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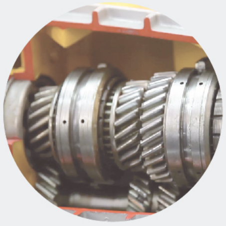
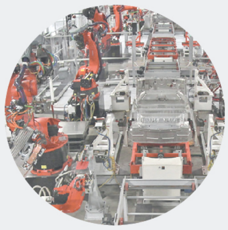

Design and implementation of a supplier kanban system

RAQUEL BEATRIZ GONÇALVES RALHA TRINDADE LYRA
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POLITÉCNICO
DO PORTO

DESIGN AND IMPLEMENTATION OF A SUPPLIER KANBAN SYSTEM IN THE AUTOMOTIVE SECTOR

Raquel Beatriz Gonçalves Ralha Trindade Lyra

2021

Instituto Superior de Engenharia do Porto

Mechanical Engineering Department

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P.PORTO

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Dissertation presented to the Instituto Superior de Engenharia do Porto to fulfill the requirements necessary to obtain a Master's degree in Industrial Engineering and Management, carried out under the guidance of Dr. Eng. Maria Teresa Ribeiro Pereira co-supervision of the Dr. Eng. Marisa João Guerra Pereira De Oliveira.

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Abstract

This project was developed with the company Gestamp Palau S.A. The purpose of the project was to design a non-electronic consignation supplier Kanban System in a high variability context. This project resulted from the company's request to change its current child parts supply system from a logic needs planning push system to a Kanban consignment system.

To achieve this, we conducted four Action Research cycles. Three of these culminated in the development of a Kanban solution. All the solutions developed used the Kanban formula proposed by Toyota. However, each solution used a different tactic to determine safety stock and/or demand. Of the three solutions developed, the last one was considered to be the best for the specific conditions of this case. In this final solution the number of kanbans was defined considering that the demand in the Kanban formula was equal to the machine's maximum consumption - an oversized system. To make it possible to store the number of kanbans in the area available it was necessary to establish a supplier frequency of two days. Considering that the Kanban was oversized stockouts are expected to be avoided. Additionally, the fact that the supply of the child part components will no longer use carton boxes allowed to: 1) attain the company's objective of reducing plastic and carton in the plant; 2) eliminate the operator's supermarket task of transferring some references to KLTs; and 3) standardize the packages in the supermarket (small components in KLTs).

KEY-WORDS

Supply Chain, Just-In-Time, Supplier Kanban, Consignment

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LIST OF ACRONYMS

ISEP	Instituto Superior de Engenharia do Porto
P.Porto	Instituto Politécnico do Porto
ERP	Enterprise Resource Planning
SC	Supply Chain
OEM	Original Equipment Manufacturers
AR	Action Research
SNP	Standard Number of Parts
OEE	Overall Equipment Efficiency

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1. INTRODUCTION

The present thesis was the culmination point of the master's degree in Industrial Engineering and Management of Instituto Superior de Engenharia do Porto. It is the result of a project developed from April to September 2021 in Gestamp Palau, Barcelona.

This first chapter is initiated with the exposition of the project's context and importance followed by the presentation and discussion of the research question and problem. Then the methodology options adopted in the course of this work are exposed, as well as the company where the project was developed. Finally, this chapter ends with the presentation of the structure of this thesis.

1.1. Framework and Relevance

The automotive sector in the European Union is responsible for the employment of 13.8 million people (equivalent to 6,1% of the total EU employment) and its turnover represents 7% of EU GDP (Gross Domestic Product) (European Comission, 2020). Inside Europe, Spain is the 2th biggest automaker in Europe only preceded by Germany and in the world rank occupies the 8th position (Statista Research Department, 2021). This sector throughout the years has proven to be very important for the Spanish economy; in 2020, it represented 8% of the country's GDP and employed 9% of the country's total active population. The automotive sector is also a big contributor to the country's exportations, in the case of last year, its exportations represented 12,1% of the total bulk (ANFAC, 2020). In terms of the country's production and export figures, the sanitary crisis led to their reduction in 2020 (19.6 and 15.5%, respectively), since, on one side, the manufacturers, workshops, and component suppliers stopped production and, on the other, the borders were closed. However, even if 2020 was an atypical year, the country maintained its exporter character, having exported 86% of total production. The main clients were the European markets having received 92,7% of the total of shipments. A strategic pillar of this industry in Spain has been the spare parts industry, which is highly competitive and internationally renowned contributing to more than 75% of the value of the vehicle (Montoriol-Garriga & Díaz, 2021). It is also a sector with a high exportation character, in fact in 2020, 60% (17.9 million of euros) of the turnover was due to exportations (Sernauto, 2020).

Inside Spain, the region of Catalonia is country's largest automotive industry, considering one out of five vehicles produced in the country come from this region (Generalitat de Catalunya, n.d.). This sector, in 2018, represented 10,16% of the total GDP value, only surpassed by the food industry. In the same year, Catalonia's automotive sector contributed to 23,2% of Spanish exportations according to ACCIÓ Strategy and Competitive Intelligence Unit (2019). Regionally, 75,1% of the exportations were of vehicles and the 25,7% of components and other vehicle parts.

As mentioned, in 2020, the automotive industry went through an unprecedent and almost complete halt in production that, for example, caused sales in Europe to plunge 80% by April (Hensley et al., 2021). But even before that, the industry was facing several trends, such as environmental regulations, driverless vehicles, or ridesharing, that threaten to slow growth and reduce profit margins. The combination of all these circumstances further intensified the industry's atmosphere of competitiveness (Waas et al., 2021), which consequently led the automotive business mesh to rethink their supply chain dynamics. It became imperative to increase supply chain connectivity, flexibility, visibility, and collaboration (Accenture, 2020; Steins et al., 2021). This paradigm has been linked not only but also with the application of Lean philosophy and techniques to the management of the SC (Moyano-fuentes & Sacristán-díaz, 2012).

The project developed emerged in the context of the Lean transformation that the industry where Gestamp operates has been going through. In case of the automotive sector, the OEMs (Original Equipment Manufacturers) are pressuring even more Tier 1 providers to supply value-added components at the precise moment they are needed (Rhenus Logistics, n.d.). The increase of responsibility Tier 1 suppliers is cascading to lower Tiers (2 and 3). So, it is possible to say that the supply chains are working by the Lean maxim of only delivering what the succeeding supply chain participant has consumed, which is why organizations are prioritizing the application of consumption-orientated systems, pull systems, like Kanban. Motivated by all this, Gestamp has decided to substitute the current child-part component supply by a non-electronic consignation Kanban System. This marks the beginning of the implementation of Lean techniques to the materials supply processes. It is a new and perhaps even bigger challenge than prior projects since it involves two supply chain participants with different interests which normally generates paradoxical tensions (Maalouf & Gammelgaard, 2016).

The application of Kanban has become an obvious answer to reduce inventories and implement Just-In-Time. Nevertheless, the current market unpredictability reflexes on a very high demand variability, which disfavors the design of a Kanban system. Consequently, when a supplier Kanban System is designed without considering properly the context where it is going to operate, it is likely to underperform, not being able to reduce inventory costs and not avoiding stockouts. Addressing this problem will have a practical benefit for the company where the study was conducted because they will have a tailored solution. For the mesh of companies in this area of activity the benefit is the fact that they will have an example of how a supplier kanban system was designed under the same volatile demand variations.

1.2. Dissertation Question and Objectives

To solve the enunciated research problem the two following research questions were defined:

RQ1: What practical solutions can be used to deal with demand variability when implementing a supplier consignation Kanban System in a Tier 1 automotive company?

RQ2: How can the consignment supplier's Kanban impact the relationship between a Tier 2 supplier and Tier 1 supplier?

Considering the research questions this thesis intends to answer, the objective is to design a non-electronic consignation supplier Kanban in a high variability context of an automotive Tier 1 company. To be able to do this the specific objectives are the following:

- To describe the current state of the child-part components supply through qualitative data collection methods.
- To collect from SAP database the quantitative data necessary (past stock, future consumption, packaging information, machine capacity, etc.).
- To analyze consumption forecast of 2021.

- To test different ways to compute the Kanban formula.
- To calculate the number of kanbans.
- To access each solution weakness and strengths.
- To confront against each other the different ways the number of kanbans were calculated.
- To structure the Kanban solution.

1.3. Methodology

The action research (AR) was the primary research method chosen for this thesis. In this methodology, the creation of knowledge is achieved by conducting studies developed based in a cyclical process of research and action (Guia et al., 2019) in specific and practical contexts (Koshy et al., 2010). In other words, the projects are developed through a series of continuous improvement cycles, which will enable permanent methods, data and analysis refining based on the understanding gained during previous cycles (O'Leary, 2017). Fundamentally, the purpose of the cycles of learning and acting is to allow the researcher to learn, do, reflect, learn to how do better, do better, learn from that, do it even better and so on.

A very interesting characteristic of AR is the fact that it is a collaborative method aimed to integrate multiple parts in the process of learning and making change (Cordeiro et al., 2017; Denis & Lehoux, 2009; Erro-Garces & Alfaro-Tanco, 2020).

There are variations of this methodology that include different phases, the representation of the cyclical process that is going to be adopted in this study is as represented in the following figure (see Figure 1):

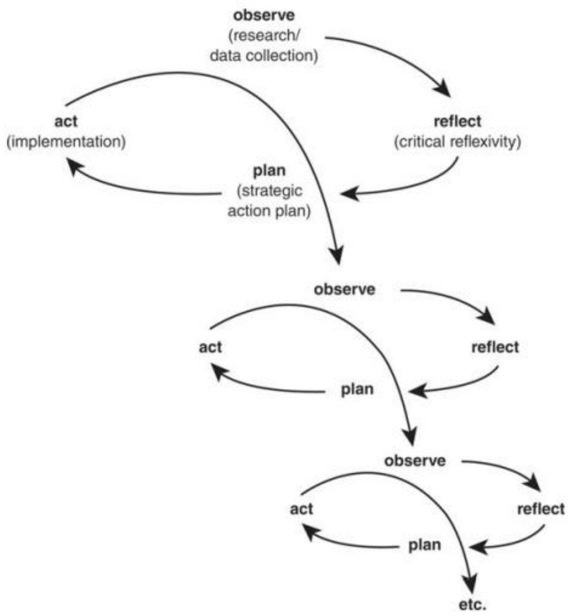

Figure 1 - Research Action cyclical process (O'Leary, 2017)

Action research was chosen to be the methodology of this thesis for multiple reasons. The first one was that this project needed to be developed in an atmosphere of participation and collaboration with the company. This synergy between the participants was fundamental for the design of a final solution that suited the company. The second reason had to do with the AR characteristic of simultaneously creating knowledge and change, meaning the continuous improvement was based in practice (Koshy et al., 2010). Using Cordeiro et al. (2017) words "it is all about making the road while walking" (p.397). Additionally, the third explanation for choosing AR was the fact that the solution besides suiting both parts had to be a practical one, which was only possible if the work was developed based on knowledge acquired on-the-ground and in a specific context.

The development of this study comprehended four action research cycles. All of them begun with an observation phase, whose primary purpose was to gather information to extend the researcher understanding of the stakeholder's experience and perspective (Stringer, 2014). This information gathering can be done through different methods, depending on the type of study and on the information needed.

The first observation phase of this project was more exhaustive then the following ones since it aimed to contextualize the company's activities and the project. To understand what the company's expectations were in relation to the project and in what point of development it was upon the arrival, an initial meeting with the project responsible and with the logistics manager was scheduled. Additionally, through non-participant observation[1] it was possible to comprehend how the current supply of child-parts is processed, which involved the collection of field notes, and images. The observations were complemented by the "corridor talks" with the plant operators. Even though, this project aimed to design and implement a consignation Kanban solution for child-parts supply, this consignation system was already used in other plants of the group. Considering this, the company was able to facilitate a procedure from another plant. It explained how the consignation agreement between the supplier and manufacture was going to be handled, the communication routes, the payment schedule and so on. Additionally, there was also the requirement of collecting quantitative data (e.g., historical consumption and stock data, future consumptions, supply amounts, etc.) to extend knowledge beyond descriptive information.

The subsequent observation phases, the aim was to semi-structurally record information relevant to evaluate the solution developed.

In parallel to all iterations, it was conducted a literature review whose purpose was "to extend and clarify participant understanding of the issue" (Stringer, 2014, p.126). In the literature review conducted in this thesis the main purpose was to provide a framework of how authors have been designing Supplier Kanban Systems and what other strategies they have establish to reduce inventory and improve supply chains functioning.

In Figure 2 the collection methods used during the observation phases of the action research developed are synthesized.

[1] According to (O'Leary, 2017) non-participant observation is when "the observer is physically present but attempts to be unobtrusive" (O'Leary, 2017).

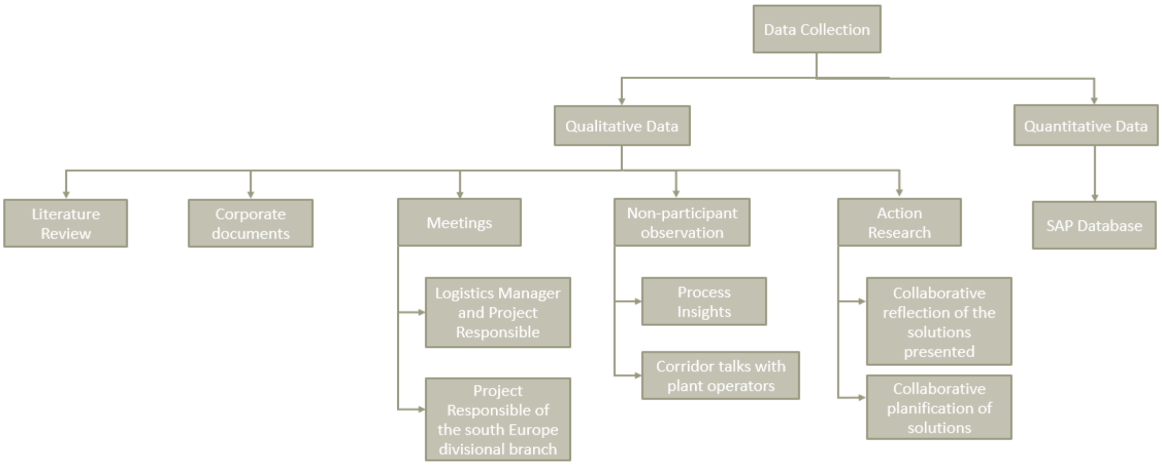

Figure 2 - Synthesis of the data collection methods

Succeeding every observation period came a reflection phase where the information accumulated was analyzed with the intent of finding the best course of action for the next iteration (Stringer, 2014, p.140). The analysis of the information gathered included the computation of descriptive statistics and also the use of interpretative questions (mainly why). Every time the analysis was concluded, a meeting with the team responsible for the project was schedule to collaboratively discuss the solution presented. The conclusions retrieved from the analysis served as a base to the planification phase.

As mentioned, the research process of this thesis consisted of four action research cycles. In all of this cycles the observation and reflection phases were done together as well as the planification and acting. In Table 1 the iterations and steps of this project are summarized.

Table 1 - Action research iterations and steps

Step \ Iteration	1st.	2nd.	3rd.	4th.
Observation and Reflection	Current state information gathering through meetings, corporate docs. And non-participant observations. Analysis of the information collected from SAP database through descriptive statistics. Parallel literature review.	Semi-structurally report of key aspects. Analysis of the results obtained using descriptive statistics and interpretive questions. Presentation of conclusions to the logistics manager and the project leader.		
Planification and Acting	Collaborative planning of a solution to the demand problem found during observation. Outlier analysis in KNIME and excel. Calculation of the number of kanbans using Kanban Formula	Collaborative planning of a solution for material shortages. Definition of the service level desired for each client. Calculation of the number of kanbans using Kanban Formula	Collaborative planning of a solution to reduce the number of kanbans. Determination of the machine's max capacity Calculation of the number of kanbans using Kanban Formula	Prospection of the space needed and elaboration of the Terms of reference report.

1.4. Corporate Presentation

Gestamp is an international group expert in designing, developing, and manufacturing metal components and assembly parts for automobiles. It was founded in 1997, in Spain, with the aim to be "a global technology supplier" (Gestamp, 2020a). Through the years, it evolved from a local stamping business to a global company operating in the main auto manufacturing hubs (Gestamp, 2020b). This was possible due to the intense value given to innovation and to the excellence of the products offered. And so, what began as a company only focused on cold stamping is now a company with a wide range of metal transformation technologies present even in new emerging markets.

According to the latest Sustainability Report the group's vision is "to be the automotive supplier most renowned for our ability to adapt our business to create value for the costumer, while maintaining sustainable economic and social development" (Gestamp, 2020b, p.5). Matching the company's website (Gestamp, 2020c), sustainability is one of Gestamp's core principles, but more than a principle the company views it "as a long-term business model that seeks to create value for all stakeholders" (Gestamp, 2020b, p.12). This model is established in three different dimensions: economic, social, and environmental. When it comes to this last one, the company has the specific goals of **diminishing** material waste through the circular economy model established and greenhouse gas emissions with initiatives like renewable energy supply and **implementing/maintaining** a certified Environmental Management System (ISO 14001 and EMAS). In the same report, Gestamp declares that in 2020 a total of 21.585 tons of "Non-Hazardous Waste" were generated, of this 12% corresponded to paper/cardboard.

As mentioned, Gestamp has expanded the selection of goods it offers, presenting nowadays four different types of products (see Figure 3). Within the group there is a branch (Gestamp Loire, 2020) dedicated to the design and manufacturing of all types of hydraulic presses and to the design, machining, construction, tuning, prototyping, and monitoring of dies. Then, there is also a wide portfolio of Body-in-White (BIW) products, that are large components and assembly parts like bonnets, roofs, doors, mudguards, among others. The group has a vast experience in relation to the production of chassis parts. Lastly, with the acquisition of Edscha (markets leader for door hinges and checks (Edscha, 2020)) in 2010 the product portfolio begun to include hinges, door checks, electrical systems, etc.

Figure 3 – Gestamp's scope of products

The focus of Gestamp manufacture activities is directed to the products that are sold directly to the OEMs[2], making the company a Tier 1 supplier. A Tier 2 supplier would be Gestamp supplier that consequently integrates products from suppliers of Tier 3, who provide less finished sub-assemblies, components, and materials (Gestamp Automoción, 2016; Leskova, 2016).

1.4.1. Gestamp Palau

The study developed was carried out in Gestamp's plant of Palau. Originally this plant was bought in 1996 by Estampaciones Sabadell. In 2011, Gestamp acquired 40% of this company and total Management of Palau's plant and later in 2016, attained full control. Nowadays, this plant produces pieces for six different OEMs (Figure 4). Beside these clients they also sell to other tier 1 companies and to other plants within the group.

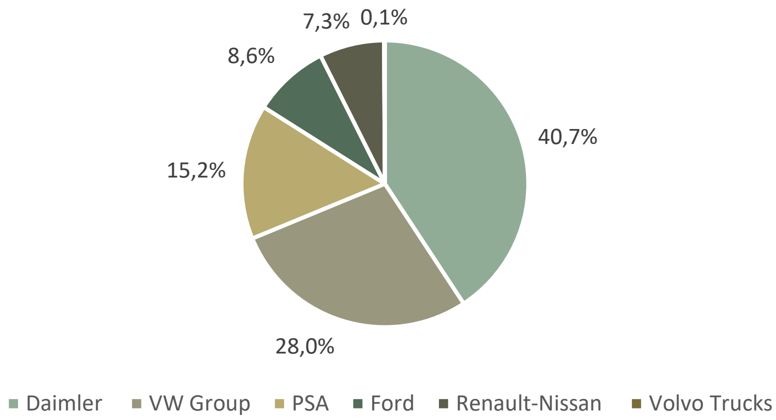

Figure 4 - Gestamp Palau main clients

[2] OEMs means Original Equipment Manufacturers

Within the group each firm can have different productive processes, in the case of Gestamp Palau the processes available are blanking, cold stamping, assembling, and finishing. There is just one line dedicated to first process that consists in cutting sheets of metal into blank units. The cold stamping "involves the transformation of a sheet of metal, at room temperature, inside a forming die under pressure" (Gestamp Automoción, 2016, p.80). In this subsidiary, there are five Tandem Presses - the material is moved by robots from press to press in five or six operations, normally used for large parts (see Figure 5); one Transfer Presses - the material is moved between stations, inside the die, by transfer bars in up to six operations, usually used for medium size parts with cupped shapes (see Figure 5); one Progressive Press - the material is not cut but feed through the press, once finished the stamped part is separated from the material strip, typically used for small size parts; and one Hydraulic Press. Regarding the assembly process there are 20 welding cells with MIG/MAG and resistance technology. Finally, the finishing process is the cataphoresis painting. Shortly, the pieces from previous stages are arranged in a support and placed in a chain that runs through all 3 phases of this automated process, the placement and removal of parts are the only activities that require human intervention. Firstly, the parts are degreased and prepared for the painting (pre - treatment), then they are painted by immersion and lastly, they are dried and polymerized (Gestamp Aveiro, 2016).

