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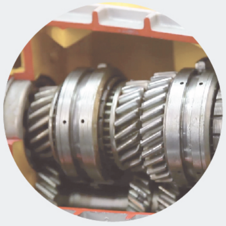


IMPROVEMENT IN RESOURCE MANAGEMENT FOR AN AUTOMOTIVE COMPANY'S IN-PLANT PARTS FEEDING SYSTEM

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RESUMO

A competitividade no setor automóvel tem vindo a aumentar devido à crescente sofisticação do mercado bem como à constante mud*a*nça nas preferências e requisitos dos clientes. Para se manterem competitivas, as organizações procuram formas de se tornar mais responsivas e flexíveis. Neste sentido, há uma crescente preocupação em assegurar um sistema de abastecimento de componentes bem estruturado e eficiente, tanto a nível externo como interno que esteja alinhado com a filosofia Just-In-Time e com os princípios Lean, evitando desperdícios e contornando a variabilidade associada ao setor. Esta variabilidade decorre não só da crescente diferenciação dos produtos que leva à adoção de *multi and mixed model assembly lines* como da incerteza e variação na procura dos clientes resultante do aparecimento do surto de um novo coronavirus (COVID-19) a nível mundial.

O presente projeto de dissertação, conduzido através da metodologia Action-Research (AR), foi realizado na Gestamp Palau S.A., empresa a operar no setor automóvel, e centrou-se na melhoria da performance do sistema *milk run* de abastecimento interno de componentes ao departamento de soldadura. Foram detetadas várias problemáticas que estariam a comprometer a eficiência deste serviço logístico entre as quais a falta de estudo e documentação de fluxos de materiais bem como das operações a serem desempenhadas pelos trabalhadores e a sua quantificação temporal. A existência destes problemas traduzia-se na dificuldade de planeamento e gestão dos recursos (humanos e materiais) necessários para desempenhar o serviço de abastecimento de componentes às células de soldadura.

As ações levadas a cabo para abordar todos os problemas identificados, culminaram no desenvolvimento de uma ferramenta de simulação e apoio à decisão na gestão do sistema de abastecimento de componentes. Esta tem como principal objetivo facilitar, a curto ou a longo prazo, o planeamento e balanceamento da equipa logística bem como a gestão dos materiais movimentados consoante a variação da carga de trabalho causada pelas diferentes situações de procura ao departamento de soldadura.

A análise realizada às simulações feitas com recurso à ferramenta e em conjunto com o departamento de logística e o especialista do estudo dos tempos, revelou que esta produzia resultados fiáveis, objetivos e devidamente ajustados às variações da procura dos clientes bem como ao mix de produtos e componentes existentes no departamento de soldadura. Assim, é expectável um aumento da eficiência do serviço de abastecimento de componentes às células de soldadura uma vez que o planeamento e gestão dos recursos humanos necessários é feito de forma dinâmica, flexível e balanceada evitando sub ou sobre aproveitamento dos mesmos. Para além disto, existe uma maior perceção dos materiais a ser movimentados, da carga de trabalho individual que cada atividade representa no trabalho dos operadores bem como dos diferentes tempos de reaprovisionamento (*lead times*) necessários consoante cada instância de produção.

Atualmente é estudada a implementação oficial da ferramenta na Gestamp Palau como uma metodologia para potenciar a eficiência do sistema de abastecimento ao departamento de soldadura, assim como a sua extensão a outros fluxos internos com características semelhantes.

Palavras Chave: Sistema de abastecimento de componentes, *milk run*, eficiência, força de trabalho, carga de trabalho, variabilidade, ferramenta de simulação e apoio à decisão.

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ABSTRACT

Competitiveness in the automotive sector has been increasing due to the growing sophistication of the market as well as the constant change in customer preferences and requirements. To stay competitive, organizations look for ways to become more responsive and flexible. In this sense, there is a growing concern to ensure a well-structured and efficient component supply system, both externally and internally, in line with Just-In-Time philosophy and Lean principles, avoiding waste and circumventing the variability associated with the sector. This variability arises not only from the growing differentiation of products that lead to the adoption of multi and mixed model assembly lines, but also from the uncertainty and variation in customer demand resulting from the emergence of the outbreak of a new coronavirus (COVID-19) worldwide.

This dissertation project, conducted through the Action-Research (AR) methodology, was carried out at Gestamp Palau S.A., a company operating in the automotive sector, and focused on improving the performance of the milk run system for internal supply of components to the welding department. Several problems were detected that could compromise the efficiency of this logistic service, including the lack of study and documentation of material flows as well as the operations to be performed by the workers and their temporal quantification. The existence of these problems resulted in the difficulty on planning and managing the necessary resources (human and material) to perform the service of supplying components to the welding cells.

The actions taken to address all the problems identified, culminated in the development of a simulation and decision support tool for the component supply system management. Its main objective is to facilitate, in the short or long term, the planning and balancing of the logistic team, as well as the management of the materials handled depending on the variation in the workload caused by the different situations demand to the welding department.

The analysis carried out on the different simulations made using the tool, together with the logistics department and the specialist in the study of times, revealed that it produced reliable, objective and adjusted results to variations in customer demand as well as to the existing product mix in the welding department. Thus, an increase in the efficiency of the service of supplying components to the welding cells is expected, since the planning and management of the necessary human resources is done in a dynamic, flexible and balanced way, avoiding its under or overutilization. In addition, there is a greater perception of the materials to be handled, of the individual workload that each activity represents in the operators' work, as well as of the different replenishment lead times needed according to each production instance.

Currently, the official implementation of the tool at Gestamp Palau is being studied as a methodology to enhance the efficiency of the parts feeding system to the welding department, as well as the possibility to extend it to other internal flows with similar characteristics.

Keywords: Parts feeding systems, milk run, efficiency, workforce, workload, variability, simulation and decision support tool.

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LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

List of Acronyms

AR	Action-Research
BOM	Bill of Materials
CT	Cycle Time
ERP	Enterprise Resource Planning
ESB	Gestamp Palau S.A.
FIFO	First-in, First-Out
ISEP	Instituto Superior de Engenharia do Porto
JIT	Just-In-Time
JJ	Junjo
KB	*Kanban*
KMS	Kaizen Management System
KLT	*Klein Lagerung und Transport* or Packaging and Transport of Small Components
MES	Manufacturing Execution System
MHS	Material Handling Systems
MRP	Material Resource Planning
MRS	Milk run Systems
MRST	Milk run Service Time
MS	Microsoft
MTM	Methods -Time Measurement
MTM-UAS	Methods -Time Measurement – Universal Analyzing System
MTS	Make-To-Stock
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OLC	Operating Loading Chart
PDCA	Plan, Do, Check and Act
PLC	Programmable Logic Controller
P.Porto	Instituto Politécnico do Porto
RLT	Replenishment Lead Time
SAP	*Systeme, Anwendungen und Produkte in der Datenverarbeitung*
SC	Shift Consumption
SDCA	Standardize, Do, Check and Act
SKU	Stock Keeping Unit
SMED	Single-minute exchange of dies
SNP	Standard Number of Parts
SSST	Setup Supermarket Service Time
SW	Standard Work
TDT	Train Displacement Time

TFM	Total Flow Management
THOEE	Throughput considering OEE
TPS	Toyota Production System
VDI	Association of German Engineers
ZQHR	SAP Routing transaction
ZQLM	SAP Bill of Materials transaction
ZQNE	SAP Packaging Standard transaction

List of Abbreviations

Nop	Number of operators
Obs	Observation

List of Symbols

∂	Positive safety factor
%	Percentage

1. INTRODUCTION

This dissertation aims to study and improve the performance of a component supply system within an automotive tier one supplier. The project was developed at the logistic department of Gestamp Palau S.A. in collaboration with Kaizen department within the scope of the dissertation to conclude the master's degree in Industrial Engineering and Management of the Instituto Superior de Engenharia do Porto (ISEP).

This dissertation presents the context of the project to be developed and the identification of the research problem as well as an overview of the research questions and objectives that derive from the identified problem. The methodology adopted to conduct the research as well as a brief presentation of the organization where the project takes place is also presented. To conclude, a report outline is provided.

1.1. Project Background

The automotive industry plays an important role in manufacturing sector and makes up a large share in country's economy. It has a high rate of input and output, as a production tool and a durable consumer good. Whether in production, sales and consumption stages, it is an important source of revenue and an employer generator (Belhadi et al., 2021; Brar & Saini, 2011).

Due to consumer's changing preferences and the consequent need to respond to them quickly, the competition in this industry has intensified such that auto manufacturers had to improve their means to manage and minimize its wastes, production times and cost (Brar & Saini, 2011; Macduffie et al., 1996). To manage costs, and align with Lean and Continuous Improvement techniques, either internal or external part's supply to the point of use on the assembly line must be assured by adopting or reinforcing just-in-time (JIT) philosophy in the organizations, and eliminating *muda* (Japanese for wasted resources in non-value-adding work), muri (people overburden) or *mura* (workload variation) (Fortuny-Santos et al., 2020; Patel et al., 2017; Silva et al., 2021).

In the automotive sector, companies need to offer a wide range of different products (Faccio, Gamberi, Persona, et al., 2013a). According to Clark & Fujimoto (1991) this increase on product variety arises from such factors as changes in energy prices and trade structures, internationalization of the market, and the growing sophistication of customers. This results in a steady increase in the number of car models that are being offered worldwide. Regarding production systems, the consequence is the adoption of multi or mixed-model assembly line configurations in organizations where the workstations continue to be dedicated to a product family but are also able to produce several different models (Battini et al., 2009; Emde & Boysen, 2012a).

Another factor influencing production systems is the recent outbreak of a novel coronavirus, named COVID-19 by the World Health Organization, which has pushed the global economy and humanity into a disaster, with the automotive sector being one of the most affected industries (Nayak et al., 2021). Its propagation alongside successive lockdowns created immense uncertainties in demands and disruptions in global supply chains (Belhadi et al., 2021).

In this context, according to Battini et al. (2009) and Emde & Boysen (2012a), one significant challenge is to establish a reliable, flexible and efficient part feeding system to the assembly stations. On the one hand component shortages lead to line stops and assembly station idleness, and on the other hand enlarged stocks near the lines increase inventory costs and obstruct the assembly process due to the lack of space within the plant (Emde & Boysen, 2012b).

In order to achieve efficiency whilst following the JIT approach, a growing number of manufacturers are therefore adopting Total Flow Management (TFM) tools that are in line with Lean and Kaizen principles, and aim to achieve smooth flow of materials and information throughout the processes inside supply chains such as Supermarkets, In-plant milk run and *Kanban* to improve efficiency (Alnahhal et al., 2014; Faccio, Gamberi, Persona, et al., 2013a). Being decentralized logistics areas, supermarkets allow the delivery of frequent small batches, producing inventory reductions near the lines and avoiding long distance trips to production systems. The connection between storage areas and workstations is made through the in-plan milk run concept, operated by a *Mizusumashi* handler, who drives a tow-train (vehicle towing small wagons) to deliver the required components to consumption points (stations) and to collect empty handling units to be refilled for the next trip in the inventory position (supermarket) (Droste & Deuse, 2011; Gamberi et al., 2008; Gil Vilda et al., 2020).

The present dissertation was developed in a company operating in the automotive sector, Gestamp Palau S.A., in collaboration with the logistic and kaizen departments who are currently raising their concern on the continuous improvement aiming to reduce non-added-value tasks within their internal logistic processes. One of the short-term objectives of Gestamp Palau S.A. is to eliminate all forklifts that currently carry out transport operations on the shop-floor. In addition to the expected improvement in the efficiency of internal logistics, a reduction in risks associated to these operations is also expected. Some actions were already concluded in this regard. In the welding department of the company, an in-plant milk run system was recently implemented to perform the parts supply service to the assembly line. This action was followed by the creation of a supermarket of components and by the introduction of the *kanban* concept. Being aware that a good system of milkruns is able to increase significantly the efficiency of the overall production logistics, the company wants to take full advantage of the investment made.

The existing setting, characterized by great variability**,** has called for a need to understand whether the existing parts feeding system to the welding department of Gestamp Palau is now operating in an efficient way. When analyzing the internal logistic flows of the welding area, several problems were identified that could compromise the performance of the system. More importantly, a methodology for resource management, either human or material, was identified as an imperative to efficiently conduct and adjust the internal supply of components to the different production sequences deriving from demand variations.

1.2. Research Questions and Objectives

Considering the problem framed, the pertinence of the present dissertation is based on improving the operation of the parts supply system to the welding department of Gestamp Palau S.A., from a resource planning and management perspective. This system is inserted in the internal logistic processes of the organization which in turn is one of the main focuses of the company in terms of objectives related to waste elimination and continuous improvement.

To provide orientation throughout the dissertation, the following research questions were defined and will be addressed along the different stages of the project:

RQ1: What type of difficulties can be found whilst planning and managing an efficient part's feeding system in a multi/mixed-model assembly line?

RQ2: What are the possible ways to address the difficulties identified in RQ1 within an automotive company in a current context of demand variation?

To approach the research questions, the following general objective was defined: To improve the efficiency and performance of the supply system of components to the welding department of Gestamp Palau S.A. In order to achieve the general objective, the following specific objectives were established:

- Carry out theoretical research that frames the different domains and pillars regarding internal logistics and a literature review on assembly lines, parts feeding systems and the importance of its alignment with just-in-time and Lean paradigms.
- Proceed to an in-depth study of the current processes and techniques applied in Gestamp Palau S.A., specifically the internal parts supply currently being operated.
- Develop a resource management system that allows for the planning and balancing of the workload and workforce needed in the performance of the welding parts feeding system considering different production scenarios in Gestamp Palau.

1.3. Methodology

Farooq & O'Brien (2015) emphasize that the successful application of a research methodology, to study a particular research case or phenomenon, is very much dependent on clear and defined research objectives. Therefore, the investigator must decide which methodology best addresses and yields credible results to the research questions under investigation (Breakwell et al., 2010).

The present research aimed to study the internal logistic flow regarding the process of parts feeding to an assembly system placed in a multi/mixed-model industrial environment. For this study, an Action-Research (AR) methodology was adopted - a sequential analysis of events and approaches by problem solving producing actual research in action, as opposed to research about the action (Martins et al., 2020).

The choice of conducting an AR methodology in this study can be based on the fact that, contrary to a case study, an action researcher is not only an independent observer but becomes part of the process changes and implementations, and makes the evaluation of the impact of certain intervention technique the subject of research (Rich & Piercy, 2013). In general, AR is appropriate when the research question leads to an unfolding series of actions overtime in a given group, community or organization, and when the action-researcher can understand how and why the actions taken can change or improve some aspect of a system, learning from it and contributing theory to the body of knowledge (Coghlan & Brannick, 2001).

Thus, the development of this dissertation was based on the five cyclical stages of this methodology described by (Susman & Evered, 1978). The method involves diagnosing, action planning, action taking, evaluating, and specifying learning. The explanation of the work done in each one of the stages is presented below Figure 1.

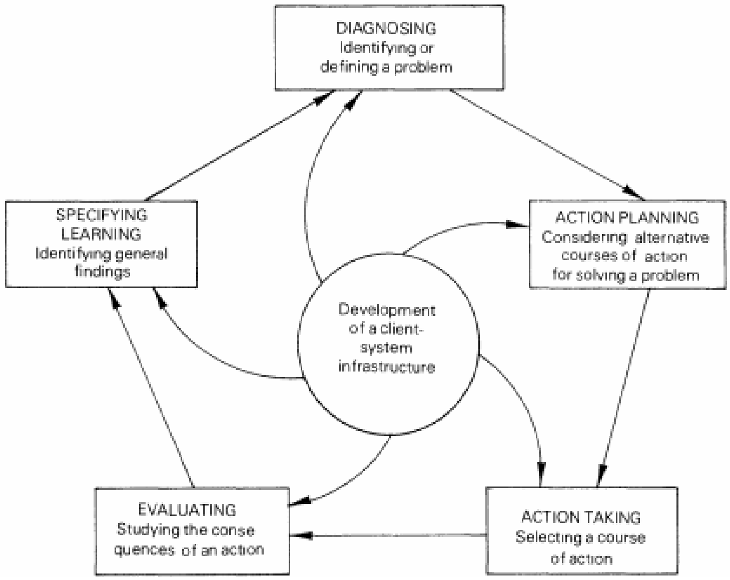

Figure 1 - Action-Research Methodology Cycle (Susman & Evered, 1978)

Diagnosing: in this first stage, the currently operating parts feeding system was analyzed through observation via *gemba* walks, corridor talks with the shop-floor operators, and formal meetings with both the logistic manager and remain departments involved in this AR cycle. This allowed the subsequent identification of the problem and the generation of further knowledge on its nature, its root causes and negative impact they can have in the system. To summarize this problem survey, it was used the *Ishikawa* diagram.

Action Planning: analytical and corrective actions were defined in this stage in order to address and mitigate the root causes identified in the previous stage.

Action Taking: the third stage of AR methodology consist of enforcing the actions outlined in the Action Planning stage. First, analytical actions were taken which addressed some of the root causes indirectly affecting the efficiency of the parts feeding system. This was required to allow the performance of the corrective and improvement action that intended to address the remain root causes directly affecting the performance of the system.

Evaluating: during this stage, the compliance evaluation of the action plan is carried out alongside an evaluation of the outcome in each one of the actions performed in the previous stages. Besides this, a critical analysis of the practical results was made to understand the positive and negative impact of the changes.

Specifying Leaning: in the last stage of AR methodology, conclusions were drawn from the work developed throughout the dissertation project. Whether the work addressed the research questions raised will be discussed.

In this specific case, the experimental AR was performed in collaboration with a client system (organization) in nearly all stages, such as setting up experiments for taking actions and evaluating their consequences.

1.4. Company Presentation

In this sub-chapter, a brief presentation of the corporation is presented, along with its history, range of products, vision, and principles. A detailed description is then given about the company that hosted this dissertation project, addressing the chronological events that were in the base of its formation, the main clients and each one sales percentage, some internal marks achieved and its infrastructure.

1.4.1. Gestamp Group

Gestamp is an international Spanish group dedicated to the design, development, and manufacture of metal automotive components. The group specializes in developing innovatively designed products to achieve increasingly safer and lighter vehicles, thereby reducing energy consumption and environmental impact (Gestamp, 2021).

Since its creation in 1997, Gestamp has moved from being a small local stamping company to a global company operating in the main auto manufacturing hubs. Throughout its more than 20 years of experience, Gestamp has become a global technology provider due to the high added value it offers to its customers in terms of technological content, investments in production automation and international development (Gestamp, 2021).

With more than 100 factories and being installed in 23 countries, it is possible to stand in the main manufacturing centers worldwide and close to its customers, offering global solutions that cover the entire production process from product design to the supply on manufacturer’s assembly lines (Gestamp, 2021).

Figure 2 - Gestamp Group Logotype (Gestamp, 2021)

This international company (logotype presented in Figure 2) develops products with an innovative design in order to, as its slogan states, be “Working for a safer and lighter car”, which can offer improved energy consumption and reduced environmental impact. Gestamp offers a wide range of technologies addressing the industry requirements to achieve the right balance between safety, performance, weight, and cost. It produces Body-In-White components such as Closures, Upperbody and Underbody; mechanisms like Hinges and Door Checks and Chassis components such as Rear Twist Beams, Control Arms and Subframes (Gestamp, 2021) as shown in Figure 3.

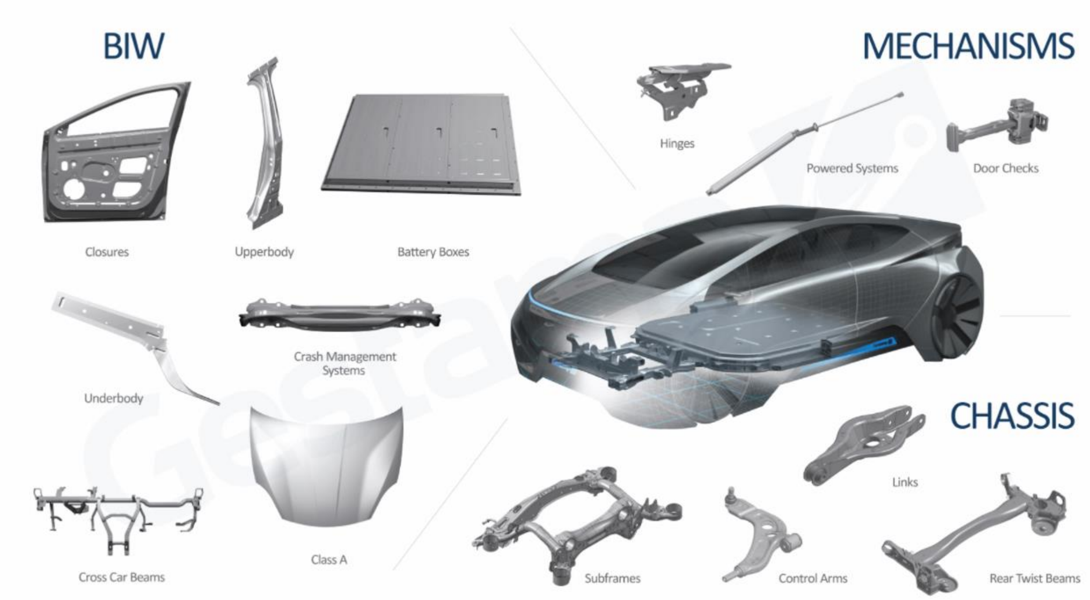

Figure 3 - Gestamp Group range of products (Gestamp, 2021)

With the challenge of being at the forefront of innovation, Gestamp devotes a great effort to research and develop cutting-edge technologies. Therefore, innovation is the support on which its future strategy is established. Gestamp bases its actions on its vision and in five corporate principles (Figure 4).

Vision

“ *To be the most renowned automotive supplier for our ability to adapt our business to create value for the customer, while maintaining sustainable economic and social development.* ”

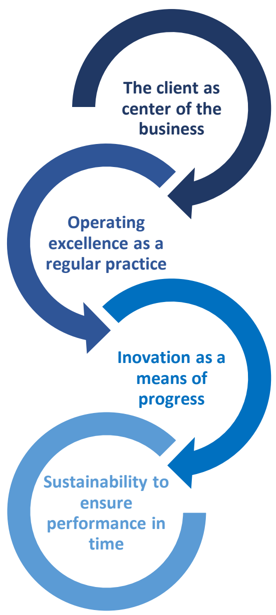

Figure 4 - The 5 corporate principles. Source: Own Elaboration. Adapted from (Gestamp, 2021)

1.4.2. Gestamp Palau S.A.

The present dissertation project was carried out at Gestamp Palau S.A., one of Gestamp's subsidiaries in Spain, which started its activity in 2016, after the acquisition of the former company *Grupo Estampaciones Sabadell*. This group was dedicated to the production of stamped and embedded parts for the automotive sector, including welds and sets of assemblies, molds, and metallic dies. In Figure 5 it is possible to understand the process of acquisition and foundation of Gestamp Palau S.A.

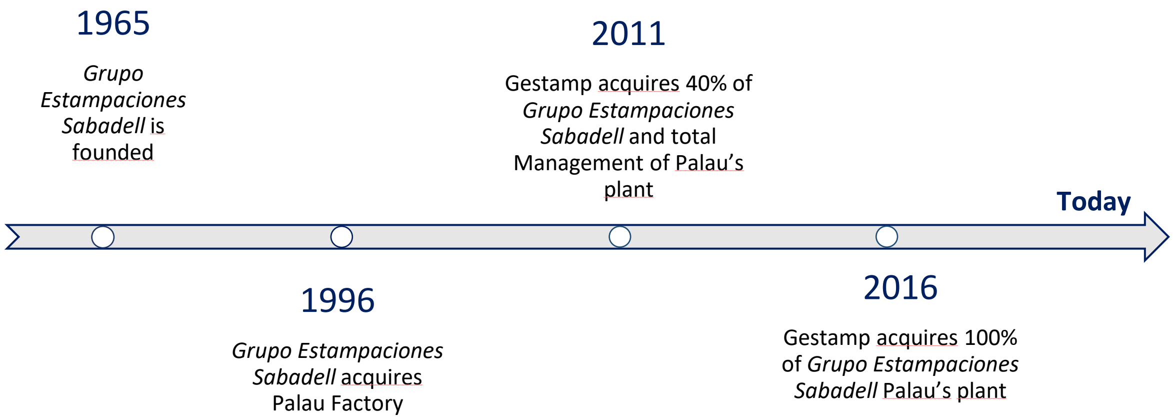

Figure 5 – Chronological events on Gestamp Palau S.A. foundation. Source: Own Elaboration

Currently, Gestamp Palau S.A. is located in Palau-Solità i Plegamans, a village placed in the province of Barcelona, more specifically in *Polígono Industrial de Riera de Caldes*. In this factory, as in other factories in the group, only a part of Gestamp products is produced, as there is a productive specialization of each factory in a certain set of products. The most prominent products manufactured at Gestamp Palau are Body in White, Chassis & Platform, Bumpers, Blanks and Painted parts. Gestamp Palau is classified in the hierarchy of automotive component suppliers, as a Tier 1 supplier, which means that it purchases raw materials and parts from lower-level suppliers (Tier 2 and 3) and delivers finished subsystems directly to the final assembly lines of the Original Equipment Manufacturers (OEM). As shown in Figure 6, the OEM that represents the largest sales volume of Gestamp Palau (41%) is the Daimler-Benz Group followed by the Volkswagen Group (10%), however the second largest fraction of sales (31%) is destined to other factories of the Gestamp Group.

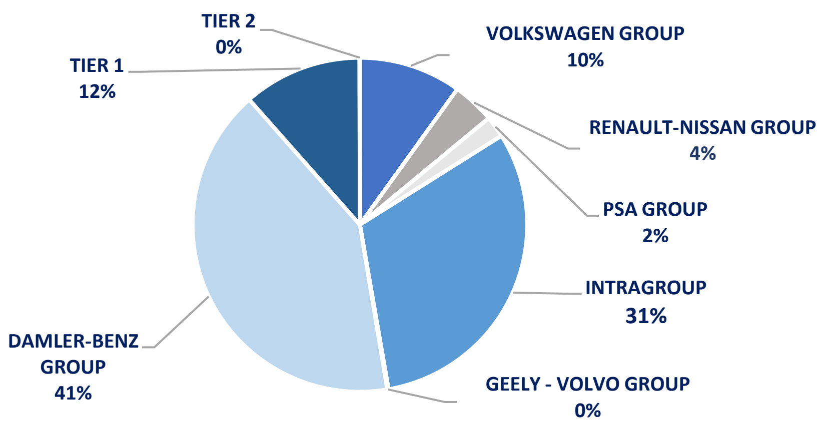

Figure 6 - Gestamp Palau S.A. sales 2021. Source: Own Elaboration

The concern with continuous improvement led the company to certify the quality management system according to the international standard ISO IATF and the environmental management system according to the standard ISO 14001. In addition to these certifications, Gestamp Palau places a large part of its concern in satisfying its customers, having already several certifications directed to specific customers, such as: VW Group Formel Q (A Level 94%) and PSA QSB +, continuing in seeking to achieve a wider range of certifications.

Gestamp Palau's factory infrastructure is divided into two large industrial facilities called Phase 1 and Phase 2, as shown in Figure 7, where the activities related to production, logistics, maintenance and quality take place. There are also an office area that comprises three floors, with the Administrative Management, Human Resources, Engineering, IT, Logistics, Planning and Kaizen departments on the first floor. The last two floors are occupied by the Division that coordinates all Gestamp plants located in Southern Europe, more specifically located in Spain, Portugal, France and Turkey.

Figure 7 - Gestamp Palau S.A. facilities

1.5. Report outline

The present dissertation is organized into six chapters, structured according to how the work was planned and conducted. The project background, the research questions, the objectives, the methodology adopted, and a presentation of the company are presented in this Introduction, regarding chapter 1.

The subsequent section, Chapter 2, is dedicated to the performed theoretical framework and literature review on relevant themes addressed by the project.

Chapter 3 is dedicated to presenting the work developed in the first two stages of the AR methodology Diagnosing and Action Planning.

Subsequently, Chapter 4 refers to the third stage of the AR methodology (Action Taking) which aims to put into practice the actions planned in the previous stage. Here, the methods and tools used to solve each of the problems previously identified are presented in order to chronologically reflect the development of actions and problem solving in the company.

Chapter 5 corresponds to Evaluation stage of AR methodology presenting the results of the conducted actions as well as its critical analysis. Also, the last stage of the methodology (Specifying Learning) is addressed in this chapter by discussing and responding to the research questions.

Finally, Chapter 6 aims to present the project’s main conclusions, final considerations, limitations, and future research recommendations to complement the present study.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

To align the project with the company's objectives, in the first part of this chapter (2.1 – 2.7), a theoretical framework about topics such as Lean Thinking and how it can be successful in organizations is addressed, as well as the description of some of the pillars that support it, such as the concepts of JIT and Kaizen. Through the approach of these pillars, it is possible to establish the connection point to the TFM tools, used to create basic reliability throughout the system and an efficient flow in production and in internal logistics processes. Some of the tools presented are In-plant milkrun, Supermarket, Synchronization, Border of Line and Standard Work.

The second part of this section starts in the sub-chapter 2.8 and entails a review of the research, discussions and approaches carried out by different authors regarding issues related to the internal logistics flow, more precisely with important problems and decisions to be considered when adopting supply systems to assembly production. The first theme addresses the different types of assembly model systems existing in industries in order to understand which one tend to create more problems when managing parts supply systems, more focused in the automotive sector, where this dissertation project is taking place. The second theme refers to the type of decision problems present in the literature that are associated with the internal flow of components when adopting a milk run system with tow-trains (better known as *Mizusumashi*) to feed assembly systems in the shop-floor. In addition, lines of thinking of several authors to approach each of the decision problems are exposed. Finally, the third theme emphasizes and explains the importance of applying certain Lean thoughts and continuous improvement tools, also in the scope of in-plant milk run systems.

2.1. Lean Thinking

Lean Thinking has its origins in the Toyota Production System (TPS) by Taiichi Ohno in the 1990s initially applied in the automobile industry. This philosophy was originated in Japan, after World War II, at Toyota Motors Company, with the objective of conquering the market with flexibility, reliability, and improvement of overall customer value. Toyota Motors Company's worldwide success demonstrates the validity of Lean Thinking principles and concepts (Yamamoto et al., 2019). Thus, nowadays the term “Lean” is found almost everywhere, from industries, whatever the scope of production, to offices or even startups and software development entities. The underlying concept though is the same: “maximize the customer value with minimum waste” (Alefari et al., 2017, p.756).

According to Womack and Jones (2003), defining value is the critical starting point for lean thinking and this definition can only be done by the ultimate customer. Value is meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time. The same author points out that “Yet for a host of reasons value is very hard for producers to accurately define”(Womack & Jones, 2003, p.16).

For this reason, it is necessary for companies to identify the wastes and to design out the 3M´s overburden (muri), unevenness (*mura*), and waste (*muda*) therefore maximizing activities that add value from the customer's perspective. The 3M´s are described by Yamamoto et al. (2019) as follows:

Muda - Represents any activity that involves the use of resources without creating value for the customer. The seven activities where this type of waste can occur are: Unnecessary processing that does not add value to the product (Over-processing); Unnecessary production that is not aligned with customer requirements (Over-Production); Any movement of product, materials or of a person's body that is not otherwise required to perform value-added processing (Transport and Motion); The excess of inventory being a risk to damage, obsolescence, spoilage, and quality issues (Inventory); The time wasted whether due to shortages, unbalanced workloads, need for instructions, or by design (Waiting) and any process, product, or service that fails to meet specifications (Defects). Later, in the 90's, an eighth wastage was added, which is the Non-use of the knowledge of the people who make up the organization. In this case, this knowledge is not considered to be an important contribution to process improvement. Figure 8 illustrates the eight wastes mentioned before.

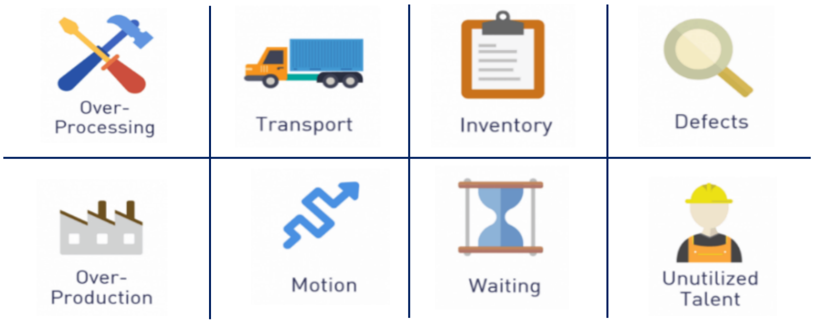

Figure 8 - The 8 wastes (McSharry, 2019)

Muri - It is linked to the overload of equipment or operators, requiring them to operate at a more intense pace, using more force, for a longer period than they can withstand. This type of waste has the potential to cause more damage to the safety and health of employees. Muri manifests itself in employee turnover, medical leaves, system outages and downtime, and poor decision-making.

Mura - Includes inconsistencies and variations in the production chain (quality, cost, delivery), in the workload of operators or in operations when activities do not go smoothly. *Mura* means "variability" and is a concept that represents the lack of stability and reliability. Too much *mura* means unpredictable variations from moment to moment.

Alefari et al. (2017) emphasizes that senior management commitment has been widely considered as a vital factor to implement Lean Thinking. This commitment can be demonstrated by establishing a clear vision, ensuring sufficient financial resources, and providing a good strategic leadership. However, is desirable that the transformation into Lean can be driven from the shop-floor establishing both top-down management commitment to change and a bottom-up groundswell of participation and ideas.

The TPS, is based on two fundamental concepts (pillars) that allow continuous flow of production throughout the company or supply chain: Jidoka and JIT (Ohno, 1988). The first is defined as automation with a human touch, that is, the machine's ability to detect defects and stop production, which ultimately allows for superior performance in terms of quality. The JIT concept, based on pull production, that is, pulled by the customer, defends the existence of a production process in continuous flow where parts only reach the workstation when they are needed and in the necessary quantity, thus eliminating sources of waste such as material, displacement, among others (Ohno, 1988). These pillars are supported on a basis consisting of level production (Heijunka), use of stable and standardized processes (Standard Work) and continuous improvement (Kaizen). Figure 9 is a representation of the TPS house, its pillars and concepts.

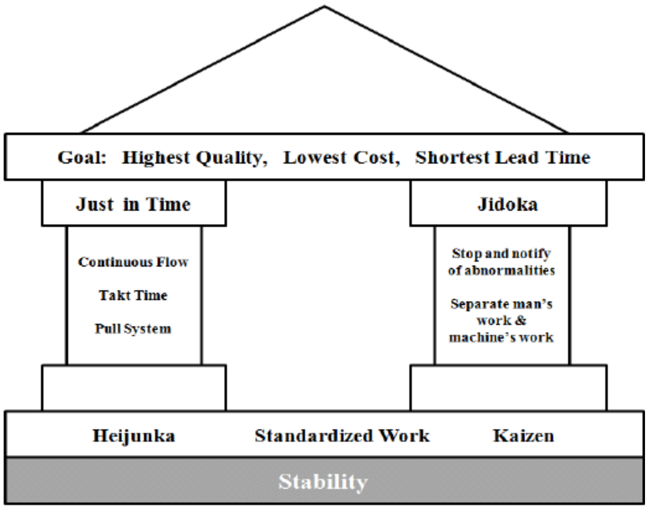

Figure 9 - Toyota Production System House (Simboli et al., 2014)

In the next two sub-chapters, the pillars of TPS referring to JIT and Kaizen will be described in a more detailed way once they are aligned with the scope of the present project.

2.2. Just-In-Time (JIT)

With the rapidly fluctuating economic backdrop of the 1980s, many North American manufacturers were forced to adjust their manufacturing approach to retain and regain their position in an increasingly competitive global market. The American mindset of using the longest lead time to produce the largest lot size for the lowest price would hold if producers were to base the price only on manufacturing costs (Mohammadi-Khashouie, 2003). However, there is no benefit on this mindset if the manufacturer is not producing exactly what customers want, exactly when they need. An innovative approach adopted in repetitive manufacturing and other industries to answer this question is the JIT strategy (Hannah, 1987).

As referred previously, it is not possible to talk about Lean without addressing this concept. The ever-increasing variety of products makes it inevitable to have to meet the wide differences in customer orders, thousands of different components need to be delivered just-in-time to a variety huge number of assembly lines that exist, for example, in the automotive industry (Emde & Boysen, 2012b).

