distance reduction of 19,941 m/day;
2. Variate as many allocations as possible until the efficiency is less than 25 m/day per allocation to vary. This corresponds to varying 114 allocations (or alternatively n=110), resulting in a total distance reduction of 26,151 m/day;
3. Variate as many allocations as possible until the maximum reduction is reached. This corresponds to varying 174 allocations (or alternatively n=50), resulting in a total distance reduction of 26.569 m/day.

After showing the results to the decision maker, she opted for the second suggested solution, *i.e.*, varying 114 allocations to achieve a total distance reduction of 26.151 m/day. In this way, it would be possible to almost achieve the maximum distance reduction (26,151 m/day instead of 26,569 m/day [98%]), by changing only 114 of the 224 allocations (51% of all allocations).

6 – Conclusions and Future Work

SAS ranks among the world leaders in the cockpit and center console module assembly market. To maintain this prominent position, it is crucial to focus on the continuous improvement of its processes to ensure that the company continues to be involved in new projects from its customers. In this context, this master's thesis was developed focusing on the improvement of production and logistics processes of the SAS plant, located in Palmela.

The main objective established for the present thesis was to improve SAS's production and logistics processes, by improving its processes' efficiency through the elimination of waste activities. For this, a first identification of improvement opportunities was done, and then subsequent recommendations were made regarding actions to improve the processes.

The initial step was to observe the operations in the field, through *Gemba* walks and by interviewing the people involved in the various processes, with the aim of being able to characterize in detail the current situation of the plant's operations. This step of observation and characterization proved to be a complex and time-consuming process due to the high complexity of the plant's processes that rely on a high number of components. This can be justified by the fact that this factory's process consists of assembling products that are made up of a wide variety of components (more than 600 Part Numbers) throughout a high number of workstations (32 production workstations), contrarily to the cases found in the literature, which deal with physical and chemical transformation processes of materials with a few workstations. The mapping through the MIFD tool served its primary function in helping to visualize the overall project and identify opportunities for improvement. After the current MIFD was built, it was presented to the multidisciplinary team. After the validation of the diagram by the team, 8 opportunities for improvement were identified. In this meeting the responsibilities of each person and department for the study of each opportunity were also defined, being the author fully responsible for the study of Improvement Opportunity #2, the reduction of the distances travelled by the logistic operators during the picking activities. After the identification of the improvement opportunities, the future state MIFD was built, representing the impact of the improvement opportunities in the material and information flows.

For the detailed study of Improvement Opportunity #2, a SLAP mathematical model was created with the minimization of the distances traveled during picking activities as the objective function, and by using the allocation of materials through the picking positions as the decision variables. Additionally to this, a sensitivity analysis was made to the maximum number of picking material-position allocations that can vary (n), given the current configuration of the warehouse with the objective of achieving the best results (reduction of distances) at the expense of the least number of changes in the allocations. Finally, the results were presented to the decision maker (Logistics Director of SAS) who chose to achieve a reduction of 26,151 m/day (98% of the result achieved when varying all allocations), by varying only 114 of the 224 total allocations.

After studying each of the eight improvement opportunities identified individually, it was concluded that only six of them would be accepted for implementation. These six improvement opportunities consisted in:

- the reduction of the distances travelled by the logistics operators during picking activities, through a more efficient allocation of materials in the picking positions;
- the reduction of the movements of the Kitting 1 workstation operator through a more efficient layout;
- the digitization of the T-100 document, thus reducing not only the time operators spent handling the sheet but also reducing the waste associated with paper;
- the elimination of IPs stock by having operators sequence the components directly from the AGV racks, reducing the time spent handling these components;
- changing the configuration of stations on the assembly line, thus allowing fewer interruptions in the line, due to lack of customer orders, and thus gaining production uptime;
- the reduction of component movements between stock and one of the mezzanines, thus gaining more time for value-added activities.

However, taking into account that the factory works 24 hours a day and that the implementation of these improvements would have to occur during a time when production is not running, the implementation of the improvements would have to be done during the summer break, and therefore the author was not able to observe the results in the shop floor. Nevertheless, the impact of each improvement opportunity was estimated. Thus, it is possible to state that, after the implementation of the six selected improvement opportunities and through a total investment of 124.500 € it will be possible to reduce 190,27% of operator time in total that, until today, is used for NVA activities (waste). In this way, it can be stated these thesis' objective has been achieved. By cutting waste activities, the logistics and production processes become more efficient, and, with this, the company becomes more competitive and assures a better position to win future customer projects.

Following are some suggestions for future work to keep the focus on the continuous improvement of the plant:

- Due to the fact that the operator of the MIKO 3 workstation has to sequence a large number of components, it is suggested to study the possibility of implementing a pick-to-light system. With this system, a decrease in sequencing errors (picking of incorrect components) is expected and it is also estimated that the operator's sequencing capacity will increase, thus allowing the operator to sequence a larger number of components per time period.
- During the Gemba walks, it was possible to notice that the logistic operator responsible for the sequencing of the Radios, Clusters and *Manetes* spent a lot of time scanning the labels of the components and the sequencing boxes. This activity is classified as an NVA activity, however it is essential to ensure that there is no possibility of stopping the assembly line due to an error in the sequencing. With this in mind, it is suggested to study the possibility of automating the scanning of both the component labels and the sequencing boxes when it comes to the sequencing of the RCM.
- When observing the operations on the shop floor, it was noted that the logistics operator responsible for picking the components needed in the MIKO Mezzanine spends a large part of his time (approximately 1 minute per box of material) raising and lowering the components

between the shop floor and the mezzanine. It is therefore suggested that a study be conducted into the possibility of implementing an elevator. This way, the operator would not have to spend any time waiting for the components to move up and down the mezzanine and spend that time on VA activities.