(A) (B)

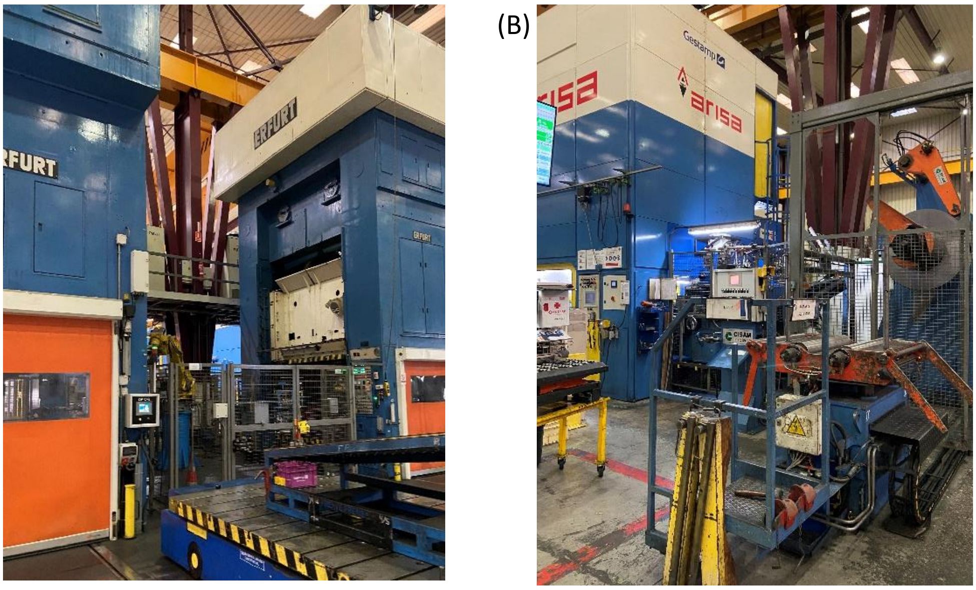

Figure 5 – (A) Tandem Press; (B) Progressive Press

1.5. Dissertation Outline

The present study is divided in five chapters, and it follows the general guidelines of academic works. The first chapter is entitled Introduction and it covers the project's context and importance, the research question and problem, the methodology approach chosen and the company where the study was developed. The following chapter is dedicated to the theoretical framework of the project. In this it is presented an overview of the evolution of the manufacture paradigms, the techniques Lean manufacturing uses with special focus on the Kanban system, the concepts of supply chain management and lean supply chain management and the strategies that can be used to increase collaboration in the supply chain. The third chapter is dedicated to the study developed and it is divided according to the Action Research phases (methodology chosen for the project). This section includes an exposition of the initial state of the project, the explanation of how and why the various solutions were developed and an analysis of each solution. The fourth chapter starts with a summary of the development process of this project, then the three solutions are compared against each other to understand each strength and weaknesses and to finish the research questions are discussed. In the last chapter are presented the main conclusions of this project, as well as a few suggestions for future work.

2. LITERATURE REVIEW

Since the birth of manufacturing, where products were crafted to customer requirements, through the mass production era and up till this day, manufacture has evolved through multiple paradigms (Hu, 2013). The beginning of this chapter starts with a brief overview on how the manufacture progressed through all these paradigms. Once concluded the historical contextualization, the focus shifts to Lean System basics.

In an increasingly competitive environment and to respond more promptly to customers, manufacturer's efforts are focused on the implementation of JIT techniques and integration of supply chain participants (Taylor et al., 2015). The implementation of JIT can be achieved through the application of different techniques, but the one explored in this work is the Kanban System. In this specific case, Kanban is going to be applied only in a segment of the supply chain (SC), more precisely between supplier and manufacturer. Following this line of thought, then it is explained what supply chain management is, the difficulties that lead to the dissemination of Lean application in the SC, and a collaborative strategy to improve the connection between participants. Lastly, the idea that pull and push systems are not compatible is demystified by explaining how the ERP and Kanban can coexist and even support each other.

2.1. From Mass Production to Toyota Production System to Lean Manufacturing

In the beginning of the twentieth century, Henry Ford revolutionized the manufacturing industry when introduced a new manufacturing system – Mass Production. This new way of operating was based in the principle of specialization, the highly skilled labor was responsible for designing and setting up assembly lines and the unskilled labor for producing and assembly highly standardize products (Hindle, 2008). With this new paradigm the cars were produced in mass allowing the company to smash its price (from USD1200 in 1909 to USD295 in 1928 (Wulff, 2014)). The turning point was Ford's introduction of Model T, the universal car: "Any customer can have a car painted any color that he wants so long as it is black" (Ford, 1922,p.66)

Following World War II, in 1950 and after twenty years, Toyota's leaders visited Ford and GM US's plants to study their manufacturing system. They were expecting many big technology advances (Liker, 2004), however they were surprised to find out that not many changes were made to the mass production practices. After the visit they were convinced this was not the path to invest in, as the Japanese market was too divided and small to absorb mass production like the US market (Liker, 2004). Upon their return to Japan, all their efforts were redirected to establish a manufacturing system that would truly suit Toyota. From this point onward started the development of Toyota Production System (or TPS). The core principles of TPS were to reduce costs and improve efficiency, through the eradication of overall wastes (Monden, 2012) and "to make full use of worker's capabilities" (Sugimori et al., 1977, p.555). In this new system, according to Shingo (1989), the profit corresponded to the difference between the price the client was willing to pay and the production cost, which was a direct consequence of leaders acknowledging customers importance in achieving success (Houshmand & Jamshidnezhad, 2006).

Toyota kept developing their new manufacturing concept, expanding it to the supply chain, and with time their impressive results started to gain more and more attention. Even so, it took a few years for the Western world to really start paying attention. This turn happened when Womack et al. (1990) introduced the third manufacturing system called Lean, based on the Toyota Production System. According to J.P. Womack and Jones (2003) Lean can be defined as a "way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively" (p.15). Fundamentally, Lean philosophy pretends to combine the best features of craft production and mass production: the delivery of a wide range of products, at the lowest cost and with the highest quality.

2.2. Lean Fundamentals

Lean was summarized by Swink et al. (2013): giving customers only the products they want, as quickly as they want, only with the features required and with perfect quality, in the minimum lead time, while wasting no labor, materials or equipment. In a way to achieve Lean objectives, J.P. Womack and Jones (2003) established the five principles that now are used by managers as guidelines to the lean methodology:

1) **Specify Value** in customer's perspective, essentially understand what they are looking for, when, with what capabilities and how much they are willing to pay for it.
2) **Identify the value stream** from product development phase until customer delivery and then classify and eliminate non-value-adding activities.
3) **Create an interrupted flow** of all the activities that add value or cannot be eliminated.
4) **Let customers pull value,** giving them what they want only when they want it. There are various ways to implement a pull system such as hand delivery or Kanban systems.
5) **Pursue perfection** systematically eliminate new layers of non-valuable activities exposed with the implementation of previous steps. Improvement efforts are never over, there is always space for improvement (Kaizen).

2.2.1. The 7 + 1 Wastes

As referred, in lean systems processes performance needs to be continuously improving, which is only possible through the systematic identification and elimination of wastes. There are three major categories of waste: (1) *mura* which is demand, production, or process variability; (2) *muri* that relates to employees and processes overload; and (3) *muda* that corresponds to all activities that do not add value. Within this latter category, it is possible to identify the following basic types of wastes (Helmold, 2020; Swink et al., 2013; Torielli et al., 2011):

1) **Transportation**: unnecessary material transportation leads to extra handling, larger storage areas, damaged products, over-staffing, excessive energy consumption, extra paperwork hand-offs and lower productivity. The typical reasons behind this waste can be unfavorable layouts; misplacement of materials; Interim storage of material; and unleveled production.
2) **Motion**: excessive resource movements, causes low productivity, high lead times and capacity and ergonomic issues. This is explained by inaccurate analysis of workflows, inadequate layouts, no standardize methods and poor organization.

3) **Overproduction**: generates excessive stock, extra storage space, unnecessary handling, complex information management and high utility costs. Usually this happens because of product complexity, poor market forecast and production according to supposed optimal batch sizes.
4) **Waiting**: resources wait for work, leads to reduce productivity and efficiency, high lead time and capacity, and underutilization of resources. A few reasons that can lead to this type of waste are unbalance workload, long process setup times, unlevel scheduling, missing materials/tools and insufficient synchronized material and information flows.
5) **Defects**: needless scrap, rework, or correction, which leads to high disposal costs, missing shipment dates, customers returns and loss of confidence and additional need for material, tools, and rework space.
6) **Overprocessing**: unnecessary operations, causes longer lead times, reduced productivity, high production costs and excess energy consumption. This is a result of insufficient analysis and design of processes and inefficient processes.
7) **Inventory**: holding raw materials, semi-finished parts, work in progress or/and finished goods more than needed. As a result, there is in-process packaging, complex tracking systems, capital costs, search efforts, double handling and difficulties find problems. This can be justified by just-in-case logic, problems with planning and logistics operations and unreliable supplier performance.
8) **Underutilization of employee's capabilities**: failure to use employee's suggestions.

Inventory often hides the rest of types of wastes a company might have. Usually, high inventories allow production to continue without realizing the urgency to eliminate overproduction, defects, overprocessing, etc. The inventory level can "serve as a measure of the health of an operating system (…) The more inventory needed for the system to work, the less healthy the system is" (Swink et al., 2013, p. 290). Actually, in accordance to Giannoccaro et al. (2003) inventory in manufacturing organizations usually represents from 20 to 60% of total assets.

2.2.2. The House of Lean

Toyota Production System kept evolving until eventually it was summarized in a simple scheme called House of TPS (see Figure 6). Throughout the years this representation became a cultural icon in the manufacturing world (Liker & Morgan, 2006) and it was accepted as the House of Lean too.

To represent TPS system, a house was chosen since it is a structural scheme, that is only as strong as its foundation, pillars, and roof. The support elements allow achieving the TPS goals (roof): best quality at shortest cost and lead time, guaranteeing safety and high morale.

Figure 6 - The house of TPS (Liker & Morgan, 2006)

The left pillar holds probably the most popular aspect within Lean. The Just-In-Time system first got attention in 1973, when it proved to be recession-resistant during the Japanese oil crisis (Hirano, 2009b). However, it was created many years before based on the American supermarkets reposition system where the replenishment orders were only triggered when the shelves were emptied out. Essentially, JIT system consists in delivering the right part, to the right place at the right time, allowing the creation of an uninterrupted flow, this makes it a client-oriented system.

Just-in-time introduced the pull concept in the manufactory world, which opposed the push system, popularized in the era of mass production. In a push logic, products are pushed to downstream stations based on a schedule or simply because the preceding operation finished. The adoption of this type of system covers line imbalances or bottlenecks since production keeps going even though there is no demand. In harsh contrast, in pull systems the downstream stations when needed resort to upstream stations for what they need in just the right amount. Consequently, if there is a bottleneck it is immediately exposed as it will cause a halt in production. The difference between these two systems lies in the information and material flow.

There are various mechanisms to implement pull-system, but the most popular one is Kanban (Rahman et al., 2013) , while in the case of push-systems it is the ERP.

The right pillar refers to Jidoka that is defined automation with a human touch to guarantee reliability, flexibility, and precision (Kerber & Dreckshage, 2011). The two foundations are Heijunka, that means leveling production schedule in variety and volume and stability and standardization. In the center are people and waste reduction that combined will be the force to continue improving overall activities.

2.3. Kanban System

The Kanban system was developed by Taiichi Ohno to control and coordinate production between processes and to implement JIT. Is the first and likely the most widely applied card-based system among CONWIP, POLCA or COBACABANA (Frazee & Standridge, 2016; Prakash & Chin, 2015; Thurer et al., 2020; Thürer, Stevenson, Protzman, et al., 2016).

Kanban application has been reported to enable normal and obsolete inventory reduction, as there is less "just-in-case" inventory; flow improvement through process synchronization;

overproduction prevention, because it limits process capacity; responsibility delegation, since visual control allows operators to make production and inventory decisions; process control simplification; improvements acceleration; and quicker answer to clients (Cimorelli, 2013; Gross & McInnis, 2003).

For organizations to be able to make the most out of the Kanban system there is a set of rules that need to be followed (Hirano, 2009a; Ohno, 1989; Thürer, Stevenson, & Protzman, 2016).

1) Downstream processes withdraw items from upstream processes. "The later process (customer) goes to the earlier process (supermarket) to acquire the required parts (commodities) at the time and in the quantity. The earlier process immediately produces the quantity just taken (restocking the shelves)" (Ohno, 1989, p.26). Functioning as a nervous system, passing consumption information from downstream to upstream processes, much like human's nerve information (Hirano, 2009a).
2) Upstream processes only produce what was withdraw since Kanban is a demand-based system. With rule 1, the feedback loop is established.
3) There is no product without a kanban. Production is only initiated if there is a signal, which prevents overproduction and excessive transports.
4) A kanban card must be attached to all goods, to serve as a work order. In other words, for example, if a part with a WIP kanban is withdrawn with withdraw kanban then they must circulate together (part + withdraw kanban). This happens to avoid removing two or more parts to be removed with one only kanban.
5) Products have to be 100% defect free, before being sent downstream.
6) The number of kanbans should be reduced, to keep discovering improvement needs.

2.3.1. Types of kanbans and Material Transferring Schemes

Kanban can either be viewed or as a scheduling system that builds outputs according to actual usages instead of forecasted usage (Thürer, Stevenson, & Protzman, 2016); or as a card which is the literal sense of the word, serving both as a transaction and as communication device (Gross & McInnis, 2003). Typically, if Kanban is written with capital letter refers to the system.

There are two main types of kanban cards: production and withdraw. The difference relies in the action each kanban triggers: a production kanban gives a signal to initiate production and a withdraw signals inventory is going to be removed (which generates a replenishment order). Both these types of kanbans can be further separated into two groups. The production kanban can be a signal kanban, typically used in cases where production is in lots (Hirano, 2009a) or an in-process kanban used small quantities production (Smalley, 2004). The withdraw kanban can either be an inter-process kanban used to move parts from storage area to a downstream process in the facility or a supplier kanban, which is similar but functions with external suppliers.

In systems with more than one production stage it is possible to have different material transferring control schemes, the most popular are the single and dual card. These approaches have been explored by authors like Gstettner & Kuhn (1996), Berkley (1991) and Krieg (2003).

1. Single-Card (SK) System

This types of control system is the simplest to implement, and is used when the distance between consecutive stations is small (Huang & Kusiak, 1996). In this type of system each container has kanban card that is removed when the container moves to the stage *i+1*, this triggers production in stage *i*; once the parts in stage *i* are ready these are transported to *i+1* (Giordano & Schiraldi, 2014). In this case, the material transfer is immediately (Berkley, 1992). The kanban that circulates in this system is generically called production order kanban (POK) (Sert & Mümüne, 2020).

2. Dual-Card (SK) System

It is called dual card system since it uses withdraw cards to specify the quantity the station *i+1* needs to withdraw from the output buffer of station *I*; and production kanbans to indicate the quantity station *i* needs to produce to replenish the quantity the succeeding station removed (Sert & Mümüne, 2020). This kind of control system is used when there is a moderate distance between consecutive stages and the parts to transport are too heavy to do it instantly (Berkley, 1992). The cards can be withdrawn only when there is a fixed number of cards or on a predefine time interval (Krieg, 2003).

In companies with Kanban system implemented throughout all operations there are various kanban loops functioning. In Figure 7, the interaction of these loops is represented. As customers make orders, finished products are shipped from the finished goods warehouse and kanban cards are removed and placed in a kanban card collection board. These cards are then returned to the kanban board in work cell #2, giving sign to start production (production kanban). As production starts the WIP inventory produced by the previous station (work cell #1) is consumed, consequently, releasing new kanban cards and triggering production in work cell #1. This cell uses raw materials that come in bins from the supermarket and as these bins get emptied out, they are returned to the supermarket, triggering off an order to the supplier (withdraw kanban). This synthetizes the flow of cards within the entire processes, however the flow of materials is reversed. The exchange of materials in the system is done on a logic of empty-full bin, meaning, for example, the work cell #1 sends to the supermarket empty bins which is going to return full bins. A relevant side note needs to be made to the tools that support the implementation of Kanban system. Namely, there are the supermarkets “where raw materials are stored near their point-of-use, so customers can pull them as needed” (Gross & McInnis, 2003, p. 185), working in the same logic food supermarkets work. And there are the *milk-runs* that are shipments with multiple pickups and deliveries by the same truck on a predefined route, delivering goods based on customer needs.

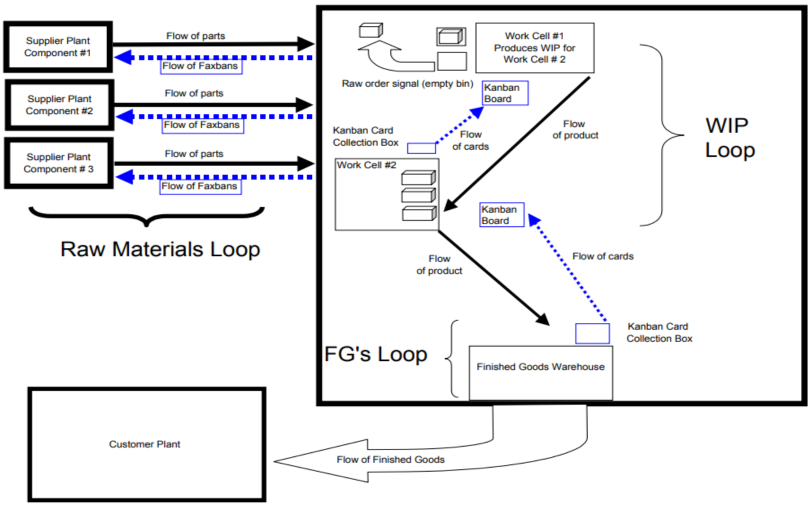

Figure 7 - Different Kanban loops (Gross & McInnis, 2003)

An important observation made by Lane (2019) is that when getting started with Kanban companies must first start with internal Kanban loops (in the production are), as it will allow to gain experience before starting the kanban with suppliers that has more uncontrollable variables.

Regarding the raw materials loop, in literature it is possible to find studies that prove that the implementation of this type of system can have positive repercussions. Mackerron et al. (2014) through case-study methodology developed a framework for the implementation of supplier e-Kanban that enchanted operational tasks and inherent problems. This project presented the downsides such as, the supplier only got paid when the material provided reached the final stock; the payment process was not as clear as initially expected and the attachment of paper kanbans was not ideal considering the type of materials in study. On another hand, Pirabarkaran et al. (2018) conducted an action research study to reduce warehouse inventory by implementing a supplier Kanban system in an automotive company. In parallel, they carried out an action research thesis to develop an implementation framework to guide the process at the company. With their study, they managed to save 28% of space which implied 3880€ less money spent in rent per month; to reduce the number of workers from 24 to 15, spending less 39 thousand euros per year; and to eliminate the necessity of double-handling and extra paperwork. The study conducted by Ali et al. (2012) had the same purpose of reducing the inventory of raw materials in a producer of temperature controls. The authors used the formula introduced by Toyota to size the supplier kanban. Even though in this study the company was still negotiating with the supplier, the implementation of kanban would constitute an improvement in terms of raw material and work in process inventory. According to the results obtained by Satoglu & Ucan (2015), the supplier Kanban system reduces the time the production planner spends controlling the production requirements (in this case approx. 72%). In this study, the inventory increased but the authors explained that the improvement of material replenishment, the elimination of stock-outs and the reduction of setup times compensated the inventory holding costs incurred.

2.3.2. Kanban Sizing

1. STANDARD KANBAN SIZING

There are two ways to calculate kanban quantities (1) based in current process data or (2) based in current schedule quantities. The benefit of the first one is that it allows to optimize kanban quantities based in current process data, but it implies in-depth calculations. On the other hand, the second approach is more direct, making kanban implementation quicker and also usually there is the underlying guarantee that this schedule supports production. However, chances are that inventory levels will not improve significantly like in approach 1 (Gross & McInnis, 2003).