JIT emphasizes a continual process of removing waste and inefficiency from the production environment through high quality and small lead times (Ohno, 1988). According to Ichikawa (2009, p.2276), “JIT is a system in which necessary items are received just in time as they are needed in the production line”. In other words, "Just-In-Time" refers to the actual production system whereby operations are activated just (and only) as they are needed (Mohammadi-Khashouie, 2003).

Toni et al. (2015) refers that to achieve the goals of JIT philosophy, the techniques with pull logic guarantee the best results as opposed to the traditional push logic. The *Push* paradigm is characterized by production decisions based on forecasted demand in the master production schedule and make/purchase order issuances based on stock levels. In this kind of strategy, parts are released to the next station as quickly as possible to avoid problems such as starvation at the downstream stations, inability to respond to changing patterns of demand and high volume of work-in-process, both in the form of semi-finished and finished products. If this type of problems happen, the system may suffer from high inventory holding costs (Ghrayeb et al., 2009).

Contrary, the *Pull* paradigm allows for maintaining flow manufacturing which means that all materials are brought into the process (or into the plant from suppliers) only when demanded by production activities. In turn, the production activities are triggered by costumer demand as well as the material acquisition (Mohammadi-Khashouie, 2003).

The major benefits to be gained from the use of the JIT pull type systems are to reduce inventory levels (of raw materials, work-in-process, and finished goods), identify quality problems therefore reducing scrap and rework; reduce manufacturing lead times and a have a greater flexibility in changing the production mix; a smoother flow of production with shorter set-up times, multi-skilled workers, and reduced space requirements. Bottlenecks to efficient production are identified, focused upon, and eliminated until new bottlenecks appear thereby regenerating the improvement cycle (Mohammadi-Khashouie, 2003; O'GRADY, 1988).

According to Ghrayeb et al. (2009), it is possible to combine these two paradigms in a way that they cover each other's weaknesses and strengths, which will lead to a more beneficial system with higher performance. In companies that adopt this hybrid system, it is important to realize that to get the best result out of this system, JIT concept is vital. The combination of hybrid push/pull system and JIT concept will enable companies to keep the buffer levels low (Figure 10), while reacting fast to demand on the shop floor (Akincilar & Rad, 2013; Ghrayeb et al., 2009).

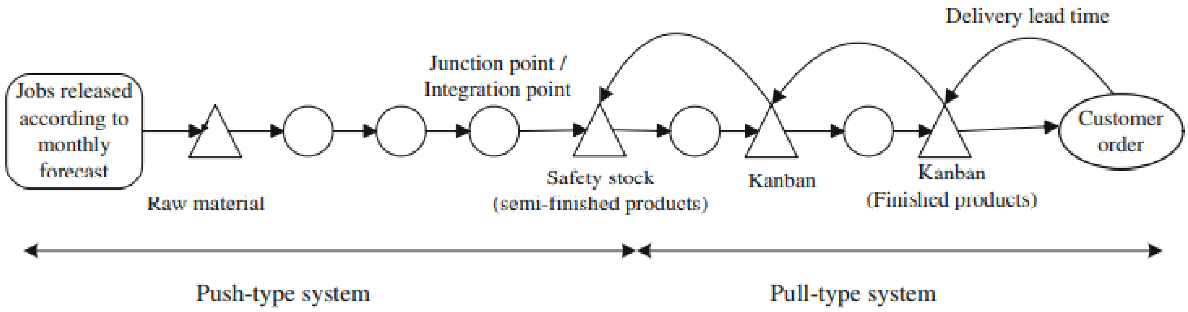

Figure 10 - Hybrid System (Push and Pull System) (Ghrayeb et al., 2009)

With this new way of thinking and leaving the old behind paradigm of adopting the push system by itself and by achieving reduction of inventory levels, the problems existing inside the organizations are revealed, promoting change initiatives and continuous improvement.

2.3. Kaizen

Kaizen is a Japanese compound word involving two concepts: Kai (change) and Zen (for the better) (Palmer, 2001). In this way it means "change for the better", however, this topic has several descriptions in the literature review. According to Imai (1986), Kaizen's Institute founder, it is a continuous improvement process involving everyone, managers, and workers alike. Broadly defined, Kaizen is a strategy to include concepts, systems, and tools within the bigger picture of leadership involving and people culture, all driven by the customer. Team (1992) explains that Kaizen stands for the daily struggles occurring in the work area and the way to overcome it and that it can be applied to any area where there is a requirement of improvement.

Daniels (1995) states that the way to achieve fundamental improvement on the shop-floor is to make possible operators to establish their own measures, to support business strategies and to use their knowledge to drive the Kaizen activities. That is so because it is assumed that employees have constant and direct contact with shop-floor real time situations that may could identify the origin of the problems or wastes allowing kaizen methodology to eliminate mistakes and imperfections in the functioning of an organization. In short, an organization's path to success leads through improving its internal processes and involvement of all its members (Kamińska, 2015). The focal point of the new organizational model is the creation of a flow both of materials and information, across any supply chain. In order to be effectively managed, such a system must be complied with the application of some kaizen pull-flow principles (Gallo et al., 2013):

Quality first: While discussing quality, there are several definitions from well-known classics mentioned by specialist literature, such as: Deming, Juran, Crosby or Feigenbaum (Kamińska, 2015). In a general way, quality concept is perceived as a predicted degree of singularity and reliability of a product with simultaneously maintaining the lowest possible costs and adapting to the requirements of the market. In other words, quality is the capability of a good or service to meet set objectives and must be planned, controlled, and improved as well as it should be taken into account at each stage in product life from its design to measuring customer satisfaction (Kamińska, 2015).

***Gemba* orientation:** *Gemba* orientation means "go to the *gemba*" (the place to make improvement) and change the working habits of people for the better.

Coimbra (2013) considers the following *gemba* orientation attitudes important to avoid those misconceptions:

- Going to *gemba*.
- Thoroughly observing the reality.
- Checking the *gembutsu* (the real things, the elements of that reality, such as tools, materials, and information).
- Speaking from the basis of observed and validated data.

Waste elimination: Kaizen defines seven forms of waste (*muda*) and targets their elimination as a way of achieving competitiveness and excellence. These seven wastes were already explained in sub-chapter 2.2.

People development: This principle places a great deal of emphasis on teamwork, training, and involvement of people in the improvement activities. Making people aware and conscious of the improvements done will allow to change habits in a more efficient manner (Gallo et al., 2013).

Visual standards: The visual aspect of the standard is an important factor, and seems to work efficiently if the standard is based on visual displays (pictures, drawings, and creative word pictures) available for everyone in the organization, than if it is a text-based descriptive standard and instruction usually seen in many *gemba*s (Abdulmouti, 2018).

Process and results: This principle assigns equal importance to the process and the result. If the kaizen methodology is correctly followed, becomes crucial having a look in detail at the process and analyze the ways to improve it, as well as it is important to look at the result once it is a commonly agreed target for the company (Coimbra, 2013).

Pull-flow thinking: The essence of this principle is already explained in the subchapter 2.3.

The Kaizen Institute discloses a continuous improvement model based on Kaizen fundamentals and methodologies. This model is called Kaizen Management System (KMS) and is represented in Figure 11.

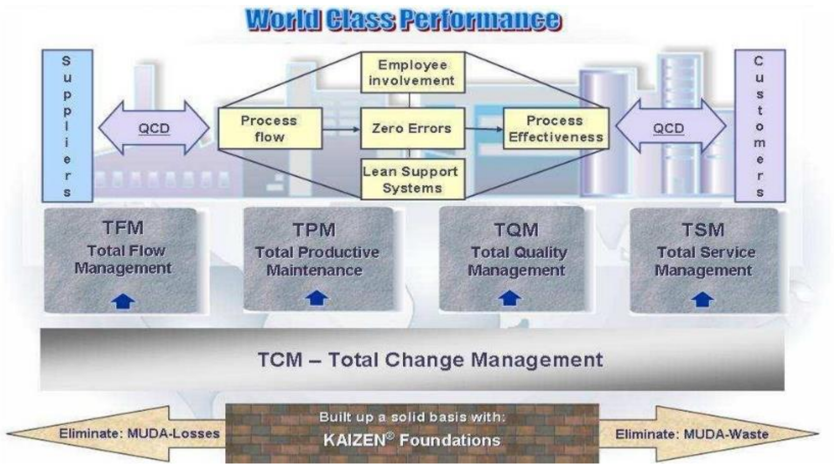

Figure 11 - KMS (Kaizen Management System) (Institute, 2012)

The KMS uses tools to address the implementation of improvements in different types of processes within an organization. However, to achieve a sustainable system it is necessary to know "which" tools to use and "how" to use them. KMS tools are as follows (Rocha, 2012):

- Total Flow Management: model which creates flow across the entire value chain, eliminating activities that do not add value.
- Total Productive Maintenance: equipment management methodology that aims to maximize the overall efficiency of the equipment.
- Total Quality Control: quality improvement support methodology.
- Total Service Management: methodology that aims to eliminate waste in production support areas.

- Total Change Management: methodology to support change management in organizations that supports the other previous mentioned tools. It includes building the ability for change while providing direction towards achieving it.

Since the areas that comprise the object of study of this dissertation are included in the Total Flow Management Model, it was only considered pertinent to carry out a more detailed approach to this tool.

2.4. Total Flow Management (TFM)

Total Flow Management (TFM) is a management model for integrated logistics, applied to the entire supply chain of a given company both in manufacturing and services activities. It is applied in the first instance with the aim of creating an internal pull flow with maximum operational efficiency and free of non-value added. The main objective is to achieve a higher level of service provided to customers and to improve, therefore, their satisfaction through reduction of total lead time, as measured coverage of stocks, eliminating *muda* processes, creating benefits in terms of cost reduction, and working capital, increased productivity, and quality (Gallo et al., 2013).

As shown in Table 1, five pillars support the TFM model, each one of them comprising important concepts and tools used to create and maintain an efficient flow of materials and information in supply chains.

Table 1 - Total Flow Management pillars Adapted from (Gallo et al., 2013)

V. Supply Chain Design (SCD)		
II. Production Flow	**III. Internal Logistic Flow**	**IV. External Logistic Flow**
Low Cost Autonomation	Production Pull Planning	Logistic Pull Planning
SMED	Leveling	Deliver Flows - Outbound
Standard Work	Synchronization	Source Flows - Inbound
Border of Line	In-Plant Milk Run/*Mizusumashi*	Milk Run
Line and Layout Design	Supermarket	Storage and Warehouse Design
I. Basic Reliability		

In the following sub-chapters, the TFM pillars which represent a greater contribution to the development of the present dissertation will be described. These ones are the Basic Reliability (I), the Production Flow (II) and specially the Internal Logistic Flow (III).

2.5. Basic Reliability (I)

Basic reliability pillar is related to the Toyota concept of basic stability, which says that to create flow, the organization need to achieve a certain level of basic stability in terms of the 4M's (manpower, machines, materials, and methods). At the beginning of any TFM project, organizations should evaluate the level of reliability on people and processes in order to avoid problems when starting to implement the other flow pillars (Coimbra, 2013).

Manpower: One of the critical variables for the basic reliability are the human resources (manpower) of the organization. In this field aspects like punctuality, absenteeism and workload balance must be monitored once they can disturb the flow. Also the creation of standardized tasks proves to be very important to reach the stability of the workforce (Rocha, 2012). According to Gallo et al. (2013), an important tool to be adopted is SDCA (Standardize, Do, Check and Act). This cycle should start by creating the standard that will solve the particular problem, taking into consideration also the views of employees and operators. The next step would be to transfer the standard through the training/lessons (phase Do) so that the new habit is established directly in the field. As this establishment takes time to be digested it is necessary to ensure and monitor the implementation, activating the stage (Check), carrying out *gemba* walks, internal audits to establish corrective action plans in case of non-conformities. If everything is working as expected it is possible to start doing the task according to the standard defined (stage Act).

In accordance to Prayuda (2020) and Sokovic et al. (2010), if organizations combine the above mentioned tool with the PDCA cycle (plan-do-check-act) process-oriented approach, they will be able to, step by step, achieve quality improvements (Figure 12) once SDCA is standardize to achieve process stability and PDCA implements changes to improve it.

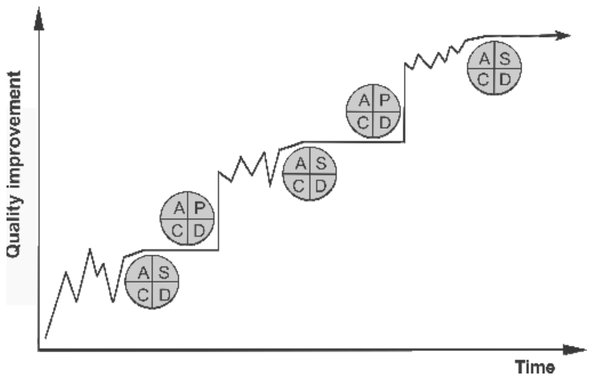

Figure 12 - Quality improvement methodology (Sokovic et al. (2010)

Machine**:** Besides human resources, companies must feel confident in the equipment and machines they make available, since their lack of availability, whether due to breakdown, long setup times or other causes, makes it impossible to create a flow. The Overall Equipment Effectiveness (OEE) measurement tool was launched by Nakajima in 1988 with the goal to achieve zero breakdown and zero defects related to equipments (Muchiri & Pintelon, 2008).

This concept "is a three-part analysis tool for equipment performance based on its availability A, performance P, and the quality rate Q of the output" (Muchiri & Pintelon, 2008, p.5). Therefore, it is calculated according to equation 1:

$$\mathrm{OEE} = \mathrm{A} * P * Q \quad \mathbf{1)}$$

Companies use this metric to identify for an equipment the related losses for the purpose of improving total asset performance and reliability. Confusion exists as to whether OEE indeed measures effectiveness (as depicted by its name) or it is an efficiency measure. Indeed, the OEE tool is a measure of effectiveness (Muchiri & Pintelon, 2008, p.5). This is an agreement with the definition in literature that OEE measures the degree to which the equipment is doing what it is supposed to do based on availability, performance, and quality rate (Williamson, 2006).

Material: Gallo et al., (2013) points out that "Problems related to basic material reliability occur if there is lack of supply of components or raw materials needed to begin production activities" (p.642). To address these problems, companies may adopt various tools of the TFM model that will be addressed further.

Method: The greatest difficulty in achieving basic stability is the mobilization and commitment of each one to always do their mission well. There should be low variability in the methods used in an organization and they must be suitable and tested to help the organization achieve its goals. When change is accepted as a factor of organizational improvement, the basic stability of a company is more easily achieved (Rocha, 2012).

2.6. Production Flow (II)

After achieving basic stability in the organization, the second step in implementing the TFM model is to improve the Production Flow. According to Coimbra (2013), this pillar has five domains, each one with a specific objective:

- Creation of one-piece flow (ideally, one piece at a time, from raw materials to finished product). This objective can be achieved applying techniques included in the domain **Line and Layout Design**.
- Minimization of the waste of operators' movements. **Border of line** and **Standard Work** are the domains that help to eliminate this kind of *muda*.
- Mass customization. The **SMED** (single-minute exchange of dies) domain is used to reach the flexibility that will allow to achieve the efficient production of small lots.
- Simplification before automation. Once achieved the previous objectives in a company (simplification), automation can be implemented and therefore it will represent lower investments than if the other domains of Production flow would not be achieved (**Low-Cost Automation**). This domain by itself can provide to companies many benefits once it increases mechanization and achieve great levels if productivity.

It was decided to further describe the domains Border of Line and Standard Work once they are inevitably related with the scope of the dissertation project.

2.6.1. Border of Line

An important domain of improvement in Production Flow (II) of TFM model is the Border of Line. Despite Border of Line is one of the aspects to consider when trying to achieve the Line Design domain, it deserves a separated improvement once it interfaces with Internal Logistics flows (III). It is the place where the supplier places the various units with the components/parts, which are then removed by the line operator to manufacture the product.

This concept refers to the design of the location and containerization of all the necessary raw materials and component parts in the assembly line. Coimbra, (2013) affirms that a well-designed border of line must fulfill four major criteria:

- The location of all parts must minimize the picking movement of the line operators.
- The location of parts and containers must minimize the movement of the supply logistics workers.
- The time needed to change parts from one product to another should be close to zero.
- The decision to replenish or resupply should be intuitive and instantaneous.

As the main focus is on minimizing workers' movements by locating parts as close as possible to their point of use, there are different ways to arrange and localize materials in cells or production lines. Regarding this and seeing Figure 13, parts or container of parts can be presented to the front of the operator's immediate working area (Front Location) or behind the worker (Rear Location). Normally, the rear location is used when it is impossible to use the front location (for example in car assembly lines) because it increases workers movements. One way to avoid so many movements is to prepare in advance one kit of the parts needed for each product in the line. This is called kitting (Coimbra, 2013).

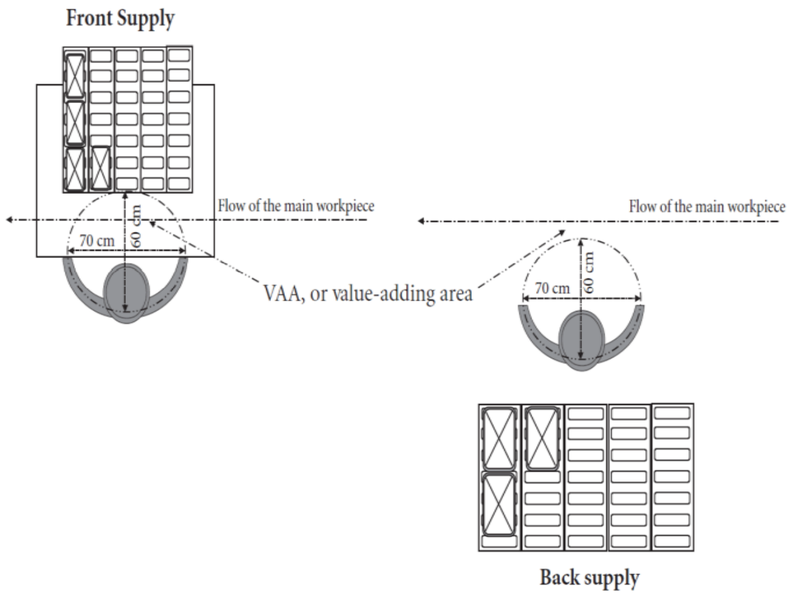

Figure 13 - Parts location at the Border of Line (Coimbra, 2013)

Regarding the supply of the border of lines, this can be done through two methods: *kanban* supply or *junjo* supply, concepts that will be explored further down this dissertation.

2.6.2. Standard Work

Standard Work (SW) tool is the baseline for Kaizen and means to create wasteless process as much as possible and create the standard document of the current best practice to maintain the developed status. As the standard is improved, the new standard becomes the baseline for further improvements, and so on (Vajna & Tangl, 2017). Thus, SW consists of standardizing the best possible work method, with the least amount of waste, producing the product with the best quality at the lowest cost (Liker & Meier, 2006). According to Vajna and Tangl (2017) , "Improving standardized work is a never-ending process" (p.67).

The essence of SW can be summarized as follows: To watch the movements of the worker. From this, make a spaghetti diagram mapping the movements around a physical work layout, and measure the time taken to perform each movement. Following these general steps, the *muda* of movement become visible and then appears the need to eliminate it. To do this, companies should make improvements and create robust work standards (Coimbra, 2013).

The knowledge about working times, by activity or job position, is an important element, as only through such knowledge it can be possible to:

- Assess workers' performance.
- Plan workforce needs.
- Determine available capacity.
- Determine the price/cost of a product.
- Compare work methods - Schedule operations.
- Establish incentives (prizes).

Cycle times are determined based on the work measure, one of the components of the work study. This is composed of a set of procedures used to determine the time required, according to certain standardized measurement circumstances, for the execution of tasks involving human activity. This required time is called standard time (Sarmento, 2012). Table 2 2 summarizes the main techniques used to measure work and then will be described in a more detailed way the ones with more importance to the development of the present dissertation.

Table 2 2 - Techniques to measure work; Adapted from (Sarmento, 2012)

Technique	Description
Timing	Intensive direct or continuous observation technique. Appropriate for manual or semi-automatic tasks with short and repetitive cycles
Work Sampling	Extensive direct observation technique suitable for tasks with non-repetitive cycles or with very long cycles
Pre-Determined times system	Timing system with fundamental motions computerized or in tables
Synthetic timing system	Task time databases similar previously obtained, in general in the company itself

Pre-Determined times systems are indicated for tasks that cannot be observed or have a short cycle. Is a system that consists of allocating basic times to a set of basic movements with which it is intended to describe the movements commonly used in work situations. In this way, it is possible to decompose any movement of a work situation in a sequence of basic movements.

"Therbligs" is the designation of the best-known basic movements. These are used by most pre-determined timing systems, with slight adaptations. The most famous Pre-Determined time system in the world, and probably the most used is the MTM (Methods-Time Measurement) of Maynard, Stegemerten and Schwab (1948) (Sarmento, 2012).

With the success of MTM, several companies adhered to this method, but as many of the industries had long cycle times, many basic movements that were hard to disaggregate, thus creating the Methods-Time Measurement – Universal Analyzing System (MTM-UAS). With the use of MTM-UAS it is possible to determine the best work method in order to obtain the shortest cycle time of the activity. The MTM-UAS method has pre-determined times for each basic activity performed, considering the distance traveled to perform the activity, in addition to the weight of parts that may be being handled, among other aspects. As the MTM-UAS is based on pre-determined times, the method is also used to perform simulations of activities, planning the workstation, and obtaining the best method together with the shortest cycle time needed to execute the operation, with that you can check operating scenarios without having to stop a production line. With this system, many activities can be avoided or just simplified. For all this reasons, the MTM-UAS becomes an improvement tool, and not just a measurement tool (Melo & Brito, 2014).

Standard work allows for employee turnover, ensuring greater flexibility, less risk of musculoskeletal disorders, reduction of waste, such as incorrect procedures and unnecessary movements (Losonci et al., 2011).

2.7. Internal Logistic Flow (III)

Internal logistics flows play a crucial role in many modern industrial production systems since its fraction makes up to 10% of overall production costs. It is expected the role of this TFM pillar to grow due to increasing automation grade of production systems and to the need for more flexibility resulting from the increasing on product heterogeneity (Vasyutynskyy et al., 2010). Fabri et al. (2020) refers that internal logistics flows analysis is a relevant issue for companies, in particular for those that face a scenario with high variable demand. As the design of internal logistics flows is challenging, the TFM model comprises some tools used to design, improve, and maintain a smooth material and information flow within internal logistics. It was decided to further describe the domains Supermarket, Synchronization, and In-plant milk run/*Mizusumashi* once they are inevitably related with the scope of the present dissertation project.

2.7.1. Supermarket

In order to be aligned with JIT principles, a growing number of manufacturers are therefore adopting the so-called Supermarket concept. These decentralized storage areas are scattered throughout the shopfloor, normally nearby assembly productive areas, and serve as an intermediate store for components required (Faccio, Gamberi, & Persona, 2013). From the supplier side, establishing decentralized incoming goods zones and supermarkets in the vicinity of assembly stations allows to delivery small but frequent baches of parts hence minimizing stocks at the workstations and distances travelled (Gyulai et al., 2013).

In these kinds of warehouses, handling operations usually have to be fast (Faccio, Gamberi, & Persona, 2013). For this reason, parts/references are normally easy to access by the supplier, have a proper and unique place to be stored, and are visible and identified with visual management reducing time on picking[1] activities. Besides this, supermarkets must meet ergonomic criteria's, therefore many manufacturers use special storage equipment such as gravity shelves and modular pipes which also allows to respect FIFO principle (First-in, First-Out). Also, the containers used to stock and move parts from the supermarket to the assembly lines are typically standardized and optimized in line with the parts typology (Faccio, Gamberi, & Persona, 2013).

Another strong point of the supermarket concept is that the quantities consumed are associated to a *Kanban* that gives order to replenish. Thus, instead of analyzing average consumption levels, the *Kanban* system allows to replenish immediately after utilization. From an intuitive view it is possible to understand which references need to be replenished by just looking at the supermarket (Brito, 2017).

According to Emde and Boysen (2012a), on the downside, supermarkets consume space on the factory floor, which is scant and expensive, and thus they are typically less space-efficient than traditional warehouses. An effective implementation of the supermarket-concept also necessitates some investment in equipment, staff, and maintenance. Finding the optimal compromise regarding this trade-off and investigating the operational benefits of supermarkets are important issues to be reviewed in an Internal Logistic Flow.

Taking as an example the automobile industries that is car assembly flows, the possible types of supermarkets include Flow racks (also called *kanban* racks) for small and medium-sized plastic containers and pallets of plastic containers, big containers on wheeled bases at ground to prepare special trolleys with sequenced parts (Coimbra, 2013).

2.7.2. Synchronization (KB/JJ)

Synchronization is related to the flow of information that allows to signal the start of production, or the start of the picking and delivery of components to the production area. Regarding the internal transportation of materials to the lines or cells, the worker using the synchronization information is the *water spider,* also called *Mizusumashi* or In-plant milk run. He sees when a container needs to be moved to a certain point of use and who orders a line to start production of a certain item. For this system to work efficiently, the synchronization should be done on the *gemba* with physical devices that allow the workers to understand and therefore to react quickly (Coimbra, 2013).

Synchronization is associated with two logistic loops: the *kanban* logistics loop and the *junjo* logistics loop and they will be described in the context of milk run/*Mizusumashi* worker.

[1] Picking is the operation of collecting various types of components from a storage location.

Kanban is the Japanese word for "card" or "instruction card" that normally contains information regarding the type and quantity of pieces contained in a box/unit and allows managing the JIT production method (Monden, 2012). This type of system generally can use two types of *kanban* cards, production, and transport. The production *kanban* has the function of informing an upstream process the quantity of parts removed by a downstream process, and consequently trigger the production of the respective pieces, in the quantities indicated by the number of *kanban*s. In turn, the transport *kanban* aims to authorize the movement of material from the storage location of the previous process to a subsequent process (Monden, 2012).

The *kanban* system is related to the in-plant milk run worker, to the supermarket, and to the border of line, allowing synchronization between these last two elements.

The *Junjo* system is similar but is related to “sequenced delivery” and has the advantage of reducing the size of *kanban* storages (as an example, the border of line will not have to maintain a location for the three or more different parts but only one location in which to put the sequence).

In a *kanban* loop, the milk run supplier arrives at the border of line and checks to see if there are any empty boxes available. The logistic train picks the empty box with the card attached and goes back to the supermarket and picks another identical box to deliver in the next loop. This is the most basic *kanban* delivery loop normally called *Full-Empty box* system (Coimbra, 2013)(Figure 14).

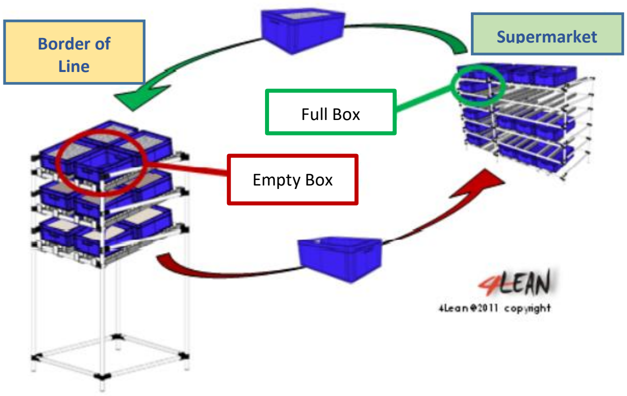

Figure 14 - Full-Empty box system (4Lean, 2011)

In a *junjo* loop, the milk run supplier receives a picking list that has the parts listed in the sequence needed by the operator (who is the internal customer). The *Mizusumashi* picks these parts and delivers them in a handling unit in the border of line in the required position. The *full-empty box system* can also be applied but only with one location for different parts (Coimbra, 2013).

2.7.3. In-Plant Milk Run/Mizusumahi

Through Lean Production, Taiichi Ohno identified transport activities as a waste that did not add value to the final product and saw the need to eliminate it from the production line. In the industrial environment, eliminating all transport activities is impossible, so for the good functioning of a company, it is important to organize and synchronize what and when it will be transported to avoid failures or interruptions in production (Tellini et al., 2019). One of the ways to achieve this is to adopt efficient Material Handling Systems (MHS) whose goal is to increase material flow by ensuring the availability of material when and where they are needed, while minimizing handling and storing costs, together with an increase in material handling vehicle usage rate. Also provide an improvement in safety and working conditions as well as facilitate the manufacturing process (Sule, 2008).

In industries, the supply and collection of the finished product can be carried out either with manually or automated material handling systems. Usually, the automated system requires high investments and has low flexibility, since both the supply and the collection are performed by automatic guided vehicles, often in a rigid way (Tellini et al., 2019). In the manual system, there is a resource called *Mizusumashi* or an Inbound/In-plant milk run system tool as well-known as logistic train. Bozer and Ciemnoczolowski (2013) described in-plant milk run systems as route-based, cyclic material handling systems that are used widely to enable frequent and consistent deliveries of containerized parts on an as-needed basis from a decentralized storage area (supermarket) to multiple line-side deposit points on the factory floor (border of line).

This system is based on frequent deliveries of small number of materials that can be raw materials, waste, semi-finished and finished goods. Usually, there are two separate tugger routes, one delivering components, and the other removing finished goods and they are allocated to specific areas of the manufacturing system (Alnahhal et al., 2014). Usually, each tugger train transports a set (variable) of wagons, normally between one and five, concerning the cargo to be transported (Tellini et al., 2019).

Referring to an example regarding the type of units the milk run can transport, in the automotive industry, it is possible to observe at the plant, a train of wagons with shelves supplying small and medium plastic containers, a train of wagons with pallets on wheels supplying big containers or even a train of wagons with wheeled bases with special fixtures supplying parts with variable-cycle inside *junjo* loops (kit containers from picking supermarkets)(Coimbra, 2013).

Karkoszka and Korytkowski (2016) consider important that, in the moment of designing milk run logistics, the appropriate area covered by one milk runner and the optimal itinerary within the appointed area should be carefully defined. These decisions affect the supply cycle time, how much material should be carried and further and how much material should be in the input buffers (border of line) at the workstations.

Besides this, the process of supplying material along the route can be coupled or decoupled with the picking process at the supermarket. The first one means that the picking process is performed by the tow-train driver and the path through the supermarket is included in the route. The second one mentioned (decoupled), means that material supply and picking processes are clearly separated as the tow-train driver enters the supermarket and stops at a specific area being the picking process at the supermarket carried out by another operator (Urru et al., 2018). According to Alnahhal et al. (2014), in decentralized supermarket system, the decoupled routes seem not very effective because in this case, an operator should be there for every supermarket which increases the labor costs.

The adoption of an in-plant milk run by organizations has some steps (Figure 15) that must be taken in order to carry out an efficient implementation of this tool (Harris et al., 2003).

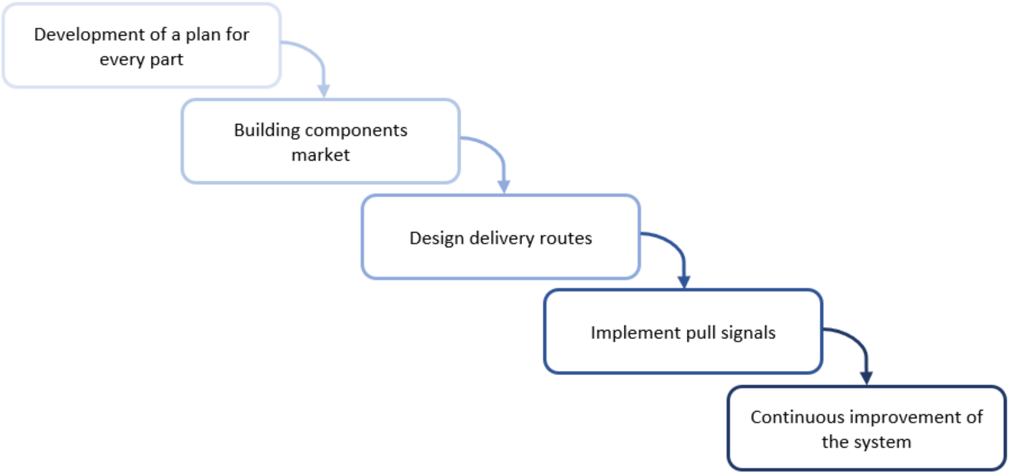

Figure 15 - In-plant milk run implementation steps

The first step is based on gathering the necessary information about every part (materials and semi-finished parts) in the system to define the amount and frequency of deliveries. The second step is to build a supermarket by designing maximum inventory levels and rules for operating the market. The third step consists of choosing the vehicle type, capacity, time period and itinerary. In the fourth step, the number of containers is determined and pull signals are implemented. To sustain the milk run system (fifth step) in a good shape, standardization should follow the design step, supplemented by a small step by step improvement (kaizen)(Karkoszka & Korytkowski, 2016).

Milkrun Systems (MRS) have numerous advantages compared to traditional forklift supply. In usual situations, forklifts move pallet sized containers of raw materials or semi-finished products close to the point of use in production areas in an unorganized manner, as well as finished goods to the finished-goods warehouse. In this kind of MHS neither the route or the cycle time are standardized once the forklift driver operates according to orders as they are received, and there is no capacity control. Thus, during some periods of the day the forklift can be overloaded with orders and during other ones, not loaded at all. The fact that there are no supermarkets storing flow containers, makes that the logistic tasks involved become nonlinear, which makes them very time-consuming (Coimbra, 2013). The load capacity of the forklift is also limited in terms of the number of parts it can carry at any given time which means that it must make many empty trips back and forth generating *muda* in the organizations.

Using milk run system, the tow-train picks up and drops off small quantities of materials, providing a cheaper, more reliable, and more predictable service. Contrary to the forklift system, material supply occurs on a just-in-time basis and it has been proven to reduce material handling distances within facilities (Alnahhal et al., 2014).Furthermore, tuggers are safer, more maneuverable, and less expensive than forklifts. Specially in the automotive sector, *Mizusumashi* is more interesting than the use of a forklift truck, because, when it connects several wagons, the MRS in a single lap, following the route, can supply and lift packages from more than one line/cell, optimizing internal logistics. A considerable gain for companies adopting milk run is the improvement of the safety and organization of the materials handling in the shop-floor (Tellini et al., 2019). Therefore, due to the growth of knowledge about the different MHS and its advantages and disadvantages, the dictum of ‘forklift-free plant’ began circulating in industry (Schmidt et al., 2016).

2.8. Problem of materials supply to assembly lines

According to Zhu et al. (2008), traditional mass production systems were based on assembly lines dedicated to one product or model that were produced in large quantities. These systems were based on high productivity through the principles of economics of scale and division of labour among the stations. A typical example of such a system is the original Ford Model T assembly system. These same authors mention that today's marketplace does not works like that anymore. Nowadays, customers demand high product variety and short lead times, thus companies that understand these new circumstances and respond to them quickly, with appropriate products, can gain a significant competitive advantage (Macduffie et al., 1996).

Zhu et al. (2008) believe that, as a result of this paradigm, assembly lines must be designed to be responsive to customer needs while at the same time accomplish mass production quality and productivity.

Baudin (2004), Becker and Scholl (2006) and Mohammadi-Khashouie (2003), in their research, identified and explained three types of assembly lines designs that exist in industries presented in Table 3.

Table 3 - Types of assembly lines existing in industries

Type of Assembly Lines	Description
Single-Model Assembly Lines	Assembly lines that have been only used in single type or model production. In these lines, there are large quantities of products which have the same physical design. Here, operators execute the same amount of work when the parts arrive at the workstation
Multi-Model Assembly Lines	An assembly line where different products are manufactured in batches. This line is often used when there are significant differences in the production process between the products. This requires a rearrangement of the workstation equipment (considerable setups)
Mixed-Model Assembly Lines	Assembly lines where produced items keep changing from model to model continuously, that is, more than one product or model is manufactured. The models at a mixed-model assembly line may differ from each other with respect to some physical attributes such that their production requires different tasks, times and/or precedence relations. However, the setup time is almost zero between models

An example of growth of product variety is the automotive sector. This industry needs to offer a wide range of different products and to quickly respond to customer demands that change every day leading to the necessity of a daily variation in the production sequences. As a result, in these cases, the typical configuration of the production system is the Mixed-Model Assembly System or the Multi-Model Assembly System (Faccio, Gamberi, Persona, et al., 2013b). The description presented above of each one of these systems allows to understand that they have an enormous hunger for a very diverse range of parts, making the organization of a well-run logistics network one of the most vital tasks to ensure that final assembly runs smoothly and efficiently (Emde & Boysen, 2012a).