- Regarding the mathematical model that aims to solve the SLAP problem, it is proposed as future work to quantify the connection between a picking position and a warehouse (or line-side presentation position) by the actual time it takes an operator to travel that route, instead of using the Manhattan Distance, that does not take into account the difference in speed while traveling in a straight line versus the speed while traveling around a curve. In addition to this, it is also suggested to study the possibility that instead of using a discrete factor (r_m) that defines whether or not a component can be stored in the second level of a rack, to consider the weight of the boxes of each component when making the allocations, considering the ergonomics and safety of the logistics operator.

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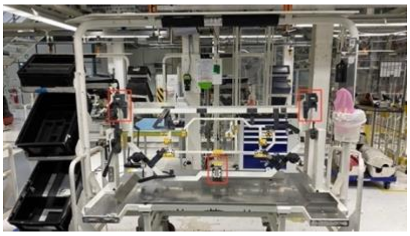
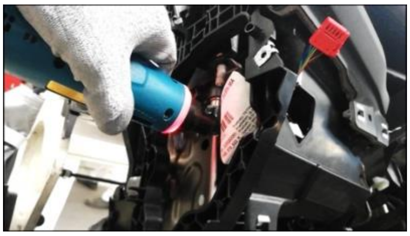
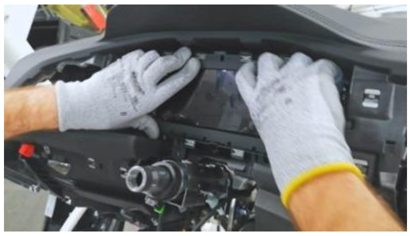
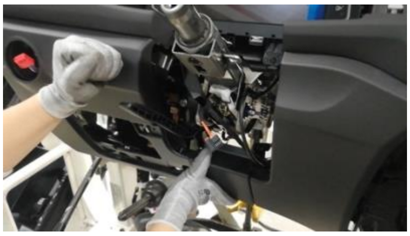
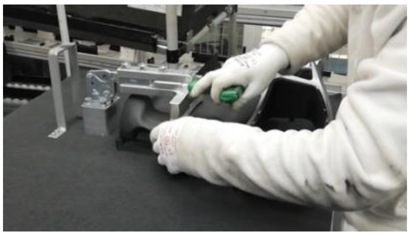
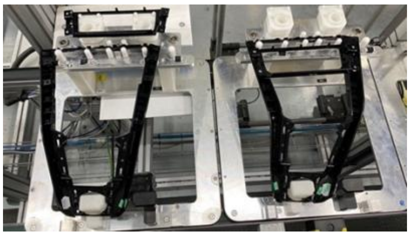
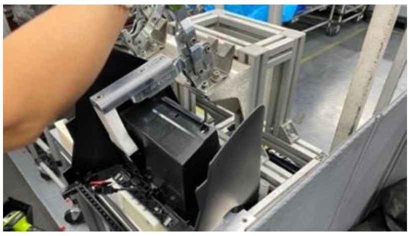
Appendix

Annex 1 – Examples and explanations regarding the 32 workstations.

Brake Pedal: Trolley with Fixture. The three fixture supports are highlighted by red rectangles.		**Wiring Harness A**: Operator of workstations Wiring Harness A and B positioning the wiring harness on the fixture.	
Wiring Harness B: Assembly of the gateway module on the wiring harness' ISU.		**Kitting 2**: Full kitting boxes sequenced in the Kitting 2 workstation, already introduced in the trolley.	
Heater: Positioning of the CCB on the fixture.		**CCB**: Tightening of the wiring harness' ISU to the fixture.	
Cables Channels: Connecting the KESSY plug to the KESSY module.		**ISU**: Tightening of the anti-crash bracket to the CCB.	
Air Channels: Assembly of the front air channel to the heater.		**Steering Column**: Assembly of the steering column to the CCB.	
Kitting 1: Full kitting boxes, sequenced in the Kitting 1 workstation, waiting for being introduced in the assembly line.		**PDC**: Assembly of the driver feet air channel to the heater.	
Mass: Parking of loose wirings for the following IP assembly.		**Pre-IP**: Tightening of the airbag to the IP.	

IP: Tightening of the IP to the CCB.		**IP A**: Assembly of the cluster to the IP.	
Console: Assembly of the driver lower cover to the IP.		**Glove Box**: Tightening of the glove box to the IP.	
Sold FS: Assembly of the top column cover to the FS cover.		**Sold BFS**: Pre-assembly table with both FS and BFS covers being checked by a color sensor.	
Solar Sensor: Assembly of the FS cover to the IP.		**Air Vents**: Assembly of the display support to the IP.	
Lower Cover: Display assembly to the display support.		**Steering Switches**: Assembly of the driver lower cover to the steering switches.	
Lights Command: Assembly of the right air vent grill to the IP.		**EOL**: Operator testing if the air vents are working properly.	
E-Check: Tester positioned on the cockpit waiting for the connections to be done, for starting the electric test.		**Measurements**: Robot measuring different points of the finished cockpit.	

Blend MIKO: Conveyor belt with two jigs. The left jig carries unprocessed parts, and the right jig carries the assembled part.		**MIKO 1**: Tightening of the arm rest to the central MIKO support.	
MIKO 2: Assembly of the USB plug in the MIKO lower cover.		**MIKO 3**: Assembly of the climate module in the MIKO cover support.