The process of sizing kanban consists basically in determining the number of cards per product that are going to be put in circulation to guarantee the system works. The formula to calculate the number of kanbans is (Chan, 2001; Jothishankar & Wang, 1992; Sugimori et al., 1977):

$$y = \frac{D(T_{order} + T_{transit})(1+ \propto)}{a} \quad (1)$$

Where,

$y = Number\ of\ Kanban$

$D = Demand\ per\ unit\ time$

$T_{order} = Time\ to\ place\ and\ acknowledge\ an\ order$

$T_{transit} = Supplier\ delivery\ Time$

$\propto = Policy\ variable\ (safety\ margin)$

$a = Container\ capacity$

In relation to the value of $\propto$, Co and Sharafali (1997) propose no more than 10% and a should be limited to 10% of demand. It is clear that in the beginning stages these values might are difficult to attain, and like Sugimori et al. (2007) mentioned these are not fixed and are always opened for improvements.

In the simplest case, the number of kanban cards is going to be two, which is commonly called in literature Two-Bin system. This type of system is popular in hospitals to control inventory of disposable items (Kanet & Wells, 2019).

In literature related to Kanban, it is possible to encounter many alternatives to calculate the number of kanbans besides the formula proposed by Toyota (Silva et al., 2016). The alternative used by Braga et al. (2020) was simulation, where he considered demand a noise variable and the security stock equation (to better simulate the real trade-off companies face between stock level and service level). He was able to present a model applicable in an industry context but limited to only four products. A combination of simulation and a metaheuristic (Tabu-Search) was used by Kageshima and Inoie (2014) to reduce inventory and lost sales in a two-card system. On the other hand, Faccio et al. (2013) and Lolli et al. (2015) used mathematical models to solve the kanban dimensioning issue, with the aim of minimizing costs. While in the first study the objective function included inventory, handling, and stock-out costs, the second study only considered inventory and handling costs. In both researches, the mathematical model presented proved to be applicable in a real and quite simple industry context, Faccio et al. (2013) was even able to achieve a 35% reduction in cost.

Another option used by many authors is the genetic algorithm (GA). For example, Hou and Hu (2011) developed a multi-objective GA to determine the optimal kanban size and kanban number, exploring the existing trade-off between these two parameters. Sajedinejad et al. (2020) with a GA explored the impact of correctively determining both production and withdraw kanban numbers in SC costs. Alternatively, Braglia et al. (2014) determined the optimal number of cards using GA with the aim of reducing total time throughput and work-in-process. While Widyadana et al. (2010) compared the performance of GA and an hybrid version of GA when solving kanban number issue in a dual-card kanban system for a multi-product SC.

Different from previous authors, Aghajani et al. (2016) proposed a mixed-integer nonlinear programming model (MINLP), to determine the number of kanbans, number of batches and lot size to reduce total cost. Yet Baradaran and Akhavan (2019) to determine the withdraw kanban number developed a mathematical Bi-Level optimization model, with non-linear objectives, that was solved with a GA and its feasibility was tested with simulation. This study limitation is that the model needed to be further developed to include more than one product.

2. Kanban Sizing under Uncertainty

The standard Kanban system is an appealing method to implement. However, it is not suitable in all situations. The Kanban system has two simultaneous roles (1) to limit WIP and (2) to be an inventory buffer. When there are no high fluctuations, there is a small number of kanbans in circulation, and a low level of inventory is maintained. However, when the environment is not stable the Kanban system requires a high level of inventory to cover demand changes and a large number of kanbans, thus increasing the holding costs (Li, 2013). Essentially, in cases where demand suffers significant fluctuations, not even standard Kanban can prevent product shortages or excesses (Hirano, 2009b). In this line of thought, Monden (2012) advances that according to Toyota, variations until 10% of demand can be supported by changing the Kanban parameters without revising the entire system, while Gross and McInnis (2003) consider that if variations exceed 25-30%, then the implementation of standard Kanban should be reconsidered.

Recognizing Kanban's shortcomings and considering that the context where it was developed in everything differs from today's context of turbulence and volatility, researchers have explored ways of adapting the system in other to improve its performance. As it was designed to function with stable conditions, in the current environment, an optimal and fixed number of kanban cards often underperforms (Framinan & Pierreval, 2012; Kessinger & Gray, 2011). There are two strategies used to overcome this problem, either the number of kanbans is dynamically adjusted or the lead time. Once again looking at the formula proposed by Toyota:

$$y = \frac{D(T_{order} + T_{transit})(1+ \propto)}{a}$$

If the value of y is fixed, and D increases lead time $(T_{order} + T_{transit})$ reduces. In this case, if firms are not quick to make such changes it will work beyond necessity. On the other hand, if D decreases then lead time increases, opening the opportunity to *Syojinka*, decrease number of workers. This type of solution is characterized by constant kanban quantity and nonconstant lead time, there is another type of system where the number of kanbans varies in time, but the lead time is constant (Kerber & Dreckshage, 2011). At Toyota, within the plant the system used is constant quantity, whereas with supplier is constant lead time (Monden, 1994).

The adaptive Kanban system when compared to standard Kanban, according to Xanthopoulos et al. (2018) can reduce costs up to 44,8% in uncertain environments. The kanban number adjustment can be done using different approaches. For example, Klug (2016) developed a simple heuristic that quickly determines the number of cards, by systematically changing environment conditions using Monte Carlo simulation. Le et al. (2013) also proposed the alteration of the number of cards and production capacity through Markov analysis. Belisário and Pierreval (2015) used genetic algorithms to establish adaptive control policies and Renna (2015) applied a fuzzy control strategy, but this method had numerous parameters that hardened its reproduction. In relation to the adjustment of the lead-time, Selçuk (2013) compared static lead-times with dynamic ones and was able to conclude the latter perform much better when there is variability.

2.3.3. Kanban Implementation Framework

In the literature, there are a lot of different Kanban implementation frameworks (Gross & McInnis, 2003; Mackerron et al., 2014; Pirabarkaran et al., 2018). The one proposed in "Kanban Made Simple" by Gross and McInnis comprehends a set of seven steps. The first one is dedicated to the data collection, which is crucial to guarantee the project's success, since the calculations are based on this information. After gathering all the data, an analysis needs to be conducted to confirm if the information retrieved is reliable. In other words, it is necessary to check if the data really reproduces the way company works. Once all the data is compiled, the second step is to size the Kanban. The third step is the Kanban design, whose purpose is to decide how Kanban will be implemented. It is important to establish what will be the visual signs, how materials will be controlled, what training will be necessary and so on. The outcome of this phase will be a plan to guide the implementation of Kanban. After establishing this plan and before the implementation starts, the forth step is to explain to everyone how the Kanban will work. Then the Kanban implementation can start. The sixth step is the Kanban audition, which often gets overlooked, but it is important to understand how the system is behaving and how everyone is adapting to it. Finally, there is the improvement of the Kanban, meaning it is time to progressively decrease the number of kanbans to expose problems and find solutions. However, this cannot be done all at once, otherwise it might cause system failures.

2.4. Supply Chain

On one end of every business transaction there is a supplier and on the other a customer, in between these two there are processes and facilities that link both ends. The supply chain is the link that intertwines all these entities. Generically can be defined as a series of processes by which value is added and through which it is delivered to final customers (McLean, 2017). In the words of Beamon (1998) and Swink et al. (2013), supply chain includes the whole set of organizations implicated in product's design, transformation of raw materials, consumption and disposal. In Figure 8, it is possible to see the major entities involved in a company's supply chain and the information flow that connects them. In accordance to Laudon and Laudon (2014), the supply chain is divided in two sections: upstream and downstream. The first section involves the company's suppliers, the suppliers' suppliers and so on. The downstream section includes organizations in charge of distributing and delivering products to the end customers.

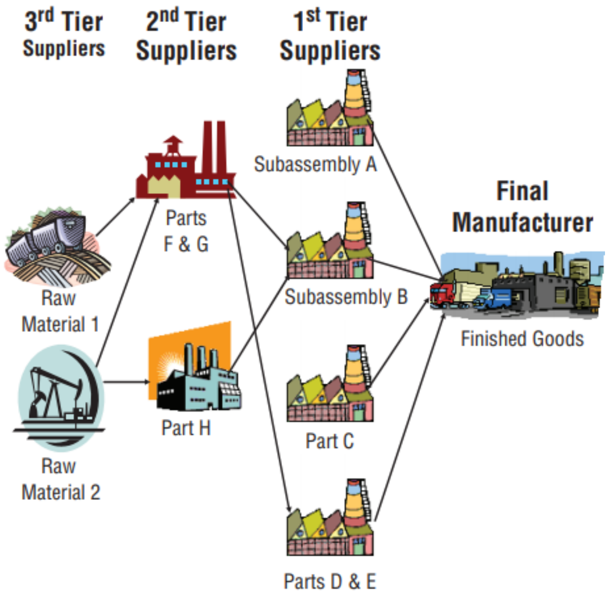

Figure 8 - Supply Chain representation (Swink et al., 2013)

Efficient supply chain management is crucial to ensure business continuity (Cabral, I. & Cruz-Machado, 2012), to obtain time efficiency across the entire network and to make good use of resources (Plenert, 2007). In order for entities of a SC to achieve these results, Arbulu and Ballard (2004) state that participants need to have a better understanding of what is supply chain management, its dynamics and how its application can increase their competitive advantage. Even though it seems simple enough, doing this nowadays is more complex than it might seem. The first difficulty SC participants encounter is, like Zimmer (2002) points out, the fact that all of the companies connected have distinct profit motives, which hardens coordination task.

The second big challenge is the "volatility, uncertainty, complexity, and ambiguity" (Packowski, 2013, p.5) that has characterized current markets, thus complicating companies' management tasks. Customer's behavior is the biggest factor that contributes to market variability and volatility, as their purchasing intentions vary from demand forecasts. Additionally, circumstances in the supply chain are constantly changing in a rhythm that is hard for companies to keep up, this uncertainty repercusses to upstream entities of the SC. As supply chains become global there is a clear increase of complexity due to the almost impossible mission of synchronizing all entities involved. Ambiguity arises when the links that connect various entities are weak because of lack of information.

Thirdly, on a planning perspective, Packowski (2013) advances that traditional planning approaches, like ERP, can complicate the task of managing SCM. An ERP (Enterprise Resource Planning) is a software system that combines a company's planning systems and data throughout, integrating and solidifying the planning process of all business functions. Before ERP, different business functions used to plan separately their processes and the integration was done manually. As time went by, ERP evolved to serve as a bridge between companies, customers, and suppliers. Embedded in the ERP there is a system like MRP (Material Resource Planning), which determines "how much and when to produce using a time phased schedule based in lead time" (Swink et al., 2013, p. 469), based on a push logic.

The downside is that it is highly dependent of the inputs it uses to determine the plan. If the inputs are wrong, performance will be poor, which, therefore implies good coordination between SC firms to ensure the best results.

The two problems pointed out by Packowski (2013) with ERP and subsequently with whichever system embedded is that, first it relies in demand forecast and the ineffectiveness of inventory/buffers when dealing with variability. Usually, peaks in orders in one point of the supply chain grow continuously as orders progress upstream the SC – Bullwhip Effect (see Figure 8). As a result, inventory across all firms vary dramatically from excesses to disruption.

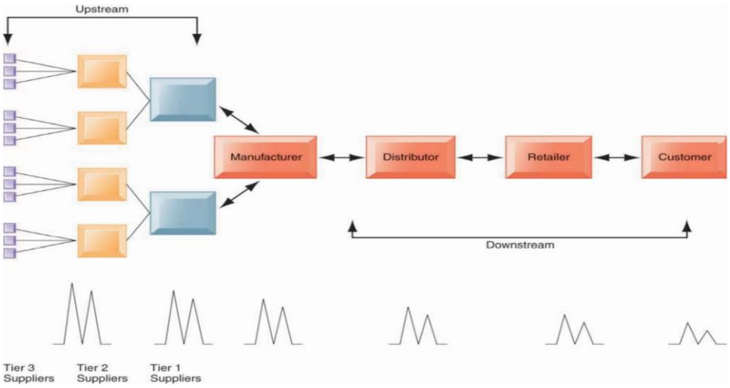

Figure 9 - Bullwhip Effect (Laudon & Laudon, 2014)

2.4.1. Lean Supply Chain Management

The three circumstances enunciated previously led to the diffusion of Lean Supply Chain Management (LSCM) paradigm (KB & Abott J, 2005), where lean practices are applied from supplier order placement to client delivery (Ghobakhloo, 2020, p.2386).

Lean SCM aims to integrate product, service and information flows from upstream suppliers to downstream customers, creating a collaborative and continuous flow (Basu & Wright, 2008 and Vitasek et al., 2005). This general and integrative paradigm, focused in long-term commitment to SC partners, moves away from functional and independent paradigm, centered around power negotiation (Agarwal et al., 2006; Frazzon et al., 2015). The lean approach in supply chain all parties to respond more efficiently and quickly to customer needs (Srinivasan, 2004) which consequently means more flexibility, productivity, competitiveness, profitability and agility (Behrouzi & Wong, 2011). The following list includes a series of practices characteristic of a lean supply chain (Cao & Zhang., 2011; Simpson & Power, 2005; Wu, 2003):

- Relationships with long term chain entities are based in trust and commitment
- Limited number of suppliers
- Raw materials and components should be supplied by one or two suppliers
- Frequent communication between SC entities
- Supplier involvement in product development
- High delivery frequency

As mentioned integration is an crucial characteristic of LSC, one of the key drivers to achieve this is JIT, since it synchronizes operations from all members (Claycomb et al., 1999).

In literature is possible to encounter various studies highlighting how lean practices impact positively SC performance. In "Lean Supply Chain Planning", it is mentioned that organizations that switched to LSCM report improvements in managing variability (31% decrease in variability), which in turn led to a reduction of 35% in inventory and 40% in cycle time and a 4.4% increase in service level (Packowski, 2013). Regarding collaboration within LSCM even though it implies a very difficult coordination, Kim & Ha (2003) concluded that it can improve performance benefiting both suppliers and buyers. More recently, Pozzi et al. (2018) was able to deduct that collaboration and integration in the SC improves the global performance, as opposed to independent management strategies.

In an empirical investigation conducted by Kumar et al. (2018) in the context of an emerging economy, researchers report that lean implementation positively affects supplier selection practices and production while the opposite happens in terms of delivery and logistic services practices. Considering these results, the authors conclude that the relationship between lean management and sustainable SC is not as forthright as some other studies advance. The results obtain might be explained by the conclusion both Jayaram et al. (2014) and Tortorella et al. (2018) found with their studies: in emerging economies LSCM finds more obstacles than in developed economies, and so Lean practices need to be adapted to the country context of where they are being applied.

2.4.2. Buyers - Suppliers Agreements (Retailer managed consignment inventory)

In traditional supply chains, each party manages its own inventory, production and/or distribution. The pressure to reduce costs and increase responsiveness is no longer an exclusive concern of a single company, it has become something common to all members of the supply chain, which is the reason why they are combining efforts to eliminate stocks of low movement (Malhotra et al., 2017). Consequently, there has been a clear hunt for programs that instigate inventory reduction costs through cooperating systems (Gronalt & Rauch, 2008). One example is the Inventory Consignation program (IC) which is a modern approach to shift ownership costs from the buyer to the vendor. In this paradigm, the supplier stores his product in the buyer’s installations under the agreement that the later only pays for the goods once they are consumed (Sen et al., 2021). Buyers are really inclined to this type of solution since they have no money tied to the inventory, this is something specially interesting when the demand is uncertain. The inventory to hold may be defined by the buyer or the supplier, in the first case it is called “retailer managed consignment inventory (RMCI) and in the second vendor managed consignment inventory (VMCI), respectively” (Bieniek, 2019, p.1758). In recent years, VMCI has become one of the most discussed as it instigates collaboration and information sharing between trading partners (Angulo et al., 2004; BOSCH, 2016). Hosseini et al. (2014) defines VMI as a strategy between a vendor (manufacturer or supplier) and a buyer, in which the “supplying organization takes full control of the inventory management and replenishment decisions for retailers.” (p. 295) In this system, the buyer passes the supplier inventory information and the later uses this to manage inventory and place orders, considering buyer special capacities and service level for stocks. As a result, (1) the authority and responsibility of the replenishment process rests with the supplier and (2) the buyer role changes from managing inventory to renting space (Mishra & Raghunathan, 2004). With the VMI application strategy, suppliers have better insights into customer demand, more flexibility in production scheduling, and simplified decision-making regarding quantity and distribution (Ryu et al., 2013). Additionally, one of the most talked about advantages of vendor-managed inventory is the reduction of the bullwhip effect formerly mentioned (Disney & Towill, 2017; Ernawati et al., 2021; Hosseinia & Mehrjerdi, 2016; Swink et al., 2013).

In summary, the difference between RMCI and VMCI relies on the who lies the responsibility of making orderings, on the first case it lies on the buyer and on the second on the supplier. According to Malhotra et al. (2017) the RMCI is a middle term between traditional inventory management and VMCI.

2.5. Kanban and MRP Compatibility

Kanban and MRP function in two opposite logics, while the first is a reactive system which responds to customer orders, the second is a forward-looking system, that bases its results in future demand. According to Cimorelli (2013), Kanban de-couples planning and execution, while MRP attempts to integrate these two activities, pushing operations according to the plan. Even though at first it seems these two systems do not share any common ground, in reality they can coexist and can be compatible.

It is undeniable that MRP systems have weaknesses such as, for example, the dependence on forecasts, the need to have experts managing the system, the time it requires to update which makes it resistant to change (Gross & McInnis, 2003) and the poor real time shop-floor control (Smalley, 2004). On the other hand, Kanban scheduling it is not a substitute of material planning, truthfully it takes the material planning information to create kanban cards (Gross & McInnis, 2003). Both systems have limitations and that is why these can work together. Agreeing with this perspective Swink et al. (2013) say “Firms often use a combination of MRP for planning and kanban (pull) scheduling to trigger production on the shop floor.” The same point is made by the authors of “Kanban Made Simple”, that conclude that it is possible to use MRP and Kanban at the same time as two complementary tools, the first handles planning tasks and the second is in charge of day-to-day production scheduling execution, whilst avoiding overproduction.

The combination of these two strategies is widely studied in literature, for example, Bianchini (2018) and Shah (2018) both investigated a hybrid MRP-JIT model: the MRP was used for material planning and for generating purchase orders, while the JIT logic was used for triggering production in the cells. Hartoyo and Arvitrida (2020) also present design for an MRP-JIT hybrid system, but with the aim of improving the collaboration between a company and a supplier under demand uncertain. In this case, MRP was used to improve the planification of material supply, while supplier Kanban was used to accelerate the operational supply of materials. This design was able to reduce in 53,3% the inventory level.

In conclusion, companies do not need to leave behind the ERP system in order to implement JIT. It is about using one strategy to potentiate the advantages of the other. Like Green et al. (2007) mentions in his work, ERP, in the perspective of a common database, with real-time information, is an important support to guarantee a successful implementation of JIT supply chain implementation. Normally, this hybrid approach is used in plants with a high-mix of products, “because it is not practical to pull between each process step, as this would require inventories at each point for each of the part numbers” (Lane, 2019, p.112).

3. EMPIRICAL STUDY

This third chapter is dedicated to the work developed during the internship period at Gestamp Palau. It was divided in four Action Research iterations.

Every iteration starts with the observation phase, in the first one the aim is to contextualize the project and understand the current situation, to enable the development of a first solution. The next observation and reflection phases are dedicated to the viability analysis of the solution developed previously. This initial phase of each cycle serves as a validation point to access if the solution presented fits or not the company's expectations. The planification and acting are dedicated to the establishment of a plan to eliminate previous problems and to the consequent development.

3.1. First Action Research Iteration

3.1.1.1. Observation and Reflection

1. Child- Parts and Productive Process

First of all, it was imperative to identify exactly which parts were going to be included in the project and in which phase of the productive process they would be used. The materials included were child-parts, like nuts, bolts and tow tubes used as assembly components in the welding cells.