Within this context, Emde and Boysen (2012a) underlines as a significant challenge, the feeding of parts to the productive stations in the assembly systems, once non-reliable and non-flexible parts supply can lead to components shortages and assembly station idleness, harming the correct internal logistic flow.

2.9. In-Pant milk run decision problems

Literature research was carried out in order to understand what kind of decision problems exist when adopting the In-plant milk run/*Mizusumashi* in organizations during the different phases previously discussed in subchapter 2.7.3 Figure 15. It was possible to understand, through the studies carried out by Alnahhal et al. (2014) that there is a great importance on studying the decision problems related to the in-plant milk run, however, to achieve an efficient internal flow and to be able to respond and adapt to more complex components feeding systems, it is necessary to also take into account others aspects that affect and are affected by the milk run system.

According to the same author, the main decisions regarding in-plant milk run using tow-trains are:

- Routing problem.
- Scheduling problem.
- Frequency of routing.
- Loading problem.
- The number of *kanban* required in the system.
- Determining of number of tow-trains.
- The number of handling operators.

When designing the delivery routes of the in-plant milk run using tow-trains, routing and schedule problems use to appear, and there are some authors trying to solve this decision problems in the literature review. The milk run Vehicle Routing can be seen as a special case of the Vehicle Routing Problem (Carić et al., 2008), which in turn is a generalization of the Traveling Salesman Problem, as referred by Gyulai et al. (2013), and aims to find the optimal set of routes for a fleet of vehicles delivering goods or services to various locations. Of course, there is large research on this theme which addresses relevant aspects of transportation of goods, but only a few are devoted specifically to In-plant milk run traffic problems. Most of the research in the field of distribution logistics is focus on methods to organize transport processes in order to minimize the fleet size, the distance traveled (energy consumed), or the space occupied by a distribution system (Bocewicz et al., 2019). According to Carić et al. (2008), this requires either updating or revision of the routing policies used, or prior planning of congestion-free vehicle routes and schedules. In this way, Bocewicz et al. (2019) conducted a study to analyze the possibility of using declarative modeling methods in solutions that provide interactive decision support for prototyping in-plant milk run traffic systems. The implemented model in a constraint programming driven solver, aimed to determine the number of transport trips and their organization in time and space needed for timely delivery of material to specific loading/unloading points and was subjected to constraints imposed by an in-plant distribution network and environment.

Emde and Boysen (2012b) identified an obvious interdependency of both problems routing and scheduling in a way that the decision variable of the routing problem serves as an input (given parameter) to the subordinate level of scheduling each train, once it determines the subset of stations to be served per tow train. On the other hand, only solving the respective scheduling problem can determine whether a specific subset of stations allows for a feasible delivery schedule given the limited train capacity. Thus, this author's paper introduces an exact solution procedure which solves both problems simultaneously in polynomial runtime.

The same author showed that the variable periods for milk runs are optimal for reducing inventory costs and space occupied in the workstations. However, Bozer and Ciemnoczolowski, (2013) believe that, from the point of view of lean manufacturing, it is better to standardize the system by stabilizing and fixing periods. They also think that, to provide as much consistent and predictable deliveries, the tow train should be scheduled to depart at constant time intervals, which the authors define as the in-plant milk run cycle time.

Decisions about the frequency of milk runner visits can be addressed by calculating the fraction of available time a workstation is idle due to lack of parts (workstation starvation) (Karkoszka & Korytkowski, 2016). Marchwinski states that "determining the delivery frequency is a balancing act" (as cited in Emde & Boysen, 2012b) and that establishing frequent deliveries mean there is less inventory (and less cost) in the system. However, specific circumstances might call for adjusting this parameter.

Karkoszka and Korytkowski (2016) adds that lengthening the cycle duration leads to lower milk runner utilization, giving him more time to handle materials to other production areas. Regarding cycle time, Alnahhal et al. (2014) pointed out as an important restriction to take into account that the necessary handling and transportation time of a milk run has to be less than or equal to the milk run cycle time (frequency) in order to maintain the planned material provision takt. Schmidt et al. (2016) suggests a way to calculate the necessary time to perform an in-plant trip (Milk run Service), that is handling and transportation time, based on a recent standardization approach of the Association of German Engineers (VDI). The presented formula is:

$$\mathrm{T_{zyk}} = \mathrm{T_F} + \mathrm{T_H} + \mathrm{T_B} + \mathrm{T_E} \qquad \textbf{2)}$$

where it considers $\mathrm{T_F}$ (the driving time according to speed and distance and additional times for gates, curves, ramps etc.), $\mathrm{T_H}$ (the time for deceleration, acceleration, and any additional operations at the stops), $\mathrm{T_B}$ (the train loading time, usually at the supermarket), and finally $\mathrm{T_E}$ (the unloading and carrier handling time at the stops).

During the research was found a very embracing paper from Faccio, Gamberi, Persona, et al. (2013) that comprises a big number of decisions. This paper presents a framework proposing an integrated approach both for long-term (static analytical model) and short-term (dynamic simulation) problems dealing with *Kanban* and Supermarket systems and with tow-train fleet sizing and management in a complex multiple mixed-model assembly system. This framework was divided into three main phases: a Static one applying an analytical simple but robust model to design and correlate the tow-train fleet size and the *Kanban* number. To assess the number of *kanban*s in the system (the level of inventory for each part at each assembly station border of line) the well-known Toyota formula was considered:

$$n \geq \frac{D * L * (1 + \partial)}{a} \qquad 3)$$

where n is the number of *kanban*, D is the consumption rate, L is the replenishment lead time, a is the stock keeping unit (SKU) and ∂ is the positive safety factor. Some authors such (Juran, 2021), regarding pull replenishment of materials, decompose the replenishment lead time L in:

$$L = torder + transit \qquad 4)$$

where $torder$ means the time to place and acknowledge an order (see empty box) and $transit$ means the supplier delivery time (deliver a full box).

In the first phase (static), the expected trips/day and the related average supply lead time were determined as a function of the tow-trains number (equal to the number of handling operators) and the service level for the assembly station supply. Given these variables and the safety stock, the number of *kanban* as well as the number of bins per trip were derived. Thus, using the results obtained in the first phase as inputs and varying them into allowed ranges, the second phase were carried out (multi-scenario dynamic analysis) to point out the best delivery frequency from the supermarket to the lines and the vehicle capacity utilization. The last phase was the performance analysis of the long-term and short-term variables and system validation (Faccio, Gamberi, Persona, et al., 2013a).

In general terms, according to Alnahhal et al. (2014), the main objectives of the above mentioned decision problems are: minimizing inventory costs, system variability, number of trains, starvation probability, distance traversed, total material handling costs and increasing utilization of workers. However, there are restrictive dimensions of in-plant milk run systems which are time, capacity and ergonomics, physical strain of the operators that must be considered properly in order to achieve an efficient in-plant milk run system (Droste & Deuse, 2011).

2.10. Lean and Continuous Improvement aspects in In-Plant milk run

The decisions and objectives mentioned in the previously sub-chapter coincide with one of the main principles of lean thinking that is minimizing wastes (*muda*) (Alnahhal et al., 2014). However, according to Fortuny Santos et al. (2020), also muri (people overburden) and *mura* (workload variation) are very common to be found in mixed and multi-model assembly systems environments. The author affirms that problems such as staffing and balancing multi-model lines have not been well studied. The same author points out that, in terms of Lean Management, designing efficient assembly processes requires computing the number of people necessary to accomplish a certain task or service and then assigning work elements to operators in an even and standardized manner.

Some papers regarding this theme suggest that mixed and multi-model assembly lines can be balanced separately according to each model they produce (Boysen et al., 2008; Kalaoglu & Baskak, 2008). Kabir and Tabucanon (1995) introduced another option that is to study each model in an independent way and then select common configurations for all models, which seems not to be an adequate method because is limited to few models and cases with long setup times. Roser (2016) proposed either balancing the line for only the most frequent model or computing, for each task, a weighted average performance time taking into account the quantities to be produced.

To solve the balancing of workload and workforce capacity, Fortuny Santos et al. (2020) presents a procedure to staff multi-model assembly lines, based on the comparison between workload and capacity. The aim of the problem is to determine the number of workstations or operators so that, given a number of models, the work elements can be assigned to workstations, when the desired daily production is known of each model assembled.

Once carried out this research, it was possible to verify that this considerations about computing the number of operators and its utilization have its focus usually in production environments (workstations) and that there is scarce literature review on the same topic regarding in-plant milk run or supermarket handling operators. Nevertheless, further along this dissertation, the considerations addressed previously will be taking into consideration when developing the work.

Regarding the same theme (balancing workload and workforce) Kumar and Kumar (2014) suggest the use of Standard work tool as a lean and continuous improvement enabler, identifying and applying four steps to implement it in an even manner: 1. Waste removal; 2. Documentation of work cycles; 3. Apply work standardization and 4. Continuous improvements. To evaluate the application of SW on their paper, the authors carried out a study of the layout, a data collection about the environment, which consider critical sub-steps helpful to remove wastes and to document processes. Additionally, Lu and Yang (2015) in their studies carried out an analysis of the parts quantity and process route of the products involved as well as a measure of operations time based on breaking down activities into elements. In what is related to the two last main steps, when a cell is not efficiently balanced, the possibility to reallocate the content of worker activities or eliminate some of them was analyzed by Kumar and Kumar (2014) with the aim of making the operator available for other activities. To help this reallocation, Lu and Yang (2015) identify the use of an operating loading chart (OLC) to help balancing and eliminating wastes. Both authors aimed to achieve the right number of operator for the tasks they were evaluating and both recognize that the results obtained must be frequently reviewed to implement changes required based on flexibility of demand (Kumar & Kumar, 2014; Lu & Yang, 2015).

An important topic to retain from this research is that the most of previously explored decision problems, objectives and lean approaches are being addressed by mathematical models, complex simulations models or metaheuristics like, genetic algorithm or tabu search, among others (Fortuny Santos et al., 2020), even though these methods usually require a greater degree of computational complexity.

3. APPLIED METHODOLOGY - DIAGNOSING AND ACTION PLANING

This chapter describes in detail the work developed in the first two stages of the methodology. Firstly, the Diagnosing stage of the AR methodology is presented with the goal of achieving an understanding of the environment where this dissertation project took place, and to do a survey of the identified problems. Then the Action Planning stage is presented, describing the underlying plan of actions used to address the identified issues.

3.1. Diagnosing

During this phase of AR Methodology, descriptions of the current situation of the organization in terms of production strategy and processes, product traceability, and information systems available are given. Since it is the object of study of this project, a description of the composition and current functioning of the welding department is made. The layout of the plant is provided with a description of the key areas to be considered in this project. This chapter also describes and explains in detail the entire current process of supplying components to the welding cells in order to further support the Action Taking phase of this dissertation. This diagnosis was mainly performed via *gemba* walk observations and collecting information via informal corridor talks and inquiries made either to department managers or operators. In the Diagnosing phase, a critical analysis of the parts feeding system to the welding cells was carried out to identify issues or problems with room for improvements and to point out the root causes for each one of them, whilst resorting to the lean tool *Ishikawa* Diagram.

3.1.1. Production Process

The first step taken to access the current situation was to understand Gestamp Palau´s production philosophy. When obtaining the first contact with the environment of the company as well as with all departments, it was possible to ascertain the production strategy used, which is MTS (make-to-stock). Thus, the company applies a push-type model that involves producing or manufacturing goods based on anticipated consumer’s forecast demand. In other words, products are stocked for covering the deliveries/sales forecasted, at least, for the next two days. The MRP (Material Resource Planning) is able to support the process of making a prognosis by analyzing per each article, its current stock, costumer’s gross needs and Gestamp’s strategy defined on SAP’s material master data. Despite this, the production accounts for a minimum batch of at least four hours of operation.

The subsequent step taken was to completely understand the whole production flow so that, at a later stage, it would be possible to study all the logistic processes inherent to the welding department. Gestamp Palau's main raw material is plate, acquired in coils or shapes, and there are three main production processes: Stamping, Welding and Cataphoresis. There is also a Blanking process used to internally produce certain types of formats, avoiding buying these materials from an external source. At the end of each process, parts can be shipped to the customer or moved on to the next process. The different paths that products can take during this production process are detailed in the flowchart presented in Figure 16.

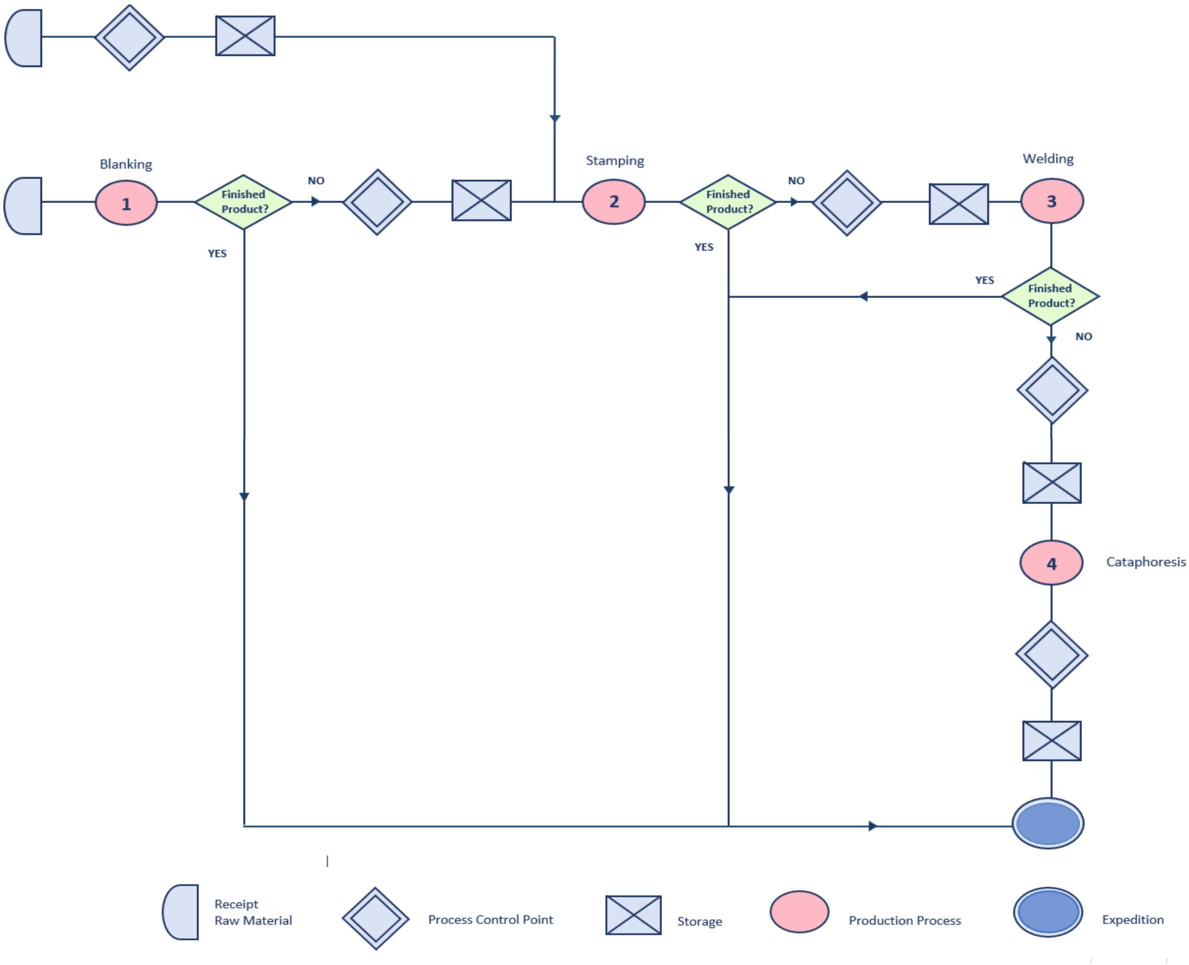

Figure 16 - Production Process FlowChart. Source: Own Elaboration

Taking into account this productive flow, the finished product can be sent to the customer only stamped (A), stamped and welded (B), or stamped, welded and painted (C), as shown in the examples from Figure 17, in the order described.

A B C

Figure 17 - Gestamp Palau finished products

As mentioned in the Introduction 1.4 sub-chapter, the production is distributed among the two facilities (Phase 1 and Phase 2) and it is possible to observe through the analysis of the layouts provided by the company that in Phase 1 (Figure 18) there are less productive operations in progress. This facility only has stamping presses and consequently has a considerable available productive area. However, it is in this facility that the majority of essential services for the organization's operation are found. In Phase 2, represented in Figure 19, there are larger and more diversified amounts of equipment to operate the four processes: Blanking, Stamping, Welding and Painting.

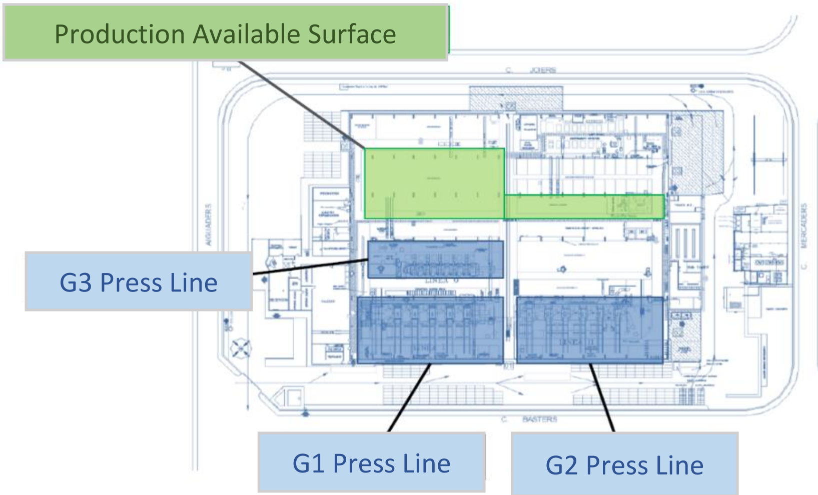

Figure 18 - Gestamp Palau Phase 1 facility

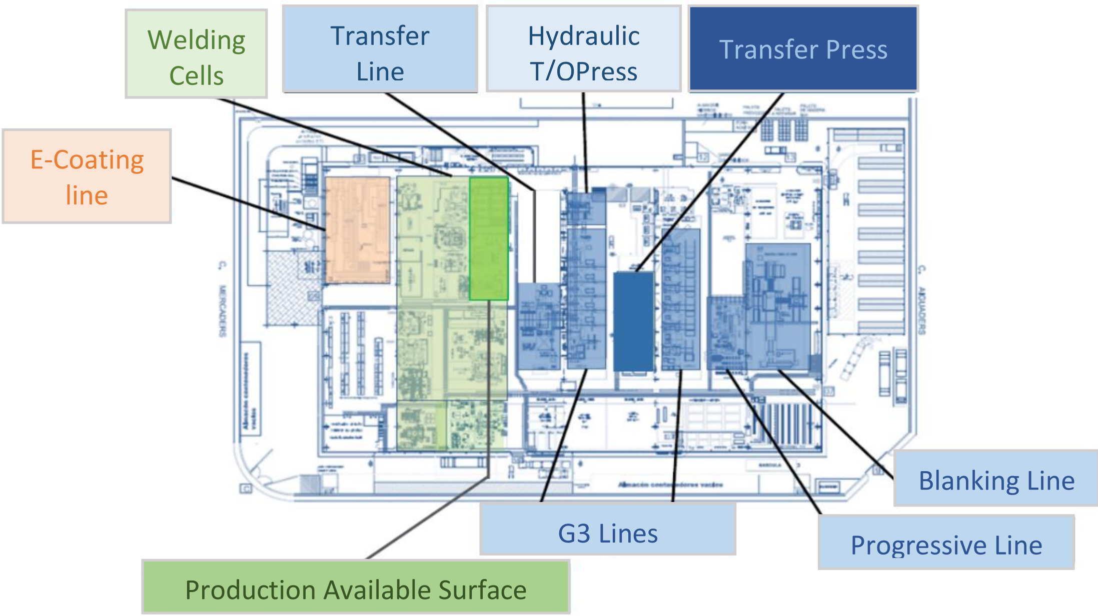

Figure 19 - Gestamp Palau Phase 2 facility

Blanking Process

This line consists of a decoiler that transfers the sheet from the coil to a flattener. Then, the sheet passes through feeding rollers to a press, which is typically mechanical and uses dies to cut the sheet into the desired shape (specific or simple). During the punching/blanking operation, the working parts (punches and dies) behavior depends on the working material (thickness, tensile strengths, yield strengths) and the tool steel ability to cope with the stresses that arise on the cutting edges. Making this process part of the production process of Gestamp Palau S.A., implies cost reductions in raw materials, to be fueled to the next process of the value chain. The machine (A) and the raw material (B) used to operate this production process are represented in Figure 20.

A B

Figure 20 - Blanking Process equipment and raw material

Stamping Process

The stamping process consists of the production of parts by plastic deformation of cold sheet metal, in which it is placed on a tool inserted in a press and subjected to force in order to acquire the desired geometric shape dimensioned in the dies. In the printing areas of Gestamp Palau, there are three types of stamping lines with different tons:

- **Progressive Lines** (A) represented in Figure 21 fed by coil (B) where the material is placed between the upper and lower die and undergoes a sequence of operations (cutting, bending, stamping) where the material advances to the next stage as the previous stage is finished.

A B

Figure 21 – Stamping process (Progressive Line)

- **Transfer lines** (A) show in Figure 22 can be fed either by coil (B) or by shapes (these can be cut internally in the Blanking lines or supplied externally (D). Contrary to the progressive line, it is composed of several dies that execute the operations individually. They are positioned in sequence on a common base and the pieces move from one stage to another, this transition is carried out through robots equipped with mechanical claws (C).

Figure 22 – Stamping process (Transfer line)

- **Tandem lines** (A) in Figure 23 fed by formats only, consists of a simple distribution of presses separated equidistant from each other. In this type of printing, there is a press and an individual die for each operation of the manufacturing process. Once an operation is finished, the part is moved to the next press, until the end of the line where the final product is obtained. The movement is performed by automated robot arms (B), which do not require human interference during the operation.

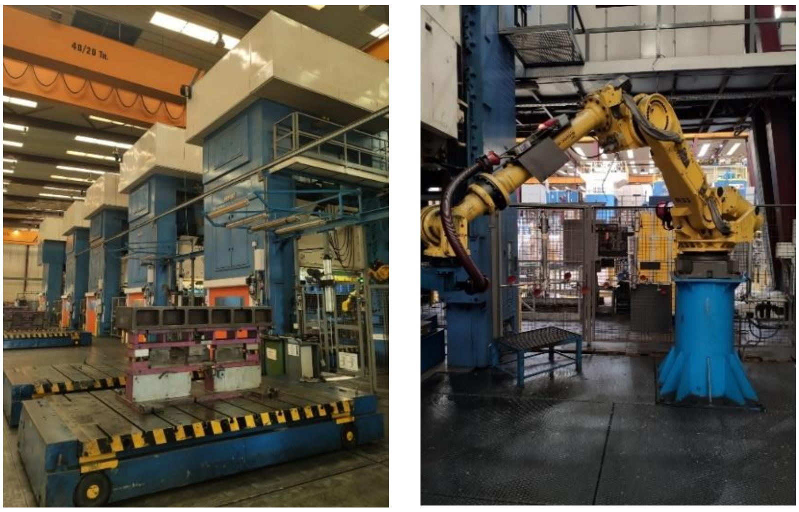

Figure 23 – Stamping Process (Tandem Line)

Welding Process

Welding involves the joining of parts that come from the stamping process or from suppliers. These parts can be welded between them and/or to one or more components (bushing, screws, nuts, rods, etc.). Gestamp Palau S.A. uses two welding processes that are operated by different type of cells like represented in Figure 24: Spot Welding (resistance) and MAG welding, depending on the final production objective. Spot welding (A) consists of the union of metals, without the addition of material, through the application of electrical current and pressure in the area, and this process is carried out using robotic cells. In MAG welding (B), a metal wire is introduced, supplied continuously by a feeder, between the electric arc and the workpiece, making the union of metallic materials by heating and melting. The weld metal is protected from atmospheric contamination by an active gas flow (MAG).

A B

Figure 24 - Resistance and MAG welding cells

Cataphoretic Painting Process

In Gestamp Palau, the E-coating/Cataphoresis process is done through a cathodic immersion electropainting and polymerizing process and has capacity of about 10000 medium size parts per day. To arrive at this workstation, parts that come from the stamping process, the welding process or even from customers who only subcontract Gestamp Palau's painting services, are collected from the stations in cars with supports to proceed to the E-Coating line. In Figure 25 it is possible to have a global view of this workstation.

Figure 25 - Cataphoretic workstation

Figure 26 shows the supports used to move and keep the products since they enter the process until they are painted.

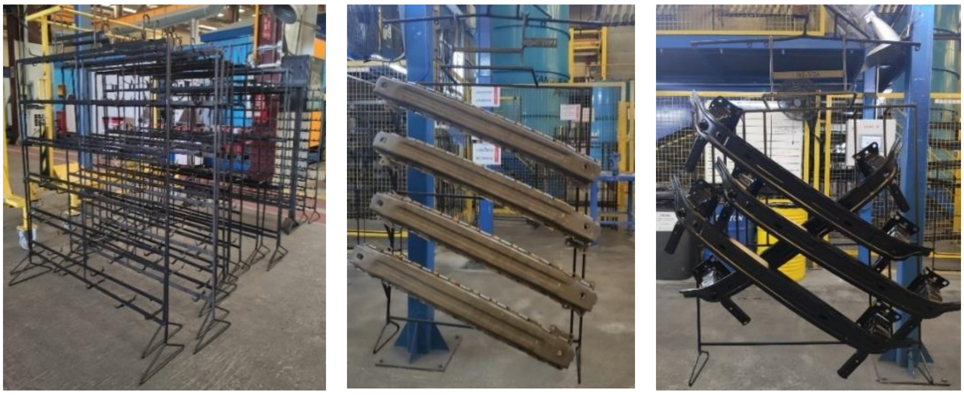

Figure 26 - Painting process input and output products

3.1.2. Product Traceability

In Gestamp Palau S.A., the products are identified with labels that provide to the company the ability to internally identify, track and trace elements of a product as it moves along the supply chain from raw materials to finished products. It provides the ability to investigate and troubleshoot issues related to a component. These labels represented in Figure 27 provide information explained below.

Figure 27 – Materials labels

The first letter of the reference that identifies the part gives information about which customer the product will be sold to, as if it is a finished product or component that will integrate it. As an example, P identifies Renault (PSA group), M identifies Mercedes, V the Volkswagen Group and R identifies Nissan.

The letter in the middle of the reference informs about where the parts come from. If it comes from an external supplier, the reference contains the K letter, and if it is raw material in form of coil or shape contains the B or F letters, respectively. This letter also gives information about the last stage the product went through. In this case, the X letter means that the part was blanked, the E means that the part was stamped, the S means that went through the welding process and the P letter means that was painted.

The remaining data in small letters contains information such as the date, time and workstation where the part was produced; Also provide information about the final product that the component will incorporate and information regarding the packing and its standard number of parts (SNP).

3.1.3. Information Systems

Regarding information systems, such as in most companies in the automotive sector, Gestamp Palau S.A. has implemented in its system the SAP ERP (Enterprise Resource Planning) software that integrates the core processes needed to run a company in a single system. This ERP gives employees of different departments easy access to real-time insights across the enterprise. When the implementation of this system occurred, it was customized aligned with the necessities of Gestamp Palau. As it is possible to observe in Figure 28, in this company, SAP gathers information from many departments, the main ones being Production, Logistics, Purchasing, Finance and Maintenance. In most cases, this system feeds other information systems in the company, and may also receive information from some of them.

One of the systems with which SAP ERP communicates is the Captor MES (Manufacturing Execution System) designed to bring technological intelligence to decision-making in the plant once real-time information. Its knowledge generation tools allow to accelerate the operational improvements (industrial metrics) in the plant, making them visible in the optimized business indicators. What feeds this system are the PLC (programmable logic controller) incorporated on the machines that essentially provide production information such as (stops on machines and respective causes, what OEE the machine is running, maintenance reports, among others).

Both systems mentioned above feed information to another information system, which is the WIS of Gestamp Palau, that aims to objectively report information and performance indicators from logistics and production so that they are interpretable and transversal to all employees of the organization. In the specific scope of the logistics department, Gestamp uses RF terminals to feed SAP ERP with information about operations from goods receipt to shipping products, that is, all materials movements (input, location, cross-docking, picking, preparation, and shipment), as well as data regarding stock inventory in the warehouse complex.

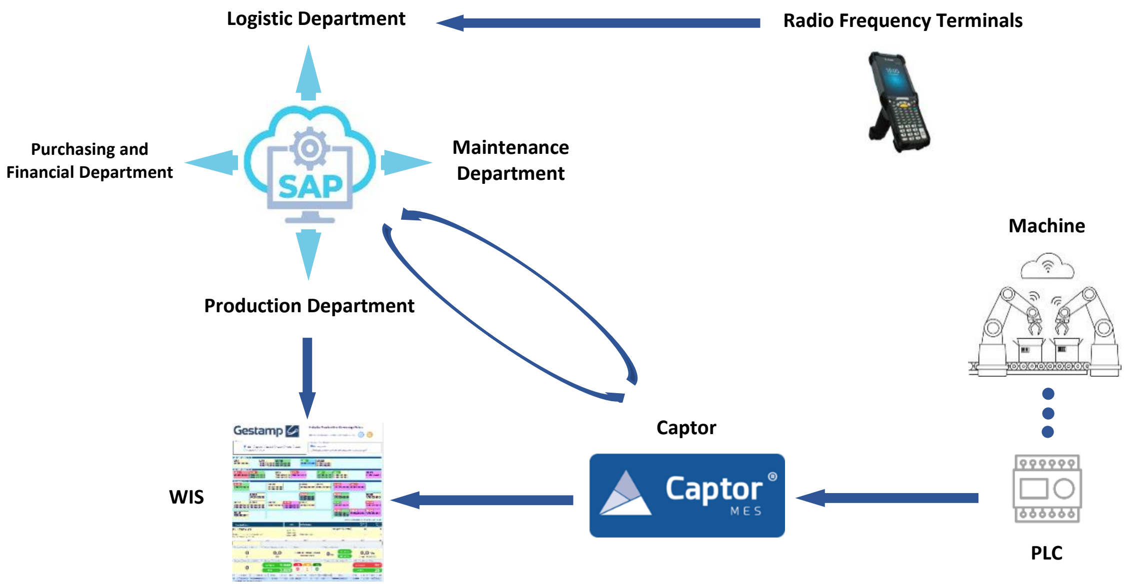

Figure 28 - Gestamp Palau information System scheme. Source: Own Elaboration

3.1.4. Welding Department

As mentioned in the previous subchapter, Phase 2 facility has a greater activity and is where the productive welding department that will be the object of study of this dissertation is located. Figure 29 shows the layout of Phase 2 provided by the company, where the areas destined to carry out the welding process are shaded in blue and the storage areas for components to supply this department are shaded in red.

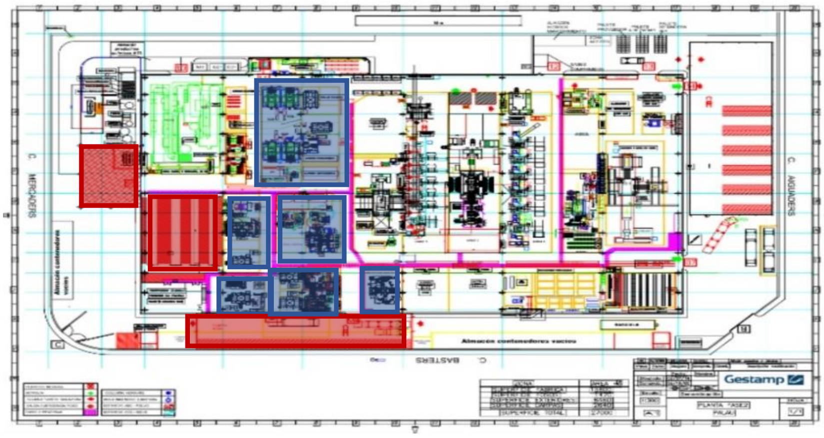

Figure 29 - Welding department areas in phase 2 facility

As shown in Figure 29, the layout provided does not allow a detailed analysis of the areas related to the welding process. Thus, a layout in Microsoft Visio Software was created, corresponding to an extraction of the global layout so that it would be possible to map all the logistic flows inherent to the welding process. This layout extraction can be seen in Figure 30 and will make it easier to understand each one further description.

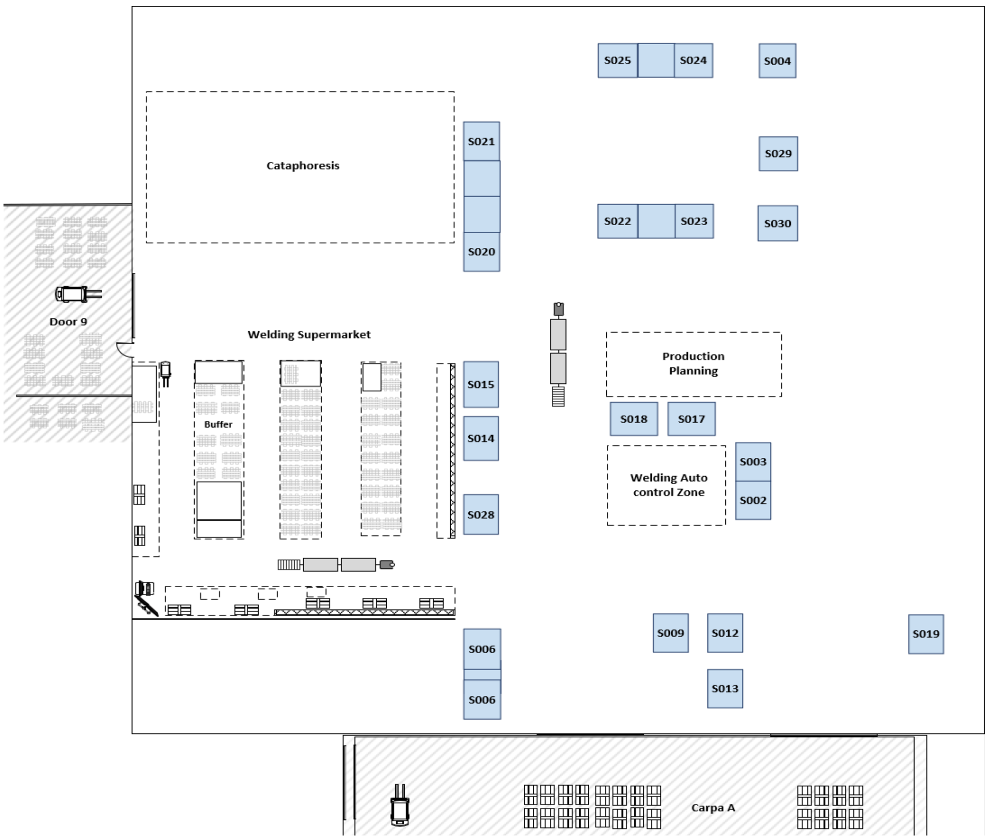

Figure 30 - Welding department layout extraction. Source: Own Elaboration

Welding Assembly area

Looking at the figure above, it is possible to observe that there are twenty-two workstations, more specifically automated welding cells that are dedicated to the assembly of components, 10 of them that use the resistance welding technique and 10 that use the MAG welding technique, there are also some with the capacity to carry out both processes (S019 e S006). These cells are identified by and S, followed by the assigned identification number.

In the welding department, the most produced products are Crash Management Systems commonly called Front/Rear Bumpers and Upper bodys. The cells are distributed throughout the plant, grouped by type of product and customer for which they produce. The S020/S021 and S009 cells produce for the Audi A1 and Audi Q3 models respectively, the group of cells that comprises S022, S023, S024, S025, S029, S004 and S030 produce for SEAT, more specifically for the LEON model and S006 to integrate the SEAT Tarraco model. The cell S015 produces for a large number of customers and the remaining cells produce for Nissan in large quantities and Ford in less quantity as it is a recent customer.

As in most companies in the automotive sector, the configuration of this production system is a multi or mixed-model assembly system. Each assembly cell in the system is dedicated to a product family but is also able to produce several different models. In other words, one cell can be able to produce different types of products (references) and the same product can be produced in more than one cell.