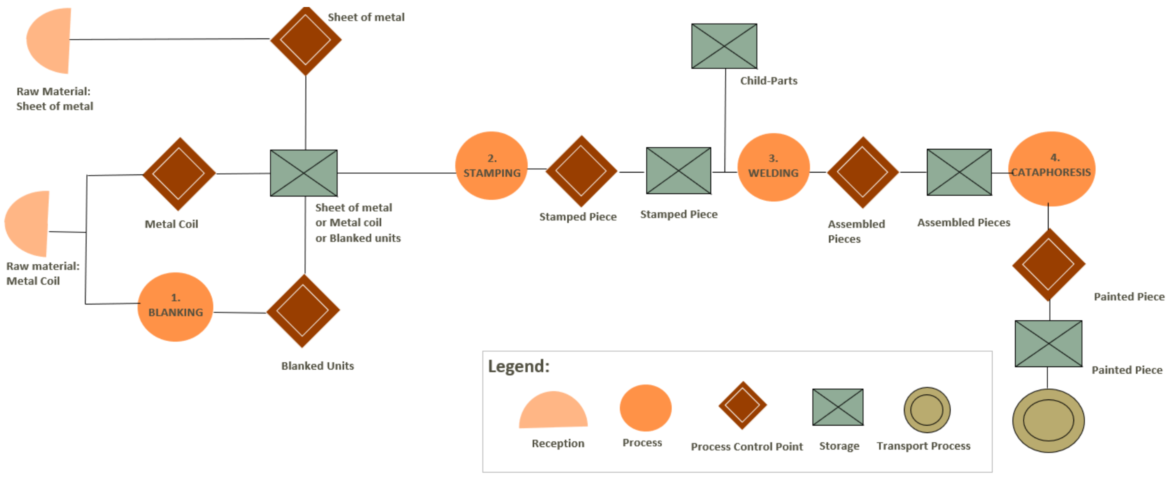

Figure 10 - Productive Process Flowchart

Based on documents made available by the engineering department and on the non-participant observations conducted, a general flowchart was designed regarding the productive processes one piece can go through in the plant (see Figure 10). The raw materials can enter the plant in the format of a sheet of metal or a metal coil; in the second case scenario the coil can be blanked first before stamping or be fed like this to the stamping machine. After being stamped the piece is stored and from there can either be sold directly or moved to welding cells to be assembled with other stamped pieces and/or child-part components. After being assembled the pieces again can either proceed to painting or be sold like that.

2. Child-part transportation packaging

All these child-part components come from the supplier in carton boxes but can go to the welding cells like this or in KLTs (or European Containers). The majority of the components (23) are transported in the supplier's packaging. Most are inserted in nut feeders with the exception of two that are directly inserted on the cell´s flow rack (see Figure 11).

(A) (B)

Figure 11 – (A) Nut feeders; (B) Carton boxes in the cell flow rack

Of the seven components that go into the welding cells in KLTs, six are included in the multi reference car called *minomi,* delivered to the cells bord of line. In the case of the other component that is not part of a *minomi* car, the materials are transferred from the carton boxes placed next to S28[3] into the KLTs and then inserted directly in the flow rack of the cell (see Figure 12).

(A) (B)

Figure 12 – (A) Minomi; (B) Welding cell S028

In what concerns the component supply to the cell, the milk-run is responsible for delivering components from the supermarket to the welding cells. However, most child-part components are not included in the materials transported by the train. All the components that are part of a *minomi*

[3] The identification of all welding cells starts with an S followed by the respective number.

car are indeed transported by the milk-run, but all the others are transported by an operator on foot that brings the necessary boxes to the cells.

3. Storage Locations

The majority of the welding cells are concentrated in one section of phase 2 where an empty-full Kanban system was implemented to improve cell supply. The delivery of full and collection of empty KLTs is done by the milk-run that circulates every hour between the welding cells and the supermarket. There are two relevant storage locations for this project: the supermarket and the child-part storage rack.

The child-part pallets are received in the dock of door 9 and then stored either on the supermarket or on the rack at the supermarket entrance (see Figure 13).

(A) (B)

Figure 13 – (A) Child-part components in the supermarket; (B) Child-part rack

The components that need to be transferred from the carton box to the KLT are stored in the supermarket. When it is needed, a full pallet is transferred either to the *minomi* preparation zone or to an adjacent area of the S28 welding cell. This happens because these components are transferred to KLTs before going to the cells, so there is a need to have a pallet located near the place where the operatio occurs. On the other hand, the components that go directly to the cells without any change of packaging are stored on the flow rack.

4. Child-part movements in Plant

There are 22 cells in the welding section phase 2. Each one produces multiple references, in some cases for more than one client. A part of understanding the components that were going to be integrated in the project was to know in which cells they were used. Direct participant observation, with the aid of SAP transactions (ZQHR) allowed to track component's movements inside the plant. To better picture this, a spaghetti diagram - a method that relies on lines to visualize the movement of objects or workers in a system (Kanaganayagam et al., 2015) - was developed (see Figure 14).

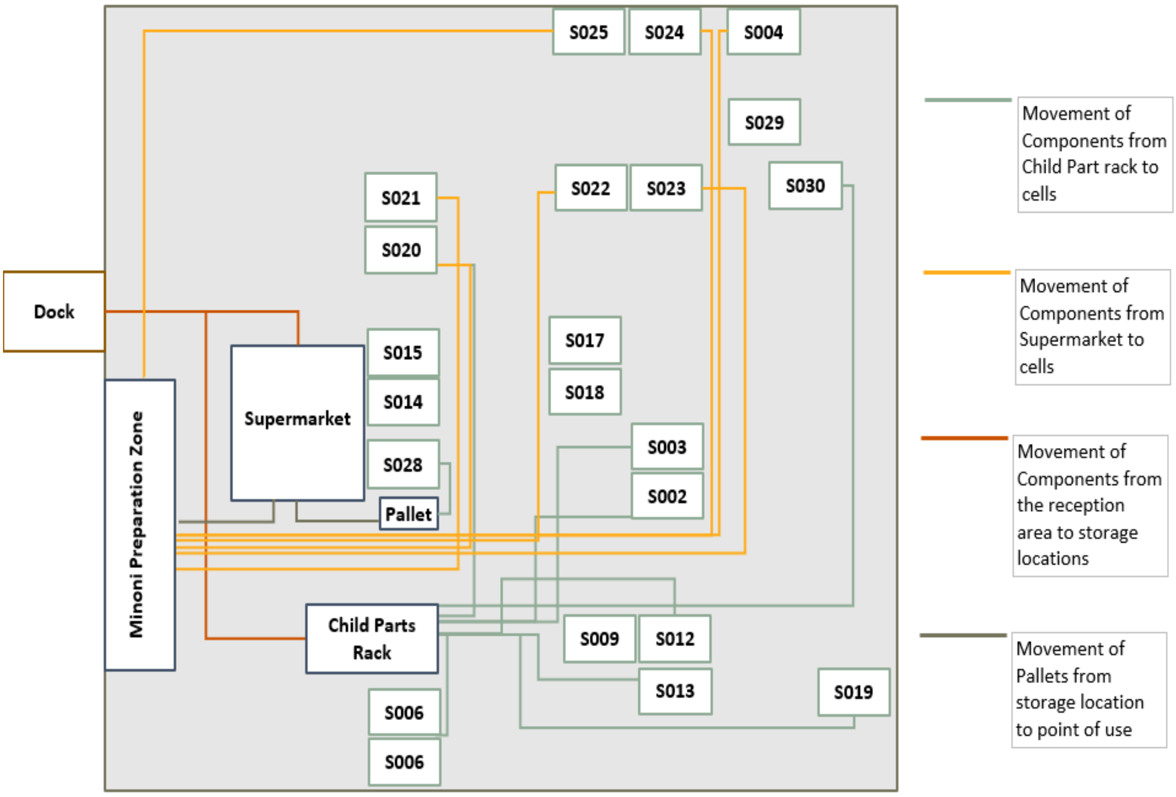

Figure 14 - Spaghetti Diagram

Besides these cells, there are a few others that are manual and are placed near the stamping lines. Even though some components are used in these manual cells their consumption is residual, so they were not included in the above spaghetti diagram above.

5. Order Planification and Placement (Material Resource Planning)

In Gestamp, the production is planned in a make-to-stock (MTS) logic and needs to cover 2 days of demand. To plan the production necessities, it is used a traditional MRP system incorporated in SAP, the company's ERP. This approach implies that the production is planned based on a push logic and that the results calculated by the MRP consider that the machines' capacity and daily hours are infinite. This in turn makes it obligatory to validate this plan against machine information and available hour, using a separate tool (Excel spreadsheet).

Each client submits their forecasts for the upcoming months and their confirmed orders for the next week, so that Gestamp's system can define the production schedule and purchasing needs. Then these purchasing orders, both firm and unconfirmed, are forwarded to each supplier via EDI or PDF depending on the technology owned. How often each supplier receives firm orders depends on their delivery schedule: for example, if the supplier delivers once a week, then he receives orders once a week. There is only the exception of one supplier of child components that delivers weekly, but the necessities are sent daily since as the orders Gestamp receives from its customers vary widely.

The VSM[4] presented in Figure 15 represents the current supply process of child-part components. The inventories seen between process are dimensioned to assure the synchronization of all the productive steps.

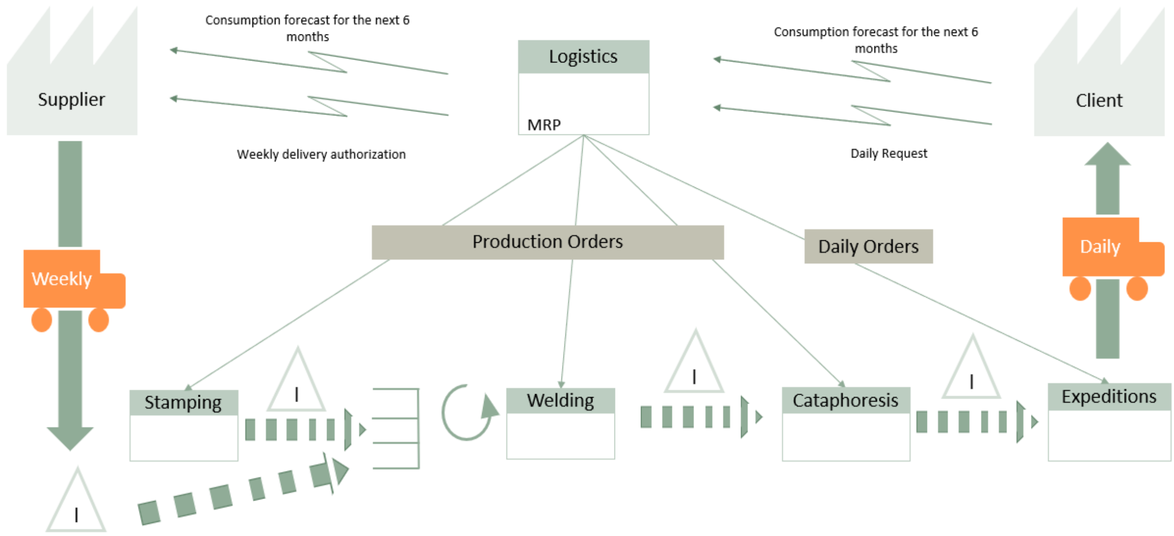

Figure 15 - Current state VSM

6. THE KANBAN SERVICE

The scope of the Kanban project had already been defined and it included 30 child-part references from six clients. At the time these were delivered by five different suppliers and the aim was to change this and have only one supplier in charge of providing all these references. This would imply that the chosen supplier chosen would have to buy from the other suppliers the references that he did not provide.

The plan was for the supplier to visit the plant and note the amount of KLTs needed to be delivered on the next visit based on the empty spaces he sees on the flow rack. Initially the idea would be for the supplier to come to plant once a week. This decision was made considering that the more visits contracted the higher the price asked by the supplier. The company would still send their demand forecast so the supplier would have a notion of the expected consumption.

Besides changing the child-part supplying dynamics, the company wanted to have these components at the plant under a consignation deal. In other words, even though the quantities defined in this project were going to be stored at Gestamp's plant, the supplier was still going to be the owner. Materials would only change ownership when they were moved to production (consumed). In terms of storage options, the company wanted to opt for flow racks that would be stored on phase 2. The locations where the materials would be stored was not completely defined at this point. However, the idea was to store these materials in gravity flow racks, which assure the maintenance of First-In-First-Out (FIFO).

[4] Value Stream Mapping (VSM) is the "process of mapping the primary material and information flows in converting raw material to finished product or creating a service of value that a customer is willing to pay for." (Martin, 2013)

Additionally, the company had the objective of eliminating all carton and plastic from the plant. One step closer to the concretization of this objective was to change the current transportation packaging (plastic bag inside a carton box) for a plastic box (KLT).

7. Information retrieved from SAP

The understanding of the current situation and the development of a solution needed to be supported by quantitative information retrieved from SAP database. It was important to analyze child-part component information like past consumption, upcoming production needs and supplier orders and past stock.

In total the information of five different transactions was analyzed. By downloading the ZMD04, the future production plan until the end of the year was collected, meaning the consumption forecast by reference and in pieces. With the ZMB51 transaction it was possible to retrieve the consumption from the previous year. Then with the transaction ZMC9 the daily number of pieces in stock since 2018 until present day was gathered. Also, with ZRCP the information about future supplier orders was retrieved. Finally, ZQNE made it possible to know the pieces per box and reference the supplier sends.

Consumption Forecast

It was decided that the daily consumption forecast would be collected from 10th of May until the end of the year and that the consumption on Saturdays and Sundays would be ignored. Even though this transaction shows the consumption on a daily basis, the data was studied by week. This decision was taken because the MRP for the closest two weeks establishes a plan with disjointed consumptions; however, for distant periods of time it aggregates the consumption of a week in just one or two days. As this transaction showed only the daily MRP results, it only had a field identifying the day of when the material is going to be consumed. As the data was going to be studied and posteriorly used in weeks, a week and month field were added to allow the creation of the dynamic table. A first analysis of the data allowed to assert that all references would have null consumption in week 31 and 32. This made sense since according to the information provided by the company this was the period of summer vacations. Consequently, if there is no production then there is no component consumption either.

Additionally, and to obtain a basic summary of the data that was going to be used to make the calculations, a few descriptive statistics were computed using KNIME. The data compiled in the dynamic table was copied to an extra excel to be read by the program. Then the following workflow was created (see Figure 16) to obtain the descriptive statistics.

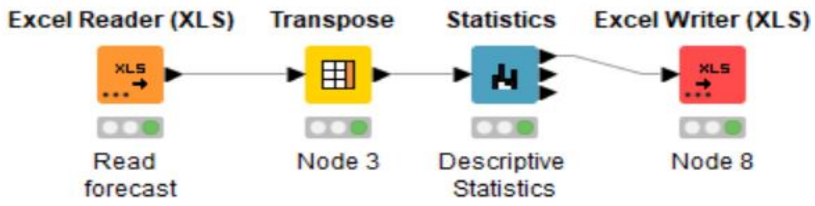

Figure 16 - Descriptive Statistics of ZMD04 results (KNIME workflow)

The average number of pieces to be used showed large discrepancies between references. Some had weekly consumptions of thousands of units while others only had a few hundreds. When looking at the standard deviation of each reference it was possible to assert that only three had a standard deviation inferior to 100. The high standard deviations values obtained for most references reflect a large amount of variation in the weekly consumption. Already on this initial phase this was seen as a very potential problematic issue since to implement Kanban, the consumption needs to be stable. The statistics obtained can be consulted in Appendix iI.

Additionally, it was noticed that twelve references had ten or more missing values, which means that they were not going to be consumed in at least ten weeks out of the 30-week span analyzed. The consumption of these references was considered intermittent (see Figure 17).

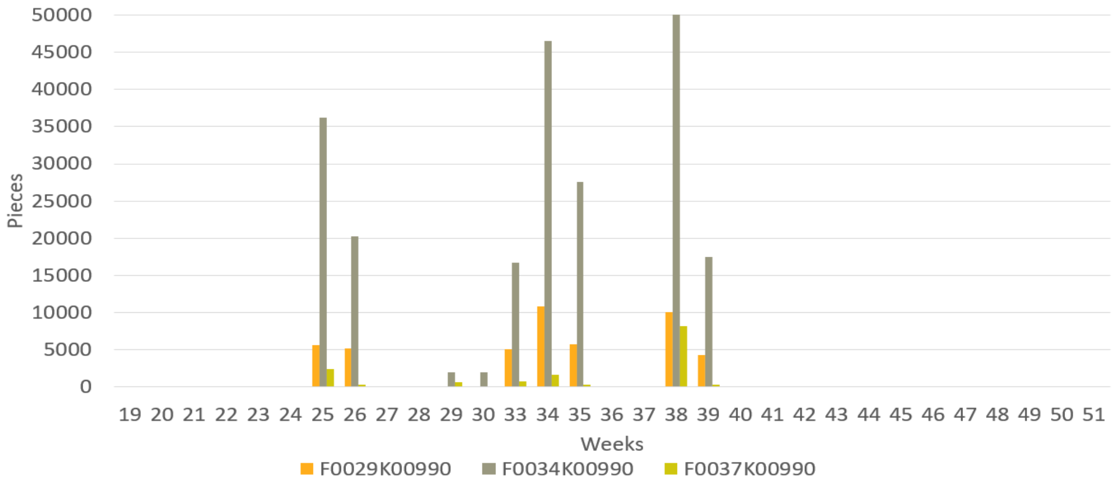

Figure 17 - References with intermittent consumption

More examples of references with intermittent consumption are shown in Appendix ii, Appendix iii and Appendix ivIV. In Appendix ii, it is shown a graph with two spare references from Volvo that are only sporadically consumed. Even so, the company decided to include these references on the project.

In contrast, there are references that throughout the 30 weeks are continuously consumed, some more steadily than others, as is the case of the references that that integrate *minomi* cars (see Figure 18).

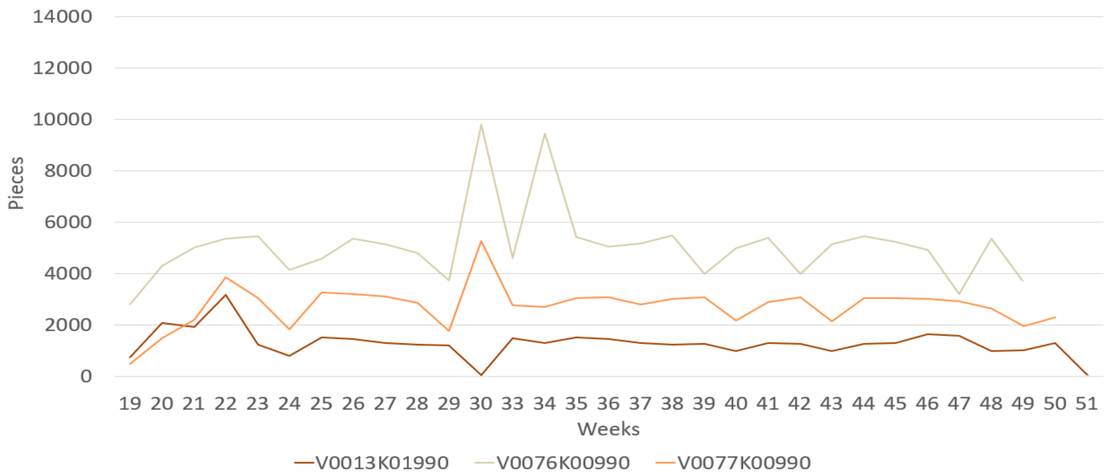

Figure 18 - References continuously consumption

PAST CONSUMPTION

Subsequently, the results from the ZMB51 were studied to see how the consumption behavior had change from 2020 to 2021. Once more, the data came from SAP in days but to keep every information on the same time scale the data was analyzed by weeks and in the same time period. In total from week 19 to week 51, in 2020, 2.617.558 child-part pieces were consumed while in 2021 the expected consumption is of 3.680.037.

To check how consumption had varied during 2020, the time period was extended to include all weeks of the year. From Figure 19, it is possible to see that in the first semester of 2020 the overall consumption was not very high. April (4) was the least productive month coinciding with the period where various governments decided to implement quarantine and close activities in most sectors. In the second semester of the year, the consumption increased significantly due to the reinstatement of activities in some sectors.

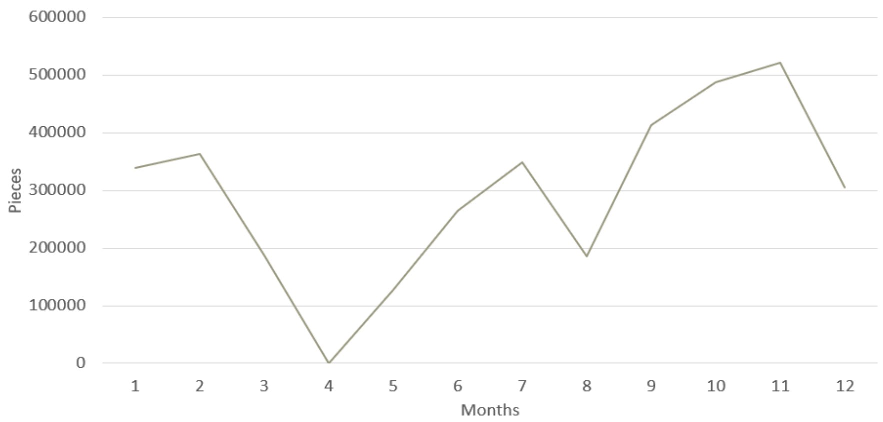

Figure 19 – Total number of pieces per month in 2020

Figure 20 aims of comparing the 2020 average weekly consumption with the expected value for 2021. The values for 2021 are higher in comparison to the consumption verified in the antecedent year, which can be explained by the fact that the industry is recovering from the turmoil caused by the 2020 pandemic burst. Similarly, to what was concluded from the forecast data, in 2020 there were also accentuated average consumption differences between references.

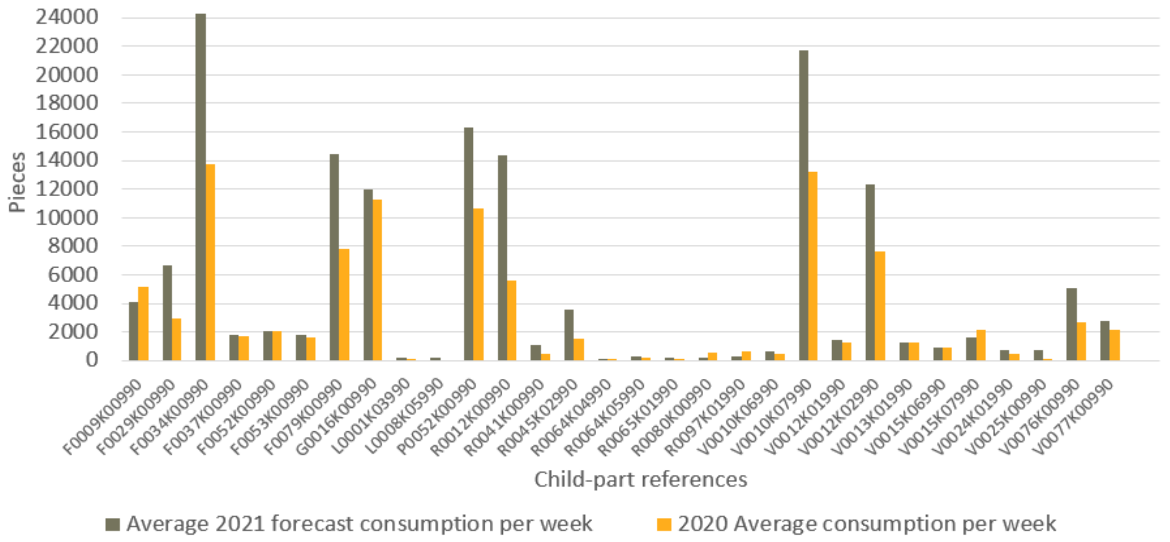

Figure 20 - Forecast consumption vs. past consumption

2020 Stock

The third transaction analyzed was the one that allowed to consult the number of pieces in stock (ZMC9) in previous years. Like before, the stock information came in days but was analyzed in weeks. In Figure 21 it is possible to see that the average weekly stock is generally high when compared to the average weekly consumption between week 19 and 51. For most references, the average stock per week can cover at least the triple average consumption.

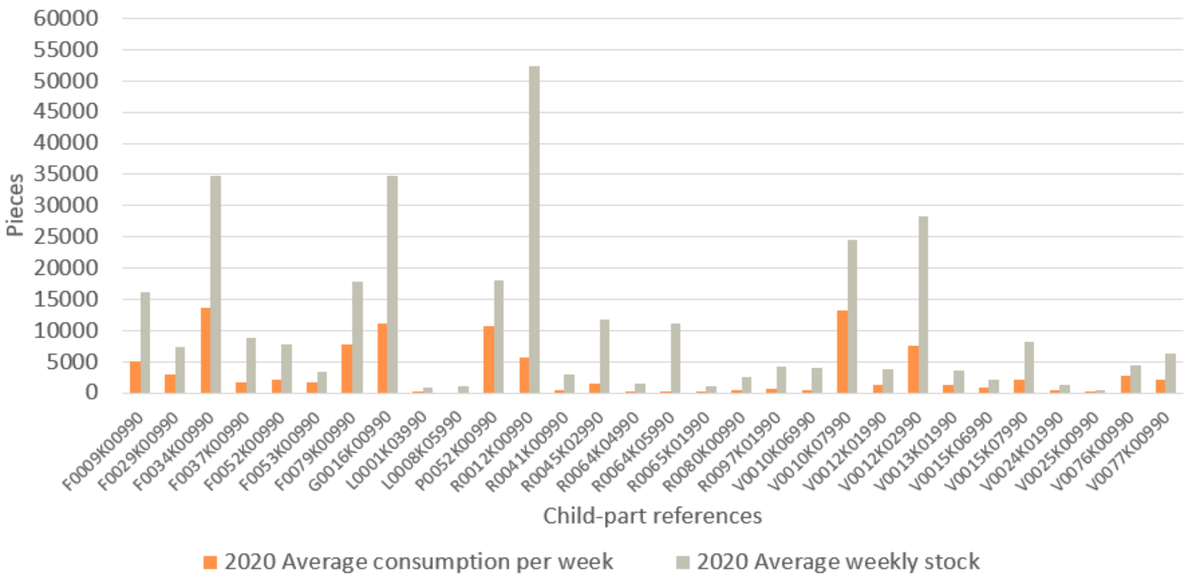

Figure 21 - 2020 consumption vs stock

SUPPLIER PACKAGING

Finally, the ZQNE transaction was collected in order to infer the number of pieces each box sent by the supplier has (SNP) for every reference. These quantities had been adjusted quite recently to follow company safety standards of a maximum weight per box of around 12kg (see Table 2).

Table 2 - Reference's SNP from ZQNE

References	SNP
F0009K00990	3000
F0029K00990	700
F0034K00990	2500
F0037K00990	2600
F0052K00990	1900
F0053K00990	1000
F0079K00990	70
G0016K00990	1100
L0001K03990	2000
L0008K05990	1000
P0052K00990	1800
R0012K00990	5000
R0041K00990	1500
R0045K02990	2700
R0064K04990	2500
R0064K05990	1000
R0065K01990	1500
R0080K00990	2500
R0097K01990	1200
V0010K06990	60
V0010K07990	2500
V0012K01990	50
V0012K02990	800
V0013K01990	75
V0015K06990	100
V0015K07990	1800
V0024K01990	90
V0025K00990	80
V0076K00990	50
V0077K00990	50

8. Additional Information

- The first letter from every reference identifies the client. For example, if a final product reference starts with an "F", it means that is a piece for Ford. In the case of the child-part references the same rule applies. From the 30 references included in the Kanban project, eight are from a client that in October is going to cease orders completely. Even so, the company chose to still include these references in the study; the references in question all start with an "R" and belong to Nissan.
- The company provided two procedures related with the supplier Kanban: one about the SAP process of creating and receiving orders; the other document explained how to liquidate the consumption of consign material.
- Prior to the integration in the company, this project had already started. At the time of the integration on the company, it had only been sent to the suppliers the consumption forecast (until the end of the year) of these references. As this was not enough for the supplier to establish a price for his service, it became necessary to make the kanban calculations and to compile every detail of the project on a Terms of Reference report. This document would be submitted to the suppliers interested in evaluating the project, so all would give a price for exactly the same service. The bridge between the company and the suppliers was going to be made by the south Europe divisional branch, since these types of projects are negotiated on a higher level to increase negotiation power.

3.1.2. Planification and Acting

The initial plan to define the number of kanbans needed was to use the formula referred in the Literature Review 2.3.2. subsection. However, and considering it was decided that the demand that was going to be used in the formula was the mean consumption from week 19 to week 51, in pieces, a plan had to be defined to overcome this problem. After a discussion with the logistics manager, it was decided that the outliers from the forecast data would be removed. According to him, final product's demand often had unusual variations and consequently the child-part's demand too, so a more conservative approach of including 99,7% of the values was taking. In regard to the other factors, the company considered that the container capacity would be equal to the current SNP (Standard Number of Parts), the policy variable would be of 15%, and the supplier visits to the plant would be once a week.

According to the plan established, before making any calculations, the consumption forecast values that did not belong to the interval $[\bar{X} - 3\sigma; \bar{X} + 3\sigma]$ were to be removed. Considering the mean and standard deviations obtained in KNIME the lower and upper limit were defined for every reference. In total, ten values were eliminated from nine different references. Afterwards, the new mean was calculated using KNIME. One side note needs to be made to explain the case of the L008K05990 reference: this reference was to be consumed only for one week. After discussing this with the logistics manager it was decided not to perform an outlier analysis and proceed with the inclusion of this reference in the project. In the following Table 3, the summary of the values obtained is synthetized, in a different color are identified the references whose mean changed due to the elimination of values outside the limits.

Table 3 - Outlier elimination limits

References	Mean	Standard Deviation	Lower Limit	Upper Limit	New Mean
F0009K00990	3543	3933	0	15342	2702
F0029K00990	1513	3077	0	10742	1203
F0034K00990	7055	14392	0	50232	5614
F0037K00990	470	1523	0	5038	213
F0052K00990	1675	1197	0	5267	1675
F0053K00990	929	993	0	3907	929
F0079K00990	14447	8392	0	39624	14447
G0016K00990	11629	6359	0	30706	11629
L0001K03990	32	152	0	489	32
L0008K05990	7	37	0	118	0
P0052K00990	14220	10831	0	46714	14220
R0012K00990	11103	7817	0	34554	11103
R0041K00990	703	510	0	2233	703
R0045K02990	2417	1717	0	7567	2417
R0064K04990	54	71	0	266	54
R0064K05990	214	279	0	1050	172
R0065K01990	106	137	0	519	86
R0080K00990	121	88	0	385	121
R0097K01990	185	148	0	630	185
V0010K06990	658	278	0	1492	658
V0010K07990	21747	7664	0	44738	21747
V0012K01990	1274	683	0	3322	1274
V0012K02990	12329	3578	1595	23064	11940
V0013K01990	1289	545	0	2925	1289
V0015K06990	683	514	0	2223	683
V0015K07990	1334	1040	0	4452	1334
V0024K01990	691	263	0	1479	691
V0025K00990	729	185	174	1283	753
V0076K00990	4903	1675	0	9926	4903
V0077K00990	2653	943	0	5482	2653

As mentioned, the plan was for the supplier to come to replenish goods once a week, the supplier on a visit *i* would bring the KLTs he saw that were consumed on his last visit (*i-1*). This meant that the KLTs noted on the visit *i* were only going to be brought on visit *i+1*. Figure 1 represents this. The supplier comes to the plant (visit *i*) and sees that the flow rack has 5 KLTs spaces empty and he has brought 3 (referring to the quantity he saw he needed to replenish on visit *i-1).* After inserting them on the rack, he notes since his last visit 2 more were consumed (5 spaces minus 3KLTs replenished). On his next visit (*i+1),* he sees 7 KLTs spaces empty and he has brought the 2 he noted on the last visit. After replenishing the rack, he knows that in *i+2* he needs to bring 5 KLTs.

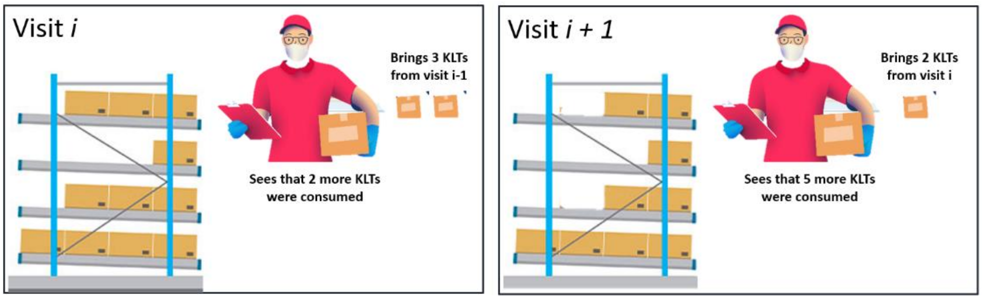

Figure 22 - Replenishment scheme

In conclusion, in each visit the supplier checks the quantities that were consumed since the last time he was at the plant, which means he takes one week to acknowledge an order (T_{order}). However, when he notes that a new order was made, he only brings it on his next visit, which takes one more week (T_{ransit}). So, this means that for a supplier that comes once a week and follows this acknowledge-replenishment strategy the lead time ($T_{ransit} + T_{order}$) is two weeks.

The computation of the Kanban formula with all the factors established in excel is shown in Figure 23. It is possible to see that, besides the formula, two excel function were added: ROUND.UP and IF. The first function was added because there are no half containers, and it was more reasonable to have surplus. The second function served to force the kanban number to be at least two, which was a decision taken by the company.

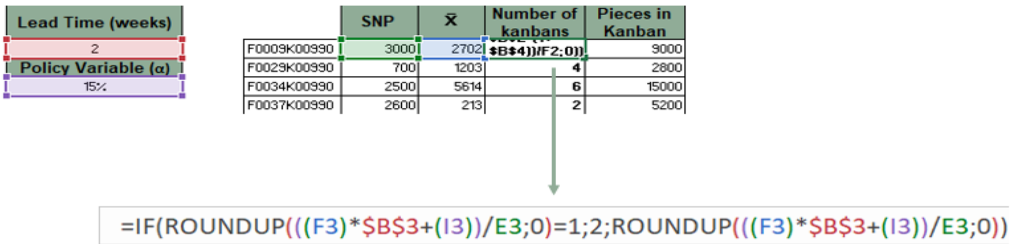

Figure 23 - Kanban formula computation on Excel

The table with the number of kanbans for all the references can be consulted in Appendix v. Additionally, it was created a graph to simplify the analysis of the results (see Figure 24).

	Reference:																V0015K07990															
	19	20	21	22	23	24	25	26	27	28	29	30	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Forecast	990	1869	345	1950	1950	3450	1950	1950	1980	1950	0	2490	2712	1950	1950	1980	1950	1950	1980	1980	1950	1950	30	0	0	0	30	0	0	30	30
Pieces in Kanban	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600	3600

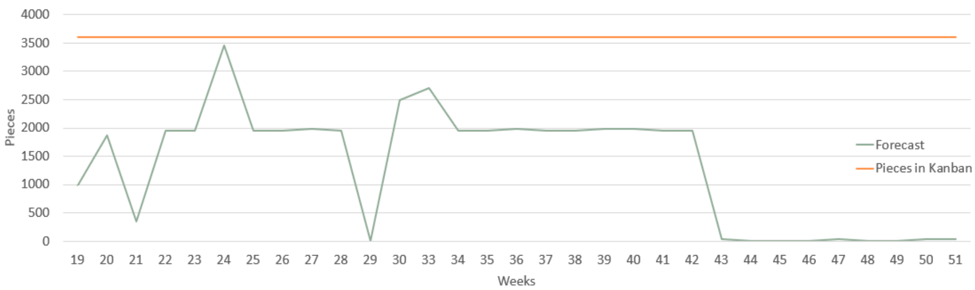

Figure 24 - Excel sheet results

The graph shown in the figure 24 had the purpose of facilitating the task of comparing the consumption forecast and the number of pieces in Kanban for each reference. The latter data was extracted by multiplying the number of kanban containers obtained by the number of pieces one container has ($Pieces\ in\ Kanban = Number\ of\ Kanbans * SNP$).

3.2. Second Action Research Iteration

3.2.1. Observation and Reflection

From the observation of the results, the following information was gathered:

- The total number of kanbans of this solution is 1151.
- Eight references had the number of kanbans forced to be two.
- The four references with highest number of kanbans (F0079K00990, V0012K01990, V0076K00990 and V0077K00990) combined have 76,7% of the total.
- Eight references were signalized because there were weeks where the consumption forecast was superior to the number of pieces in the kanban. The summary of the references and respective weeks this happened is compiled in Table 6.
- Four references with more than fifty kanbans (F0079K00990, V0012K01990, V0076K00990 and V0077K00990).

After this first observation, a more thorough analysis of the results was conducted. There was a suspicion that the SNP of various references was not optimized. To verify if this was true, considering the number of kanban calculated and maintaining average demand, policy variable and container capacity values equal to before, the Kanban formula was computed in order to calculate the lead time. In theory, it would be expected to obtain a lead time of two weeks for all the references.

In Table 4 it the lead time results obtained are shown. The eight references that presented a lead time superior to 4 weeks are highlighted in light orange. It was raised the hypothesis that these were the cases where the original number of kanbans was equal to one but forced to be two. The part of the Excel formula that forced the kanban number to be two was removed and in this way, it was possible to validate this hypothesis.

Once it was exposed what was happening with these references, the next step was to comprehend the reason why. Looking at the data it became clear that this was explained by these reference's positive discrepancy between average demand and SNP (SNP very high when compared to average demand). The fact that these reference's number of kanbans was pushed to two only aggravated this situation. The solution could not pass through the reduction of the number of kanbans, since it was a company requirement. However, even if it could be done, it would not solve the core issue, it would only make it slightly less obvious. The mitigation of this problem passes through the SNP adjustment with the Kanban formula in order to SNP:

$$Ideal\ SNP = \frac{D * 2 * (1 + 0{,}15)}{Number\ of\ kanbans} \tag{2}$$

Table 4 - Coverage in weeks of first iteration

References	SNP	No. kanbans	Pieces in kanban	Mean	Lead Time
F0009K00990	3000	3	9000	2702	2,897
F0029K00990	700	4	2800	1203	2,024
F0034K00990	2500	6	15000	5614	2,323
F0037K00990	2600	2	5200	213	21,196
F0052K00990	1900	3	5700	1675	2,958
F0053K00990	1000	3	3000	929	2,808
F0079K00990	70	475	33250	14447	2,001
G0016K00990	1100	25	27500	11629	2,056
L0001K03990	2000	2	4000	32	108,042
L0008K05990	1000	2	2000	206	8,442
P0052K00990	1800	19	34200	14220	2,091
R0012K00990	5000	6	30000	11103	2,350
R0041K00990	1500	2	3000	703	3,711
R0045K02990	2700	3	8100	2417	2,914
R0064K04990	2500	2	5000	54	80,951
R0064K05990	1000	2	2000	172	10,111
R0065K01990	1500	2	3000	86	30,334
R0080K00990	2500	2	5000	121	35,846
R0097K01990	1200	2	2400	185	11,267
V0010K06990	60	26	1560	658	2,061
V0010K07990	2500	21	52500	21747	2,099
V0012K01990	50	59	2950	1274	2,014
V0012K02990	800	35	28000	11940	2,039
V0013K01990	75	40	3000	1289	2,024
V0015K06990	100	16	1600	683	2,038
V0015K07990	1800	2	3600	1334	2,347
V0024K01990	90	18	1620	691	2,038
V0025K00990	80	22	1760	753	2,033
V0076K00990	50	226	11300	4903	2,004
V0077K00990	50	123	6150	2653	2,016

The SNP (container capacity) affination is done taking in consideration the number of pieces needed in the lead time defined with the policy variable margin and a number of kanbans priorly calculated. This adjustment was done for the eight references mentioned and the results obtained can be seen in Table 5. After the adjustment a value close to two weeks was obtained, as expected when the lead time was calculated with the formula referred earlier. As a consequence of this adjustment the number of pieces in kanban decreased, since it results from the product of the number of kanbans by the SNP.

Table 5 – SNP adjustment

References	SNP	No. kanbans	Pieces in kanban	Mean	Coverage	Updated		
						SNP	Pieces	LT
F0037K00990	2000	2	4000	213	21,196	246	492	2,306
L0001K03990	2000	2	4000	32	108,042	38	76	2,361
L0008K05990	1000	2	2000	206	8,442	237	474	2,301
R0064K04990	2500	2	5000	54	80,951	62	124	2,309
R0064K05990	1000	2	2000	172	10,111	198	396	2,302
R0065K01990	1500	2	3000	86	30,334	99	198	2,302
R0080K00990	2500	2	5000	121	35,846	140	280	2,309
R0097K01990	1200	2	2400	185	11,267	214	428	2,311

In Table 4 are also highlighted in brown the four reference whose kanban number is greater than half a hundred. This high number is also explained by these references SNPs. In these cases, these references have a negative discrepancy between average demand and SNP (SNP very low when compared to average demand). Unfortunately, there is no solution for this situation since the number of kanban could not increase as it would otherwise surpass company's safety standards.

It then seemed reasonable to further analyze the references whose number of pieces in kanban did not cover demand peaks. The summary of the references and weeks where the kanban quantity was not enough is presented in Table 6 .

Table 6 - References with material shortages

References	Weeks
F0009K00990	34, 38
F0029K00990	25, 26, 33, 34, 35, 38, 39
F0034K00990	25, 26, 33, 34, 35, 38, 39
F0037K00990	38
F0079K00990	30, 51
P0052K00990	47, 50
V0013K01990	22

Additionally, the following aspects were noticed:

- Weeks with shortages of reference F0009K00990 coincide with the weeks whose consumption forecast was an outlier, which also happens with week 34 of reference F0029K00990 and week 38 of reference F0037K00990. In Figure 25 the consumption forecast values that are not covered by the number of pieces in kanban are highlighted in orange.
- Regarding reference F0029K00990, all consumption forecast values different from zero are not covered.
- Regarding reference F0034K00990, most of the consumption forecast values different from zero are not covered.