In the group of cells that produce for the LEON model, there are those that produce the final product and those that also can carry out pre-phase of components. The product coming from these cells will integrate, as a component, the final product. Thus, this group of cells works in a continuous process and according to the one-piece-flow concept, with no work-in-process for some of the components. Currently, S004 produces in continuous for S024 and both S023 and S030 produce in continuous to S022 and S029.

Components Storage area

There are two main areas for storage of components needed in the welding process: the warehouse called “Door9” and the warehouse called “*Carpa A”*. The first area, presented in Figure 31, stores products from the previous production process (stamping) that will form part of the components to be supplied to the welding cells when producing welded parts. In this chaotic warehouse typology, the components are arranged in euro pallets containing KLT boxes (*Klein Lagerung und Transport* or Packaging and Transport of Small Components) owned by Gestamp Palau S.A. The stipulated quantity is 40 boxes per pallet.

Figure 31 - Door 9 storage area

The second component storage area (Carpa A), which is also chaotic, is also intended to store components from external suppliers and components from the stamping process that will later be incorporated into the welding process. These components are larger than those stored in Door9's warehouse and are arranged in stacked containers of considerable dimensions, as shown in Figure 32.

Figure 32 - Carpa A storage area

Welding Supermarket

It is in the supermarket area that all the components that are directly supplied to the welding cells are stored. The components are transported from the storage locations mentioned before (Door 9 and *Carpa A*) to the supermarket and are disposed of in sufficient quantities to supply the production process.

This area has recently undergone improvements as the components were previously disposed of in conventional shelving and, at present they are disposed of in pallets placed on the ground allowing for a better reach by the logistic workers and reducing the time of the logistic train picking activities. In Figure 33 the change made is observed.

Figure 33 - Supermarket area before and after improvement

Therefore, the smaller components from Door 9 warehouse are arranged on the floor, existing one pallet from each component reference and being grouped by cell for which they are provided. The components transported from *Carpa A* in containers, are arranged next to the walls allowing the preparation of multi-reference cars, called "*Minomi* cars". Within this supermarket area, there is a buffer area where pallets from Door9 warehouse that could not be placed in the warehouse or that have more turnover are placed, as well as pallets containing carton boxes with child parts (nuts, bushings, among others) that come from supplier. Considering these aspects, in the supermarket area there are a large number of logistic flows, and it requires setup and maintenance activities.

Border of Line

The border of line of the welding cells is the storage that receives the components transported from the supermarket, either in KLT or in *Minomi* handling units (described later in this chapter). Next to each workstation there is a FIFO shelve that has different assigned locations to each one of the component references. There are two types of FIFO shelves in the shop-floor, the fixed ones (Figure 34), placed next to more dedicated cells (produce a small number of products), and the movable ones (Figure 35) placed next to the cells with a larger mix of products. For each location/component in the shelves is already established a maximum number of KLT (number of *kanban*s) as shown in Figure 36. The replenishment of this area is made applying a *kanban* loop. Regarding the *Minomi* cars, there are specific areas drawn in the floor, normally two areas for the same *Minomi*, to perform the logistic loop, in this case called *junjo* loop (Figure 37).

Figure 34 - Fixed FIFO shelve

Figure 35 - Movable FIFO shelve

Figure 36 - Nº of kanbans label

Figure 37 - Minomi area in shop-floor

3.1.5. Current status of welding cells parts supply

When the welding process takes place, it is necessary to transport the components from the supermarket to the border of line at the workstations.

In the current system at the welding department, the forklifts were already removed and substituted by an in-plant milk run system, already physically implemented and carried out by logistic handler (*Mizusumashi*). This operator drives a tow-train that travels an established route and replaces the necessary components according to the *kanban*/leveling system full box-empty box. It means that during the route, the visualization of the order is created by the empty box/unit and in the next route the supplier must replace as many boxes/units as the orders created in the previous route for each component. This process is explained further in the scheme presented in Figure 38.

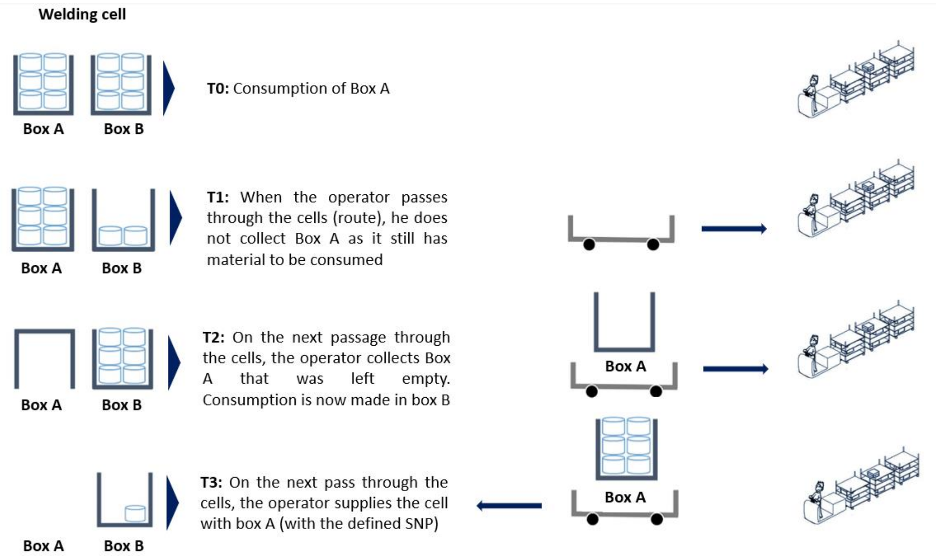

Figure 38 - Kanban Empty/Full box process in the welding cells parts supply. Source: Own Elaboration

It is determined, in the present status, that the time between routes is 1 hour for all production scenarios. Currently, most cells are supplied using milk run system, with the exception of those that are feed on child parts (nuts, bushings, among others) such as S028, S003 and S002, in which the supply is carried out manually. The picking tasks are all performed in the supermarket area, differing only in the type of location to pick up the components. The supplier can load the tow-train from the KLT pallet area (A) as well as from the container area (B) with larger components. Figure 39 shows the two types of locations.

A

B

Figure 39 - Welding supermarket picking locations

Regarding the handling units where the parts are transported to the cells (Transportation Packaging), this may vary depending on the components, in the following ways:

- **KLT Gestamp ESB** – These handling units (Figure 40) are picked from the pallet area and store smaller components. Its dimensions are 0,397x0.297x0.220 (mm) and specific cars are used for its transportation as shown in Figure 41. The first lane of the car transports the empty KLT boxes, and the following two lanes must transport the full KLT boxes to supply the workstations. There are no specific locations in the car regarding each component.

Figure 40 - Gestamp ESB KLT box

Figure 41 - KLT car

- **KLT Supplier** – These handling units (Figure 42) are also picked from the pallet area and store components purchased externally from suppliers. Its dimensions are: 0.400x0.300x0.250 (mm) and they are transported in the same type of car as KLT Gestamp.

Figure 42 - KLT supplier box

- ***Minomi* Car/Multi-Reference Car** – These handling units are subjected to a previous preparation in the container picking area where they are picked and intend to store and move larger components (stamped or purchased) and also child parts, that is, they can transport up to four different components depending on the situation. Currently there are 15 different types of *Minomi*, and for each type there are about 3 and 4 cars. Figure 43 shows an example of two different *Minomi* cars.

Figure 43 - Example of Gestamp Palau's Minomi cars

Despite the existence of these three types of handling units in the transport of materials, KLT Gestamp ESB boxes prevail over the others.

In the current situation of supplying to the welding cells, Gestamp Palau S.A. has only one tow-train to allow the supplier to carry out the described service (Figure 44) and three cars available to transport KLT boxes.

Figure 44 - KLT and Minomi tow-train

In terms of human resources, Gestamp has its own workers, however depending on demand variation, it may subcontract workers to carry out certain services. In this specific case, the activities performed by the in-plant milk run operator as well as the supermarket setup activities are two of the services to which Gestamp allocates workers of both types (internal and subcontractors). At the present time, it is determined that between 3 and 4 workers are needed in total to perform the two services depending on low or high customer demand, respectively. Currently, of these 3/4 workers, one is assigned to perform the in-plant milk run service and the rest to the setup supermarket service.

3.1.6. Problem Identification

As mentioned in previous chapters, the design, implementation, and continuous improvement of the internal supply of components to the production areas are key actions to ensure a continuous flow of materials and information that is in line with Lean and Just-In-Time principles.

It was identified that the substitution of forklifts with an in-plant milk run system carried out by the TFM *Mizusumashi* tool, is an effective means to perform this service. Its objective is to transport the materials stored in the supermarket to the border of line at the assembly workstations in an efficient manner.

This dissertation project has the welding department of Gestamp Palau S.A. as its object of study, which is characterized by its flexibility and capacity to cover a large mix of products (multi or mixed assembly model line). Thus, the focus of this project is directed to the current internal supply system of components to the automatic welding cells, which was found to lack management, planning and control of the resources needed in this logistic service, particularly with respect to milk run and supermarket logistic services. For this reason and continuing in Diagnosing phase of the AR methodology, there was a need for identifying and defining the problems which arose from the aforementioned issue. The problems will be exposed and explained next in this sub-chapter.

P1. Workstations Starvation

In Gestamp Palau S.A. welding department, it is possible for production operators to communicate the existence of stoppages in the production process, as well as to identify the cause that led to these stoppages. Using the Captor MES software, which compiles this information, it was possible to carry out an analysis of the existing causes of production stoppages.

Data from a three-month period was extracted in order to quantify and visualize the impact of the different causes in the total of the three work shifts (Morning, Afternoon and Night). Considering this project focuses on the supply of raw materials to the welding cells, the cause “Lack of Raw Material” was further analyzed, in the graph created from the data collected (Figure 45). Its analysis allowed to assert that this cause was one of the most frequent and with a great impact on the proper functioning of the welding production process. Looking at the values, it appears that during the three-month period and considering the three shifts, the welding cells stopped approximately 330 times due to the lack of components. This value is noticeably high, since it represents 15% of all the time the workstations were stopped.

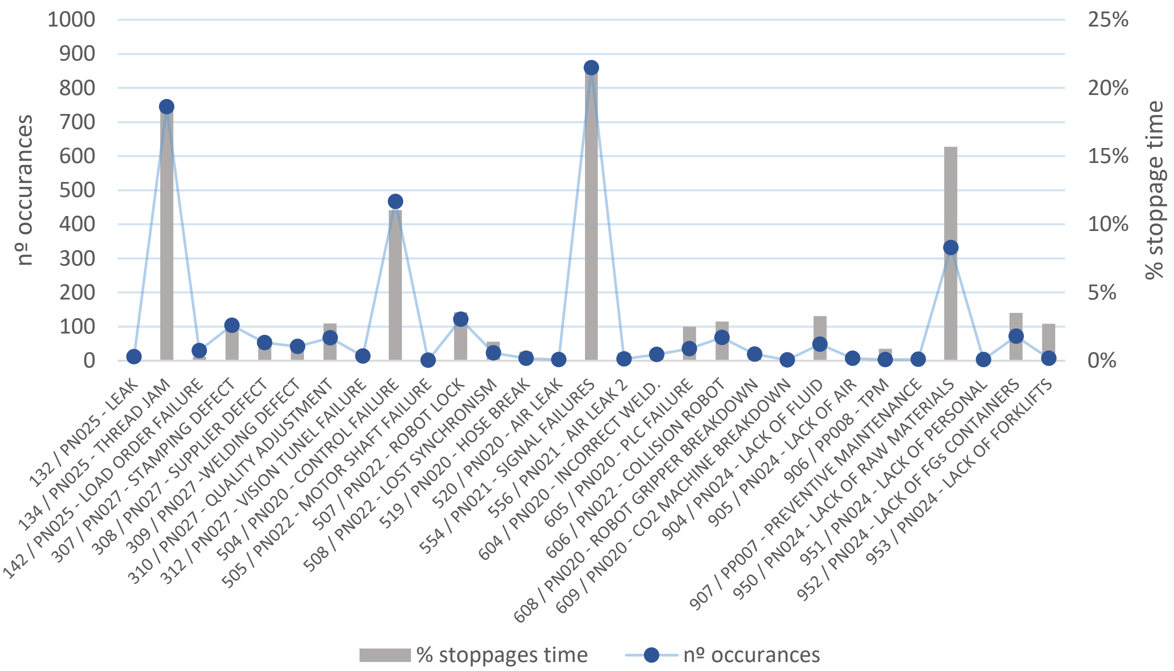

Figure 45 - Graph of production stoppages causes. Source: Own Elaboration

In order to further understand the problem, another graph was created considering the same period of time but only with respect to the impact of “Lack of Raw Materials” cause in each one of the shifts, individually. Observing Figure 46, it is possible to assert that the morning shift is the one where the parts feeding systems has a smother functioning. The values show that it is the shift with the least occurrences and time wasted in stoppages due to lack of materials supply. This fact is corroborated with the observation carried out through the *gemba* walks made during the shifts. In spite of not having conducted any observations during the night shift, the afternoon shift was found to have the worst organization and reliability in the system, since unnecessary motions, transports and non-compliance with established rules for the supply system were detected. The discrepancies between the three shifts with regard to the parts supply system led to the conclusion that there are standardization and management issues on this service. These are going to be explored further and detailed in the problems stated hereafter.

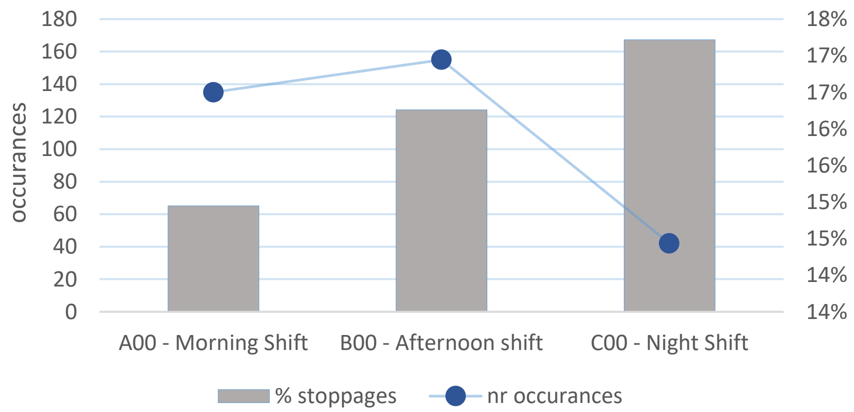

Figure 46 - Graph of the comparison between shifts production stoppages due to lack of raw materials. Source: Own Elaboration

P2. Lack of Identification and Standardization of Tasks

One of the factors that can lead to material shortages in the welding cells is related to the lack of identification and standardization of the activities carried out in the two services under analysis (milk run and setup of supermarket). Through *Gemba* walks it was possible to perceive that at present, the operators perform the tasks in a disorganized manner once the process and its activities are not documented or properly identified. This creates some variability (*mura*) in the system when performing these two services within a work shift but also between shifts and makes the human resources available unreliable.

The fact that these two services can be performed, in the current situation, by subcontractor workers can also be a problem in standardizing activities.

P3. Difficulty on balancing and planning the logistic team

One of the problems that the company desired most to be solved was the difficulty in planning and balancing the workload and workforce. This difficulty may be related to the lack of standardization of activities as well as to the lack of knowledge about the impact that each activity represents on the operators' work during their available work period.

Beside this, the variation of client's demand, that represents in practical terms, the variation of the number of welding cells in operation with considerable mix of products make this planning a difficult situation for the organization to manage.

P4. Unmapped Material Logistic Flows

Another situation that was considered a problem was the lack of mapping, identification and detail of the logistic flows of materials regarding the parts supply to the cells as well as the supply of the supermarket and its maintenance and preparation activities. This situation is intrinsically related to the previous problems, since uncertainties in the existing movements/flows make the establishment, documentation, and allocation of tasks to workers difficult and inaccurate.

If there is no flow mapping, it is difficult to apply further improvements to the system, since management may not be taking into account all the existing movements in the current state and therefore impair the efficiency of an existing flow with the implementation of the new improvement.

P5. Difficulty on planning material resources

Still regarding materials, also in this field it is necessary to have a planning that allows the organization to take decisions. In the present situation, the company is not aware of the amounts of materials handled either by the milk run or supermarket operators. Consequently, without this notion, it is impossible to manage the fleet sizing of the tow-train as well as to measure the necessary workload, once each material has an associated unit time in what refers to material handling and storage.

P6. Avoidable transports along the shop floor and non-compliance with the *Kanban*

As mentioned in the exposition of problem 2, the inexistence of standards, rules and documented tasks associated with each operator means that they may not perform the service with the expected performance. Once again, through *gemba* walk, it was possible to observe that, despite having defined a cycle time of 1h, that is the time between routes of the milk run tow-train through the cells, some workers do not comply with this time and perform numerous turns on the factory floor, not respecting the *Kanban* method (full-empty box) and consequently not efficiently managing the tow-train fleet capacity.

Still on the factory floor, in communication with the workers, it was noticed that sometimes they need to travel on foot to supply certain cells that for some reason were left with stock out.

These situations represent unnecessary transport or motion (*muda*) being identified the lack of training, communication, and instruction of workers as the most obvious cause for these wastes. However, another possible cause could be the maladjustment of the current cycle time of the milk run given the number and type of cells in operation, as well as the type of products being processed.

Once the problems and sub-causes were identified, they were summarized using the *Ishikawa* Diagram tool. Also known as a cause effect diagram or fishbone. It can simply be represented through bevel line segments which lean on a horizontal axis. In the head of each axis are represented the root causes and sub-causes which produce the global effect, represented in the head of the main axis (Doshi et al., 2012). Causes are usually grouped into major categories to identify the sources of variation. According to Liliana (2016) the categories typically include: Man, Machine, Material, Method (4M's), however sometimes these can be grouped into other two categories as well such as environment, management and measurements depending on the purpose of use (Doshi et al., 2012).

In this specific case, it was identified the "Inefficiency of the welding cells parts supply" as the global negative effect produced by the coexistence of the causes/problems listed above. Through the exposure analysis carried out previously for each problem, they were assigned to each of the main categories, thus completing the diagram presented in Figure 47. It is possible to predict that the resolution of many of the causes/problems will be addressed almost simultaneously once there is a greater level of interdependency and relation between them.

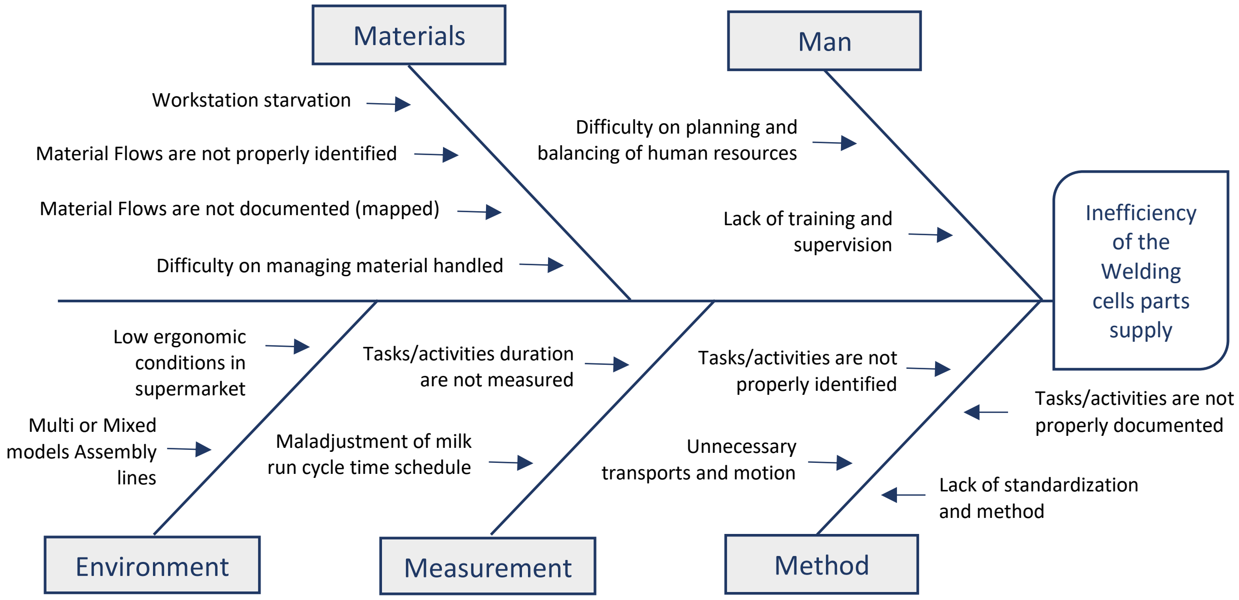

Figure 47 – Ishikawa Diagram. Source: Own Elaboration

3.2. Action Planning

As explained above, the welding department at Gestamp Palau S.A. is characterized as a case of multi/mixed model assembly line in the automotive industry (term addressed in sub-chapter 2.8 of the literature review), which makes the resource planning and management of the parts feeding system a complicated task for the organization. Customer demand, as well as the organization of the company's production plan, means that, over the days and sometimes over a shift, different cells must be activated to carry out the manufacturing of different products (output materials).

In collaboration with the company's Logistics and Kaizen departments, the problems listed above were analyzed and it was concluded that, regarding priority-setting and objectives of the organization, the focus should be directed to problems P3 and P5 solving, that is, balancing and planning the logistic team and materials management, respectively. On the one hand, the real need for human resources is not known, either in supplying components service to welding cells by the milk run, or in the service performed in the supermarket where the materials need to be replenished are prepared. This increases variability and waste since currently 3/4 workers are defined to carry out the two services, which may be over or under dimensioning the system, over or undertaking advantage of the workers, thereby not achieving the desired efficiency. On the other hand, with regard to materials, there is no perception of the number of materials handled in the performance of the two logistic services and for this reason becomes difficult to plan and balance the fleet sizing in the tow train, i.e. to be aware of the material resources needed to efficiently carry out the supply of parts.

In this sense, it was found worthwhile for the company to create a simulation and decision support tool that would enable the creation of instances and that could be used both by management in a long-term resource planning perspective and by the logistic workers (logistic supervisor) in a short-term perspective of autonomous management on the shop-floor. Still within the scope of creating the tool, it was considered pertinent that it should be as objective, intuitive, and dynamic as possible in order to standardize its use so that it would require little maintenance over time.

However, it was identified that it would be impossible to start developing the tool if the three problems P4, P2 and P6 were not addressed (Finish to Start relation), so it was decided to handle these issues in the first place.

The establishment of actions to address the different problems, allowed the assessment regarding the relation between actions and problem solving and the perception that the practical development of the tool would try to cover most of the identified issues. Table 4 intends to summarize the action plan, identifying the order in which the actions will be put into practice as well as defining what problems will be addressed with their performance.

It should be noted that the actions to be taken have different characteristics. The first three will be performed in a more analytic strand and in alignment with Standard Work techniques, the fourth one in an implementation context.

Table 4 - Problem solving action plan

Action Plan	P1	P2	P3	P4	P5	P6
1. Material Flow Mapping				x		
2. Identification of Tasks, Activities and Technical Actions		x				
3. Study of Times		x				
4. Simulation and Decision Support Tool	x		x		x	x
4.1 Tool scope and specifications establishment						
4.2 Tool Framework definition						
4.3 Tool Design and Development						

4. APPLIED METHODOLOGY - ACTION TAKING

The present chapter refers to the third stage of the AR methodology (Action Taking) which aims to put into practice the actions planned in the previous stage. Here, the methods and tools used to solve each of the problems previously identified will be presented in order to chronologically reflect the development of actions and problem solving in the company. Throughout the chapter, the decisions taken on choosing a specific path in detriment of another to solve a specific problem as well as some difficulties and obstacles found during this stage will be highlighted.

4.1. Material Flow Mapping

In sub-chapter 3.2 (Action Planning) it was established that the mapping of material flows would be one of the analytical actions to be taken to support problem solving.

It was thought to map the flows in the layout provided by the company, however, due to its complexity, an extraction of it was designed in Visio Software, and there the material movements were identified in a more perceivable, objective, and visual manner.

Taking into account the areas of the welding department that are the focus of this dissertation project, two mappings were carried out:

1) Parts/components supply flow from the supermarket to the welding cells’ border of line.
2) Inbound/outbound and internal flows in the supermarket.

The mappings will subsequently be presented with an instructive legend, accompanied by a detailed explanation of each one of the flows.

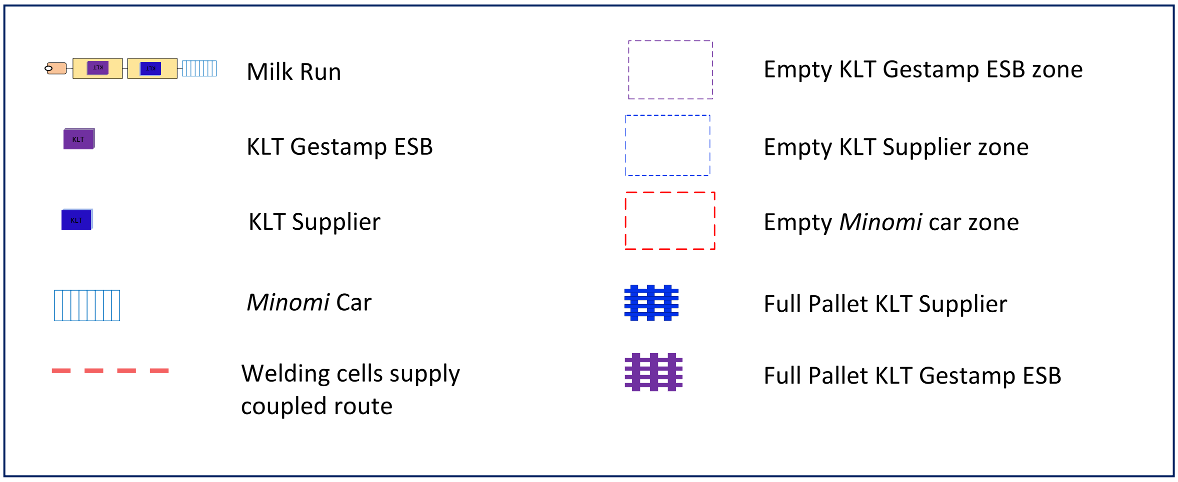

Figure 48 - Mapping 1) legend

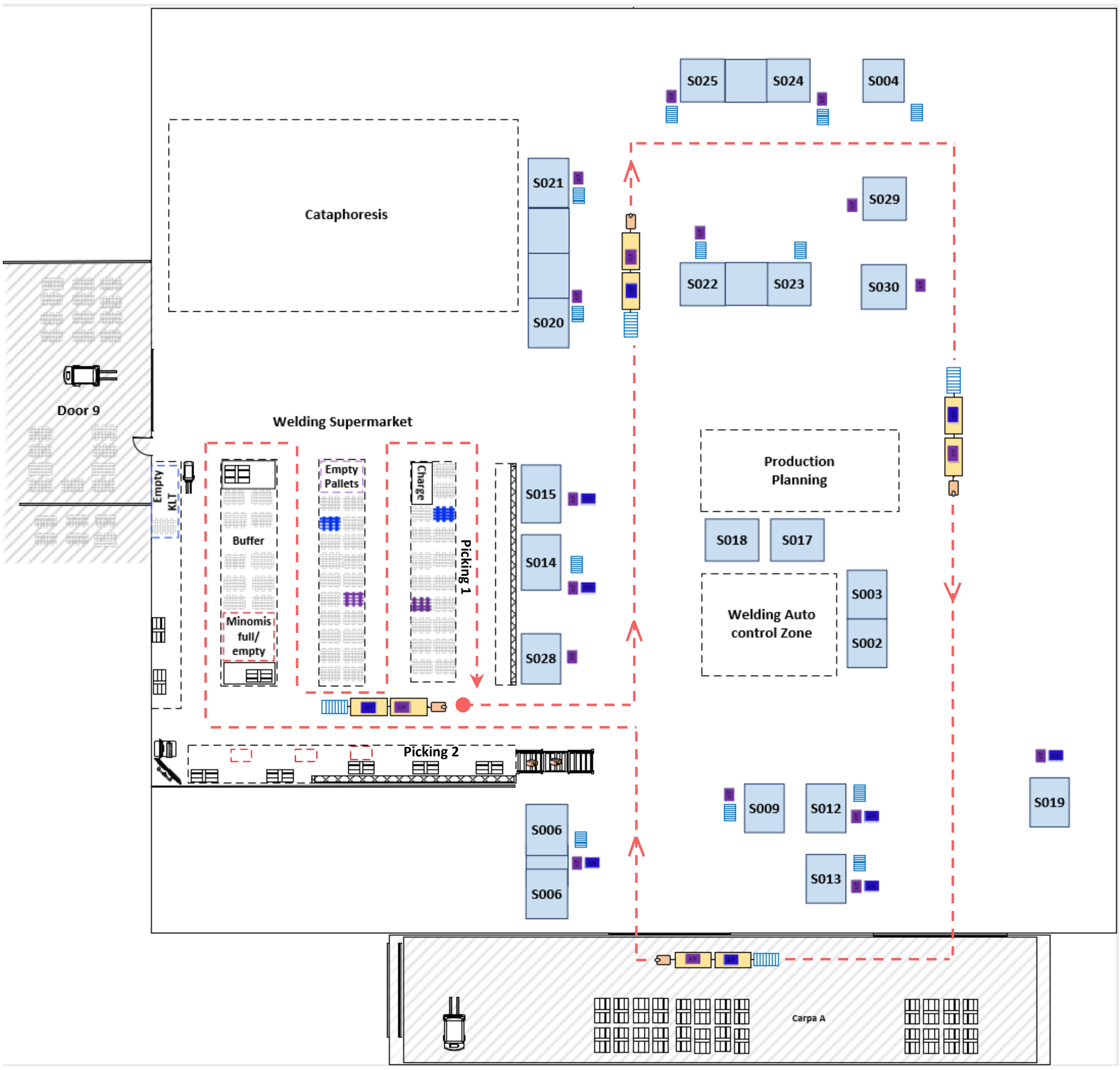

Figure 49 – Mapping 1): parts supply flow from the supermarket to the cells border of line. Source: Own Elaboration

With the elaboration of the mapping 1) showed in Figure 49 and with the support of the legend presented in Figure 48, it is possible to clearly observe the route taken by the in-plant milk run as well as its picking and stopping points for supply (workstations).

In addition, it is possible to retrieve that the route, which is 366 meters in total, is coupled since the milk run handler not only runs through the production area to supply the components to the cells, but also runs through the supermarket. When the milk run arrives at the supermarket, the first operation it performs is the unloading of the tow-train in the "*Minomi* full/empty" area leaving the empty *Minomi* cars and in the "Empty KLT" area leaving the empty KLTs in the assigned pallets. It then proceeds to the picking of the components stored in KLT in the “picking 1” area presented in the layout and finally to the loading of the *Minomi* cars in the same area where it had left the empty ones, then returning to the starting point where the tow-train must wait for the schedule defined to start a new route.

Another aspect in which this mapping revealed to be pertinent, was in helping to understand what kind of handling unit each cell is supplied with. As it is possible to see from the icons represented on the side of the workstations, not all the cells are fed with the same type of units. Those that work with both larger and smaller components, need to be supplied with *Minomi* cars and KLTs and the ones that work only with smaller components, are normally supplied with KLT Gestamp ESB and/or with KLT from supplier.

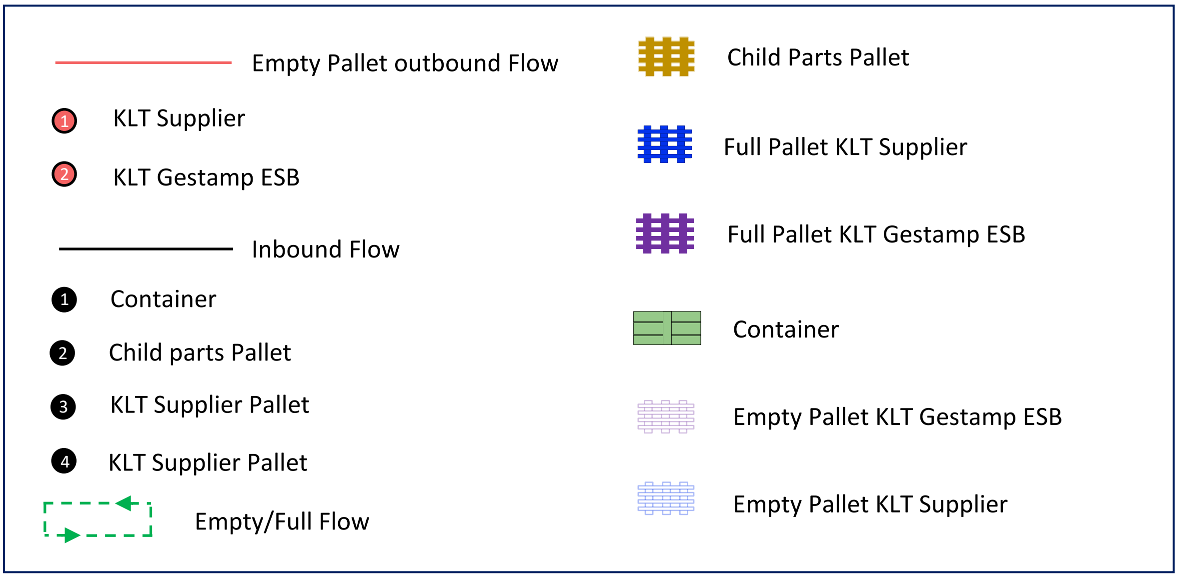

Figure 50 - Mapping 2) legend

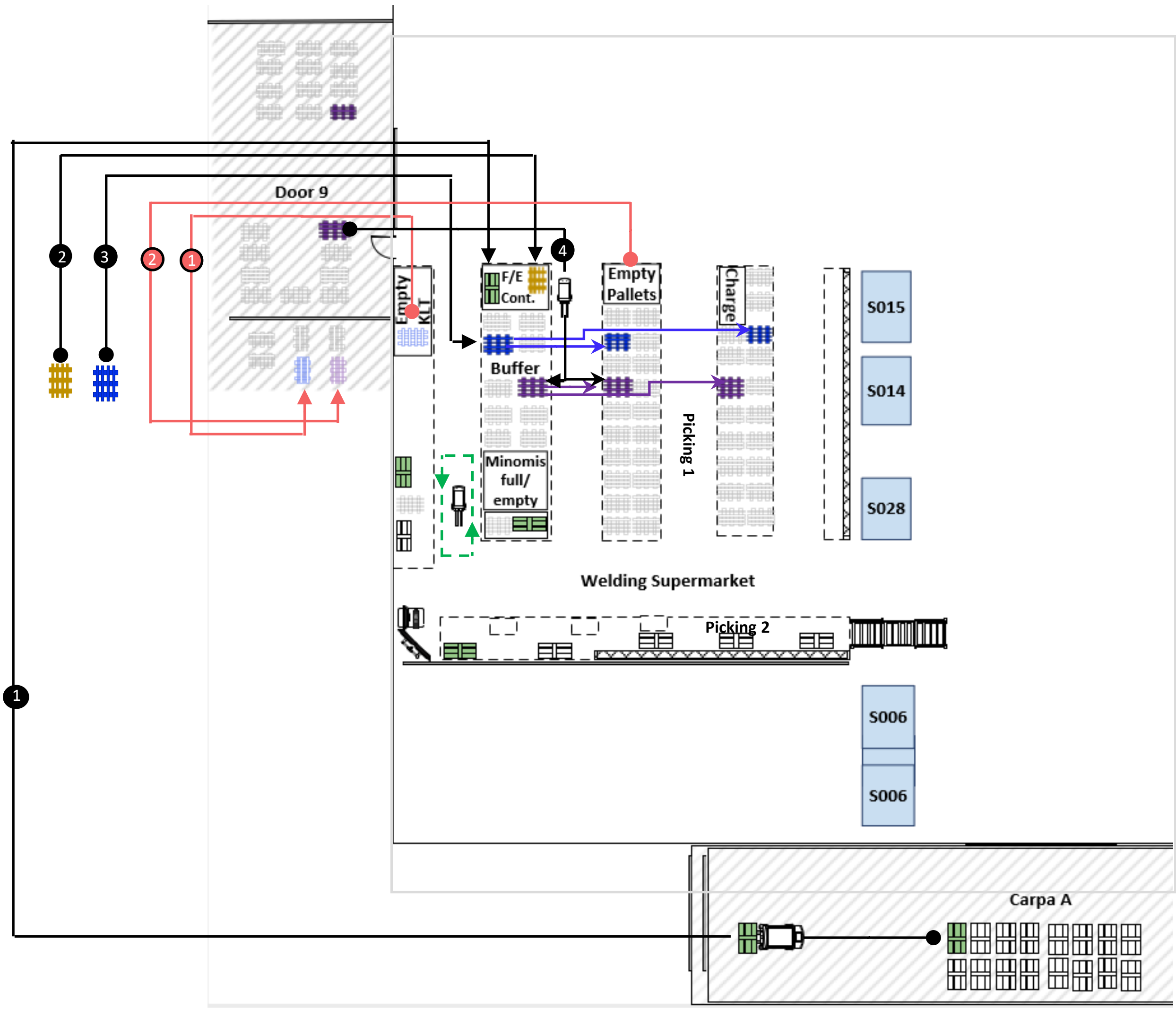

Figure 51 - Mapping 2): Inbound/outbound and internal flows in the supermarket. Source: Own Elaboration

The elaboration of the mapping 2) presented in Figure 51 and the legend from Figure 50, helped to understand all the existing flows related to the supermarket zone. There are four inbound flows drawn in black and two outbound flows drawn in red.