Reference:															
	19	20	21	22	23	24	25	26	27	28	29	30	33	34	35
Forecast	0	185	0	0	0	320	8065	5155	1675	2795	2970	1110	8250	15890	6335
Pieces in Kanban	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000

F0009K00990																
	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Forecast	2600	3435	15600	6100	2240	1480	1860	2425	1665	2045	2425	4080	1850	2230	2610	4440
Pieces in Kanban	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000

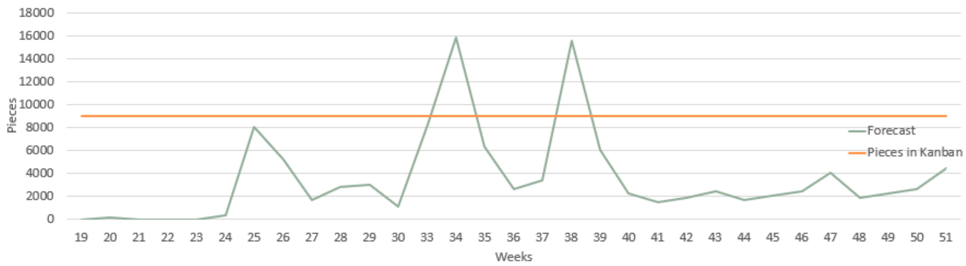

Figure 25- Reference whose consumption forecast is higher than number of pieces in Kanban

Of this set of eight references, it was noticed that three have more than twenty weeks with consumption equal to zero, even though they have a positive skewness. This implies that these reference's boxplots have a longer upper tail, and their mean is superior to the median. Even though the mean is sensible to these high values it is also sensible to the zeros. Specially in the case of F0029K00990 and F0034K00990 that are not consumed most of the time, but when they are, the consumption is very high, it is possible to conclude that using the average consumption with a safety margin of 15% is definitely not the best option.

A meeting with the logistics manager and the rest of the team involved in the project was schedule in order to present the solution developed and the conclusions found. From this meeting two points were made: first there were too many weeks where the number of pieces in kanban could not even cover consumption forecast; and second even if the SNP could be adjusted down that would not be done for now since it would make the supplier increase the price asked for the service.

3.2.2. Planification and Acting

Considering the company stance regarding the first solution it was imperative to plan and design a new Kanban system. The next solution used again the Kanban formula but this time a safety stock was calculated for every reference, instead of using a policy variable common to all references. This new iteration intended to design a Kanban system that could cover most of the material shortages, but this did not mean that all would be eliminated. For example, if the service level defined was of 99%, it would be expected that in 1% of times the safety stock will not be enough.

In this specific case, as the lead time would be fixed, there is only the necessity to protect the system from the demand variability. Considering this and the new plan established, a safety stock was calculated for every reference according to the following formula (King, 2011; Wild, 2018):

$$Safety\ Stock\ (SS) = Z * \sqrt{Lt} * \sigma_{demand} \quad (3)$$

The Z-score value is related with the service level established. For example, for an inventory that is enough for 98% of the time, the Z-score is approximately two, which means that the safety stock calculated is going to protect the system against two standard deviations from the mean. It was decided that rather than assuming one service level for all clients, it would vary depending on the client. This value was defined by the company considering each client relevance. For the references of Volkswagen, PSA and Ford a service level of 99% was considered, for the references of Renault- Nissan of 95% and for the two references of Volvo of 85%.

To apply the Kanban formula, the mean was used but without removing the outliers, since when using a service level inferior to 100% the outliers are already being excluded. Regarding the other parameters, no alterations were made to the Kanban system: the supplier should visit the plant once a week and the SNPs were the ones defined based on weight standards. The formula computed was again the Toyota's Kanban formula, with the only alteration being the policy variable determination:

$$y = \frac{D * (T_{order} + T_{transit}) + SS}{a} \tag{4}$$

The number of kanbans obtained can be seen in Table 7.

Table 7 - Second solution number of kanbans

References	SNP	Mean	Standard Deviation	Z- score	Safety stock	No. Kanbans
F0009K00990	3000	3543	3933	1,28	7120	5
F0029K00990	700	1513	3077	2,33	10138	19
F0034K00990	2500	7055	14392	2,33	47425	25
F0037K00990	2600	470	1523	2,33	5018	3
F0052K00990	1900	1675	1197	2,33	3945	4
F0053K00990	1000	929	993	2,33	3272	6
F0079K00990	70	14447	8392	2,33	27654	808
G0016K00990	1100	11629	6359	2,33	20954	41
L0001K03990	2000	32	152	1,04	224	2
L0008K05990	1000	7	37	1,04	55	2
P0052K00990	1800	14220	10831	1,65	25275	30
R0012K00990	5000	11103	7817	1,65	18241	9
R0041K00990	1500	703	510	1,65	1190	2
R0045K02990	2700	2417	1717	1,65	4006	4
R0064K04990	2500	54	71	1,65	166	2
R0064K05990	1000	214	279	1,65	651	2
R0065K01990	1500	106	137	1,65	321	2
R0080K00990	2500	121	88	1,65	205	2
R0097K01990	1200	185	148	1,65	346	2
V0010K06990	60	658	278	2,33	917	38
V0010K07990	2500	21747	7664	2,33	25254	28
V0012K01990	50	1274	683	2,33	2250	96
V0012K02990	800	12329	3578	2,33	11791	46
V0013K01990	75	1289	545	2,33	1797	59
V0015K06990	100	683	514	2,33	1693	31
V0015K07990	1800	1334	1040	2,33	3426	4
V0024K01990	90	691	263	2,33	865	25
V0025K00990	80	729	185	2,33	609	26
V0076K00990	50	4903	1675	2,33	5518	307
V0077K00990	50	2653	943	2,33	3108	169

3.3. Third Action Research Iteration

3.3.1. Observation and Reflection

From the observation conducted it was possible to collect the following information:

- The total number of kanbans of this solution is 1799.
- The three references with highest number of kanbans (F0079K00990, V0076K00990 and V0077K00990) combined have almost 71,37% of the total.
- Six references had the number of kanbans forced to be two.
- Two references were signalized because there were weeks where the consumption forecast was superior to the number of pieces in the kanban.

– Five references with more than fifty kanbans (F0079K00990, V0012K01990, V0076K00990 and V0077K00990).

In this solution, the number of kanbans increased 56,2% in relation to the first solution presented. This is justified by the fact that these two iterations used two different tactics to handle demand variation. Even though both solutions used the average consumption forecast, on the first one, it was performed an outlier analysis. On the other hand, on this latter iteration the consumption forecast was used without any outlier analysis, and the safety stock calculated had in attention the data variability.

The reference that had the highest increase in number of kanbans was F0079K00990 (+333), followed by V0076K00990 (+81). Each reference increase in terms of number of kanbans was not a direct consequence of high standard deviation, but rather a consequence of a high ratio of standard deviation/SNP. For example, F0034K00990 was the reference with highest standard deviation (14392) but was not the one with highest increase in number of kanbans because each container of this reference had 2500 pieces. In contrast, F0079K00990 had a lower standard deviation (8392), but as each container only had 70 pieces a significant increase in number of kanbans it was confirmed.

In this iteration the problem of references whose number of pieces was not enough to cover consumption forecast peaks was solved for most references. Still, F0009K00990 had two weeks (34 and 38) where the kanban quantity would not cover the consumption forecast (see Figure 26); the same happened for F0037K00990 in week 38.

Reference: F0009K00990

	19	20	21	22	23	24	25	26	27	28	29	30	33	34	35
Forecast	0	185	0	0	0	320	8065	5155	1675	2795	2970	1110	8250	15890	6335
Pieces in Kanban	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000

	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Forecast	2600	3435	15600	6100	2240	1480	1860	2425	1665	2045	2425	4080	1850	2230	2610	4440
Pieces in Kanban	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000

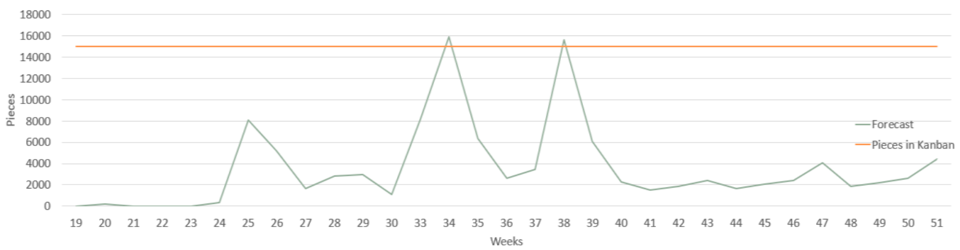

Figure 26 – Demand peak coverage obtained in the second iteration

Once again, a meeting with the decision makers of the project was scheduled to discuss this new solution. The fact that for most references the number of pieces in kanban covered the consumption forecast peaks was a positive point highlighted. However, this solution did not please completely the team decision makers.

Amidst this discussion, a new restriction of space was raised. It was imposed that these materials could only occupy approximately 25 m^2. Subsequently, even though the numbers indicated that the number of KLT calculated could not be stored in the area available, a prospection of the space needed was requested, using a general flow rack.

To do said prospection it was used the dimensions of flow rack from Kanban Storage (2020) that even though it probably would not be used in the future, it gave an idea of the space needed. The flow rack considered had 1900x1230x2340 mm and 2,337m^2, having three levels of shelfs. The useable width was of 1790mm and depth of 1200mm. Regarding the KLT, it had been settled that all the references would be supplied in containers with same dimensions and to do so, the KLTs had to have 400x300x147 mm. This meant that the rack would fit four lanes of three KLTs each (Kanban Storage, 2016), with the 400mm KLT facing forward. It is important to mention that each lane can only have KLTs from the same reference, but one level can have various references.

To calculate the area it would occupy, first it was asserted how many lanes each reference would need according to the number of kanbans it had. For example, as each lane as 3 KLT, a reference with 12 kanbans would need 4 lanes. After doing this for every reference, the total number of lanes was summed and then divided by the total number of lanes one rack has (12). In the end, a total of 51 racks would be needed, which meant that they would occupy 119,2 m^2. The results obtained can be consulted in Table 8.

These results were communicated to the team and as it was clear this solution was considered not to be feasible.

Table 8 - Space occupied by the number of kanbans

References	SNP	No. kanbans	No. Lanes
F0009K00990	3000	5	2
F0029K00990	700	19	7
F0034K00990	2500	25	9
F0037K00990	2600	3	1
F0052K00990	1900	4	2
F0053K00990	1000	6	2
F0079K00990	70	808	270
G0016K00990	1100	41	14
L0001K03990	2000	2	1
L0008K05990	1000	2	1
P0052K00990	1800	30	10
R0012K00990	5000	9	3
R0041K00990	1500	2	1
R0045K02990	2700	4	2
R0064K04990	2500	2	1
R0064K05990	1000	2	1
R0065K01990	1500	2	1
R0080K00990	2500	2	1
R0097K01990	1200	2	1
V0010K06990	60	38	13
V0010K07990	2500	28	10
V0012K01990	50	96	32
V0012K02990	800	46	16
V0013K01990	75	59	20
V0015K06990	100	31	11
V0015K07990	1800	4	2
V0024K01990	90	25	9
V0025K00990	80	26	9
V0076K00990	50	307	103
V0077K00990	50	169	57
Total no. lanes			612
Total no. racks			51
Area occupied by the racks (m2)			119,2

3.3.2. Planification and Acting

Taking into account the fact that the previous solution still did not satisfy the team, a new one had to be thought and developed. To establish a plan for the next solution, another meeting with the logistics manager was conducted. In this meeting it was decided that the daily demand would be equal to the maximum consumption rate per day. In other words, it would be considered that the welding machines would be producing products on full capacity during the day, consuming the maximum possible number of components (child-part references). This new solution would contrast sharply with the previous solutions developed and presented, since the determination of demand would not be equal to the necessities forecast. The reason that supported this decision of not using the forecasts was the fact that the production planner more often than not adjusted the schedule made by the MRP, either anticipating or delaying production based on the conditions (for example, unexpected or canceled orders). For instance, when this decision was made, the company had just recently gotten the information that one of the clients that would initially be inactive in August was working, coinciding with the plant's summer vacations. This led to the anticipation of production during the month of July in order to produce enough stock to guarantee that the client's demand was covered. It was even discussed the hypothesis of using the contracted maximum value of "father" products that can be order per week. However, this did not go through for the fact that even though there is a maximum quantity each client can order per piece, production can be anticipated.

Considering that using the maximum consumption rate per day would change the demand units from weeks to days, the lead time would start to be in days too. However, if the lead time of two weeks was maintained the number of kanbans could not be store in the area available. So, in this meeting it was decided that the best option would be to reduce the lead time.

Besides the two-alterations mentioned, the plan included the alteration of the SNPs of the references that were incorporated on *minomi* cars. This change was made with the purpose of eliminating the extra activity of transferring pieces from the supplier packaging to the KLT involved in *minomi* car preparation. The new SNP was aligned with the number of pieces of the other *minomi* car components, in an effort to standardize these transportation elements.

The team in charge of the project asked to have an option where they could input the average daily consumption to check if the lead time could be altered. This was useful, in the case the company for example during vacation wanted to propose the supplier the alteration of visit's frequency.

The alteration of the number of supplier visits, implied that the lead time would be now of four days. Even though the time unit changed from weeks to days, the acknowledge-replenishment strategy is the same. The supplier every two days is going to bring the number of KLTs he saw consumed on his last visit, which means that he takes two days to check the amount consumed (T_{order}) and two more to replenish it ($T_{transit}$). So, the lead time is four.

Regarding the determination of the demand, the information from three other transactions had to be collected in order to know the maximum consumption of each reference. The ZQHR gave information about which welding cells each child-parts went to and the production rate per hour (in Figure 27 under the name "zqhr.Psto Tbjo" and "Cantidad base ref. salida"). Then the ZQLM indicated the "father" product where the child-parts were incorporated as well as the BOM quantity, in Figure 27 correspond to "Material" and "BOM QT.", respectively. Finally, the ZQLM gave information about the average daily consumption until the end of the year ("Tabla7. NDM" in Figure 27). In both the ZQHR and ZQLM there were references that had been substituted by others and were no longer produced. To easily distinguish them ZLCN was downloaded to help clear the data. The aim was to connect all these transactions in only one table with all the information needed. To do so the excel function VLOOKUP would not work, since it only returns the first value it finds, and the problem was that one reference could be produced in various welding cells and can be assembled to different "father" product. To detour this problem, "Merge Queries" excel function, which allows to combine in one query two other queries connected by a common column, was used. In this case, first a merge between ZQHR and ZQLM was made by reference ("Component" column) and then the result was merged with ZLCN by "father" product ("Material" column). In Figure 27, it is presented a portion of the table that obtained after the two merges.

Merge between ZQHR + ZQLM + ZLCN					
Material	Componente	BOM QT.	zqhr.PstoTbjo	Cantidad base ref. salida	Tabla7. NDM
F0011S00990	F0009K00990	1	S003	286	94,309
F0020S00990	F0009K00990	1	S003	286	84,553
F0009S00990	F0009K00990	1	S003	**320**	77,854
F0012S00990	F0009K00990	1	S003	286	54,634
F0021S00990	F0009K00990	1	S003	286	46,829
F0018S00990	F0009K00990	1	S003	**320**	41,301
F0010S00990	F0009K00990	1	S003	314	12,358
F0019S00990	F0009K00990	1	S003	**320**	12,358
F0048S01990	F0009K00990	1	S017	136	380,528
F0022S00990	F0009K00990	1	S017	**179**	32,358
F0013S00990	F0009K00990	1	S017	**179**	20,813
F0024S00990	F0009K00990	1	S017	178	18,211
F0014S00990	F0009K00990	1	S017	**179**	10,407
F0023S00990	F0009K00990	1	S017	181	0
F0047S00990	F0009K00990	1	S017	136	0
F0048S00990	F0009K00990	1	S017	136	0
F0048S02990	F0009K00990	1	S017	136	0

Figure 27 - Resulting table from the two merges

In Figure 27, the materials with NDM equal to zero (null consumption), meaning that for whatever reason these materials are no longer produced, are highlighted in orange. In particular example shown, this child-part reference is consumed in two different welding cells, S003 and S017, and is incorporated in thirteen different materials. To find the maximum consumption it was considered that both cells would be producing the father product at maximum production rate. In the example both cells have multiple references with the highest production rate, but it can only produce one at a time. So, it makes it indifferent which one it is. It only matters that in S003 a maximum of 320 components are consumed per hour and in S017, 179. These quantities were summed directly since the BOM was one, then the sum was multiplied by 21,9 which was the maximum number of working hours available (three shifts of approximately seven point three hours each). Finally, the result was multiplied by 0,82 to take in consideration the cells OEE (Overall Equipment Efficiency)[5].

[5] The OEE is a performance indicator and is obtained from the product of machine availability (A), production rate (PR) and quality rate (QR) (Relkar & Nandurkar, 2012). As closer to 1 the better.

In Figure 28, the maximum consumption values obtained for each reference, considering all the factors mentioned (BOM, hours available and OEE) are presented. Meanwhile, one of the initial references (P0052K0990) was eliminated since the father component stopped being produced by the company.

	Welding Cells																					Consumption per hour	Consumption per day	Consumption with OEE
Component	S002	S003	S004	S006	S009	S012	S013	S014	S015	S017	S019	S020	S021	S022	S023	S024	S025	S028	S030	SM04	SM06			
F0009K00990		320								179												499	10928,1	8962
F0029K00990		274																				274	6000,6	4921
F0034K00990	432																					432	9460,8	7758
F0037K00990	446																					446	9767,4	8010
F0052K00990		356																				356	7796,4	6394
F0053K00990										246												246	5387,4	4418
F0079K00990																		220				220	4818	3951
G0016K00990		419																				419	9176,1	7525
L0001K03990									180												680	860	18834	15444
L0008K05990																					230	230	5037	4131
R0012K00990						210		64			104									400		778	17038,2	13972
R0041K00990							21															21	459,9	378
R0045K02990						126					78											204	4467,6	3664
R0064K04990											26											26	569,4	467
R0064K05990											52											52	1138,8	934
R0065K01990											52											52	1138,8	934
R0080K00990																				200		200	4380	3592
R0097K01990																				68		68	1489,2	1222
V0010K06990				17																		17	372,3	306
V0010K07990	328																				229	557	12198,3	10003
V0012K01990												34										34	744,6	611
V0012K02990												68							120			188	4117,2	3377
V0013K01990													34									34	744,6	611
V0015K06990					16																	16	350,4	288
V0015K07990											252											252	5518,8	4526
V0024K01990																	25					25	547,5	449
V0025K00990														33								33	722,7	593
V0076K00990															58							58	1270,2	1042
V0077K00990			34													36	35					105	2299,5	1886

Figure 28 – Maximum Consumption

In the following Table 9, it is possible to check the results obtained from this iteration. Besides changing the lead time and the way of determining demand, the SNP of the six references transported in *minomi* cars was changed (highlighted in light orange in Table 9). It is also important to mention that the policy variable in this case was not considered. As it was not possible to have consumptions higher than the maximum the machines can produce, no policy variable was considered.

Table 9 - Results from the third solution

References	SNP	Demand	No. kanbans
F0009K00990	3000	8962	12
F0029K00990	700	4921	29
F0034K00990	2500	7758	13
F0037K00990	2600	8010	13
F0052K00990	1900	6394	14
F0053K00990	1000	4418	18
F0079K00990	70	3951	226
G0016K00990	1100	7525	28
L0001K03990	2000	15444	31
L0008K05990	1000	4131	17
R0012K00990	5000	13972	12
R0041K00990	1500	378	2
R0045K02990	2700	3664	6
R0064K04990	2500	467	2
R0064K05990	1000	934	4
R0065K01990	1500	934	3
R0080K00990	2500	3592	6
R0097K01990	1200	1222	5
V0010K06990	60	306	21
V0010K07990	2500	10003	17
V0012K01990	55	611	45
V0012K02990	800	3377	17
V0013K01990	72	611	34
V0015K06990	80	288	15
V0015K07990	1800	4526	11
V0024K01990	33	449	55
V0025K00990	33	593	72
V0076K00990	36	1042	116
V0077K00990	60	1886	126

Once these quantities were calculated a small interface was created by company's requirement. The lead time (LT) was calculated for each reference by multiplying its number of kanbans by the respective SNP, and the result of this divided by the average daily demand inserted by the user (Kanban formula in order of LT). The frequency ($T_{transit}$) it was calculated by dividing the lead time obtained by two, since $T_{transit}$ is equal to T_{order}. As it is possible to see in Table 10, for the example considered, there are three references with frequency of approximately two days. The rest have very high values. This means the supplier needs to come to plant every two days because of three references. If it was not for these references the supplier could come to the plant with lower frequency.

Table 10 – Functionality added

References	SNP	No. kanbans	Average daily demand	Lead Time
F0009K00990	3000	12	692	52
F0029K00990	700	28	495	39
F0034K00990	2500	13	2564	12
F0037K00990	2600	12	124	252
F0052K00990	1900	14	262	101
F0053K00990	1000	18	218	82
F0079K00990	70	220	2545	6
G0016K00990	1100	27	2800	10
L0001K03990	2000	31	30	2066
L0008K05990	1000	17	7	2428
R0012K00990	5000	11	3229	17
R0041K00990	1500	2	209	14
R0045K02990	2700	6	694	23
R0064K04990	2500	2	13	385
R0064K05990	1000	4	52	77
R0065K01990	1500	3	26	173
R0080K00990	2500	6	36	416
R0097K01990	1200	4	36	134
V0010K06990	60	20	161	7
V0010K07990	2500	16	4677	8
V0012K01990	55	44	316	7
V0012K02990	800	17	2737	4
V0013K01990	72	33	293	8
V0015K06990	80	14	208	5
V0015K07990	1800	10	401	44
V0024K01990	33	53	162	10
V0025K00990	33	70	159	14
V0076K00990	36	113	790	5
V0077K00990	60	123	628	11

3.4. Forth Action Research Iteration

3.4.1. Observation and Reflection

From the initial observation it was possible to collect the following information:

- The total number of kanbans of this solution is 970.
- The three references with highest number of kanbans (F0079K00990, V0076K00990 and V0077K00990) combined have 48,4% of the total.
- Only one reference had the number of kanbans forced to be two.
- The number of kanban pieces obtained for every reference would be able to cover demand peaks.

There was a decrease in the number of kanbans of approximately 46% and 18% in relation to the second and to the first iteration, respectively. In fact, this reduction only happened due to the tradeoff between demand and lead time. As mentioned, in this iteration the demand for each reference was considered to be the maximum consumption rate, which was significantly higher than average demand used in previous iterations. For instance, the maximum consumption of reference G0016K00990 was more than 3 times higher than average demand. The discrepancy between the maximum consumption and the average demand was particularly blatant in both L references. There was only the exception of one reference (V0076K00990) whose maximum consumption was very close to the average demand used on the first iteration (a 3% difference). These very high values for demand were compensated by the lead time reduction. For example, if the lead time was equal to previous solutions (10 days) then the total number of kanbans would increase to 2335.

Once the analysis was concluded, another meeting with the responsible was scheduled team to present and discuss the solution. In the end, this solution was accepted as the final one and the project was clear to move to the next phase of development (rack dimensioning). In Figure 29 the VSM of the new supply system of child-part is represented.

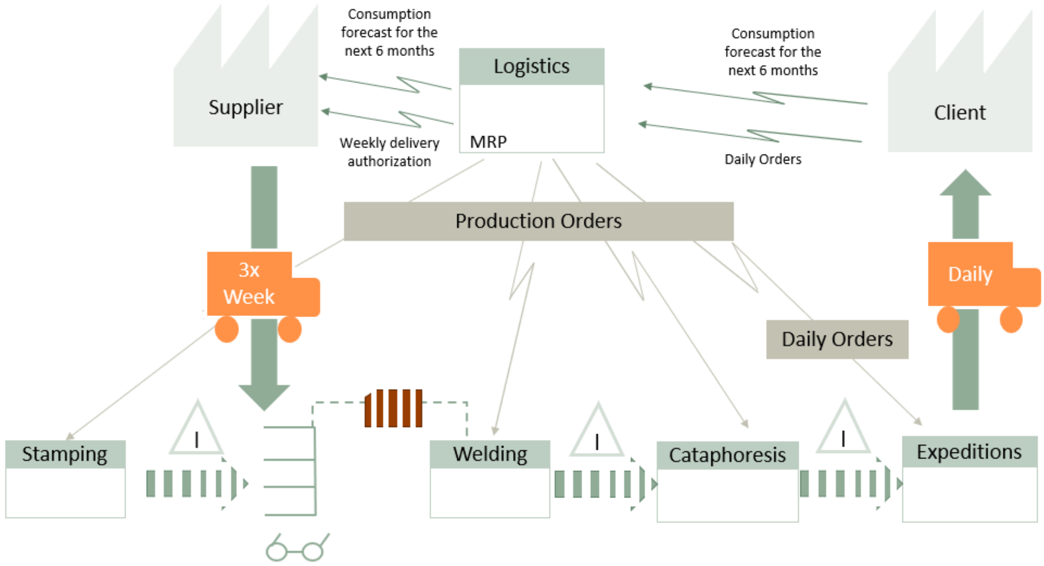

Figure 29 - VSM of the kanban system

3.4.2. Planification and Acting

Considering that this last solution was accepted by the company, to complete the project it was required that a provisional study of the flow rack dimensions was performed. The aim was to give an estimative of the dimensions of the flow racks, which references would be store in each type of rack and where they would be placed. The point was to transmit this information to the supplier so he could access and accept, or counter propose the company's suggestion. As said before the plan was for the kanban racks to occupy more or less 25 m^2, distributed between the entrance of the supermarket, the supermarket, and the side of S28.

Additionally, once everything was settled, all the project details had to be compiled in a Terms of Reference.

It was thought that it would be best to have two different dimensions of racks, one with less depth to be placed on the supermarket entrance substituting the current one, and other of larger depth to be kept on the supermarket. To make the provisional dimensioning of the rack, the following considerations were taken into account:

- According to a study conducted by London Imperial College and published by the scientific journal *The Lancet* (NCD Risk Factor Collaboration (NCD-RisC), 2020), on average a man in Spain is 176cm tall and a woman is 162cm. Considering this information and the company's safety standards, the lowest level would be at least 700mm from the ground and the highest would be of 1550mm for boxes of ≈12 Kg (empty KLT could be stored on a higher level).
- In accordance to Home (n.d.) a clearance of at least 80 mm is needed to load and unload containers.
- From the information given to the company the slopes should have an angle of 5 degrees.
- The company asked for the racks to have a return level.

Based on this information, the flow racks would have:
- Distance between levels of 250mm (height of the box + 100mm clearance).
- Lowest level at 700mm from the ground.
- Four levels of storage with an inclination of 5 degrees.
- One top-level for the return of empty KLTs with no inclination.

Another thing that had to be revised at this point was the container where the materials would be stored. Until here the KLTs that were going to be used were ones with 397x297x220mm since the SNPs of seven references would only fit this KLTs. However, with the reduction of the SNP of these references smaller KLTs could be used. The KLTs that were chosen had 300x200x147mm and were the same that were used on the *minomi* cars. Still regarding the KLTs topic it was decided that they would be stored with the 300mm side facing forward.

As mentioned, two types of racks would be designed. The dimensions would be:

- The lesser depth (S) rack would have a total width of 1500mm, and 1390mm would be usable. Its usable depth would be of 800mm. It would be able to fit 4 lanes (Kanban Storage, 2016) of 4 KLTs each.
- The deeper rack (B) would have a total of 1500mm, and 1390 mm would be usable. Its usable depth would be of 1200mm. And it would be able to fit 4 lanes (Kanban Storage, 2016) of 6 KLTs each.

In Table 11 the summary of the dimensions of both types of racks and of the KLTs can be consulted.

Table 11 - KLT and rack dimensions

		Dimensions (m)
KLT	Width	0,2
	Depth	0,3
	height	0,147
Rack type S	Area	1,245
	Depth	0,83
	Width	1,5
	Lanes per level	4
	KLTs per lane	4
	Levels per rack	4
Rack type B	Area	1,845
	Depth	1,23
	Width	1,5
	Lanes per level	4
	KLTs per lane	6
	Levels per rack	4

Figure 30 shows the rack's front dimensions and the levels heights of the two types of racks.

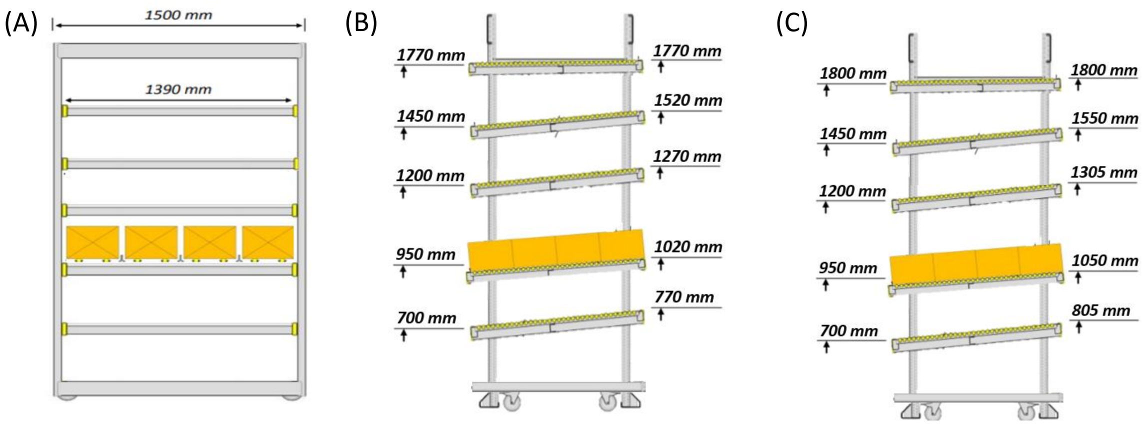

Figure 30 – (A) Front view; (B) Side view rack S; (c) Side view rack B

To calculate the amount of flow racks needed as well as the space they would occupy, it had to be decided where each reference would be stored (on the supermarket or at its entrance). The references that incorporate *minomi* cars, the two that were inserted on the cell flow rack in carton boxes and the one that is consumed in cell S28 would be stored in the supermarket. The remaining references would be stored at the entrance of the supermarket. Depending on the type of the rack where the reference was going to be store the letter S or B was attributed (see Table 12). Once this was established, taking into consideration both the number of KLTs that fit per lane of the respective flow rack and the number of kanbans calculated, it was determined the number of lanes each reference would occupy.

Table 12 - Reference's distribution and number of lanes needed

References	No. kanbans	Rack Type	No. Lanes
F0009K00990	12	S	3
F0029K00990	29	S	8
F0034K00990	13	S	4
F0037K00990	13	S	4
F0052K00990	14	S	4
F0053K00990	18	S	5
F0079K00990	226	B	38
G0016K00990	28	S	7
L0001K03990	31	S	8
L0008K05990	17	S	5
R0012K00990	12	S	3
R0041K00990	2	B	1
R0045K02990	6	S	2
R0064K04990	2	S	1
R0064K05990	4	S	1
R0065K01990	3	S	1
R0080K00990	6	S	2
R0097K01990	5	S	2
V0010K06990	21	B	4
V0010K07990	17	S	5
V0012K01990	45	B	8
V0012K02990	17	S	5
V0013K01990	34	B	6
V0015K06990	15	B	3
V0015K07990	11	S	3
V0024K01990	55	B	10
V0025K00990	72	B	12
V0076K00990	116	B	20
V0077K00990	126	B	21

For example, the first reference has 12 KLTs and was going to be stored in the smallest racks (S) which per lane can hold 4 KLTs, so the total number of kanbans of this reference would occupy 3 lanes. In total, it would be needed 5 of type S and 8 of type B. This meant that the area needed would be 21 m^2 (see **Erro! A origem da referência não foi encontrada.**Table 13).

Table 13 - Area occupied

	Number	Area (m^2)
Racks of type S	5	6,23
Racks of type B	8	14,76
Total	12	20,99

With this information the references were distributed by type of rack. After doing this it was concluded that the reference's distribution (on a smaller or bigger rack) could be rearranged to decrease the number of racks (see Table 14). This was noticed since there were two racks of each type that were not completely full. Initially, there were three V references that were stored on racks of type S, but if they were stored on the bigger racks, it was possible to reduce the number of racks of type S. Initially these references were assigned to the smaller racks because they are incorporated in nut feeders. However, as the idea was for the *mizusumashi* to include these references in its route, it was thought that it would not be much different to store them on the racks at the supermarket. Before making any decision, this option was discussed with the logistics manager who approved this alteration.

Table 14 - New distribution

References	No. kanbans	Rack Type	No. Lanes
F0009K00990	12	S	3
F0029K00990	29	S	8
F0034K00990	13	S	4
F0037K00990	13	S	4
F0052K00990	14	S	4
F0053K00990	18	S	5
F0079K00990	226	B	38
G0016K00990	28	S	7
L0001K03990	31	S	8
L0008K05990	17	S	5
R0012K00990	12	S	3
R0041K00990	2	S	1
R0045K02990	6	S	2
R0064K04990	2	S	1
R0064K05990	4	S	1
R0065K01990	3	S	1
R0080K00990	6	S	2
R0097K01990	5	S	2
V0010K06990	21	B	4
V0010K07990	17	B	3
V0012K01990	45	B	8
V0012K02990	17	B	3
V0013K01990	34	B	6
V0015K06990	15	B	3
V0015K07990	11	S	3
V0024K01990	55	B	10
V0025K00990	72	B	12
V0076K00990	116	B	20
V0077K00990	126	B	21

With this alteration, one rack off type S was eliminated and so the final area occupied by the total number of racks of each type would be 19,74 m^2 (see Table 15).

Table 15 - Final area occupied

	Number	Area (m^2)
Racks of type S	4	4,98
Racks of type B	8	14,76
Total	12	19,74

Additionally, it is important to mention that with this distribution all lanes of the twelve racks are occupied by a refence. However, 23 lanes are not completely filled which means that there is space for more KLTs of the respective reference. The proposed distribution for the racks can be consulted in Figure 31:

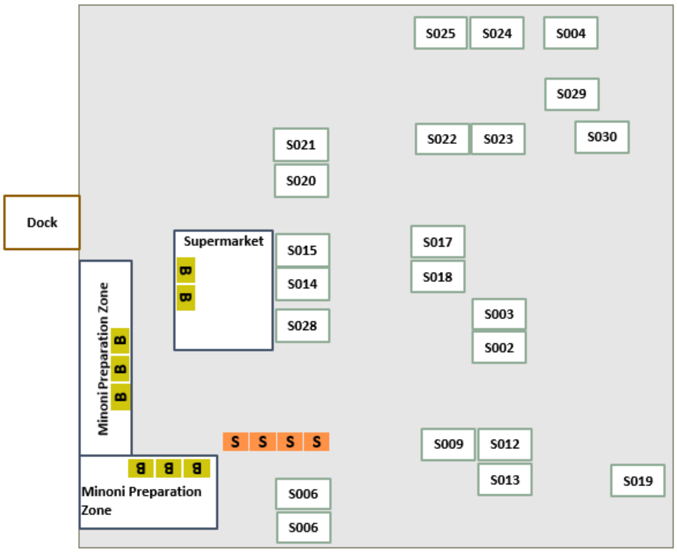

Figure 31 - Racks distribution

After this provisional study was approved all the project's information was compiled in a Terms of Reference. This document was revised by the logistics manager who sent it to the south Europe divisional branch so they could pass it along to the suppliers interested in evaluating the project.

4. RESULTS AND DISCUSSION

This chapter starts with a rundown of all the stages of the project. The aim of this is to facilitate the summarization of the steps taken during the development of the solutions. Next, the three solutions developed are compared in an effort to understand the strengths and weaknesses of each one.

Finally, after this, the research questions defined in the beginning of this study are going to be discussed.

4.1. Development Process Summary

To develop the present thesis, four action research cycles were needed. From these, three Kanban solutions were developed and studied.

The process of finding a solution that fitted the company requirements was complex and it implied testing different options. To make it easier to view how the solutions evolved, it was created a schematic overview of the development process of this project. The scheme can be seen in Figure 32. Each iteration is represented by a darker green rectangle that is composed by the following sections:

- "Observation and Reflection" where the key aspects documented are presented. In the first iteration the main aspects were regarding the initial state. In the following iterations the aspects mentioned were regarding the solutions developed.
- "Problem" where the cause that led to the rejection of the solution is stressed.
- "Planification and Acting" where the plan of action established to solve the problem is defined.

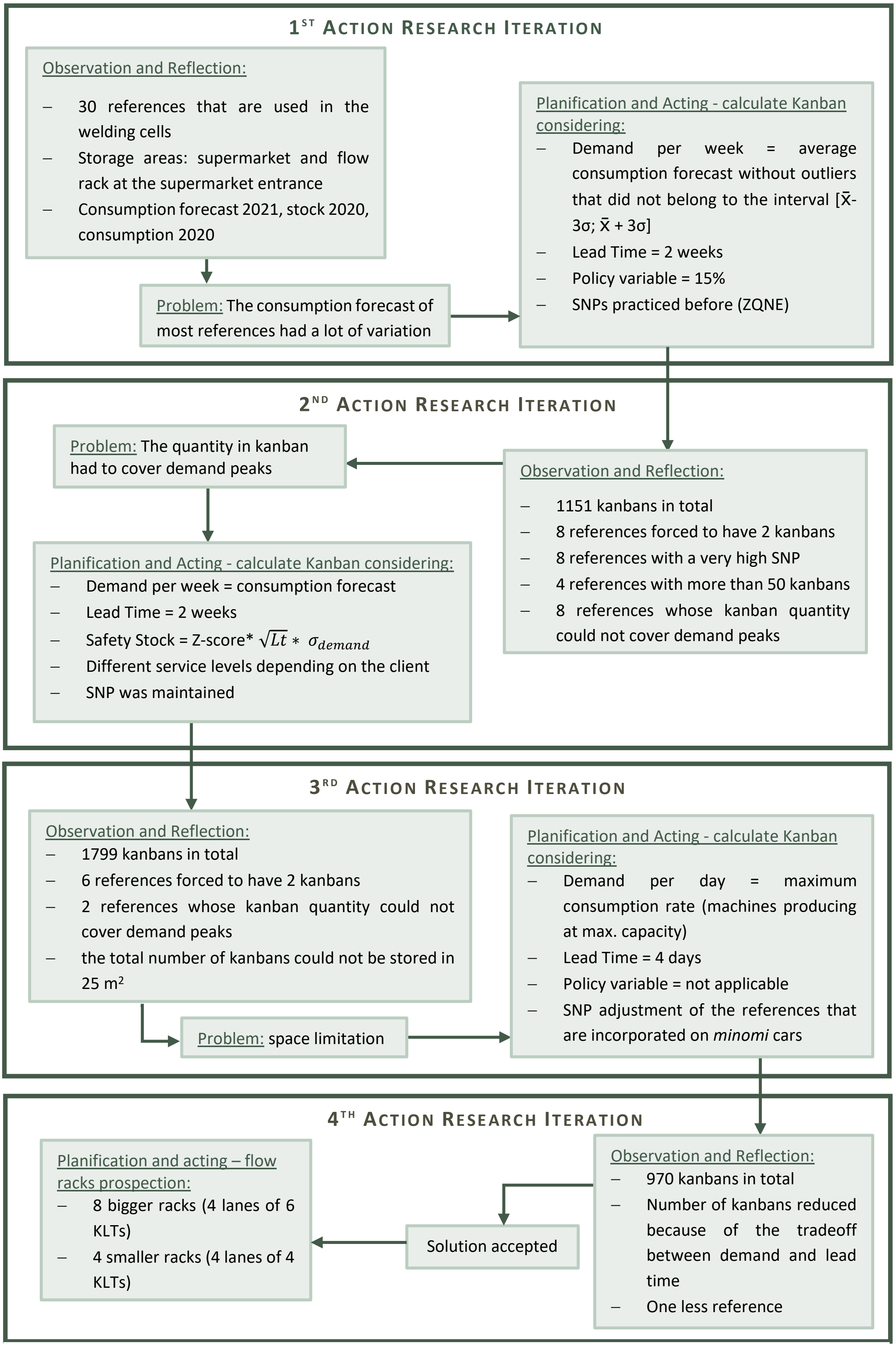

Figure 32 - Action research iterations summary

4.2. Assessment of the Solutions Developed

1. Calculation Assumptions

As described earlier the development of this project went through the presentation of three different solutions that had the purpose of answering the issues that kept arising. In all three solutions the Kanban formula was used to determine the number of kanbans. However, the first and second solutions were the ones that had more in common. In fact, the only difference between them was how the safety stock was input in the formula: in the first solution it was considered to be a fixed margin for all references; and in the second depended on the service level required for the client. From these two initial solutions to the last, various changes were made regarding the way the factors in the Kanban formula. The demand was no longer considered to be the forecast, instead it was used the maximum consumption of the machines. The lead time units were also changed from weeks to days. The values assumed for SNP were also changed. Until this last solution it was considered that the container capacity would be equal to the SNP retrieved from SAP transaction (ZQNE). This remained true for most references except for the eight that integrated *minomi* cars. Finally, one reference was eliminated due to the fact that it would no longer be produced. In the following Table 16 the considerations assumed to calculate the number of kanbans are summarized.