Regarding the inbound ones, the nº 1 represents the transport of the full big containers from Carpa A storage to the "F/E Cont." area, carried out by a forklift. The flows nº 2 and 3 represent the transport of full pallets containing child parts or full KLT from suppliers to the same area mentioned before or to the "buffer" area, respectively. The flow nº 4 represents the transport of full pallets containing full KLT Gestamp ESB boxes from the "Door 9" storage zone to the "buffer" area or to the "picking 1" area. In relation to the outbound flows, the nº 1 and 2, represent the transport of full pallets containing empty boxes either KLT Gestamp ESB and KLT Supplier to the correspondent area in Door 9 storage. All these flows are carried out by pallet trucks.

There are also flows occurring internally in the supermarket that are performed using pallet trucks. The green flow showed in the layout extraction represents the exchange of empty for full containers. When a container gets empty it is transported to the "F/E Cont." area where a new full container should be picked up and transported to the "picking 2" area of the supermarket. The remain flows (blue and purple) represent the transport of KLT supplier or KLT Gestamp ESB full pallets from the "buffer" to "picking 1", in case that this material is not transported directly to the latter zone mentioned from "Door 9".

The realization of this analytical action was in part facilitated due to the performance of *gemba* walks and corridor talks with the operators that work in these areas of the shop-floor.

4.2. Identification of Tasks, Activities and Technical Actions

Once identified all material flows inherent to the parts feeding system to the welding department, the second analytical action outlined in the Action Planning stage was carried out. Together with the logistic manager and the study of times technician, crucial items to consider were the identification of tasks and subsequent breakdown into Activities and Technical Actions carried out in the supply of components to production, with a view to proceed to its further documentation and standardization.

As mentioned in the Diagnosing stage of AR methodology, where the entire process was analyzed, two services were identified with differentiated activities within the parts feeding system: In-Plant milk run Service and Setup Supermarket Service. The details made for each of the services is represented in Table 5 and Table 6.

Table 5 – Tasks, Activities and Technical actions performed in In-plant milk run service

Service	Task	Activity	Technical Action
In-Plant milk run service	**1.**Tow-Train picking in Supermarket Area	**1.1** Get off the train	Approaching KLT car
		1.2 Leave empty KLTs on pallet	Collect KLT from KLT car
			Move to "Empty KLT" area
			Leave empty KLT on pallet
			Return to KLT car
		1.3 Leave empty *Minomi* car in correspondent area	Unhook empty *Minomi* car
			Move to the correspondent area
			Leave empty *Minomi* car in the area
			Return to *Minomis*
		1.4 Load a KLT on train's car	Crouch
			Collect full KLT in "Picking 1" area
			Move to KLT car
			Leave KLT on KLT car
			Return to "picking 1" area
		1.5 Load a *Minomi* Car in train	Collect *Minomi* car in correspondent area
			Move to the train
			Crouch
			Hook *Minomi* car in train
			Return to *Minomi* cars area
		1.6 Get on the train	Move to the tow-train
	2. Tow-Train supply to the welding Cells	**2.1** Get off the train	Approaching welding cell
		2.2 Supply KLT to the cell	Collect full KLT from KLT car
			Move to FIFO racks in the cell
			Leave full KLT
			Return to KLT car
		2.3 Collect empty KLT from the cell	Collect empty KLT from the FIFO racks in the cell
			Move to KLT car
			Leave empty KLT on KLT car
			Return to FIFO racks in the cell
		2.4 Supply *Minomi* to the cell	Unhook full *Minomi* car from the train
			Collect full *Minomi* car from the train
			Move to correspondent area in the cell
			Leave *Minomi* in cell
		2.5 Collect empty *Minomi* from the cell	Collect empty *Minomi* car from the cell
			Move to the train
			Crouch
			Hook empty *Minomi* car to the train
		2.6 Get on the train	Return to tow-train

Table 6 – Tasks, Activities and Technical actions performed in setup supermarket service

Service	Task	Activity	Technical Action
Setup Supermarket Service	**3.** Manage Pallet full of empty KLT	**3.1** Transport Pallet full of empty KLT to the correspondent area	Take pallet truck
			Remove completed pallet of empty KLT
			Wrap pallet with plastic material
			Move to Door 9 storage and leave the pallet in the correspondent area
	4. Manage containers in supermarket	**4.1** Order a new container at SAP station	Check containers filling level
			Move to SAP workstation
			Order a new container
		4.2 Change from empty to full container	Take pallet truck
			Collect empty container
			Move to "F/E Cont." area
			Leave empty container is the area
			Collect a new full container from the area
			Move to "picking 2" area
			Leave container in the area
	5. Manage full/empty KLT pallets in supermarket	**5.1.** Supply full KLT pallet from Door9 to Buffer in supermarket	Take pallet truck
			Move to Door 9 storage
			Look for full pallet of the specific reference
			Take the full KLT pallet
			Move to "buffer" area
			Leave pallet
			Declarate logistic movement
		5.2. Supply full KLT pallet from Door9 to Supermarket	Take pallet truck
			Move to Door 9 storage
			Look for full pallet of the specific reference
			Take the full KLT pallet
			Move to Supermarket ("picking 1" area)
			Uncover pallet
			Collect the labels
			Place labels in each KLT
			Take empty pallet
			Place the new full KLT pallet
			Take pallet truck with empty pallet
			Move to "Empty Pallet" area
			Leave empty pallet in the area
		5.3. Supply full KLT pallet from buffer to supermarket	Take pallet truck
			Move to "buffer" area
			Look for full pallet of the specific reference
			Take full KLT pallet
			Move to "picking 1" area

			Uncover pallet
			Collect the labels
			Place labels in each KLT
			Take empty pallet
			Place the new full KLT pallet
			Take pallet truck with empty pallet
			Move to "Empty Pallet" zone
			Leave empty pallet in the zone
	6. Supermarket "picking2" area preparation	**6.1.** *Minomi* Car Preparation Example	Approach *Minomi* car to preparation area
			Take tool to separate parts
			Separate parts with tool and place them in *Minomi* car
			Open carton box with child parts
			Fill *Minomi* car KLT with child parts
			Open carton box with child parts
			Fill *Minomi* car KLT with child parts
			Close *Minomi* car
			Collect completed *Minomi* car

4.3. Study of Times

This sub-chapter is intended for the temporal quantification of the different activities and work elements previously identified in order to understand the impact of each activity in the operators' work. Gestamp Palau S.A. has a specialized technician in the study of the times as well as the *ItemsaSoft Procesos* (AppProductivity4.0) software that enabled this action to be carried out. This software has the possibility to use different pre-determined time systems to study and calculate operation's time. The system chosen for this project was the MTM-UAS (Methods-Time Measurement – Universal Analyzing System) which has specific tables containing the fundamental motions and rules for its usage. The choice was the MTM since the method for studying times is faster in this system, which was convenient considering the temporal scope of the present project. In order to streamline the process, the video recording of the operations performed by the workers supported the analysis of certain actions that happen more sporadically on the shop-floor.

Figure 52 shows the tables that supported the analysis of times during this phase of the project. Taking into account the distances and the type of movements performed by the workers, the complexity and precision in handling materials, its weight, among other characteristics of the movements, values were associated with the work elements that allow reaching a time value on the desired time scale, of each activity or task. Figure 53 shows an example of one of the studies carried out referring to the activity of *Minomi* car preparation.

Motion Length in cm	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	1	2	3

Get and Place			Code	1	2	3
				TMU		
	Case of Get	Case of Place				
≤1 kg	easy	approx.	AA	20	35	50
		loose	AB	30	45	60
		tight	AC	40	55	70
	difficult	approx.	AD	20	45	60
		loose	AE	30	55	70
		tight	AF	40	65	80
	handful	approx.	AG	40	65	80
> 1 kg to ≤ 8 kg		approx.	AH	25	45	55
		loose	AJ	40	65	75
		tight	AK	50	75	85
> 8 kg to ≤ 22 kg		approx.	AL	80	105	115
		loose	AM	95	120	130
		tight	AN	120	145	160

Place		Code	1	2	3
			TMU		
	approx.	PA	10	20	25
	loose	PB	20	30	35
	tight	PC	30	40	45

Motion Length in cm	≤ 20	> 20 to ≤ 50	> 50 to ≤ 80
Distance Class	1	2	3

Handle Tool	Code	1	2	3
		TMU		
approximate	HA	25	45	65
loose	HB	40	60	75
tight	HC	50	70	85

Operate	Code	1	2	3
simple	BA	10	25	40
compound	BB	30	45	60

Motion Cycles	Code	1	2	3
one motion	ZA	5	15	20
motion sequence	ZB	10	30	40
re-position and one motion	ZC	30	45	55
tighten or loosen	ZD	20		

Body Motions	Code	TMU
Walk / m	KA	25
Bend, Stoop, Kneel (incl. arise)	KB	60
Sit and Stand	KC	110

Visual Control	VA	15

Figure 52 - MTM tables

Hoja 1 de 2

Gestamp

Análisis de los elementos

Código del estudio:	**P_08/2**	Fecha Impresión:	31/08/2021
Descripción estudio:	**Minomi car preparation S021 - V0014K**	Fecha del estudio:	20/05/2021
		Técnico analista:	CA
Código del puesto:		Operario:	
Descripción puesto:		Creado por:	Celestino
		Creado:	20/05/2021
Carpeta:	\\ESTUDIOS\PICKING		
Modelos:			

Detalle elementos

1 Código: **010** Sistema : MTM - UAS Analysis TN: **3,80 (SEG)**

Descripción Approach Minomi car to preparation area

nº	Descripción	Código	TMU	Q	F	Total TMU
1	Tomar carro	AA1	20	1		20,0
2	Desplazar a zona de trabajo	KA	25	3		75,0
					TMU=	**0.095,00**

2 Código: **020** Sistema : MTM - UAS Analysis TN: **4,00 (SEG)**

Descripción Take tool to separate parts

nº	Descripción	Código	TMU	Q	F	Total TMU
1	ir a buscar herramienta	KA	25	4		100,0
					TMU=	**0.100,00**

3 Código: **030** Sistema : MTM - UAS Analysis TN: **8,79 (SEG)**

Descripción Separate parts with tool and place them in Minomi car

nº	Descripción	Código	TMU	Q	F	Total TMU
1	Tomar y situar	AH3	55	1		55,0
2	Situar	PA1	10	1		10,0
3	Apretar y aflojar	ZD	20	1		20,0
4	Tomar y situar	AJ3	75	1		75,0
5	Tomar y situar	AJ1	40	1		40,0
6	Situar	PA2	20	1		20,0
					TMU=	**0.220,00**

4 Código: **040** Sistema : MTM - LOG Analysis TN: **10,79 (SEG)**

Descripción Open carton box with child parts

nº	Descripción	Código	TMU	Q	F	Total TMU
1	Abrir env.c/cart.pleg.c/herr.1 corte<=50X50X50 cm.	PBFE	135	1		135,0
2	Abrir env.Bolsa.s/herram.<=50X50X50 cm.	PBBB	135	1		135,0
					TMU=	**0.270,00**

5 Código: **050** Sistema : MTM - UAS Analysis TN: **15,58 (SEG)**

Descripción Fill Minomi car KLT with child parts

nº	Descripción	Código	TMU	Q	F	Total TMU
1	Tomar un puñado y situar	AG2	65	6		390,0
					TMU=	**0.390,00**

6 Código: **060** Sistema : MTM - UAS Analysis TN: **2,00 (SEG)**

Descripción Close Minomi car

nº	Descripción	Código	TMU	Q	F	Total TMU
1	Tomar y situar	AA3	50	1		50,0
					TMU=	**0.050,00**

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Figure 53 - Example of an activity time study

In addition, the software allows an integration between times calculated using the MTM-UAS and times measured using timing, i.e., the same study can contain elements measured using both techniques. It was then defined that in these cases, repetitive actions would be calculated with the MTM-UAS and the frequent actions using timing.

In order to make this study more reliable, separated measurements of the time of certain activities were carried out i.e., only by using MTM-UAS or only by using chronometer, since it was considered pertinent to confirm and compare the results obtained through the use of the MTM tables and what is observed and timed in real time with timing method.

In the tables presented in the previous sub-chapter, the tasks are broken down into more detailed elements (activities) and these into even more detailed (technical actions). The study of times technician pointed out that it would be more efficient to measure the time of the activities in the case of using timing and to measure the time of the technical actions in the case of using MTM-UAS and subsequently to sum the values of the different actions associated with an activity. In this way, the temporal quantifications observed in Table 8 were obtained for each activity. In this table, the *Minomi* car preparation activity (6.1) is not contemplated since each *Minomi* has different characteristics, therefore different elements which consequently give rise to different preparation times. The durations calculated by MTM-UAS for each *Minomi* car are shown in Table 7.

Table 7 – Minomi cars preparation times

Minomi	Setup Time (sec)	Setup Time (h)
C99MIN01	243,00	0,068
C99MIN02	760,20	0,211
C99MIN03	760,20	0,211
C99MIN05	636,00	0,177
C99MIN06	812,40	0,226
C99MIN07	611,40	0,170
C99MIN08	831,00	0,231
C99MIN09	623,40	0,173
C99MIN10	612,60	0,170
C99MIN11	612,60	0,170
C99MIN12	712,80	0,198
C99MIN13	272,40	0,076
C99MIN14	712,80	0,198
C99MIN15	712,80	0,198
C99MIN16	780,00	0,217

Another measurement was made using timing, which corresponds to the time elapsed in a complete route performed by the tow-train without stops at a constant speed of 5km/h over 366 meters. The result obtained was 247 seconds.

The measurement of the duration of activities sometimes required dialogue with workers and interruption of their normal work procedures. For this reason, it should be noted the availability and willingness to be involved shown by the workers operating in each of the analyzed logistics services.

Table 8 – Activities Time

	Activities	Description	Obs. 1	Obs. 2	Obs. 3	Obs. 4	Obs. 5	Average Chronometer (Seconds)	Average Chronometer with fatigue (14%) (Seconds)	MTM (Seconds)
In-Plant milk run Service	1.1	Get off the train	1,44	4,97	2,70	2,89		3,00	3,42	3,00
	1.2	Leave empty KLTs on pallet	9,98	10,21	14,75	9,11		3,67	4,18	4,31
	1.3	Leave empty *Minomi* car in corresponding area	5,78	7,87	3,98	7,88	6,87	7,10	8,09	9,19
	1.4	Load a KLT on train's car	4,68	3,61	3,41	3,89		3,90	4,44	7,67
	1.5	Load a *Minomi* car in train	5,00	4,8	4,76	4,00		4,64	5,29	8,66
	1.6	Get on the train	3,80	2,65	3,58			3,34	3,81	3,42
	2.1	Get off the train	5,36	3,36	3,01	4,89		3,75	4,28	3,00
	2.2	Supply full KLT to welding cell	12,31	9,65	8,28	9,16	6,55	9,19	10,48	12,28
	2.3	Collect empty KLT from welding cell	9,16	4,84	10,66	15,99		3,39	3,86	5,24
	2.4	Supply Full *Minomi* car to welding cell	16,14	7,29	10,35	7,00		10,20	11,62	12,76
	2.5	Collect empty *Minomi* from welding cell	7,28	6,86	8,89	9,00		8,01	9,13	12,9
	2.6	Get on the train	3,62					3,62	4,13	3,42
Setup Supermarket Service	3	Transport full pallet of empty KLT to the corresponding area	142,00	167,00	139,00	130,00		144,50	164,73	
	4.1	Order a new container at SAP Station	20,00	19,70	17,20	25,00		20,48	23,34	
	4.2	Change from empty to full container	205,76	226,34	210,10	215,12		214,33	244,34	
	5.1	Supply Buffer from Door9 Warehouse	152,80	165,45	147,00	170,23	180,00	161,10	183,65	
	5.2	Supply Welding Supermarket (picking 1) from Door9 Warehouse	306,00	289,34	302,00	311,11	317,78	305,25	347,98	
	5.3	Supply Welding Supermarket (picking 1) from Buffer	246,00	239,34	230,57	257,45	252,89	245,25	279,59	

Once the approach to the first three analytical actions was completed, it was possible to move on to the action of developing the simulation and decision-support tool.

4.4. Simulation and Decision Support Tool Development

The first step taken in carrying out this action was the decision about the software to be used in the development of the tool. In sub-chapter 2.8 of the Literature Review, it was observed that many of the authors resorted to mathematical models, meta-heuristics or simulation models that required the use of very specific programs to carry out the optimization and/or resolution of the problems. In the specific industrial context in which this dissertation project was developed, the company requested the tool to be carried out in Microsoft Excel and to dynamically interact with SAP, since the use of other type of software would require a high computational complexity and the acquisition of another software that is currently not part of the resources available in Gestamp Palau.

4.4.1. Tool Objective and Specifications

Considering the existing fluctuations in customers demand in automotive industry (accentuated due to the pandemic crisis the world is facing) and the mix of finished goods produced by the company, the general aim of the developed tool is to facilitate the planning and management of the resources needed in the operation of the parts supply system to the welding department of Gestamp Palau.

When brainstorming about the creation of the tool, some specific objectives and requirements were established that it should cover in a way to meet the objectives either from the company and the research. According to the specifications listed below the tool should:

R1. Allow the user to create instances, either in real-time context or in a simulation context, that is, the user must be able to inform the tool about the products being produced and the assigned welding cells.

R2. Be prepared to compute and display the Number of Operators (human resources) needed in each one of the two logistic services (In-Plant milk run and Supermarket Setup) and required in total for both services. This calculation must be in accordance with the generated instance as well as with the considered period of working time.

R3. Compute the number of materials handled either during the tow-train route and during the activities performed in supermarket, in a certain time-period. Also, should provide to the user the information about the fleet size of the train in each turn and emphasize the critical route, i.e., the turn where the tow train had the bigger utilization.

R4. Help the user to know the time interval between routes (cycle time), that is, schedule the start time of each route.

R5. Be fed with data from SAP, as automatically as possible in order to minimize interactions with the user in this regard and keep the information as updated as possible (e.g., added or removed cell from the plant, added or removed products or parts from the system, renaming references).

R7. Display the outputs to the user in a robust, simple, and intuitive way in order to be perceived by the majority of the members of the organization. Also, should need the minimum maintenance actions as possible.

4.4.2. Tool Framework

A Framework was created (Figure 54) with the aim to facilitate the comprehension of the structure and organization of the tool. Were identified three main stages regarding its functioning: Input Definition, Data Processing and Output Generation. The figure below presents, in brief, the data selection, gathering and junction processes of the inputs deriving from different sources, the intermediate calculations that are produced using the data base created and the desired outputs obtained. The framework also reflects the interactions between the software and the final user (company) and will serve as support to the further explanations about all the comprised phases carried out to create and develop the simulation and decision-support tool.

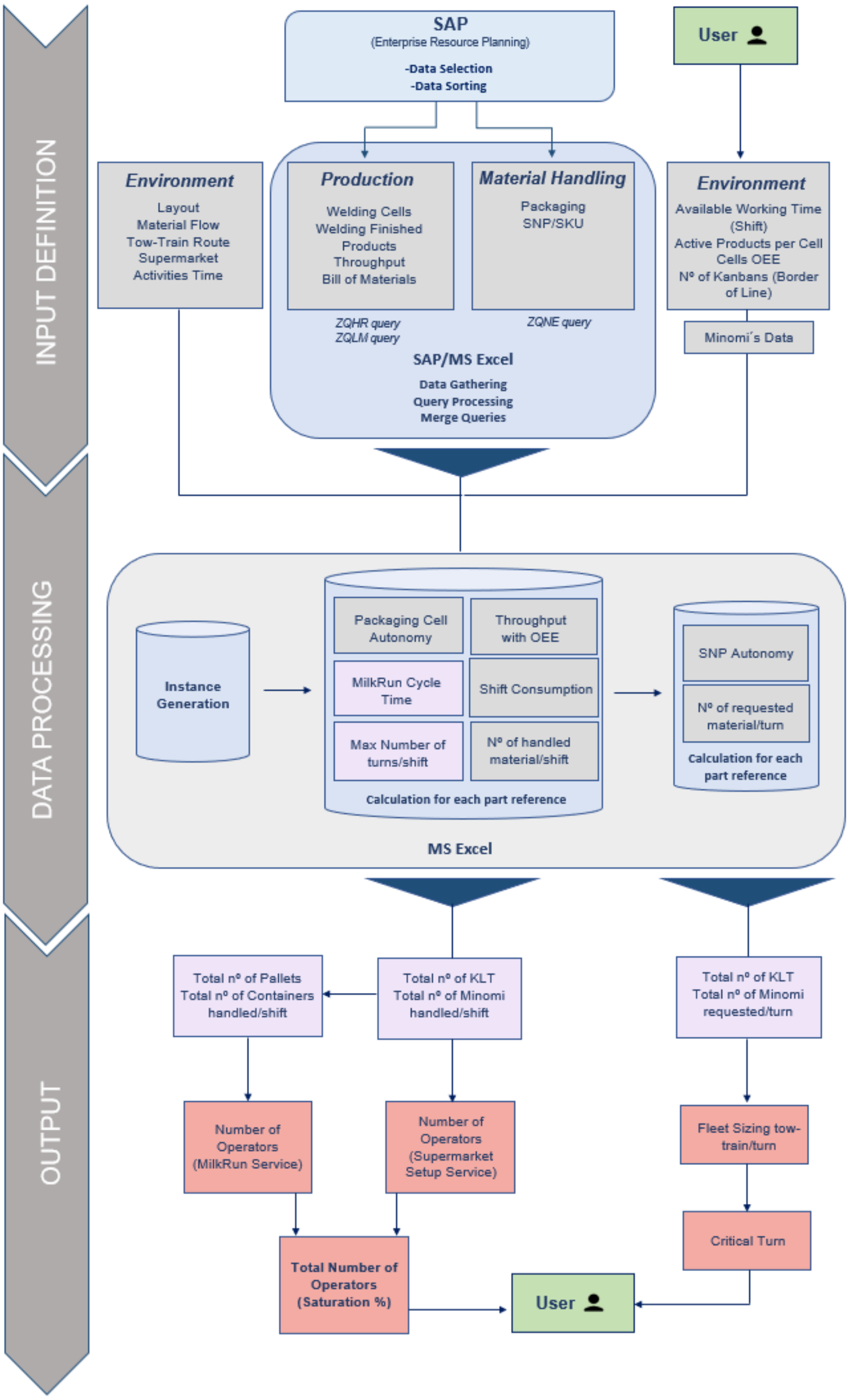

Figure 54 – Simulation and decision support tool framework. Source: Own Elaboration

4.4.3. Tool Design and Development

Input Definition Stage

Data Selection and Sorting: Inputs from SAP

The first step in the development of the tool was to select and sort the range of data that it should cover. As seen in Figure 54, meeting the requirement R5 presented before, the data source chosen to feed the tool was the ERP used in Gestamp Palau (SAP). Besides the common transactions used in all the organizations that have SAP implemented, Gestamp Palau has its customized transactions to consult, manage and export information from the system. These are identified as they start with letter Z and are recurrently used by company members. When opening and executing a transaction in SAP, it shows the information in the standard form. However, there is the possibility to create a variant of the standard by sorting only the information needed. Also, by executing the variant it allows to create a layout structure in order to choose the important columns or fields to consult.

Regarding data from the system in SAP, three transactions were used. These are the ZQHR, ZQLM (both provide information related to Production) and ZQNE (provides information related to Material Handling).

The variant created from the transaction ZQHR (Routings) was used to:

- Select only data from output references produced in welding department.
- Exclude output references/products that are obsolete (Appendix A).
- Exclude from the range of welding cells, the ones that are not affected by the milk run System that supplies KLT and *Minomi*s, meaning, the ones that are not supplied with components stored in the supermarket.
- Select only transaction fields that provide relevant information to the tool, through the creation of a layout included in the variant. These were Welding Cell (workstation), Material (output reference/product) and throughput (parts/h).

From the application of the variant, it was possible to delimit the range of workstations in 15 welding cells and the range of output references in 55 products (Appendix B).

The variant created from the transaction ZQLM (Bill of Materials) was used to:

- Select the components assigned to each output reference produced in the welding department.

The variant created from the transaction ZQNE (Packaging Standard) was used to:

- Sort only the packaging norm determination class (ZSTO – storage type).
- Select only transaction fields that provide relevant information to the tool through the creation of a layout included in the variant. These were Material (input reference), Class Determination, Packaging Standard, Container and Quantity (SNP); with this layout the "Packaging Standard" field has also been sorted so that it shows only the original standards, excluding all the alternative ones.

It is possible to see how these variants and layouts were created in SAP in more detail, referring to the Figure 81,Figure 82 and Figure 84 of the developed guideline presented in Appendix D.

Environmental Considerations

Besides the data from the information system, to proceed with the development of the tool so that it could reflect the most reliable data and in accordance with the real situation, it was necessary to consider the environment in which the component supply system takes place. For this reason, the performance of the actions described before was crucial, once it was possible to understand the arrangement of the different welding cells (layout), the route taken by the tow-train supplier and the flow of materials, as well as to identify and quantify the duration of the activities carried out along the route and in the supermarket zone.

Some of the environmental considerations need to be inserted by the user. However, some of these inputs were already incorporated throughout the course of the tool development e.g., the Available Working Time (considered as a shift duration), the welding cells OEE per reference, the number of *kanban*s (units) already established in the border of line FIFO racks and the Material handling information about the *Minomi* cars. This information only needs to be updated and maintained by the user to ensure the proper and reliable functioning of the tool. Yet, the Instance generation (activation of products per cell) is an input that must be changed each time the user pretends to see outputs related to a simulation or real production scenario.

Difficulties: Regarding the Data Sorting and Selection phase, difficulties were found in identifying the output reference/products to be excluded from the ZQHR transaction variant, since, in SAP, not all the modifications made to the welding products had been updated. Examples of these situations can be: a reference no longer produced in a cell and starts to be produced in another, or start to be produced in both, appearing in the ZQHR associated with wrong cells; a reference no longer produced at all in the plant or just introduced into the system for a prototype, but still documented in the system; or technical changes of mechanical character made in the products that cause the reference to change its name, existing two identical products with different names in the system.

Another difficulty found involved one of the handling units used to transport components, specifically with kit cars (*Minomis*). Unlike KLT boxes, these do not have data entered in SAP, that is, it is not possible to extract from the system its nomenclature, packaging standard or SNP, information that is necessary for the processing phase of the tool. With regard to the components transported in this type of packaging, SAP only contains data related to storage when it arrives from the supplier. In addition to this fact, the quantities of components that go inside *Minomis* were not accounted for.

To rectify this failure, packaging standards were created in SAP for the different *Minomi*s, naming each one of them and counting the SNPs of each transported component. However, this action did not obtain the expected result due to the variability associated with these Kit cars and to the fact that there is no rule/logic in the system to combine this information with the rest, making this data subject to update and maintenance in the tool.

All these anomalies were detected either via *gemba* walk or via communication with the different departments and had a great importance for the project in the sense that the tool can produce results with a high degree of objectivity and reliability, since Garbage-in, Garbage-Out and such is not desired.

Data Gathering and Preparation

After defining the inputs from the system that would feed the tool, it was necessary to find a way to gather and combine them into Microsoft Excel. To this end, an analysis and research of different possible ways to perform this action was carried out. The different possibilities are presented in Table 9 as well as a brief explanation. Afterwards, it is given a justification of why it was chosen one method over the remaining ones.

Table 9 – Data gathering, and preparation analyzed options

Data Gathering and Combining Data Options	Description	Chosen Option
SAP/MS Excel (VlookUp Function)	It is the method used in most Excel tools created in the company today. It consists of exporting data from different SAP transactions to auxiliary excel files and copying them to different sheets of the workbook where the tool operates (manually or using a VBA macro). To combine the data in Excel, the "VlookUp" function is used, which gathers information from the various transactions taking into account the common key sought, creating the dataset that forms the basis of the tool.	
SAP/MS Excel (Relationships)	With regard to data export, the proceeding is the same as the first option mentioned. To combine the data in Excel, it is first converted into a table format to later allow the of use the Excel feature "Relationships" in order to create relationships between the different data tables (transactions). These can be "Many-to-One", "One-to-Many" or "Many-to Many" type of relationships. The result of establishing the relationships is the support data base to the tool.	
SAP/MS Excel (Merge Queries)	Data from different transactions present in SAP is exported to different auxiliary Excel/CVS files. However, the manual operation of copying data from these files to the workbook where the tool operates is eliminated. In this option, in the main workbook, is used the "get data from" feature, creating different queries in the workbook that have a connection with the auxiliary files. To combine the data in Excel, the "Merge Queries" feature is used, where it is possible to select which field serves as the key to perform the combination. The merge of all transactions creates the database that supports the tool.	X

Initially, the first method presented was considered, since it is already known by the members of the organization. However, there were some restrictions to this option regarding the use of Excel's "VlookUp" function and the nature of the data to be joined.

As mentioned in previous chapters, Gestamp Palau production system is characterized by being a multi-mixed model assembly type. Consequently, in the company's welding department, each cell is prepared or enabled to produce various products (output references) and each of these can also be produced in several cells.

For this reason, a problem arises with regard to missing data when joining the ZQLM transaction (which informs about the constituent components of each product) with the ZQHR transaction (which provides information on which cells the products are produced). This happens since the common key in both transactions to look for in "VlookUp" is the Product (output material) and the standard form of this Excel function only returns the first of the records found. For instance, in certain cases, occurred that the final database did not show the products associated with all the cells that have the possibility of producing it, which would later make it impossible to consider these workstations in the creation of instances in the tool and would produce less viable results. In addition, the same product in different cells can have different throughputs which reinforces the importance of combining all the data in a proper way.

This problem led to the need to search for options to join data without producing this type of error and which at the same time could require less manual interaction with the user. The first alternative found was the second option described in Table 9. It was thought that this method would solve the problem as it would allow to establish "Many-to-Many" relationships (i.e., a material is produced in several cells and a material has several components). However, the "Relationships" feature is not able to create this type of relation directly, and all attempts made to create it indirectly continued to produce the same missing data error.

The second alternative found, where the "Merge" feature is used to combine the data, was the option chosen for the creation of the tool support database, since, in addition to not producing the error described above, its use is more automatic and requires less effort from the user, since the process of creating queries and merges only needs to be done once and the only action required by the user is to select the "Refresh All" feature to update all connections created in the main WorkBook.

In the tool guideline presented in Appendix D, all the steps of querying and merge processing performed in this project are described in detail and illustrated with figures.

As a result of the joint made, was created a table that serves as the basis for the tool. An extraction of it can be observed and analyzed in Figure 55 in order to understand the origin of each type of information.

The first three fields reflect information from the ZQHR transaction such the manufactured product (Output reference), the Welding cell where it is assembled and also the associated Throughput, that is, the number of pieces that are produced per hour. Fields four and five of the table come from the ZQLM transaction, associating to each product the components that make it up (Input References) as well as the necessary quantity of each component to form the final product (BOM Quantity). Finally, the last two fields refer to the ZQNE transaction that associates to each component the type of packaging where it is stored (Original Packaging) and the number of parts that compose it (Original SNP).

ZQLM

ZQHR

ZQNE

Fixed Data						
Welding Cell	Output Reference	Throughput (Pieces/h)	Input Reference	BOM Quantity	Original Packaging	Original SNP
S020	V0012S00990	34	V0012E04990	1	C994322ESB	25
S020	V0012S00990	34	V0012E03990	1	C994322ESB	42
S020	V0012S00990	34	V0012E00990	1	C994322ESB	42
S020	V0012S00990	34	V0012E05990	1	C994322ESB	25
S020	V0012S00990	34	V0012K02990	2	C99CARTON	800
S020	V0012S00990	34	V0012E01990	1	C994322ESB	42
S020	V0012S00990	34	V0012E02990	1	C994322ESB	42
S020	V0012S00990	34	V0012K01990	1	C99CARTON	50
S020	V0012S00990	34	V0012K00990	1	C99CICS10	102
S021	V0013S00990	22	V0013E01990	1	C994322ESB	50
S021	V0013S00990	22	V0013E00990	1	C994322ESB	50
S021	V0013S00990	22	V0013E04990	1	C994322ESB	40
S021	V0013S00990	22	V0013E03990	1	C994322ESB	42
S021	V0013S00990	22	V0013K01990	1	C99CARTON	75
S021	V0013S00990	22	V0013K02991	1	C993215	300
S021	V0013S00990	22	V0013K00990	1	C99CICS10	240
S021	V0013S00990	22	V0013E05990	1	C994322ESB	40
S021	V0013S00990	22	V0013E02990	1	C994322ESB	42
S021	V0014S00990	34	V0013E04990	1	C994322ESB	40
S021	V0014S00990	34	V0013E03990	1	C994322ESB	42
S021	V0014S00990	34	V0013K01990	1	C99CARTON	75
S021	V0014S00990	34	V0013E00990	1	C994322ESB	50
S021	V0014S00990	34	V0013E01990	1	C994322ESB	50
S021	V0014S00990	34	V0013K02991	1	C993215	300
S021	V0014S00990	34	V0013E02990	1	C994322ESB	42
S021	V0014S00990	34	V0013E05990	1	C994322ESB	40
S021	V0014S00990	34	V0014K00990	1	C99CIESP10	200

Figure 55 - Merge between ZQHR, ZQLM and ZQNE data transactions (Main table)

As mentioned previously, some data was not presented in the information system and was considered important to carry out the subsequent calculations in the tool and obtain the desired outputs. Thus, in order for this data to be combined with the existing one, it was necessary to create auxiliary tables that are subject to maintenance and manual updating by the final user. The tables can be seen in Figure 101,Figure 103Figure 105 of the Appendix D and refer, respectively, to information on the OEE by product and workstation, on the number of *kanban*s defined by the company at the border of line of each component, and on information related to material handling regarding the components transported in *Minomi*. Figure 56 shows the fields added to the existing fixed data deriving from the auxiliary table's information.

Fixed Data										
Welding Cell	Output Reference	Throughput (Pieces/h)	Input Reference	BOM Quantity	Original Packaging	Original SNP	Packaging Cell Capacity	THOEE (Pieces/h)	Transportation Packaging	Transportation SNP
S020	V0012S00990	34	V0012E04990	1	C994322ESB	25	3	28,9	C994322ESB	25
S020	V0012S00990	34	V0012E03990	1	C994322ESB	42	3	28,9	C994322ESB	42
S020	V0012S00990	34	V0012E00990	1	C994322ESB	42	3	28,9	C994322ESB	42
S020	V0012S00990	34	V0012E05990	1	C994322ESB	25	3	28,9	C994322ESB	25
S020	V0012S00990	34	V0012K02990	2	C99CARTON	800	1	28,9	C99CARTON	800
S020	V0012S00990	34	V0012E01990	1	C994322ESB	42	3	28,9	C994322ESB	42
S020	V0012S00990	34	V0012E02990	1	C994322ESB	42	3	28,9	C994322ESB	42
S020	V0012S00990	34	V0012K01990	1	C99CARTON	50	NC	28,9	C99MIN05	55
S020	V0012S00990	34	V0012K00990	1	C99CICS10	102	2	28,9	C99MIN05	55
S021	V0013S00990	22	V0013E01990	1	C994322ESB	50	3	18,7	C994322ESB	50
S021	V0013S00990	22	V0013E00990	1	C994322ESB	50	3	18,7	C994322ESB	50
S021	V0013S00990	22	V0013E04990	1	C994322ESB	40	3	18,7	C994322ESB	40
S021	V0013S00990	22	V0013E03990	1	C994322ESB	42	3	18,7	C994322ESB	42
S021	V0013S00990	22	V0013K01990	1	C99CARTON	75	NC	18,7	C99MIN06	75
S021	V0013S00990	22	V0013K02991	1	C993215	300	NC	18,7	C99MIN06	300
S021	V0013S00990	22	V0013K00990	1	C99CICS10	240	2	18,7	C99MIN06	72
S021	V0013S00990	22	V0013E05990	1	C994322ESB	40	3	18,7	C994322ESB	40
S021	V0013S00990	22	V0013E02990	1	C994322ESB	42	3	18,7	C994322ESB	42
S021	V0014S00990	34	V0013E04990	1	C994322ESB	40	3	28,9	C994322ESB	40
S021	V0014S00990	34	V0013E03990	1	C994322ESB	42	3	28,9	C994322ESB	42
S021	V0014S00990	34	V0013K01990	1	C99CARTON	75	NC	28,9	C99MIN09	75
S021	V0014S00990	34	V0013E00990	1	C994322ESB	50	3	28,9	C994322ESB	50
S021	V0014S00990	34	V0013E01990	1	C994322ESB	50	3	28,9	C994322ESB	50
S021	V0014S00990	34	V0013K02991	1	C993215	300	NC	28,9	C99MIN09	300
S021	V0014S00990	34	V0013E02990	1	C994322ESB	42	3	28,9	C994322ESB	42
S021	V0014S00990	34	V0013E05990	1	C994322ESB	40	3	28,9	C994322ESB	40
S021	V0014S00990	34	V0014K00990	1	C99CIESP10	200	2	28,9	C99MIN09	51

Figure 56 - Main table joint with auxiliary tables information

These fields fetch data from the auxiliary tables through the use of the Excel functions “VlookUp” and “Concatenate”. In the “THOEE” field the following calculation is performed:

$$\text{THOEE (pieces/h)} = \text{Throughput (pieces/h)} * \text{OEE} \quad \textbf{5)}$$

This calculation is made since the OEE indicator has an influence on the throughput of manufactured products. It would only be correct to use the throughput present in the basis data for further calculations if the OEE of the workstations were equal to 100%, which in a real industrial context does not always happen. For further calculations, the resulting value of the product between throughput and OEE will be used, once again, to guarantee and improve the reliability of the generated outputs.

At this stage, another table was created that combines data from the ZQHR transaction query and data from the auxiliary table maintained by the user referring to the OEE indicator (Figure 57). The great advantage of having this table is that in the "Active" field the user is allowed to create instances and test real or hypothetic scenarios of production through the input of a binary code 1 or 0, where 1 means that the selected product is being produced in the associated cell and 0 that is not in operation. When a product is not being produced it means that the amount of its components must not be taken into account for the calculations. Thus, it is the filling of this table that triggers and manages all the intermediate and final calculations carried out in the next stage.

Welding Cell	Output Reference	OEE	Active
S020	V0012S00990	0,85	1
S021	V0013S00990	0,85	
S021	V0014S00990	0,85	1
S022	V0026S00990	0,85	1
S022	V0027S00990	0,85	
S022	V0083S00990	0,85	
S022	V0090S00990	0,85	
S023	V0026S01990	0,85	1
S024	V0023S00991	0,85	
S024	V0023S01991	0,85	
S024	V0080S00990	0,85	
S024	V0081S00990	0,85	1
S025	V0023S00991	0,85	1
S025	V0082S00990	0,85	
S028	F0079S00991	0,85	
S028	F0080S00991	0,85	1
S029	V0026S00990	0,85	1
S029	V0027S00990	0,85	
S029	V0090S00990	0,85	
S030	V0024S01990	0,85	1

Figure 57 - Instance generator

Data Processing Stage

In the sub-chapter “Tool Specifications and Objectives” it was mentioned that the overall aim of the tool was to allow the planning and management of the resources needed in the operation of the parts supply system to the welding department of Gestamp Palau.

So that the tool could be aligned with the requirements established at the beginning of this action and in order to compute the outputs represented in the tool framework, it was necessary to program the tool to perform the necessary calculations, based on all the considerations of the previous stage. This programming was made using several Excel formulas and in order to meet the instances created by the user in the "Instance Generator" table.

Part of the calculations described later appear in the tool attached to the main table (Figure 56), since they use information from it and need to be associated with each component. Other calculations will already be considered as intermediate outputs (represented in pink in the tool framework) and will be shown in the user interface.

The calculations performed in the data processing stage that associated with the main table are described below and are accompanied by the mathematical equations used to calculate them.

Shift Consumption (SC): Represents the consumption of each component during a shift, knowing its duration in hours ($\text{Available Work Time}$), the Throughput of the material produced considering the OEE (THOEE) and the required quantity of component to form the output product (BOM Quantity).

$$\text{SC (Pieces)} = \text{Available Work Time (h)} * (\text{THOEE (pieces/h)} * \text{BOM Quantity}) \qquad \textbf{6)}$$

Number of handling material per shift (Nºhm/shift): Quantifies the number of KLT or *Minomis*, to be handled from each component during a shift, knowing its shift consumption in parts, as well as the standard number of parts (SNP) present in each handling unit that is transported.

$$\text{Nº hm/shift (handling unit)} = \frac{\text{SC (pieces)}}{\text{Units SNP (pieces/handling unit)}} \qquad \textbf{7)}$$

Replenish Lead Time (RLT): Represents the time in which all KLT/*Minomi* units (defined number of *kanban*s) are consumed at the border of line, for each component. To perform this calculation, it was used the mathematical equation 3 that calculates the number of *kanban*s, set out in sub-chapter 2.9 of the Literature Review. However, for this specific case, the equation was adapted so that the result was the replenish lead time (L) and not the number of *kanban*s (n) since this latter parameter is already known. In this way, the D (consumption rate) parameter in the original equation is defined by $\text{THOEE} * \text{BOM Quantity}$ in the new equation, the n (nº of *kanban*s) is defined by nº knb and the a (SKU) is defined by Units SNP. In this specific case it was decided not to include the safety factor.

$$\text{RLT(min)} = \frac{\text{Units SNP (pieces/handling unit)} * \text{nº knb (handling unit)}}{\text{THOEE (pieces/h)} * \text{BOM Quantity}} * 60 \qquad \textbf{8)}$$

In addition to knowing this data, it is necessary to find the component that requires the smallest lead time and that will schedule the beginning of the supply routes. Thus, the calculation that determines the time between milk run routes (Ideal milk run Cycle Time) was carried out. This will vary or not depending on the number of cells and products in operation, that is, depending on the instances created by the user.

Ideal milk run Cycle Time (ICT): Represents the smallest of the replenishment lead times of all the components whose products are being produced. However, since the supply system of components to the welding cells is a case of pull replenishment of materials, it was decided to adapt equation 4 of chapter 2.9 to the calculation of this parameter as shown in equation 9.

$$\text{ICT (min)} = \frac{\text{Min(RLT)}}{2} \qquad \textbf{9)}$$

After knowing the minimum lead time, it is necessary to divide this value by two since $\text{Replenish Lead Time} = \text{torder} + \text{transit}$ (equation 4), being $\text{torder} = \text{transit}$ in the case under study. The adaptation of this equation to the study was considered pertinent since it is not desirable that the milk run perform its passage through the cells only when there is no longer available stock.

Maximum number of turns (Max nº turns): Knowing the Ideal milk run Cycle Time as well as the Available Working Time, it is possible to quantify the maximum number of turns that the tow-train can make in order to respect the working period of the operators, through the equation 10:

$$\text{Max nºturns} = \text{roundup}\ (\frac{\text{Available Work Time(min)}}{\text{ICT(min)}}) \qquad \textbf{10)}$$

In the case where the result is decimal, it was decided to round the value up in order to consider as many turns as possible in the milk run service. However, this may not respect the working time of the operators, thus it was decided to adjust the parameter Ideal milk run Cycle Time. Thus, another parameter called Maximum milk run Cycle Time was created.

Maximum milk run Cycle Time (MaxCT): Is the maximum time between routes so that the tow-train makes the necessary number of turns to meet the consumption, respecting the Available Working Time of the operators.

$$\text{MaxCT(min)} = \frac{\text{Available Work Time(min)}}{\text{Max nºturns}} \qquad \textbf{11)}$$

These last two calculated parameters are considered intermediate outputs since they constitute relevant information that must be shown to the user and that will also serve as inputs to calculate the final outputs of the tool.

On a later moment, a secondary table was created that feeds on some data previously calculated (intermediate parameters and outputs) corresponding to the main table (Figure 56). The two tables share the objective of showing the number of handling units per component moved or supplied over a period of work. However, while the calculations associated with the main table inform about the total amount needed over a shift, the secondary table created intends to compute the material orders (in handling units) that exist at each milk run route done in the shift. The necessary calculations for each component to obtain this information were as follows:

Packaging unit autonomy (SNP Autonomy): Represents the time in which a material handling unit, either KLT or *Minomi*, is consumed.

$$\text{SNP Autonomy (min/handling unit)} = \frac{\text{Units SNP(pieces/handling unit)}}{\text{THOEE(pieces/h)} * \text{BOM Quantity}} * 60 \qquad \textbf{12)}$$

<u>Number of requested materials per turn (Nº Req.Mat/Turn)</u>: Represents the number of requested handling units (KLT or *Minomi*) per milk run supply route.

$$\text{Nº Req. Mat./Turn} = \text{roundown}\left(\frac{\text{MaxCT(min)} * \text{Turn nºx}}{\text{SNPAutonomy(min/packaging)}} - \sum \text{Nº Req. Mat. Previous Turns}\right) \qquad \textbf{13)}$$

To obtain this output, it was necessary to create the logic presented in the equation above. The logic is to calculate how many packaging units are consumed or ordered until the end of each route, however as the need is to know the orders in each route, it is necessary to subtract the sum of all the orders made in the previous routes to the one being considered. In the case where the result is decimal, it was decided to round the value down since it is only perceived as a request when a KLT or *Minomi* is totally empty, that is, they were consumed in full. Also, with regard to this output, it was assumed that at the beginning of the shift the FIFO shelves at the border of line are at their maximum capacity, which does not always occur in a real situation. Figure 58 shows an extraction of the secondary table that was created to perform the mentioned logic and present the pretended output.

				KLT	7,0000	41,0000	45,0000	28,0000	44,0000	41,0000	38,0000
				Minomi	1,0000	5,0000	3,0000	5,0000	5,0000	5,0000	4,0000
Welding Cell	Output Reference	Throughput (Pieces/h)	Input Reference	Turns	1	2	3	4	5	6	7
S020	V0012S00990	34	V0012E04990		1	1	1	1	1	2	1
S020	V0012S00990	34	V0012E03990		0	1	1	0	1	1	0
S020	V0012S00990	34	V0012E00990		0	1	1	0	1	1	0
S020	V0012S00990	34	V0012E05990		1	1	1	1	1	2	1
S020	V0012S00990	34	V0012K02990		0	0	0	0	0	0	0
S020	V0012S00990	34	V0012E01990		0	1	1	0	1	1	0
S020	V0012S00990	34	V0012E02990		0	1	1	0	1	1	0
S020	V0012S00990	34	V0012K01990								
S020	V0012S00990	34	V0012K00990		0	1	0	1	0	1	0
S021	V0013S00990	22	V0013E01990		0	0	1	0	0	1	0
S021	V0013S00990	22	V0013E00990		0	0	1	0	0	1	0
S021	V0013S00990	22	V0013E04990		0	0	1	0	1	0	1
S021	V0013S00990	22	V0013E03990		0	0	1	0	1	0	1
S021	V0013S00990	22	V0013K01990								
S021	V0013S00990	22	V0013K02991								
S021	V0013S00990	22	V0013K00990		0	0	0	1	0	0	0
S021	V0013S00990	22	V0013E05990		0	0	1	0	1	0	1
S021	V0013S00990	22	V0013E02990		0	0	1	0	1	0	1
S021	V0014S00990	34	V0013E04990		0	1	1	0	1	1	1
S021	V0014S00990	34	V0013E03990		0	1	1	0	1	1	0
S021	V0014S00990	34	V0013K01990								
S021	V0014S00990	34	V0013E00990		0	1	0	1	0	1	1
S021	V0014S00990	34	V0013E01990		0	1	0	1	0	1	1
S021	V0014S00990	34	V0013K02991								
S021	V0014S00990	34	V0013E02990		0	1	1	0	1	1	0
S021	V0014S00990	34	V0013E05990		0	1	1	0	1	1	1
S021	V0014S00990	34	V0014K00990		0	1	0	1	0	1	1

Figure 58 - Secondary table (KLT and Minomi requests per turn)

Output Generation Stage

In this final stage, the intermediate and final outputs are generated, which will allow the user and the company to carry out a better planning of the resources needed in the supply system of components to the welding cells, more precisely to the milk run and setup of the supermarket services.

On the previous stage it was found that there are three data tables, the "Instance Generator", the main table and the secondary table. Activating the first one triggers the process on the last two ones. Through the calculations carried out in these tables, it is possible to obtain different outputs that will be presented further along the description of this stage.

Outputs deriving from the main table:

1) **Total number of KLT and Total number of *Minomi* handled per shift**: Through the intermediate calculation performed in the previous stage (Number of handling material per shift) it is possible, using Excel formulas and the database from the main table, to make a distinction between the total amount of KTL and the total amount of *Minomi*s needed to supply.

2) **Total number of Pallets and Total number of Containers handled per shift:** Having the values referring to the output 1) and knowing the capacity of the pallets and containers for each component reference (in KLT or Parts, respectively) it is possible to know how often it will be necessary to change pallets or containers in the supermarket and thus how many times it will be done.

3) **Number of operators of milk run Service (Nºop milk run Service)**: Represents the required number of operators to perform the milk run Service, that is, to perform the supply route with the tow-train from the supermarket to the different cells in the welding department. Obtaining this result, it is also possible to understand its saturation/utilization percentage.

   In order to calculate this output, it was first necessary to know the time spent in carrying out the milk run Service (MRST – milk run Service Time). For this purpose, it was used the equation 2 adopted in the standardization approach of the Association of German Engineers (VDI) presented in sub-chapter 2.9 of the literature review. Adapting it to the case under study, the formula used to perform the calculation was:

$$\mathrm{MRST(h)} = (\mathrm{nºKLT/shift} * \mathrm{Unit\ Time\ KLT(h)}) + (\mathrm{nº}\mathit{Minomi}/\mathrm{shift} * \mathrm{Unit\ Time}\ \mathit{Minomi}\ \mathrm{(h)}) + \mathrm{Tdt(h)} \quad \textbf{14)}$$

   In which the $\mathrm{nºKLT}$ and $\mathrm{nº}\ \mathit{Minomi}$ handled per shift is the result of Output 1) previously calculated and the unitary time spent on its movements can be calculated based on the study of times developed in action 3 presented in sub-chapter 4.3 of the dissertation. Thus, the unit times used in the above transcribed formula resulted from the sum of the train loading and unloading activities on the route performed in the supermarket zone and the sum of the collect and supply activities performed in the route through the workstations. Table 10 summarizes the activities considered for each one of the handling units and the obtained unit times. The times need to be converted into hours.

Table 10 - KLT and Minomi handling unit time

	Unit Time KLT	**Unit Time *Minomi***
	Leave empty KLT on pallet	Leave empty *Minomi* car in corresponding area
	Load a KLT on trains's car	Load a *Minomi* car on the train
	Supply full KLT to welding cell	Supply Full *Minomi* car to welding cell
	Collect empty KLT from welding cell	Collect empty *Minomi* from welding cell
Chronometer(s)	**22,96**	**34,13**
MTM(s)	**29,50**	**43,51**

Despite having resorted to the two studying of times techniques and even though the results are similar, the unit times used were those obtained by MTM-UAS since they are slightly higher and in this way, it is possible to ensure that the system is not under sizing.

Regarding the last element of the equation 14 (train displacement time - Tdt) it also has a calculation formula once again based on equation 2 of sub-chapter 2.9 which is as follows:

$$\mathrm{Tdt(h)} = (\mathrm{t.normal(h)} + \mathrm{t.stops(h)}) * \mathrm{Max\ n^{o}\ turns} \tag{15}$$

where the $\mathrm{Max\ n^{o}\ turns}$ element is the result of one of the parameters calculated in the previous stage and $\mathrm{t.normal}$ and $\mathrm{t.stops}$ are calculated using the following equations:

$$\mathrm{t.normal\ (h)} = \frac{\mathrm{Total\ time\ route\ (s)}}{3600} \tag{16}$$

$$\mathrm{t.stops(h)} = \mathrm{n^{o}\ Stops} * (\frac{\mathrm{stop\ distance\ (m)} * 0{,}001}{\mathrm{v.stop\ (km.h)}} + \big(\mathrm{tgetin(h)} + \mathrm{tgetoff(h)}\big) \tag{17}$$

Regarding the $\mathrm{t.normal}$ equation, it was established that this would be equal to the value presented in the sub-chapter 4.3 of this chapter, measured using chronometer, which refers to the time spent by milk run in performing a complete route (welding cells + supermarket), without stops. The $\mathrm{t.stops}$ formula contemplates the time that the tow-train takes when it stops at a station, that is, the deceleration time and the operator's entrances and exits time in the tow-train. Having added up all the activities carried out in a stop, this value is multiplied by the number of stops, which is equivalent to the number of cells activated by the user when generating the instance.

Having all the necessary elements, the tool is able to calculate the milk run Service Time (Equation 14). Thus, it is possible to compute the output in question (Number of Operators of milk run Service) through the following equation:

$$\mathrm{N^{o}op\ milk\ run\ Service} = \frac{\mathrm{MRST(h)}}{\mathrm{Available\ Working\ Time\ (h)}} \tag{18}$$

This number is subject to variations that must be in accordance with the instances created by the user and with possible changes in the data coming from the information system.

4) **<u>Nº of Operators of Setup Supermarket Service (Nºop Supermarket Service)</u>**: It represents the necessary number of operators to perform the Setup Supermarket Service, that is, to perform maintenance and preparation activities of the supermarket. These activities will allow it to have all the conditions so that when the milk run makes its passage through the area, it does not come across with lack of material or with possible interruptions in the route due to lack of space organization. Through this result, it is also possible to understand the operator´s saturation/utilization percentage.

In order to calculate this output, it was first necessary to know the time spent in carrying out the Setup Supermarket Service as well as to know which of the activities identified in sub-chapter 4.3 will be part of the equation. In the supermarket, pallets with KLT and Containers (with large parts that will form the *Minomi* s cars) are handled. Thus, for each type of handling support moved, the following activities were identified in Table 11:

Table 11 - Activities considered to calculate output 4)

	KLT Pallet	Container	*Minomi*
Activities	**5.2.** Supply full Pallet of full KLT from Door9 warehouse to supermarket (every 40 KLT of each component)	**4.1.** Order a new container at SAP station	**6.** Preparation of *Minomi* Car (different for each *Minomi* car)
	3. Transport full pallet of empty KLT to the corresponding area (every 40 KLT)	**4.2**. Change from empty to full container	

Following the logic of the equation created for calculating the milk run Service Time, the following equation was created for the Setup Supermarket Service Time (SSST):

$$\mathrm{SSST(h)} = \mathrm{TimePallet\ KLT(h)} + \mathrm{Time\ Container(h)} + \mathrm{Time}\ \mathit{Minomi}\ \mathrm{(h)} \quad \mathbf{19)}$$

This formula is made up of three elements that also have their own calculation equations that will be explained below in equations 20,21 and 22.

$$\mathrm{Time\ KLT\ Pallet\ (h)} = \left(\frac{\mathrm{nº\ KLT/shift}}{40} * \mathrm{Activity\ 3\ Time(h)}\right) + (\mathrm{nºPallets} * \mathrm{Activity\ 5.2\ Time\ (h)}) \quad \mathbf{20)}$$

The time for handling KLT Pallets in the supermarket is calculated taking into account the result from Output 1) (Total number of KLT handled per shift) and the time spent in activity 2. This activity is performed every 40 KLT, that is, an empty KTL pallet is transported to the correspondent zone when it is filled with it maximum capacity (40 empty KLT). Note that activity 1 referring to this handling support, is performed as many times as the Total number of pallets handled per shift, previously calculated in Output 2.

The time related to containers handling is calculated knowing the result of Output 2) calculation (Total number of Containers handled per shift) and multiplying it by the sum of the activities related to this type of handling support as shown in equation 21.

$$\text{Time Container (h)} = \text{nº Containers} * (\text{Activity 4.1 Time (h)} + \text{Activity 4.2 Time (h)}) \quad \textbf{21)}$$

The time related to the preparation of *Minomi* cars in the supermarket is calculated by total sum of the number of *Minomi*s supplied from each component times the corresponding preparation time (activity 6), as shown in equation 22.

$$\text{Time } Minomi \text{ (h)} = \sum (\text{nº}Minomi * \text{Activity 6 Time (h)}) \quad \textbf{22)}$$

These preparation times associated with each type of *Minomi* were measured in the performance of the action 3 presented before in sub-chapter 4.3 and can be consulted in Table 7.

Having all the necessary elements, the tool is able to calculate the Setup Supermarket Service Time (Equation 19). Thus, it is possible to compute the output in question (Number of Operators of Supermarket Service) through the following equation:

$$\text{Nº of Operators (Setup Supermarket Service)} = \frac{\text{SSST(h)}}{\text{Available Working Time (h)}} \quad \textbf{23)}$$

This number is subject to variations that must be in accordance with the instances created by the user and with possible changes in the data coming from the information system.

5) **<u>Total Nº of Operators and Saturation (Total nºop)</u>** – Represents the total number of operators needed to perform the two services already described. To know its value, it is necessary to sum Output 3 and Output 4, as represented in the equation 24.

$$\text{Total Nºop (Saturation\%)} = \text{Nºop milk run Service} + \text{Nºop Supermarket Service} \quad \textbf{24)}$$

Outputs deriving from secondary table:

1) **<u>Total number of KLT and Total number of *Minomi* handled per Turn</u>**: Through the result of the intermediate calculation performed in the previous stage from the creation of the secondary table (Number of Requested Material per Turn), it was possible, using Excel formulas, to differentiate the total number of orders referring to KLT and the total number of orders referring to *Minomi*, per each milk run route.

2) **<u>Fleet Sizing Tow-Train per Turn</u>**: Represents the number of cars with KLT and the number of *Minomi*s transported by the tow-train according to the instances generated by the user. At Gestamp Palau, the carts that transport boxes can carry 20 KLT. Thus, the fleet Sizing of the tow-train per turn is calculated as follows:

$$\text{Fleet Sizing TowTrain/turn} = \frac{\text{nºKLT/turn}}{20} + \text{nº}Minomis\text{/turn} \quad \textbf{25)}$$

3) **Critical Turn/Route**: Represents the route at which the fleet sizing is maximum throughout the shift. Although the user has access to consult the last two outputs addressed, it was important to show in the user interface only this latter one, as long as it would be possible to make decisions regarding fleet sizing when not complying with the company's standards.

Once concluded the explanation of how the tool was created and developed, Figure 59 shows the interface created for the user to interact with the tool both in terms of Input Definition and Output generation.

	Minutes	Hours
Rest Time	40	0,7
Available WorkingTime	438	7,3
Ideal MilkRun Cycle Time	64	1,1
Max MilkRun Cycle Time	62,0	1,0

Welding Cell	Output Reference	OEE	Active
S020	V0012S00990	0,85	1
S021	V0013S00990	0,85	1
S021	V0014S00990	0,85	
S022	V0026S00990	0,85	
S022	V0027S00990	0,85	
S022	V0083S00990	0,85	1
S022	V0090S00990	0,85	
S023	V0026S01990	0,85	1
S024	V0023S00991	0,85	
S024	V0023S01991	0,85	1
S024	V0080S00990	0,85	
S024	V0081S00990	0,85	
S025	V0023S00991	0,85	
S025	V0082S00990	0,85	1
S029	V0026S00990	0,85	
S029	V0027S00990	0,85	1
S029	V0090S00990	0,85	
S030	V0024S01990	0,85	1
S030	V0024S02990	0,85	1
S014	R0037S00990	0,85	
S014	R0038S00990	0,85	
S014	R0039S00990	0,85	1
S014	R0039S02990	0,85	
S014	R0040S00990	0,85	
S014	R0040S01990	0,85	
S014	R0051S00990	0,85	1
S015	L0008S02990	0,85	
S015	L0017S02990	0,85	
S015	L0017S10990	0,85	
S015	L0018S05990	0,85	
S015	R0011S00990	0,85	

Max Nº of Turns	Total Nº KLT/shift	Total Nº Minomis/shift	Total Nr Containers/shift	Total Nº KLT Pallet/shift
7,0	329	43	19	7

MilkRun Service		
Time KLT (h)		Time Minomi (h)
2,69		0,53
Travel Time (h)		
Get on/Get off truckie time (h)		0,002
Stop Time (h)		0,115
Normal Time (h)		0,07
Train displacement time (h)		1,2854
MilkRun Service Time (h)		4,50
Nop/Saturation		0,62

Setup Supermarket Service		
Time KLT (h)	Time Minomi (h)	Time Containers (h)
1,05	7,41	1,41
Setup Supermarket Time Service (h)		9,87
Nop/Saturation		1,352

Total Service	
Total Time (h)	14,38
Nop/Saturation	1,969

Critical Route

3

6

Figure 59 - Tool Interface

In addition to the worksheet referring to the Interface, the user can access to all the other worksheets that support the tool. The way of using the tool as well as all the possible interactions with it are described in detail in the "Tool User Guideline" presented in Appendix D.

5. APPLIED METHODOLOGY – EVALUATING

This chapter corresponds to the fourth stage of the AR Methodology (Evaluating) which aims to analyze the outcome of the actions taken in the previous stage. These actions, derived from the action plan outlined in the third stage (Action Planning), in which the actions serving as a solution to the identified problems were established, particularly to the inefficiency of the parts feeding system.

During the Action Taking stage four main actions were performed, three of which revolved around an analytical context and the other via an implementation perspective (decomposed in some sub-actions).

The first action taken concerned the mapping of material flows with the intention of addressing problem four (P4) as explained previously in this work. Here, the logistic material flows regarding both welding production area and the supermarket of welding components were identified, detailed, and documented in a clearly and objective way. The performance of this action improved the perception of all necessary transports and motions to be carried out in the in-plant milk run service and, in the setup and maintenance of the supermarket service, which was directly and indirectly useful for the subsequent approach to the remaining problems. And for future work, the mapping is expected to be helpful in decision-making situations surrounding improvements regarding this topic. In this way, it will be possible to analyze the introduction of changes in the flows without compromising the existing ones.

Upon ending the previous action, it was possible to address problem two (P2) with the second and third actions which are intrinsically related. These actions were supported on the material flow mappings and on the learning acquired during the diagnosing stage. As a result of these new actions, the identification and detailed documentation of the main tasks carried out by the operators of both logistic services (milk run and supermarket setup) was produced. Subsequently, a temporal study and quantification of each task was made. None of the presented analytical actions had been addressed before, hence why they appeared in the Action Planning stage to solve micro problems which eventually addressed the macro problems (P3, P5, P6, P1).

In collaboration with the company, it was decided to take a fourth action which was the development and implementation of a simulation and decision-support tool that could overcome the latter mentioned problems. The action of creating the tool was the focus and bulk of this work and produced the most practical outcomes. For this reason, the results and discussion focus on this work in more detail as shown in the next dedicated sub-chapter (5.1).

5.1. Results

Although the tool was developed whilst considering the requirements established when brainstorming about its creation (sub-chapter 4.4.1), it was necessary to validate it. Therefore, whether it can produce the required outputs, create reliable supports to decision-making, show desirable interaction with the user, and whether it addresses the aforementioned problems was ascertained.

Whilst diagnosing the status of the welding cells supply system, one of the information acquired was about the current workforce planning of the logistic team. In the present status, this planning is made through experience, empirical knowledge and inaccurate calculations done in a daily manner. It is currently established that depending on low/high demand from the clients the workforce varies between <u>three</u> and <u>four</u> operators, respectively. In a scenario of rising demand from all the costumers, one of the four operators is allocated to the in-plant milk run service and the remaining three to the setup of supermarket service.

Taking this into account, it was found pertinent to carry out a simulation with the tool reflecting a usual scenario of high demand. To address this scenario, the instance generator table of the tool was activated with output references from all cells existing in the welding department supplied by tow-train, meaning all cells were operational (Figure 60). For those that are able to produce only one product only one output reference was activated, and in those that can produce multiple products at a time multiple output references were activated.

Welding Cell	Output Reference	OEE	Active
S004	V0080S01990	0,85	1
S006	V0010S00991	0,85	1
S009	V0015S00990	0,85	1
S012	R0045S00991	0,85	1
S012	R0046S00991	0,85	1
S013	R0041S00990	0,85	1
S013	R0042S00990	0,85	
S014	R0037S00990	0,85	1
S014	R0038S00990	0,85	
S014	R0039S00990	0,85	
S014	R0039S02990	0,85	
S014	R0040S00990	0,85	1
S014	R0040S01990	0,85	
S014	R0051S00990	0,85	
S015	L0008S02990	0,85	
S015	L0017S02990	0,85	
S015	L0017S10990	0,85	
S015	L0018S05990	0,85	
S015	R0011S00990	0,85	
S015	R0014S00991	0,85	
S015	R0015S00990	0,85	
S015	R0054S02990	0,85	
S015	R0058S00990	0,85	
S015	R0075S00990	0,85	
S015	R0079S00990	0,85	1
S015	R0080S00990	0,85	
S015	R0103S00990	0,85	
S015	R0105S00990	0,85	
S015	R0109S00990	0,85	
S015	R0112S00990	0,85	

Welding Cell	Output Reference	OEE	Active
S015	R0128S00990	0,85	
S015	V0067S00990	0,85	
S015	V0070S00990	0,85	
S019	R0064S01990	0,85	
S019	R0064S01990	0,85	
S019	R0065S01990	0,85	
S019	V0015S01990	0,85	1
S019	V0015S02990	0,85	
S020	V0012S00990	0,85	1
S021	V0013S00990	0,85	
S021	V0014S00990	0,85	1
S022	V0026S00990	0,85	1
S022	V0027S00990	0,85	
S022	V0083S00990	0,85	
S022	V0090S00990	0,85	
S023	V0026S01990	0,85	1
S024	V0023S00991	0,85	
S024	V0023S01991	0,85	
S024	V0080S00990	0,85	
S024	V0081S00990	0,85	1
S025	V0023S00991	0,85	1
S025	V0082S00990	0,85	
S029	V0026S00990	0,85	1
S029	V0027S00990	0,85	
S029	V0090S00990	0,85	
S030	V0024S01990	0,85	1
S030	V0024S02990	0,85	1

	Minutes	Hours
Rest Time	40	0,7
Available WorkingTime	438	7,3

Figure 60 – Instance for the first simulation

Regarding the available working time, the inserted value for the simulation was 7,3 hours for a shift duration, which considers the mandatory 40 minutes established by the company for the operators to take their rest time.

As mentioned in sub-chapter 4.4.3, the tool contains three tables which requires user maintenance, one for OEE indicator, another for the number of *kanban*s established for each component in the border of line, and one for *Minomi's* data (Packaging name, SNP, etc.). Before starting the tests and simulations, all these tables were previously filled with the respective information collected. In this simulation, no changes were made to the data of two of the tables. The only one that had changes was the OEE table where a significant level of efficiency was considered for all products, meaning, an OEE of 0,85 (its usual value on average).

Once all the inputs are defined, the tool was able to compute the outputs. Regarding the in-plant milk run service one of the outputs is the Ideal milk run Cycle Time, i.e., the time between routes. Figure 61 shows that the ideal tow-train route should occur every 66 minutes in order to guarantee no shortages of components in the welding cells. Thus, considering the shift duration, the milk run can perform 6,66 turns. However, the tool rounds up this value therefore, for the milk run to be able to do 7 turns (Figure 62), the cycle time has to be adjusted to 62 minutes as seen in the Figure 61 (Max milk run Cycle Time). The information provided by this output, seeing the instance created, is aligned with the time between routes previously defined by the company (1h).

	Minutes	Hours
Ideal MilkRun Cycle Time	66	1,1
Max MilkRun Cycle Time	62,0	1,0

Figure 61 - Max milk run cycle time output for simulation 1

The outputs presented in Figure 62 represent the total number of KLT, *Minomi*, Containers and KLT pallets to be handled during the available working time. By way of example, during the shift 345 KLTs and 45 *Minomi* cars would be supplied to the welding cells by the milk run. However, for these handling units to be supplied it necessary to setup and maintain the supermarket. Therefore, 45 *Minomi* car require preparation, along with 18 containers and 7 KLT pallets which would need to be exchanged. These results would provide the company an idea of the workload needed given the created production scenario.

Max Nº of Turns	Total Nº KLT/shift	Total Nº Minomis/shift	Total Nr Containers/shift	Total Nº KLT Pallet/shift
7,0	345	45	18	7

Figure 62 - Intermediate outputs for simulation 1

However, more than having an idea, the company required this tool to quantify the workload and subsequently the workforce needed in the in-plant milk run service as well as in the setup of supermarket service. In Figure 63 it is possible to observe the computations made by the tool to calculate the number of operators needed in each one of the services and in Figure 64 the total service saturation[2] is presented.

MilkRun Service	
Time KLT (h)	Time Minomi (h)
2,83	0,55
Travel Time (h)	
Get on/Get off truckie time (h)	0,002
Stop Time (h)	0,084
Normal Time (h)	0,07
Train displacement time (h)	1,0686
In- Plant MilkRun Service Time (h)	4,44
Nop/Saturation	0,61

Setup Supermarket Service		
Time KLT (h)	Time Minomi (h)	Time Containers (h)
1,07	6,81	1,33
Setup Supermarket Time Service (h)		9,22
Nop/Saturation		1,263

Figure 63 - In-Plant milk run service and setup of supermarket service saturation

[2] Percentage of utilization of a worker during the available working time

Total Service	
Total Time (h)	13,66
Nop/Saturation	**1,872**

Figure 64 - Both milk run and supermarket total saturation

As seen from the results in Figure 63, the present high demand scenario would be need 0,61 workers for the in-plant milk run service and 1,263 workers for the setup of supermarket service, which in total requires a workforce of 1,872 workers for the parts feeding system (Figure 64). In other words, by analyzing the operation loading chart (OLC) presented in Figure 65,1 operator with 61% saturation would be needed for the milk run service, and for the supermarket service 2 operators are required. In the event one is completely saturated, the other would be 26% saturated.

However, Figure 64 reflects that in total only 2 operators are needed to perform both services (1,872) and not 3 operators as shown in Figure 63, which evaluates the services in a separated way. These results will be discussed further in the next sub-chapter.

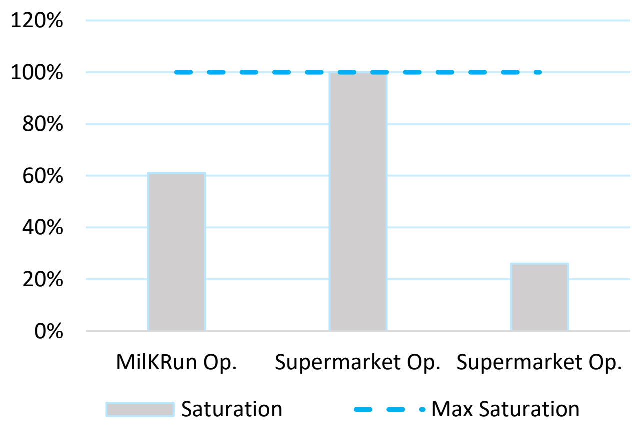

Figure 65 - Example of an operator loading chart for simulation 1

The tool is able to show the user graphical information about the saturation of each one of the activities or tasks performed in the two logistic services. This information can be consulted in Appendix C. From Figure 77 in the appendix, it is possible to conclude that the activities involving the handling of KLT represent a great percentage of the workload associated to the in-plant milk run service, which is related to the high amount of KLT to be supplied during a shift. In the supermarket service, the preparation of *Minomi* is the activity that takes more time for the operators to perform, being the factor that causes so much discrepancy in the saturation of both services. Besides the outputs mentioned before, the tool also presents information about the maximum fleet sizing that the tow-train would need to transport. In this specific case, a critical route would be at the turn number 6 in which the train would need to transport about 3 cars containing KLTs and 6 *Minomi*s. These results will be discussed further in the next sub-chapter.

After performing the previous scenario that intended to simulate large activities in the welding department, it was decided to test the tool with a reduced number of products to be assembled, meaning a low demand situation in Gestamp Palau S.A. A new instance was generated, maintaining either the same OEE and Available Working Time. The instance created can be seen in Figure 66 and the results obtained can be consulted in Table 12.