Table 16 - Calculation's assumptions used in the three solutions

		1st solution	2nd solution	3rd solution
Kanban formula factors	Demand	Average consumption forecast without outliers	Average consumption forecast	Maximum consumption
	Lead time	2 weeks	2 weeks	4 days
	Safety stock	15% margin	Z-score* $\sqrt{Lt} * \sigma_{demand}$	---
	Container capacity (SNP)	ZQNE	ZQNE	8 changes
References		30	30	29

2. Number of pieces in kanban

The next aspect compared was the number of pieces in kanban. The point was to check if the references with more consumption were the ones that had more pieces stored in plant. To verify this the number of kanbans could not be used. The reason why was that as each reference has a different SNP it happens that two reference with very similar demand values can have very different kanban numbers. So, the kanban quantity is not representative of the number of pieces stored.

In Table 17 for every solution and reference it is shown:

- Number of pieces in kanban (number of kanbans times SNP).
- Percentage of pieces in kanban (pieces/total sum of pieces).
- Percentage of consumption forecast between week 19 and 51 of 2021.

– Absolute difference between the 2021 percentage and the pieces in kanban percentage.

Table 17 - Comparison of the number of pieces in kanban

		1st solution		2nd solution		3rd solution	
References	% 2021	%	Dif.	%	Dif.	%	Dif.
F0009K00990	3,0	2,9	0,1	3,0	0	7,1	4,1
F0029K00990	1,3	0,9	0,4	2,6	1,3	4,0	2,7
F0034K00990	5,9	4,8	1,1	12,3	6,4	6,4	0,5
F0037K00990	0,4	1,7	1,3	1,5	1,1	6,7	6,3
F0052K00990	1,4	1,8	0,4	1,5	0,1	5,3	3,9
F0053K00990	0,8	1,0	0,2	1,2	0,4	3,6	2,8
F0079K00990	12,2	10,6	1,6	11,2	1	3,1	9,1
G0016K00990	9,8	8,8	1	8,9	0,9	6,1	3,7
L0001K03990	0,05	1,3	1,25	0,8	0,75	12,3	12,25
L0008K05990	0,18	0,6	0,42	0,4	0,22	3,4	3,2
P0052K00990	12,0	10,9	1,1	10,7	1,3	----	---
R0012K00990	9,4	9,5	0,1	8,9	0,5	11,9	2,5
R0041K00990	0,6	1,0	0,4	0,6	0	0,6	0
R0045K02990	2,0	2,6	0,6	2,1	0,1	3,2	1,2
R0064K04990	0,0	1,6	1,6	1,0	1	1,0	1
R0064K05990	0,2	0,6	0,4	0,4	0,2	0,8	0,6
R0065K01990	0,1	1,0	0,9	0,6	0,5	0,9	0,8
R0080K00990	0,1	1,6	1,5	1,0	0,9	3,0	2,9
R0097K01990	0,2	0,8	0,6	0,5	0,3	1,2	1
V0010K06990	0,6	0,5	0,1	0,4	0,2	0,2	0,4
V0010K07990	18,3	16,7	1,6	13,8	4,5	8,4	9,9
V0012K01990	1,1	0,9	0,2	0,9	0,2	0,5	0,6
V0012K02990	10,4	8,9	1,5	7,3	3,1	2,7	7,7
V0013K01990	1,1	1,0	0,1	0,9	0,2	0,5	0,6
V0015K06990	0,6	0,5	0,1	0,6	0	0,2	0,4
V0015K07990	1,1	1,1	0	1,4	0,3	3,9	2,8
V0024K01990	0,6	0,5	0,1	0,4	0,2	0,4	0,2
V0025K00990	0,6	0,6	0	0,4	0,2	0,5	0,1
V0076K00990	4,1	3,6	0,5	3,0	1,1	0,8	3,3
V0077K00990	2,2	2,0	0,2	1,7	0,5	1,5	0,7
Total Sum	100	100	**19,6**	100	**27,7**	100	**85,5**

The percentages calculated aim to indicate the weight the number of pieces in kanban of a reference has. On the other hand, the difference indicated if the weights are similar or not. For example, of the total number of pieces expected to be consumed 3% are of reference F009K00990. In the first solution this reference's number of pieces in kanban would represent 2,9% of the total and in the second 3%, in both the difference is very small (0,1 and 0%). In contrast, in the third solution the number of pieces in kanban would represent 7,1%, which means a difference of 4,1% from the percentage expected to be consumed. So, it is possible to conclude that if the difference is small then the weight of the reference in the solution is similar to the weight in the consumption forecast. This same logic is applied to the solution total sum of differences. The smaller the total sum the closer are the weights. The first two solution have the smallest total sum difference (19,6 and 27,7 respectively). This made sense because in the Kanban formula both considered the demand equal to the consumption forecast. The last solution had the biggest total sum value (85,5) which is explained by the fact that in this demand was not considered to be the forecast consumption. In the last solution the reference with the highest difference (12,25) was L0001K03990. In fact, this means that in this third solution in the plant 12,3% of the total of pieces in kanban would be from this reference, which is a reference which is only consumed sporadically.

One case that was considered to be interesting to mention was of the reference eliminated in the last solution developed (P0052K00990). This reference consumption forecast in pieces would represent 12% of the total of pieces that would be consumed. This meant that it was the third reference with highest consumption forecast in the period between week 19 and 51 of 2021. In a span of a few weeks this reference that had high consumption forecast would stop being produce which is a signal of the variability that characterizes this sector.

3. Stockouts and Area occupied

There are two main aspects two consider when evaluating the three solutions developed (not in order of priority): the area occupied by the total number of kanbans and the average probability of stockout (these values were calculated considering the supplier does not miss any visit). After the acceptance of the last solution, it was made a provisional study of the racks to be used. Considering this study was approved by the company, to compare the area occupied by the first two solutions it was opted to use the dimensions defined in this study. This implied that two adjustments had to be made:

1) The number of kanbans of the reference that was eliminated would not be considered.
2) The number of KLTs that can be stored for lane on the smaller rack would be of 2 and on the bigger of 4. This is due to the fact that in both first two solutions the SNPs used were still from the ZQNE transaction which meant that the KLTS would have to have the dimensions 400x300x147 mm.

In the first solution, the number of kanbans was 1134 excluding the 19 kanbans of the reference that was eliminated. The two biggest problems with this solution were area occupied by number of kanbans (41,8 m^2) and the probability of occurring stockouts (22%). The second solution had 1769 kanbans in total again (excluding the 30 kanbans of the reference that was excluded). The area occupied was of 67,2 m^2. In this solution the probability of stockout reduced significantly (2%). In the last solution the number of kanbans was only 970. The last solution had 970 kanbans which occupied 20 m^2. In this solution the stockouts are expected to be null, since the calculations were made machine capacity which makes it possible to cover the peaks.

In the end when confronting the three solutions developed it is possible to assert:

- The first solution did not fulfill any criteria.
- The second solution even though had a low probability of stockout, the number of kanbans needed would not fit the area available.
- The third solution fulfilled both criteria. However, a few references would have way more kanbans than needed.

4.3. Discussion

4.3.1. Research Question 1

The first research question that this study aimed to answer was the following:

What practical solutions can be used to deal with demand variability when implementing a supplier consignation Kanban System in a Tier 1 automotive company?

In the literature review presented in this thesis there were enunciated the main benefits companies can expect from the Kanban implementation. Nevertheless, it was also mentioned that the application of Kanban in environments with high variability is not as linear and might not bring the results expected. In the case of this project, the company where the work was conducted wanted to change its current child-part supply system from a push-logic necessities planification to a consignation Kanban system. However, the Kanban system was going to be implemented between the supplier-manufacturer without having implemented it between manufacturer-client. Furthermore, the demand variability of child-part components also made the task of designing a Kanban solution more difficult.

In this study, the two best options found to deal with demand variability were either to adjust for each reference the safety stock based on service level and standard deviation; or dimension the kanban using the maximum capacity of the machine. Between the two, the second option had a smaller probability of having stockouts. On the other hand, to make it viable the lead time had to be reduced. If not for the change, the number of kanbans could not be stored in the available area.

In literature it can be found other ways to design a Kanban system in high variability environments. Two common options are to dynamically adjust the number of kanbans or the lead time. The adjustment of the number of kanbans was considered not to be viable because the numbers would vary significantly. This in turn would be very difficult to articulate with the supplier and would imply a greater area to operate. The lead time adjustment was an option; however, it could not be done by developing heuristics. The company considered that a complex heuristic would add complexity that they did not see fit for the project at hand.

4.3.2. Research Question 2

The second research question that this study pretended to answer was the following:

How can the consignment supplier's Kanban impact the relationship between a Tier 2 supplier and Tier 1 supplier?

The supplier Kanban is a system that involves two supply chain players, in this case a Tier 1 and a Tier 2 element. Usually, for the Kanban system each player has opposite goals (Baradaran & Akhavan, 2019). On one hand, the Tier 1, that is going to hold storage costs, wants to have a reduce number of kanbans (Faccio et al., 2013). However, on the other hand, if the number of kanbans is too low then it is the system is uneconomic for Tier 2. On another perspective, it is more cost-effective for the Tier 2 to have frequent transportations since it implies higher service costs asked of Tier 1 (Satoglu & Ucan, 2015).

Even though the two parts have antonyms objectives, the consignation supplier Kanban can be beneficial for both. To guarantee that the Tier 1 and the Tier 2 can get the most out of the new supply system they have to maintain a relationship based on transparency. As there is less stock in plant, the Tier 1 (manufacturer) needs to be able to trust that the Tier 2 (supplier) will be able to meet the frequency established. On the other hand, as the link between the two parts is going to shorten the communication is going to be essential. The Tier 2 is going to be responsible for controlling the system and making adjustments when needed.

5. CONCLUSION

The last chapter of this thesis is dedicated to the presentation of the final conclusions retrieved where the project is briefly summarized. Then the limitations of the project are enumerated as well as the future work.

5.1. Final conclusions

In 2020, the automotive industry went through an unprecedent and almost complete halt in production. Even before this, the industry was facing several trends that threaten to slow growth and reduce profit margins. The combination of all these circumstances further intensified the industry's atmosphere of competitiveness which increased the pressure on the supply chains. Companies across different sectors of activity resorted to the application of Lean concepts to the supply chain to increase competitive advantages. It is in this context that the presented project appeared. The company where it was developed wanted to implement Lean supply chain initiatives. The project had the objective of designing a non-electronic consignation supplier Kanban in a high variability context of an automotive Tier 1 company.

The research methodology used to structure the development of this project was the Action Research since it simultaneously allows the creation of knowledge and change. To have a final Kanban solution four cycles of AR were needed. In the first one the observation phase was very exhaustive, and several data collection methods were used to gather the project's expectations and context. To be able to move to the next phase, the information gather was analyzed. From this the most relevant assessment was the demand variability of the child-part components. Taking this into account, it was decided that in the first solution it would be performed an outlier analysis of the forecast results before using them to calculate the number of Kanbans. The results obtained were analyzed in the beginning of the next AR cycle. The main conclusion was that the number of pieces in kanban calculated in eight cases could not even cover forecast peaks. Consequently, the planification phase of this second cycle aimed to define a solution for this issue. In the new solution it was decided that (1) no outlier analysis of the forecast would be performed; and (2) instead of using a fixed safety margin, a safety stock would be calculated for every reference based on the service level defined for every client and on the standard deviation. Once again, this solution's results were analyzed in the beginning of the third AR cycle. It was concluded that even though the amount of references whose kanban quantity could not even cover forecast peaks had reduced, this still happened in two references. Additionally, from a rough study made, it was asserted that the amount of kanbans calculated could not be stored in the area available. In consequence, a new solution was planned and developed. This time, it was decided that to calculate the number of kanbans it would be considered that the demand would be equal to the maximum consumption of the machines to avoid material scarcity. Additionally, has this meant increasing demand it was decided that the lead time units would be change from weeks to days. The results of this solution were analyzed in the fourth AR cycle. It was concluded that in fact the amount of pieces in kanban of every reference could cover forecast peaks and the amount of kanbans had reduced significantly (47% in relation to the second iteration). This solution once it was presented to the company it was approved. To finish the project, it was asked to do a provisional but more adequate to the space study of the racks that would be needed to store the kanbans. The use of two types of racks, with different dimensions, was proposed. It is expected that the total number of kanbans will occupy approximately 20 m^2.

The accepted solution for the Kanban system was oversized, as it was considered that the machines were producing all the references at maximum capacity. Although in this way certain references will have more kanbans than necessary, stockouts are expected to be close to null. As all of the KLTs will be placed in the company under a consignment, the costs will decrease significantly. The company will only have to pay for holding costs (that will be similar to before) and for the KLTs consumed. Besides this, the fact that the supply of the child-part components will no longer be done in carton boxes it will allow to (1) attain the company's objective of reducing plastic and carton in the plant (2) eliminate the operator's supermarket task of transferring some references to KLTs; and (3) to standardize the packages in the supermarket's (small components in KLTs).

5.2. Limitations and Future Investigations

At the time of finalizing this thesis, the practical advantages and disadvantages of the supplier Kanban were still not clear, since the project was still in negotiation. This made the task of empirically answering the second research question particularly difficult. As the parties involved were still reaching an agreement on the price of the service, it was not possible to better assess the effects of the supplier's Kanban on the relationship between the two. Nevertheless, from a critical point of view, the main limitation identified in the final kanban solution is the fact that the number of kanbans of all references was calculated based on the machine's capacity. This solution is best suited for references with high consumption and high variability. However, there are cases that are not justified. Particularly for the two L references that have very little consumption. In this line of thought it would be recommended that these two references only had two kanbans (two-bin system) and that the container size (SNP) was adjusted. It is also believed that for five R references (R0064K04990, R0064K05990, R0065K00990, R0080K00990 and R0097K01990) the kanban number could also be two. It may also be considered to implement an E-Kanban to replace the look-and-see method. Finally, for future work , it is being developed an paper to present in an upcoming conference.

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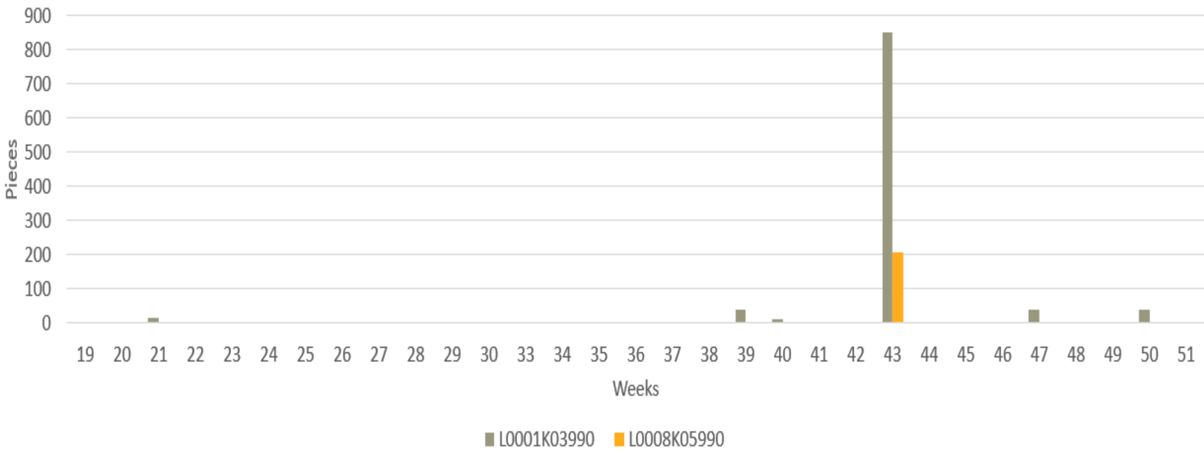
APPENDIX I

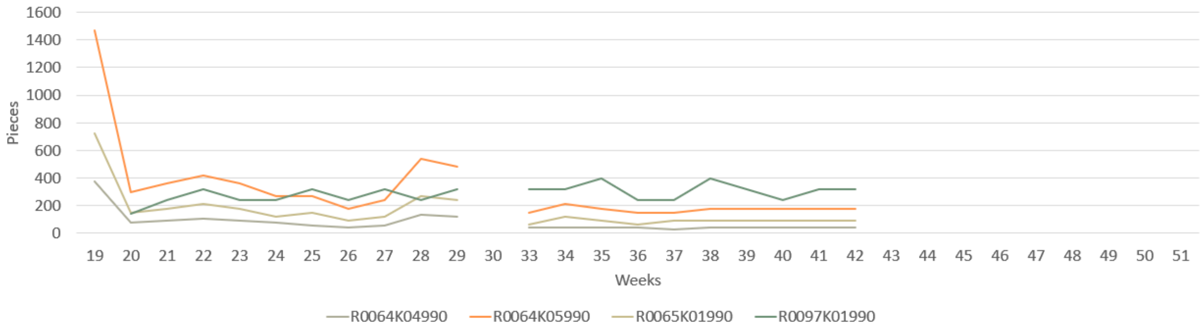
References	Minimum	Maximum	Mean	Standard Deviation
F0009K00990	0	15890	3543,065	3932,936
F0029K00990	0	10800	1512,581	3076,58
F0034K00990	0	50280	7054,839	14392,33
F0037K00990	0	8160	469,6774	1522,768
F0052K00990	0	4328	1675,484	1197,115
F0053K00990	0	3200	929,0323	992,7046
F0079K00990	1680	37380	14447,1	8392,331
G0016K00990	0	22060	11629,35	6358,982
L0001K03990	0	850	32,19355	152,2685
L0008K05990	0	206	6,645161	36,99869
P0052K00990	0	44280	14219,97	10831,49
R0012K00990	0	18937	11102,94	7817,031
R0041K00990	0	1216	702,871	509,9658
R0045K02990	0	4230	2416,742	1716,688
R0064K04990	0	375	53,70968	70,86334
R0064K05990	0	1470	213,871	278,827
R0065K01990	0	720	106,4516	137,4421
R0080K00990	0	216	121,2903	87,7444
R0097K01990	0	400	185,2258	148,2113
V0010K06990	32	1472	658,2581	278,0766
V0010K07990	5720	36952	21746,58	7663,888
V0012K01990	0	2208	1273,613	682,821
V0012K02990	2256	24016	12329,19	3578,16
V0013K01990	42	3164	1288,774	545,2903
V0015K06990	0	1500	682,5484	513,6088
V0015K07990	0	3450	1333,742	1039,513
V0024K01990	0	1316	691,2258	262,5016
V0025K00990	0	1156	728,6129	184,7973
V0076K00990	0	9800	4902,613	1674,522
V0077K00990	0	5264	2652,677	942,9592

APPENDIX II


Pieces
900
800
700
600
500
400
300
200
100
0
19 20 21 22 23 24 25 26 27 28 29 30 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
Weeks
L0001K03990
L0008K05990

APPENDIX III

APPENDIX IV


1600
1400
1200
1000
800
600
400
200
0
Pieces
19 20 21 22 23 24 25 26 27 28 29 30 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
Weeks
R0064K04990
R0064K05990
R0065K01990
R0097K01990

APPENDIX V

References	SNP	No. kanbans	Pieces in kanban
F0009K00990	3000	3	9000
F0029K00990	700	4	2800
F0034K00990	2500	6	15000
F0037K00990	2600	2	5200
F0052K00990	1900	3	5700
F0053K00990	1000	3	3000
F0079K00990	70	475	33250
G0016K00990	1100	25	27500
L0001K03990	2000	2	4000
L0008K05990	1000	2	2000
P0052K00990	1800	19	34200
R0012K00990	5000	6	30000
R0041K00990	1500	2	3000
R0045K02990	2700	3	8100
R0064K04990	2500	2	5000
R0064K05990	1000	2	2000
R0065K01990	1500	2	3000
R0080K00990	2500	2	5000
R0097K01990	1200	2	2400
V0010K06990	60	26	1560
V0010K07990	2500	21	52500
V0012K01990	50	59	2950
V0012K02990	800	35	28000
V0013K01990	75	40	3000
V0015K06990	100	16	1600
V0015K07990	1800	2	3600
V0024K01990	90	18	1620
V0025K00990	80	22	1760
V0076K00990	50	226	11300
V0077K00990	50	123	6150