Welding Cell	Output Reference	OEE	Active
S004	V0080S01990	0,85	
S006	V0010S00991	0,85	1
S009	V0015S00990	0,85	1
S012	R0045S00991	0,85	
S012	R0046S00991	0,85	
S013	R0041S00990	0,85	1
S013	R0042S00990	0,85	
S014	R0037S00990	0,85	1
S014	R0038S00990	0,85	
S014	R0039S00990	0,85	
S014	R0039S02990	0,85	
S014	R0040S00990	0,85	
S014	R0040S01990	0,85	
S014	R0051S00990	0,85	
S015	L0008S02990	0,85	
S015	L0017S02990	0,85	
S015	L0017S10990	0,85	
S015	L0018S05990	0,85	
S015	R0011S00990	0,85	
S015	R0014S00991	0,85	
S015	R0015S00990	0,85	
S015	R0054S02990	0,85	
S015	R0058S00990	0,85	
S015	R0075S00990	0,85	
S015	R0079S00990	0,85	1
S015	R0080S00990	0,85	
S015	R0103S00990	0,85	
S015	R0105S00990	0,85	
S015	R0109S00990	0,85	
S015	R0112S00990	0,85	

Welding Cell	Output Reference	OEE	Active
S015	R0128S00990	0,85	
S015	V0067S00990	0,85	
S015	V0070S00990	0,85	
S019	R0064S01990	0,85	
S019	R0065S01990	0,85	
S019	V0015S01990	0,85	
S019	V0015S02990	0,85	
S020	V0012S00990	0,85	
S021	V0013S00990	0,85	
S021	V0014S00990	0,85	1
S022	V0026S00990	0,85	
S022	V0027S00990	0,85	
S022	V0083S00990	0,85	
S022	V0090S00990	0,85	
S023	V0026S01990	0,85	1
S024	V0023S00991	0,85	
S024	V0023S01991	0,85	
S024	V0080S00990	0,85	
S024	V0081S00990	0,85	
S025	V0023S00991	0,85	1
S025	V0082S00990	0,85	
S029	V0026S00990	0,85	1
S029	V0027S00990	0,85	
S029	V0090S00990	0,85	
S030	V0024S01990	0,85	1
S030	V0024S02990	0,85	1

Figure 66 – Instance of the second simulation

Table 12 - Summary table with simulation 2 outputs

Ideal milk run Cycle Time (min)	66
Max milk run Cycle Time (min)	62
Max Nº of Turns	7
Total Nº KLT/Shift	232
Total Nº *Minomi*/Shift	29
Total Nº Containers/Shift	11
Total Nº KLT Pallet/Shift	3
Nop/Saturation milk run Service	0,42
Nop/Saturation Setup Supermarket Service	0,795
Nop/Saturation Total Service	1,216

From the results obtained it is perceivable that both workload and workforce decreased since there are fewer handling units to be transported or exchanged in the welding department during a shift. In this production scenario, a 42% saturated worker would be needed to perform the milk run service and a 79% saturated worker to perform the setup supermarket service (Table 12). This in in line with the total necessity for both services of about 2 operators (1,216). The OLC graph of this simulation can be consulted in Figure 67.

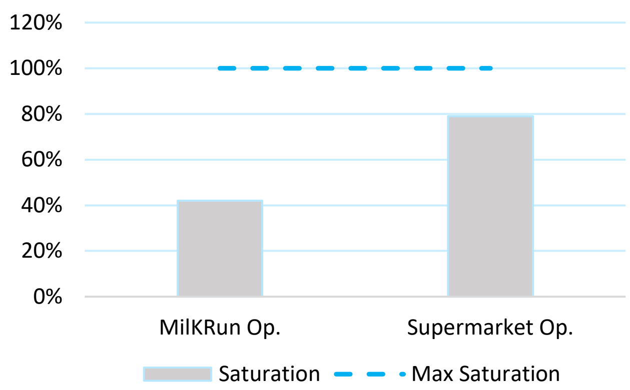

Figure 67 – Operator loading chart for simulation 2

As it was expected, the maximum fleet sizing of the train decreased. With the presented number of materials to be handled, the tow-train would transport 2 KLT cars and 4 *Minomi* cars. In Figure 77 and Figure 78 from Appendix C it is possible to observe the changes of the influence of each activity in the operators work comparing to the previous scenario.

It was found pertinent to present in this chapter a third simulation representing a possible high-demand situation like in the first scenario, though with different output references activated in this case. The instance created is shown in Figure 68 and the results obtained can be found in Table 13.

Welding Cell	Output Reference	OEE	Active
S004	V0080S01990	0,85	1
S006	V0010S00991	0,85	1
S009	V0015S00990	0,85	1
S012	R0045S00991	0,85	1
S012	R0046S00991	0,85	1
S013	R0041S00990	0,85	
S013	R0042S00990	0,85	1
S014	R0037S00990	0,85	
S014	R0038S00990	0,85	
S014	R0039S00990	0,85	1
S014	R0039S02990	0,85	
S014	R0040S00990	0,85	
S014	R0040S01990	0,85	
S014	R0051S00990	0,85	1
S015	L0008S02990	0,85	
S015	L0017S02990	0,85	
S015	L0017S10990	0,85	
S015	L0018S05990	0,85	
S015	R0011S00990	0,85	
S015	R0014S00991	0,85	1
S015	R0015S00990	0,85	
S015	R0054S02990	0,85	
S015	R0058S00990	0,85	
S015	R0075S00990	0,85	
S015	R0079S00990	0,85	
S015	R0080S00990	0,85	
S015	R0103S00990	0,85	
S015	R0105S00990	0,85	
S015	R0109S00990	0,85	
S015	R0112S00990	0,85	

Welding Cell	Output Reference	OEE	Active
S015	R0128S00990	0,85	
S015	V0067S00990	0,85	
S015	V0070S00990	0,85	
S019	R0064S01990	0,85	1
S019	R0065S01990	0,85	
S019	V0015S01990	0,85	
S019	V0015S02990	0,85	
S020	V0012S00990	0,85	1
S021	V0013S00990	0,85	1
S021	V0014S00990	0,85	
S022	V0026S00990	0,85	
S022	V0027S00990	0,85	
S022	V0083S00990	0,85	1
S022	V0090S00990	0,85	
S023	V0026S01990	0,85	1
S024	V0023S00991	0,85	
S024	V0023S01991	0,85	1
S024	V0080S00990	0,85	
S024	V0081S00990	0,85	
S025	V0023S00991	0,85	
S025	V0082S00990	0,85	1
S029	V0026S00990	0,85	
S029	V0027S00990	0,85	1
S029	V0090S00990	0,85	
S030	V0024S01990	0,85	1
S030	V0024S02990	0,85	1

Figure 68 – Instance of the third simulation

Table 13 – Summary table with simulation 3 results

Ideal milk run Cycle Time (min)	32
Max milk run Cycle Time (min)	31
Max Nº of Turns	14
Total Nº KLT/Shift	400
Total Nº *Minomi*/Shift	53
Total Nº Containers/Shift	21
Total Nº KLT Pallet/Shift	9
Nop /Saturation milk run Service	0,83
Nop /Saturation Setup Supermarket Service	1,558
Nop /Saturation Total Service	2,387

When analyzing the outputs generated in this third scenario a change in the Max milk run cycle time parameter was detected. In the two previous simulations, the time between milk run routes calculated by the tool was ~60 minutes (value in accordance with the established by the company), and in the present simulation it was ~30 minutes. As it is inversely proportional (Equation 10), the maximum number of turns needed to be performed during a shift increased to 14 turns.

As mentioned throughout this dissertation, the welding department of Gestamp Palau can produce a variable number of different products. Depending on whether the products are composed of few to multiple components, of big or small dimensions, the time they can consume in the parts feeding system operators work can have varying significance. In this specific instance, it is possible to see that the activated products require more work from the operators, since both services' saturation increased significantly compared to the first high-demand simulation made. Regarding the setup of the supermarket service, one of the reasons for this difference was the increasing number of handling units to be transported or exchanged. Regarding the milk run service it was the alteration of the two parameters referred to before (maximum cycle time and number of turns), since more turns mean more time spent on train displacements. Referring to the fleet size there were no significant changes in relation to the first scenario. The OLC graph of this simulation can be consulted in the Figure 69, considering that one of the operators working on the supermarket service is totally saturated.

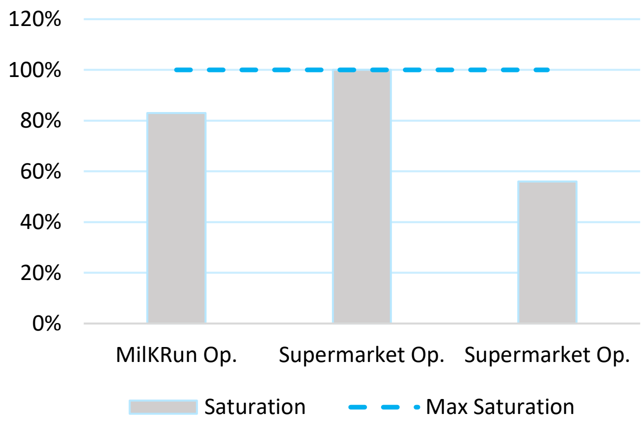

Figure 69 - Example of an operator loading chart for simulation 3

After conducting several test simulations with the tool considering hypothetical yet typical situations, it was perceived together with the logistical team and the study of times technician that the generated outputs were reliable. Thus, it began to be officially used to manage resources in the parts feeding system, by simulating real demand and production situations. It was found pertinent to present one of the real simulations made, since it reflects a totally different scenario compared to the previous instances. Due to the current pandemic situation, there are several OEM's stopping their production activity, which directly affects the Tier 1 suppliers. One example of this was the stoppage of SEAT production in week 37 and the subsequently decrease on demand during a certain period. Thus, based on real time data from the WIS information system, an instance was created in the tool where almost all SEAT references were disactivated, a few references OEE was changed, and the Available Working Time input remain the same. The instance created and the results obtained can be seen below in Figure 70 and in Table 14, respectively.

Welding Cell	Output Reference	OEE	Active
S004	V0080S01990	0,85	
S006	V0010S00991	0,85	
S009	V0015S00990	0,90	1
S012	R0045S00991	0,90	1
S012	R0046S00991	0,90	1
S013	R0041S00990	0,81	1
S013	R0042S00990	0,81	1
S014	R0037S00990	0,85	
S014	R0038S00990	0,85	
S014	R0039S00990	1,00	1
S014	R0039S02990	0,85	
S014	R0040S00990	0,85	
S014	R0040S01990	0,85	
S014	R0051S00990	0,85	
S015	L0008S02990	0,85	
S015	L0017S02990	0,85	
S015	L0017S10990	0,85	
S015	L0018S05990	0,85	
S015	R0011S00990	0,85	1
S015	R0014S00991	0,75	
S015	R0015S00990	0,85	
S015	R0054S02990	0,85	
S015	R0058S00990	0,85	
S015	R0075S00990	0,85	
S015	R0079S00990	0,85	
S015	R0080S00990	0,85	1
S015	R0103S00990	0,85	
S015	R0105S00990	0,85	
S015	R0109S00990	0,85	
S015	R0112S00990	0,85	

Welding Cell	Output Reference	OEE	Active
S015	R0128S00990	0,85	
S015	V0067S00990	0,85	
S015	V0070S00990	0,85	
S019	R0064S01990	0,85	
S019	R0065S01990	0,85	
S019	V0015S01990	0,85	
S019	V0015S02990	0,85	
S020	V0012S00990	0,85	1
S021	V0013S00990	0,85	
S021	V0014S00990	0,85	
S022	V0026S00990	0,85	
S022	V0027S00990	0,85	
S022	V0083S00990	0,85	
S022	V0090S00990	0,85	
S023	V0026S01990	0,85	
S024	V0023S00991	0,85	
S024	V0023S01991	0,85	
S024	V0080S00990	0,85	
S024	V0081S00990	0,85	
S025	V0023S00991	0,85	
S025	V0082S00990	0,85	
S028	F0079S00991	0,86	
S029	V0027S00990	0,85	
S029	V0090S00990	0,85	
S030	V0024S01990	0,85	
S030	V0024S02990	0,85	

Figure 70 – Instance of the fourth simulation

Table 14 - Summary table with simulation 4 results

Ideal milk run Cycle Time (min)	78
Max milk run Cycle Time (min)	73
Max Nº of Turns	6
Total Nº KLT/Shift	120
Total Nº *Minomi*/Shift	23
Total Nº Containers/Shift	10
Total Nº KLT Pallet/Shift	4
Nop/Saturation milk run Service	0,26
Nop/Saturation Setup Supermarket Service	0,679
Nop/Saturation Total Service	0, 941

The present instance is a case of a very low demand situation in Gestamp Palau S.A. since the group of cells that produce for SEAT is disabled and it is one of those that represents a greater weight in production of the welding department. In this way, the workload and workforce for this real scenario was very low, being only needed 1 operator to perform the total logistic service regarding the parts supply. As it is possible to see in the Table 14 and Figure 71 the operator would be 68% saturated whilst performing tasks related to the supermarket setup service and 26% saturated performing tasks for the milk run service.

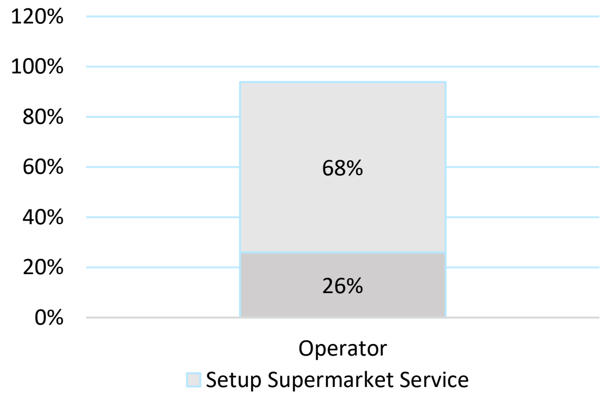

Figure 71 – Operator loading chart for simulation 4

Like in the previous scenario, the Max milk run Cycle time parameter changed in relation to the 60 minutes established by the logistic department. In this instance, the milk run must start the route through the cells every 73 minutes, performing 6 turns in total during the available working time. In this specific case, the fleet-size was smaller than in the other simulations, since the tow-train would transport 2 KLT cars and 2 *Minomi* cars, the worst case during the considered shift.

5.1.1. Critical evaluation of results

This sub-chapter intends to further analyze the outputs obtained in the simulations previously presented in this chapter. All the results are summarized in Table 15.

Table 15 - Summary table from all simulations result

	S1	S2	S3	S4
Ideal milk run Cycle Time (min)	66	66	32	78
Max milk run Cycle Time (min)	62	62	31	73
Max Nº of Turns	7	7	14	6
Total Nº KLT/Shift	345	232	400	120
Total Nº *Minomi* /Shift	45	29	53	23
Total Nº Containers/Shift	18	11	21	10
Total Nº KLT Pallet/Shift	7	3	9	4
Nop/Saturation milk run Service	0,61	0,42	0,83	0,26
Nop/Saturation Setup Supermarket Service	1,263	0,795	1,558	0,679
Nop/Saturation Total Service	1,872	1,216	2,387	0, 941
Fleet Size (Nº KLT cars; Nº *Minomi* cars)	3;6	2;4	3;5	2;2

As mentioned throughout the dissertation, the planning and management of both materials to be handled and the logistical team operating in the components supply service is done in an inaccurate fashion, without being based on a detailed study of the entire environment where this logistical service is inserted. With regard to human resources, the company stipulated that 3 or 4 workers are needed to perform the service depending on whether there is low or high demand, respectively. Analyzing the results, more precisely the output Nop/Saturation Total Service, it is possible to see that the current way of defining needs can represent *muda* for the company in some situations of demand. In the simulations that represent a situation of high demand (S1 and S3) the results varied between 2 and 3 operators needed for operating the two services, with the instances already created considering the maximum current capacity of the welding department. In the case of simulations with lower demand, the number of operators varies between 1 and 2. This means that when the company defines that it would need 4 workers (high demand situation) or 3 (normal or low demand situation), there will be, at least one unsaturated worker. This represents efficiency losses for the company as these operators could be allocated to other tasks or departments. Once these outputs are generated by the tool, they should not be immediately applied on the shop floor without proceeding to a test phase where the workers' feedback to the new planning is evaluated.

Another aspect that was noticed was related to the results obtained for the Max Milk Run Cycle Time parameter. It is known that the company established a 1-hour interval between routes taken by the milk run without distinguishing between different types of production sequences, regardless of which cells are active and with which output reference. This 1-hour cycle time was established based on the current number of *kanban*s defined for each component at the border of line, that is, by the maximum capacity existing in the cells either in KLT or *Minomi*s. Although, in simulations S1 and S2 the result was in accordance with the stipulated, in the last two instances this did not happen. Since the difference between S1 and S3 was the activation of different output references keeping the high demand situation, it was realized that this change would be related to the replenishment lead time (autonomy) of a certain component in the cell. Thus, all lead times were consulted in the tool's spreadsheet (main table database) and components were identified with the replenishment lead time of 32 minutes. In turn, through equation 8, it is known that this time is calculated based on the number of existing *kanban*s, and thus it was decided to consult the value of this parameter in the maintenance table referring to this topic for the identified components. These components integrate the output reference R0014S00991 activated in simulation 3 whose assembly is performed in cell S015. During this consultation, it was observed that for its two components, 6 KLTs were established in FIFO Racks in the border of line. Reporting this observation to the logistics team, it was immediately decided to double the number of *kanban*s for these components to have a replenishment lead time of about 60 minutes like most components to be supplied to the welding cells. In the case of simulation 4, the opposite happens, the replenishment lead time is greater than 1 hour. In summary, the critical analysis to be carried out on this topic is that, as proved by the simulations, the welding department may require different milk run cycle times depending on different demand situations. Therefore, as things stand, there should not be a defined time of 1h but an adjustment of the cycle according to what is being produced during the available working time, since there is a risk of material shortage in certain cells or passage through them before the necessary time, not complying with the JIT principle. The tool developed can be used in this sense. The other option would be to adjust the number of *kanban*s of all components so that they all have approximate replenishment lead times and are thus able to establish a uniform milk run cycle time. The tool can also help in this regard since the user can change the number of *kanban*s for the components he desires in order to achieve the required lead time.

With regard to the output Fleet Size, this reflects the maximum amount in KLT and *Minomi* cars that the tow-train will have to transport, considering the instance created. Prior to the realization of this project, tests were carried out on the shop-floor to understand the feasible fleet size to carry out the turns of the milk run so that the existing curves in the course can be done in a smooth way. It was decided that in case of transporting KLT cars and also *Minomi*s, the maximum allowed amount would be 2 KLT cars and 5 *Minomi*s, and that in case of only transporting *Minomi*s it could be 6 cars. Through the analysis in the simulations, it is understood that in the scenarios of greater demand (S1 and S3) there is at least one route in which this quantity would be exceeded, which may represent constraints in the corridors, interruption of other logistical flows or even disruption of productive activity. Thus, the developed tool previously exposes a possible fleet sizing problem so that it can be addressed before causing the mentioned issues. A possible solution to the problem could be the physical modification of the means of transporting materials, such as increasing the capacity of KLT cars from 20 units to 30 units, as the available cars are not sized specifically for the size of these handling units. Another option would be to make another tow-train available to carry out the supply of components to the cells in the moments when demand is expected to increase. Lastly, an alternative could be to slightly reduce the milk run cycle time. Doing so would perform more turns and the tow-train would be less saturated. However, it is necessary to evaluate this last option to see if it does not cause other types of inefficiencies, such as non-compliance with JIT or unnecessary transports on the shop floor.

Once the critical evaluation of the simulations results was carried out, together with the logistics department, the focus was once again given to the outputs related to the workforce. In their presentation, it was noticed that the value of the output Nop/Saturation Total Service did not always coincide with the values generated for the outputs Nop/Saturation milk run Service and Nop/Saturation Setup Supermarket Service. As an example, in S1, the workforce needed to perform the total service was about 2 operators (1,872) and the workforce needed to perform the milk run service and the supermarket service was about 1 (0,61) and 2 (1,263) respectively, thus 3 operators in total. This happens because each task or activities to be performed was, previously in the study times, specifically assigned to one of the services, making it impossible to balance the workload. Thus, it was decided to apply an improvement in the operation of the tool and a new requirement was added:

R6: The tool must offer the possibility to the user (company) to allocate and balance the workload inherent to each activity to the available operators, whilst not distinguishing the workforce by services.

Looking at Figure 72, it is possible to observe the table created in the tool where the user can enter the operator's number in front of each activity. It is also represented in the figure the correspondent output generated in the interface. The example is based on balancing the workforce obtained in the first simulation (S1).

Worker	Activities	Description	Time (h)	Saturation
1	1.2	Leave empty KLTs on pallet	0,001197222	6%
1	1.4	Load a KLT on train's car	0,002130556	10%
1	2.2	Supply full KLT to wellding cell	0,003411111	16%
1	2.3	Collect of empty KLT from welding cell	0,001455556	7%
1	1.3	Leave empty Minomi car in corresponding area	0,002552778	2%
2	1.5	Load a Minomi car in train	0,002405556	1%
1	2.4	Supply Full Minomi car to wellding cell	0,003544444	2%
1	2.5	Collect of empty Minomi from welding cell	0,003583333	2%
1		Train displacement	1,068644444	15%
1	3	Transport full pallet of empty KLT to the corresponding area	0,045758333	5%
1	5.2	Supply Welding Supermarket from Door9 Warehouse	0,096900000	9%
2		Minomis car preparation	6,814052384	93%
2	4.1	Order a new container at SAP Station	0,006333333	2%
1	4.2	Change from empty to full container	0,067787778	17%

Figure 72 – Workload balancing table (simulation 1)

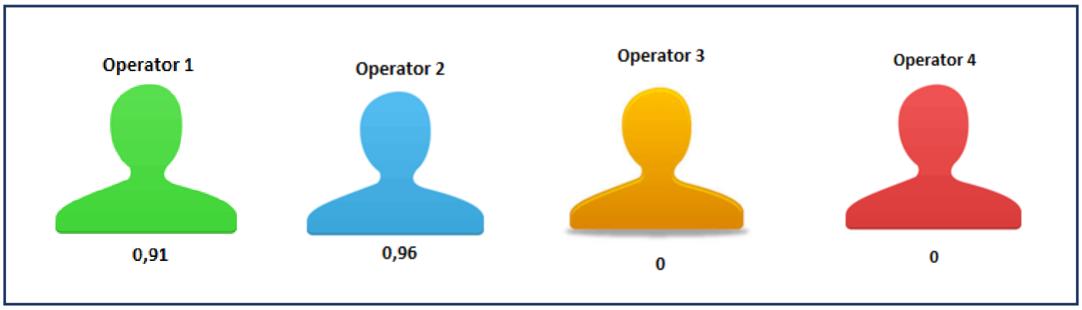

Figure 73 - Balanced workload (simulation 1)

In Figure 72 it is possible to observe that the activities are not assigned to a logistic service but to a specific worker. In this balancing example, more tasks were assigned to operator 1 as the workload that each represents is significantly smaller than the activities allocated to operator 2. In this way it was possible to concentrate the available working time workload for one situation of high demand, in two operators (value according to the output Nop/Saturation Total Service), as they will need to operate at a good work rate (>90%), as shown in Figure 73. It is necessary to highlight that any change in the allocation or balancing of workload in light of the current situation, must be well tested and oriented so that operators get involved and adapt to changes and continuous improvement of processes.

In general terms, the tool meets the requirements established by the company, presented in sub-chapter 4.4.1. It dynamically produces all the desired outputs considering the instances created by the user and the data from SAP. Asides this, it produces fast and reliable results that are presented to the user in a simple and objective way. At the final of its development, another requirement was imposed:

R7: Creation of a guideline for the user regarding how the tool was created and how to operate it.

The guideline named "Tool for Resource Management of the welding parts feeding system: In-Plant milk run KLT/*Minomis*" can be consulted in the Appendix D.

As mentioned before in this chapter the analytical actions taken addressed some of the problems raised in the diagnosing stage (P2, P4). Although these actions are indirectly related with the rest of the problems (P3, P5, P6, P1) it was only with the creation of the tool that they were expected to be solved. Regarding the welding components supply system, some of the remaining problems to address related to the existing difficulties surrounding the planning and balancing of the logistic team workforce (P3), and on managing the material resources handled during the performance of the service (P5). Problem 6 is associated with the existence of unnecessary transports and motions during the service, and noncompliance with the *kanban* and consequently with the JIT paradigm. The tool responded to these problems in the following way:

- Through the calculation of the total number of handling units to be transported or exchanged of each type it is possible to have a real perception about the amount of work required to be done during the available working time. The calculation of the number of handling units transported in each turn/route allows the fleet sizing of the tow-train in each milk run cycle to be known. These two outputs address Problem 5 in a way that facilitate the materials planning and management according to each different production scenario.
- By addressing problem 5 and knowing the activity times previously measured, the tool can compute the workload and subsequently the workforce (number of operators) needed to perform the service. It also allows the balancing of each operator saturation. These possibilities offered by the tool in alignment with its dynamic aspect of responding to any simulation allow problem 3 to be addressed by making the human resource planning and balancing easier and reliable.
- By calculating and adjusting the milk run cycle time according to number of products being assembled, the milk run operator perform his route neither late nor early, but just-in-time. Thus, properly scheduling the routes avoid unnecessary movement on the shop floor and ensures the compliance of the *kanban* system, thus addressing the problem 6.

When looking at the problem 1 (Workstation Starvation) in Action Planning stage, it was decided to try to face it with recourse to the simulation and decision-support tool. Seeing its results and capabilities already presented, it is expected that the improvement on the parts feeding system brought by the tool, would smooth the problem of workstation starvation. In the time scale of the project dissertation, it was not possible to test the tool sufficiently to obtain considerable data regarding the number of stoppages due to lack of raw material. Thus, it is only possible to have an expectation which points to a good result in this field.

From the analysis of the whole work developed to produce this tool, it was considered to be quite versatile and useful. It was identified that it can be used for both short-term and long-term resource planning. The diagram from Figure 74 shows a comparison between the moment before and after the creation of the tool.

Simulation and Decision-Support Tool

Before	After
✖ There was no resource management system regarding the parts feeding to the welding department. ✖ Planning and balancing of human and material resources based on experience and empirical knowledge	✓ There is an implemented and transversal resource management system regarding the parts feeding to the welding department. ✓ Planning and balancing of human and material resources is now based on scientific knowledge: outputs supported by concise and reliable data from an information system, by measurements, study of times and literature review on in-plant milk run systems, lean, just-in-time and continuous improvement techniques.

Short-Term Planning	Long-Term Planning
The client plans and balances the workforce and material resources before every shift starts, creating the instances with information from the production planning of the day.	The client plans and balances the workforce and materials resources before every week starts, creating instances for all the days with information from production plan of the week. In what is related to simulation and decision making, if there is a prospection of introducing or eliminating a product or welding cell from the system, the client is able to do tests and simulations in order to know the potential impact on the parts feeding system planning. The client is able to change parameters depending on his interests such as the number of *kanbans* in the border of line or the SNP capacity of a *Minomi* car to see the effect on the results.

Figure 74 - Before and after Decision Support Tool creation. Source: Own Elaboration

5.2. Discussion (Specifying Learning)

This sub-chapter corresponds to the last stage of AR methodology cycle, intending for the identification of the general learnings through giving answer to the research questions. At the beginning of this dissertation project, two research questions were raised that conducted the work developed.

The first research question *'What type of difficulties can be found whilst planning and managing an efficient part's feeding system in a multi/mixed-model assembly line?'* was approached by the literature review conducted in the second chapter from the present dissertation, more specifically by the 2.8, 2.9 and 2.10 sub-chapters. Here, were mentioned and described the three types of assembly line configurations being applied in industries, according to Baudin (2004), Becker and Scholl (2006) and Mohammadi-Khashouie (2003). These are the following: Single-model, Multi-model and Mixed-model assembly line. Contrary to the Single-model assembly line configuration, the latter two are designed to manufacture more than a product family and are thus considered more complex. Regarding parts' feeding systems to the multi and mixed-models assembly lines, the main difficulty pointed out by the researchers was the diversity and number of parts needed to be supplied to this type of lines deriving not only from its configuration but also from the growing product variety being demanded by clients (Emde & Boysen, 2012a; Faccio, Gamberi, Persona, et al., 2013b). As result of this issue, multi and mixed-model assembly lines become associated with the existence of "*workload variation*" (*mura*) and with the possibility of having *"people overburden"* (muri) since companies have difficulties such as staffing and balancing these types of assemblies.

In addition to this, Alnahhal et al. (2014) underlines the big number of different decision-making aspects inherent to parts feeding system as a great difficulty on its planning and management. The most highlighted in the literature are routing, schedule, frequency of routing and loading problems as well as decisions on the number of *kanban*s in the system and the number of operators (as stated before).

Recalling the second research question *'What are the possible ways to address the difficulties identified in RQ1 within an automotive company inserted in a current context of demand variation?'* it is possible to see that this question derives from the previous one since this dissertation focuses on a parts feeding system inserted in an automotive company with the welding department having multi and mixed-model assembly lines, then being subjected to the issues mentioned before. However, beyond this, Gestamp Palau is currently being affected by the instability created by the pandemic situation the world is facing, in the sense that costumer's demands are uncertain and inconstant which reinforce the difficulties on planning and managing components supply system to assembly lines.

Hence, arises the question of how these difficulties should be addressed and how to make a good resource planning and management within this presently complicated environment. As shown in chapter 3 corresponding to the Diagnosing stage of the A-R methodology, the welding department internal logistic flows were analyzed which allowed to do a survey of the problems affecting the efficiency of the system. In fact, several problems were contributing to workload variation and to the inability of properly adjusting the parts feeding system resources to it whilst following JIT and Lean paradigms.

In the literature review presented in this dissertation (sub-chapter 2.10), Fortuny Santos et al. (2020) emphasizes the computation of resources (both human and material) and it's balancing as mean to control the variability associated to multi or mixed-model assembly lines and to achieve efficiency. However, the opinions of Boysen et al., 2008, Kalaoglu and Baskak (2008), Kabir and Tabucanon (1995) and Roser (2016) diverge about what is the best way to address this topic. Whether to plan and balance the assembly line according to each model produced, or to study each model in separated and then study common configurations or even considering the most frequent model to be assembled. Nevertheless, these opinions focus only on production resources, when brainstorming with the company it was requested that the possible actions to perform should take into consideration all the welding assembly lines, workstations and possible models to be produced in the welding department. Whereas the goal is to achieve the most embracing and reliable resource planning and management according to different sequences of productions deriving from demand variations, then dealing with workload variation.

In the literature review most of these decision problems are addressed through methods that usually require computational complexity and a considerable knowledge of mathematical models and algorithms, heuristics, or metaheuristics. In the practical case of Gestamp Palau, there is no such available resource, either software or human to be possible to adopt these strategies and moreover it was specifically requested that the new methodology should be simple, objective and transversal to different hierarchy levels of the organization.

Therefore, to answer the second research question, the way to address the difficulties exposed in research question 1 and to be aligned with company expectations was the development of a Microsoft Excel tool with the aim of easing the resource planning and management needed in the welding department parts feeding system, according to the changes occurring in customer demands.

Before developing the tool, it was necessary to carry out some steps regarding standard work aborded in literature review by Kumar and Kumar (2014) and Lu and Yang (2015). In this sense, the welding department layout was studied and a mapping of the internal logistic flows occurring in it was created and documented. Besides this, qualitative data from the environment was collected as well as quantitative data from the information systems. This data was analyzed, specifically in what refers to parts process route, BOM and material handling. Operations were identified and broken down into elements and quantified in time.

With the contribution of these actions, it was possible to create a dynamic and effective tool to serve as a resource management system with the main objective being planning and managing the resources, either human or material, of the welding parts feeding system in order to address the difficulties presented in RQ1 in a context of demand variation.

6. CONCLUSION

The present dissertation project was motivated by Gestamp Palau's desire to explore the opportunity of extending lean and continuous improvement principles to its internal logistics operations. This chapter presents an overview of the work developed throughout the project whilst clarifying the response to the problem and objectives established in the beginning of the present report. A presentation of the main conclusions drawn after the completion of the project is given as well as a reflection about the limitations found along with future work to be developed.

6.1. Conclusions

The project was grounded in the analysis and study of the parts feeding system to the welding department of Gestamp Palau with the aim being to address issues that were compromising its efficient performance. In the first chapter of this dissertation, the context where the company operates was analyzed in order to be possible the identification of the main problem, to raise pertinent research questions and to establish clear objectives regarding the improvement of the welding department parts feeding system performance.

According to the first specific objective defined at the beginning of the project, a theoretical framework on lean and just-in-time paradigms and on kaizen tools was made to better understand the connection of these concepts with the internal logistics, more specifically to in-plant milk run parts feeding systems. A literature review was carried out that allowed to know the variety of decision problems to be solved when implementing or maintaining a milk run system. This part of the work presented in the second chapter put into perspective the difficulties associated with parts feeding systems inserted in different types of assembly lines which proved useful for answering the research questions in the sub-chapter 5.2.

The A-R methodology was used to guide the development of the work whilst following the five stages that form part of its cycle. In this report, the explanation of the methodology application was distributed along all the chapters. In chapter 3 were addressed the two first stages Diagnosing and Action Planning where the second specific objective was accomplished. In fact, an in-depth study of the processes and techniques that were being applied in Gestamp Palau parts feeding systems was carried out that allowed proper identification of the specific problems contributing to inefficiencies in the logistic service. An action plan was outlined to proceed to problem solving actions. Through the Action Taking stage described in detail in chapter 4, several problems were being addressed with the performance of analytical and implementation actions.

In the Evaluation stage of A-R methodology presented in chapter 5, the results obtained in each one of the actions taken were evaluated in order to understand its effectiveness. As result from the three first actions, the material flows, and activities performed by operators in the components supply system are now identified and documented and the time of each activity is now measured and quantified. The fourth and last action "Simulation and Decision Support Tool" addressed the third specific objective and was the core of this dissertation project taking up a large part of the time available for the project. This is because it involved careful planning in order to understand the tool's specifications and to satisfy the company's needs, interactions with the information systems in order to sort and gather the necessary data to the basis of the tool, a phased construction of logics and programming with formulas in Microsoft Excel and the verification of its reliable functioning.

In the initial situation of the project, the planning and management of the parts feeding system was based on experience and empirical knowledge. There was no quantification of the number of materials to be handled nor of the saturation that each activity represents during the working time of the operators, therefore there was no notion of the existent workload for each type of production sequence. With regard to the human resources needed to carry out the two logistical services covered by the parts feeding system (in-plant milk run and setup supermarket), a total number of 3 or 4 operators were required for their performance depending on whether the demand was low or high, respectively. Regarding the milk run cycle time, which influences the workload, it was fixed at 1h regardless of the production situation.

The sub-chapter 5.1 presents the results of some of the simulations and tests carried out on the tool that demonstrated that the parts feeding system can be operated by fewer workers than are allocated. As an example, in the simulations S1 and S3 presented in the referred sub-chapter, which both mirror a situation of high demand, the number of computed operators was 2 and 3, respectively, and not 4 as established. In the situation of low demand, for the simulations S2 and S4, the results were 2 and 1, respectively, and not 3 as stipulated. From the analysis of these results, it was possible to conclude that in fact the workforce and workload was not well managed, underusing resources and compromising the system's efficiency. Through the analysis of the simulations, it was also noticed that in two of these (S3 and S4), the milk run cycle time value was not equal to 1h, which means that, on certain occasions, the parts feeding system was not working aligned with the JIT principle. For this to be solved, either the cycle time is variable according to the production situations and the value obtained by the tool must be respected, or in case there is a fixed time, the quantities of handling units on the border of line must be adjusted to fit this fixed cycle.

As result of all Action Taking completion, the company has achieved an encompassing resource management system with simulation, test, and parametrization capabilities that is helpful on workload/workforce planning and balancing regarding the parts feeding system, on material and tow-train fleet sizing management and on milk run routes scheduling. All these outputs being adjusted to the required production instance whilst having considered the changes occurring in the information systems. In addition, it can be used from a short-term and long-term planning and management perspective.

In this sense, the tool was tested and verified at Gestamp Palau with real production instances and there was consensus that the results were reliable and concise. By using the Simulation and Decision Support Tool, it is expected to increase the efficiency of the supply system to the welding cells, and by being dynamic and generating outputs according to demand it will ensure that resources are always fully utilized and properly balanced.

Finally, with the reflection made through this chapter it is possible to conclude that both general and specific objectives established for this dissertation were approached and achieved throughout the course of this project. Besides this, an objective answer to the research questions raised in the beginning of the present dissertation was given. The output of this project contributed to the creation of a new dynamic and flexible methodology for resource management and subsequently to the improvement on the welding department parts feeding system efficiency by smoothing the impact of the variability associated with Gestamp Palau S.A. business context.

A scientific paper was produced based on the present dissertation thesis material to be submitted to the International Conference on Industrial Engineering and Operations Management (IEOM, Istanbul, 7-10 March).

6.2. Limitations and Future Research

Despite the context in which the project took place due to the COVID-19 pandemic, the presented results were achieved without substantial constraints. However, this situation interferes negatively in the regular functioning of the activities of the company, prolonging the adaption time and decelerating the problem solving.

Although the results present very satisfactory compliance to the requirements, in respect to the Simulation and Decision Support Tool, this would require further validation and improvements. To make more experiments in the shop-floor whilst involving the operator's perspective, it would be best to continuously improve the parts feeding system and to see the most concrete impact of the tool in the efficiency of the logistic service. Another future research to do in the perspective of the final user of the tool could revolve around its integration with another available information systems in Gestamp Palau such as Captor (to automatically import the OEE values) or WIS (to show the relevant outputs of the tool in the screens presented in the shop-floor within the supermarket area). Besides welding department components supply system, in Gestamp Palau there are other milk run systems (mostly serving the finished products withdraw) which could be pertinent to study. The potential application of the logic and methodology used to create the presented tool to these parts feeding/withdrawing systems could be of interest.

In addition to this, there is further scope of improvement with regard to the parts feeding system analyzed in this project e.g., the improvement of the physical structures transporting the handling units, implementation of visual management techniques, reduction of the activities time through the introduction of best practices, identification of wastes and improvement of components distribution layout in the supermarket, Carpa A and Door 9 areas. Also, would be best to standardize the process by creating work instructions to the activities performed in the parts feeding system.

As a recommendation for the company, instead of having subcontracted workers, constantly changing, operating in the parts feeding system, it could focus on specializing a group of workers to perform the tasks of this logistic service in a standard and efficient manner.

Conclusively, this project dissertation provides a general outline for future improvements and actions to be taken to increase the parts feeding efficiency.

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APPENDIX A

Workstations to Exclude
*C
SM07
SM05
CHA2
SM04
SM03
SM02
SM08
SM10
SM06
S007
S011
S026
S017
L08
S016
S018
S027
SM01

Product Ref. to Exclude	Product Ref. to Exclude
F0079S00990	R0054S01990
F0080S00990	R0054S03990
L0002S00990	R0059S00990
L0003S00990	R0069S01990
L0004S00990	R0071S00990
L0008S00990	R0097S00990
L0009S00990	R0098S00990
L0010S00990	R0099S00990
L0011S00990	R0100S00990
L0012S00990	R0102S00990
L0013S00990	R0104S00990
L0014S00990	R0106S00990
L0015S00990	R0107S00990
L0016S01990	R0110S00990
L0017S00990	R0111S00990
L0017S01990	R0113S00990
L0017S14990	R0114S00990
L0018S00990	R0115S00990
L0018S01990	R0116S00990
L0019S02990	R0121S00990
L0019S03990	R0122S00990
L0020S00990	R0129S00990
L0021S00990	R0130S00990
L0022S01990	R0236S00990
L0023S00990	R0237S00990
M0001S00990	R0238S00990
M0002S00990	R0239S00990
M0004S00900	V0012S04990
M0004S00990	V0012S05990
P0052S01990	V0023S00990
P0053S01990	V0023S01990
R0014S00990	V0023S02990
R0040S02990	V0024S00990
R0040S02990	V0025S00990
R0043S00990	V0068S00990
R0044S00990	V0069S00990
R0045S00990	V0075S00990
R0046S00990	V0075S00990
R0054S00990	V0075S01990

Figure 75 - Workstations and Output references to exclude from ZQHR variant

APPENDIX B

Workstations to include	Product Ref. To include
S015	L0008S02990
S015	L0017S02990
S015	L0017S10990
S015	L0018S05990
S015	R0011S00990
S015	R0014S00991
S015	R0015S00990
S014	R0037S00990
S014	R0038S00990
S014	R0039S00990
S014	R0039S02990
S014	R0040S00990
S014	R0040S01990
S013	R0041S00990
S013	R0042S00990
S012	R0045S00991
S012	R0046S00991
S014	R0051S00990
S015	R0054S02990
S015	R0058S00990
S019	R0064S01990
S019	R0065S01990
S015	R0075S00990
S015	R0079S00990
S015	R0080S00990
S015	R0103S00990
S015	R0105S00990
S015	R0109S00990
S015	R0112S00990
S015	R0128S00990
S006	V0010S00991
S021	V0013S00990
S021	V0014S00990
S009	V0015S00990
S019	V0015S01990
S019	V0015S02990
S025	V0023S00991
S024	V0023S00991
S024	V0023S01991
S030	V0024S01990
S030	V0024S02990
S029	V0026S00990
S022	V0026S00990
S023	V0026S01990

Workstations to include	Product Ref. To include
S029	V0027S00990
S022	V0027S00990
S015	V0067S00990
S015	V0070S00990
S024	V0080S00990
S004	V0080S01990
S024	V0081S00990
S025	V0082S00990
S022	V0083S00990
S029	V0090S00990
S022	V0090S00990

Figure 76 - Workstations and output references to include in ZQHR variant

APPENDIX C

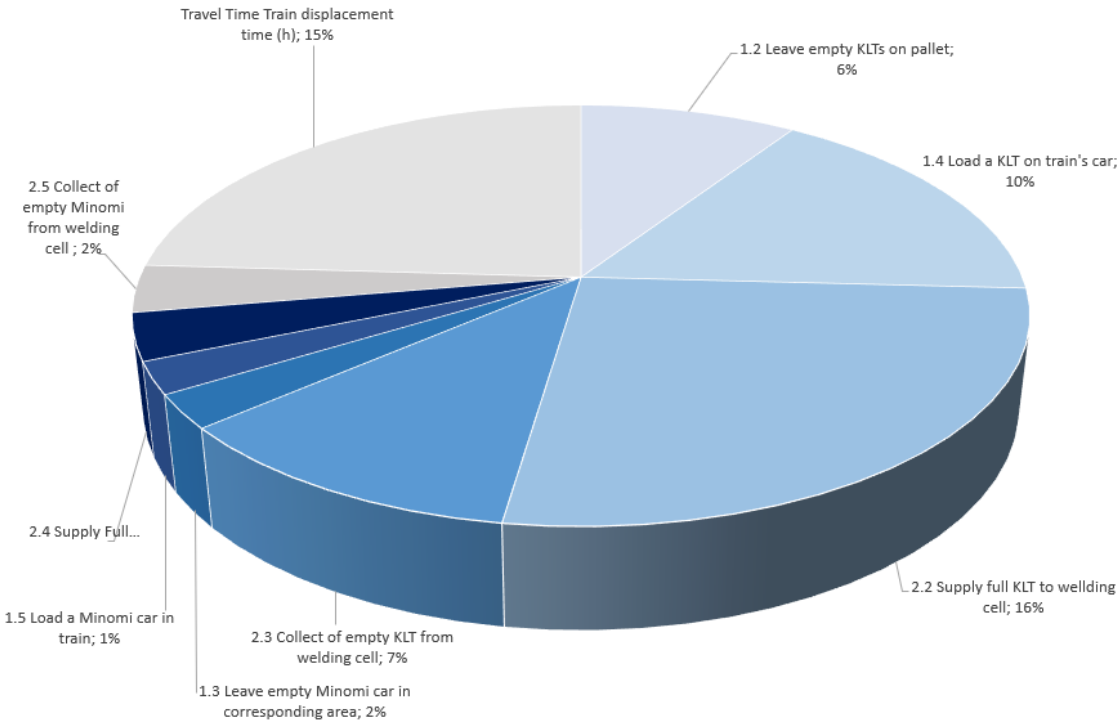


Figure 77 - Activities saturation weight (milkrun service-S1)

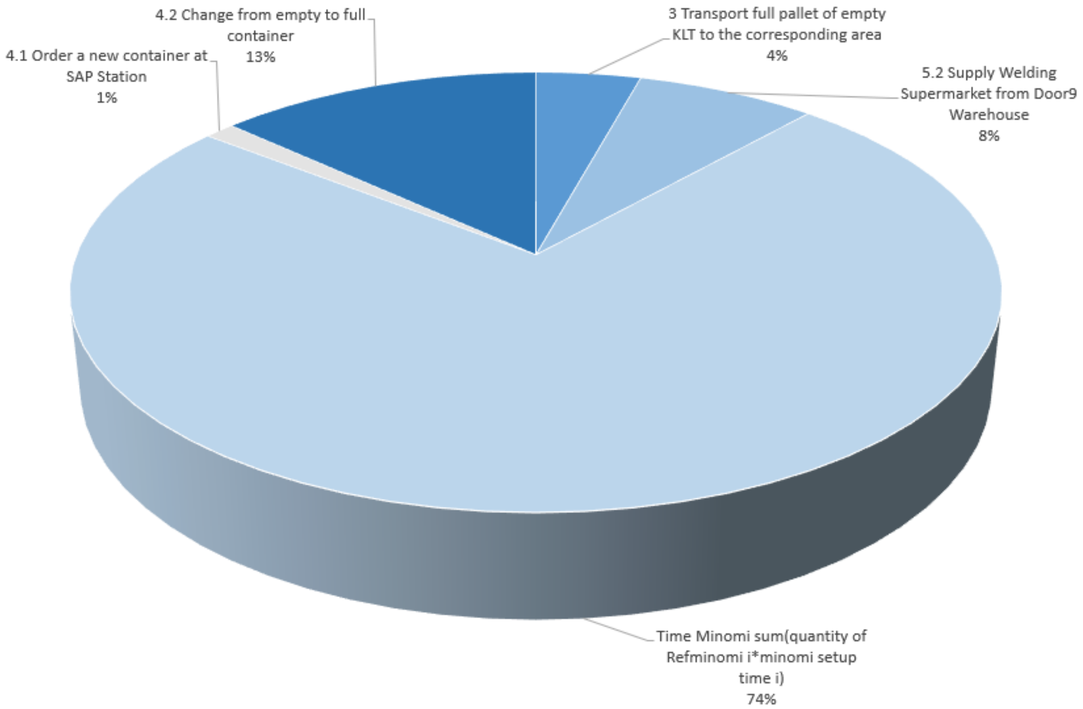


Figure 78 - Activities saturation weight (setup supermarket service - S1)

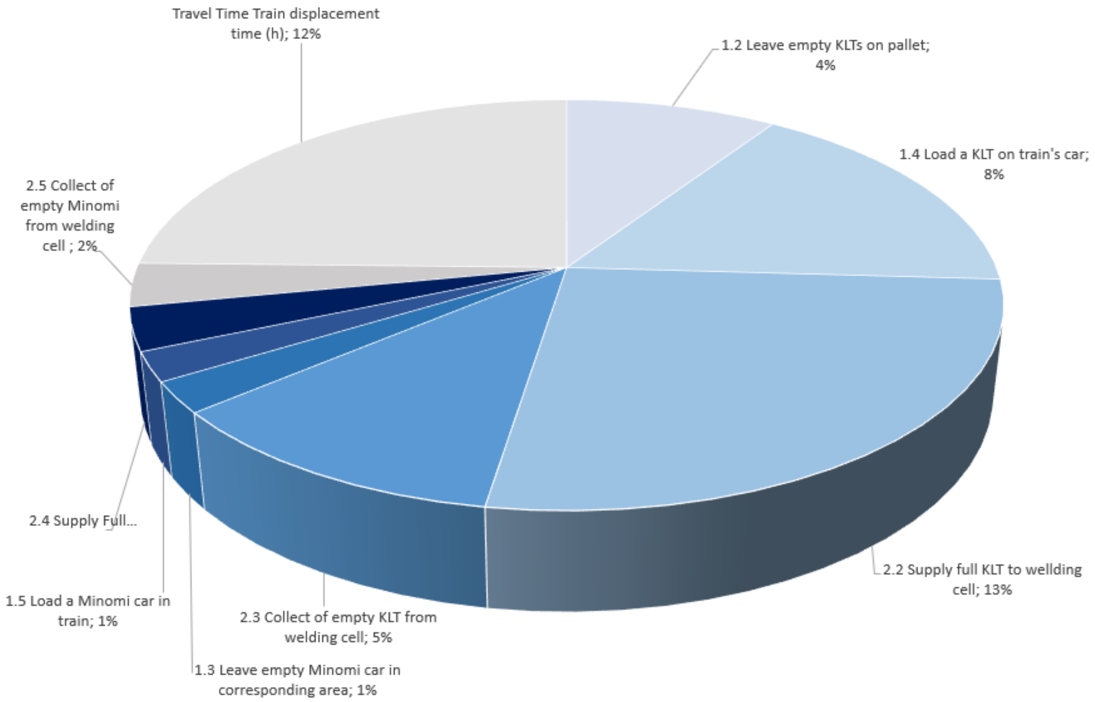


Figure 79 - Activities saturation weight (milkrun service - S2)

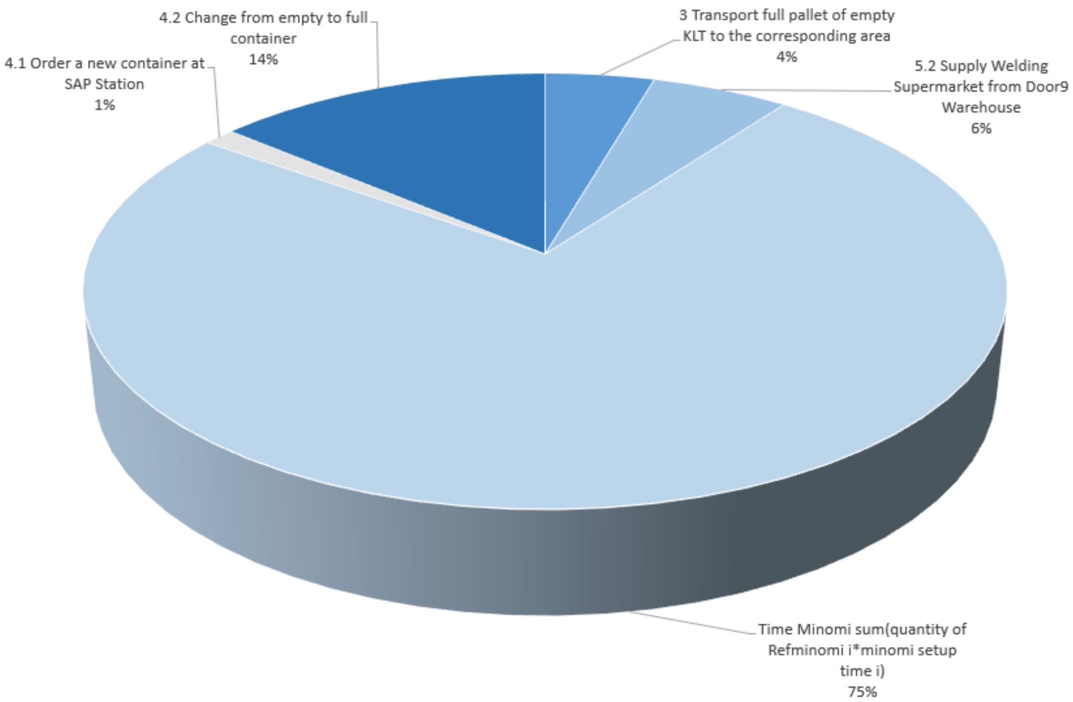


Figure 80 - Activities saturation weight (setup supermarket service - S2)

APPENDIX D

Tool for Resource Management of the welding parts feeding system: In-Plant milk run KLT/*Minomi*s

Development and User Manual

Index

Data Selection and Processing

The first step taken to start developing the present tool was the selection of the range of workstations and output products/materials that it should cover.
To make this selection, a variant of transaction ZQHR (Routings) has been created in SAP with the name **ZQHR.TOOL** that aims to:

- Exclude from the range of workstations (welding cells) those that are not affected by the In-plant milk run tow-train of KLT and *Minomi* s.
- Exclude references of materials/products that are obsolete.
- Select transaction fields that provide relevant information to the tool and exclude the others, through the creation of a layout included in the variant with the name **ESB/HR. TOOL**.

The user should activate the variant with this name by clicking the button underlined in red (Figure 81).

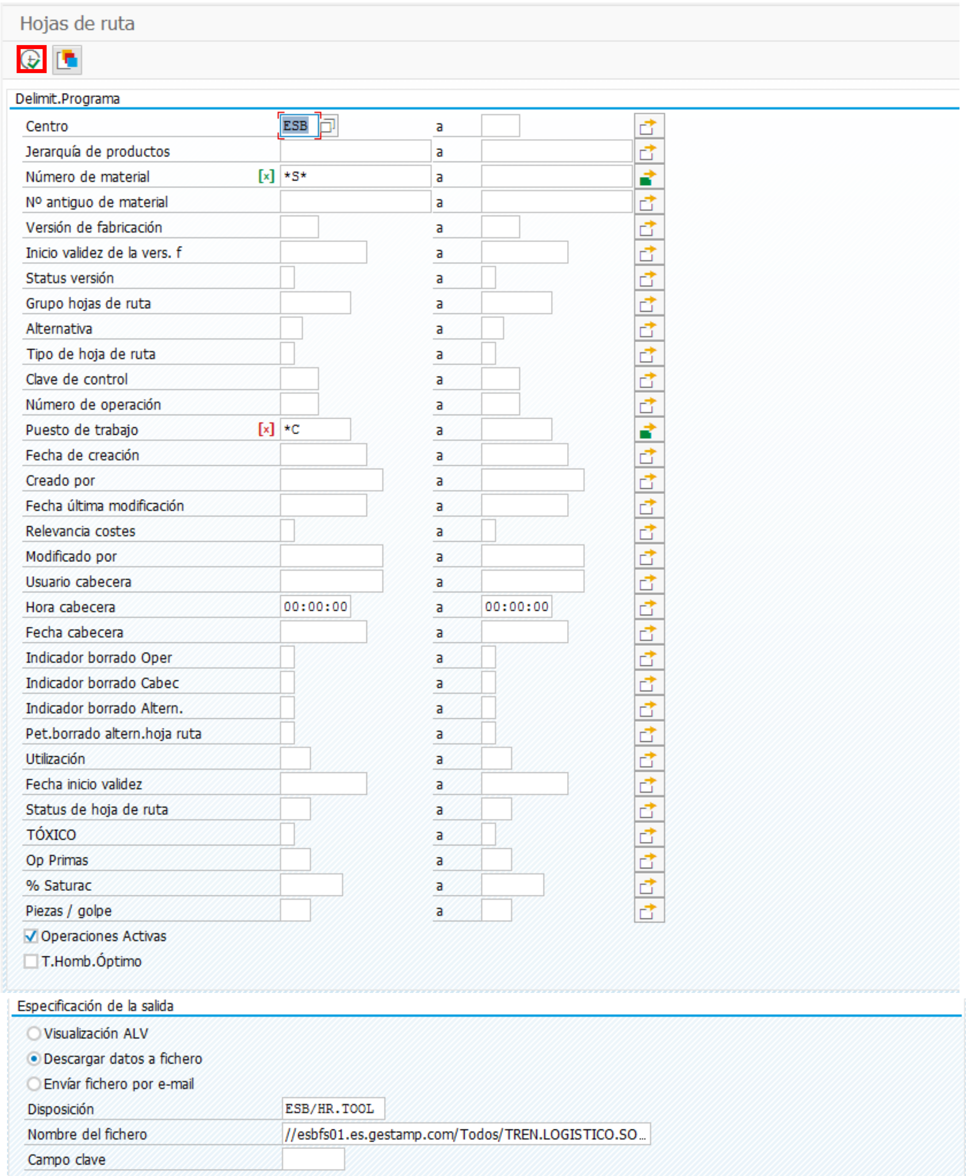


Figure 81 - ZQHR variant with defined layout and destination

In Appendix A it is possible to consult the workstations and products excluded from the range of the tool. Regarding the transaction fields that are included in the layout these were as follows (Material, Workstation, Throughput).

The second transaction that feds data to the tool is the ZQLM that will bring the components assigned to each output material (BOM). A variant named ZQLM has been applied in this transaction called **ZQLM.TOOL** (Figure 82).

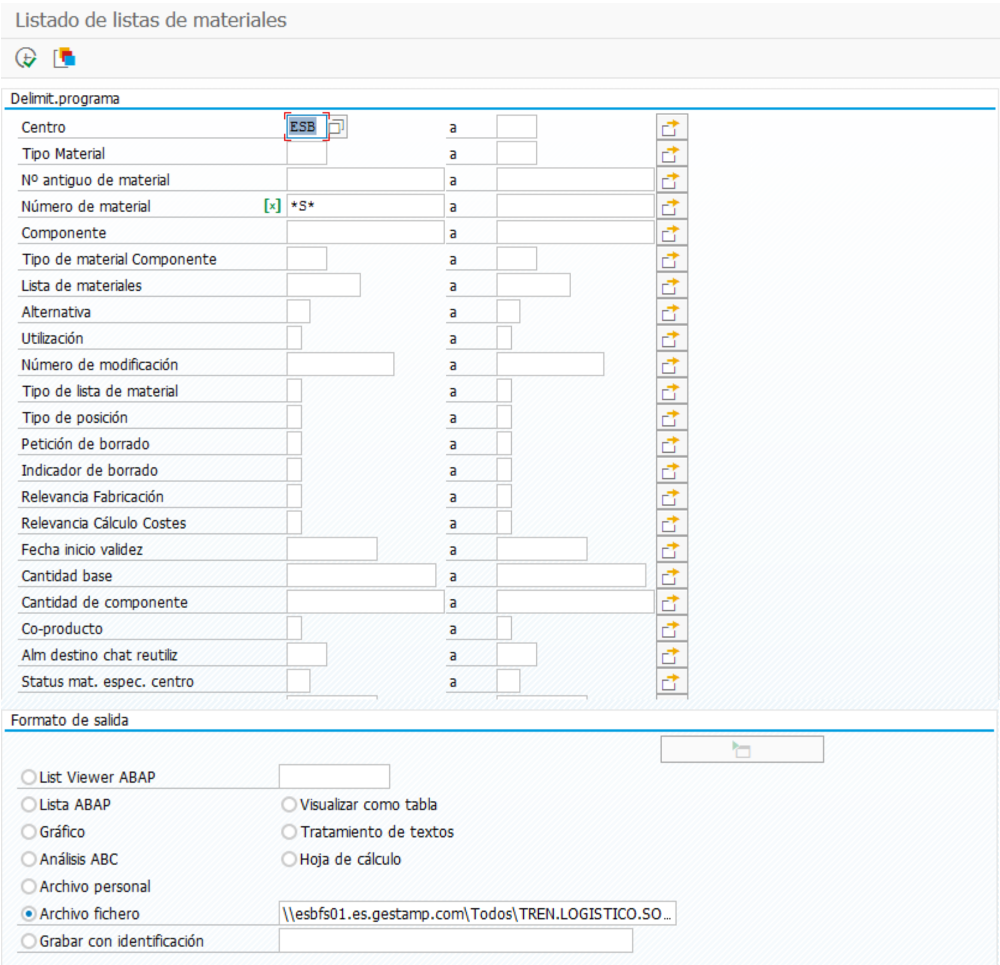


Figure 82 - ZQLM variant with defined destination

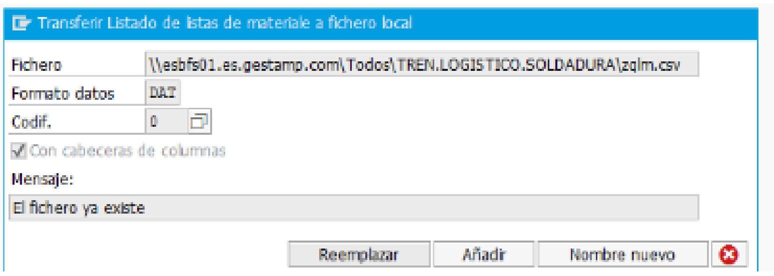


Figure 83- Column header inclusion

NOTE: When SAP prompts for confirmation to replace the file, the user must select "With column headers" (Figure 83).

Finally, the third transaction that supplies data to the tool is the ZQNE which will indicate the container where the components are stored, its SNP (Standard Number of Parts) and the packaging standard. In this case, an SAP variant of ZQNE has been created with the name **ZQNE.TOOL4** which aims (Figure 84Figure 84):

- Select the Standard Determination Type (ZSTO);
- Select transaction fields that provide relevant information to the tool excluding the others through the creation of a layout with the name **ESB.NE.TOOL1**. These were as follows (Material, Class Determination, Packing Standard, Container, SNP); With thi layout, the "Packaging Standard" field has also been filtered so that it shows only the *001 standards.

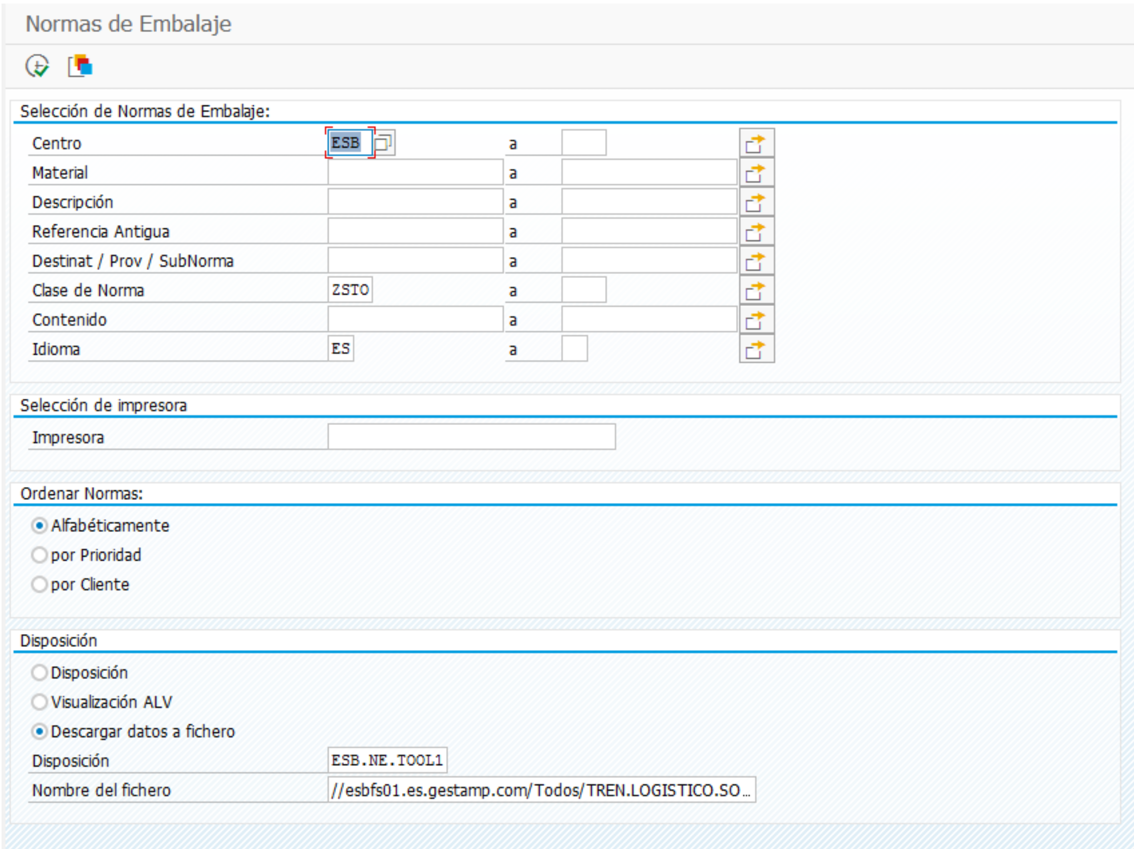


Figure 84 - ZQNE variant with defined layout and destination

NOTE: When it is necessary to add new products with components that do not previously exist in the system, variants and layouts are subject to modification and maintenance. In case where the product becomes obsolete it is also suggested to be removed from the variants or layouts that supply data to this tool.

Export SAP data to the tool

In order to feed the selected data to the tool, it was decided to use the Excel function **Combine Queries (*Merge*).** It is possible to find this function in the Excel toolbar more specifically in the separator "Data" and then clicking on "New Query" as represented in Figure 85:

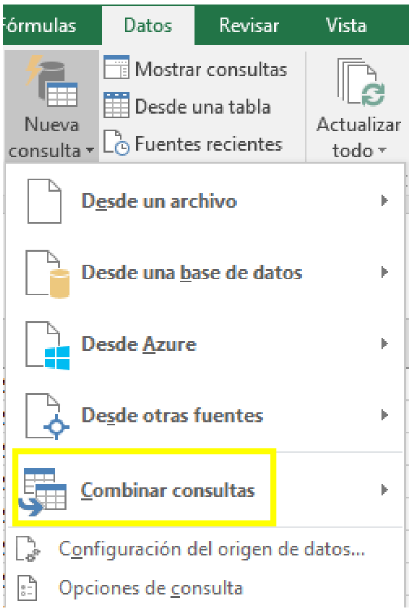


Figure 85 - How to get to the excel function "Combine Queries"

As it is possible to observe, the function allows queries to be combined. Thus, it is necessary to create in Excel the queries referring to the transactions (<u>.csv flies</u>) referred in the previous chapter, so that the user can immediately combine them, creating a database.

The variants mentioned above already contemplate the target locations of the files, creating them when activating a variant, as exemplified in Figure 86.

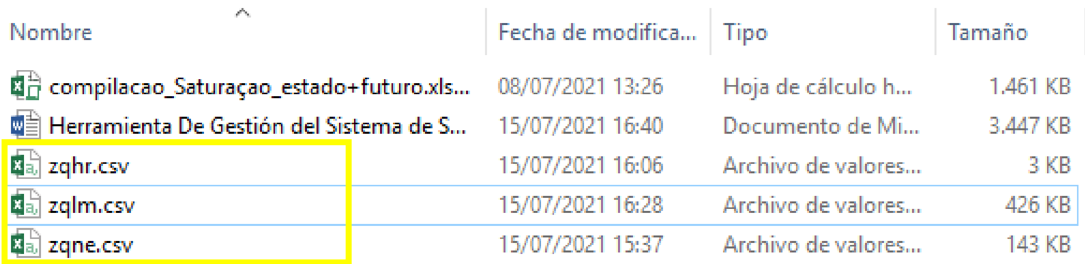


Figure 86 - CSV files created when activating the variants of the three transactions

NOTE: With the possible creation of a "*job*" in SAP, the update of the files would be preceded automatically and periodically (period to be chosen). However, while this does not exist, the user has to manually do the operation of activating the variants (in case of an introduction/removal of a product or components to the system, among others) to crush the files with new data.

NOTE: The next steps only need to be done once (already done) or in case that something happens with the CVS files, so it will be provided an explanation of how to proceed to the following actions.

Once the three CSV files are created, the Excel might find them, and the user must create the three queries. The user needs to select the "Data" separator, then the "From a File" option and "From a CSV file" sub-option as represented in Figure 87. By clicking here, it will be given the user the possibility to choose the CSV file to import from their computer location (Figure 88Figure 88).

NOTE: Both the operation of creating queries and combining them must be done in the file that the user intends to use as a final tool.

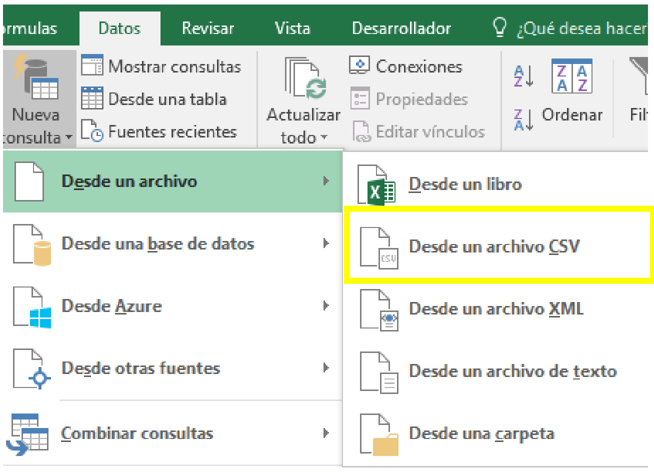


Figure 87 -Import data to excel from a CSV file (Create Query)

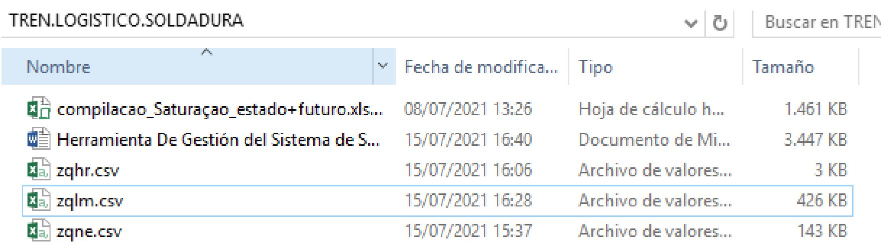


Figure 88 - Choose file to import as a query

Once the file is selected, the following will be displayed to the user (Figure 89):

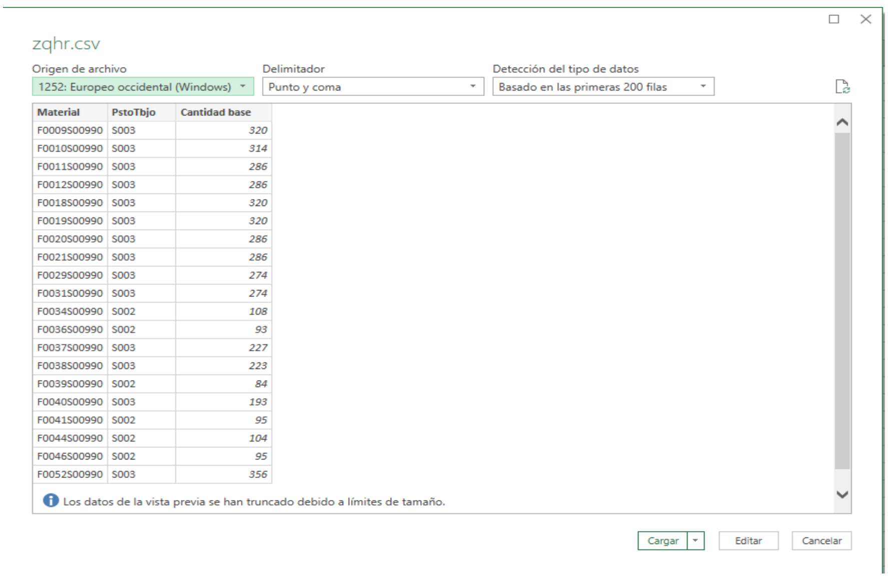
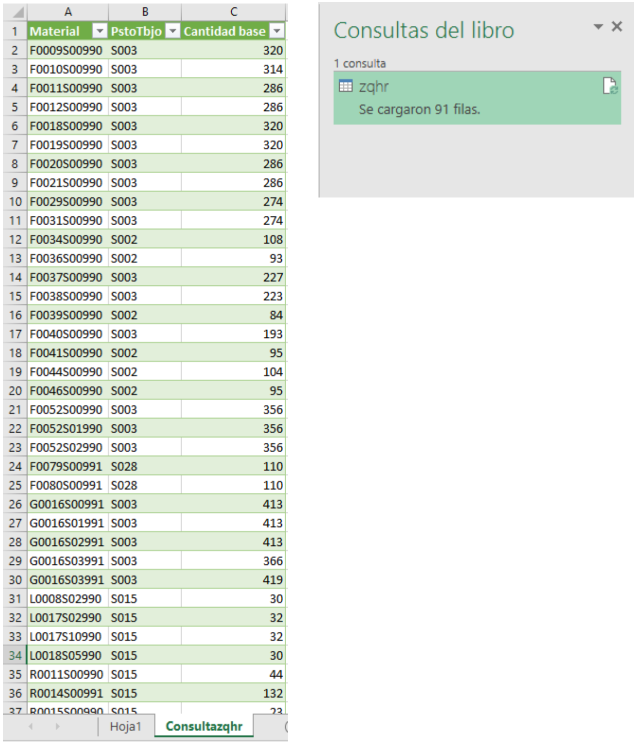


Figure 89 - Excel asks the user if he wants to upload the file or edit it

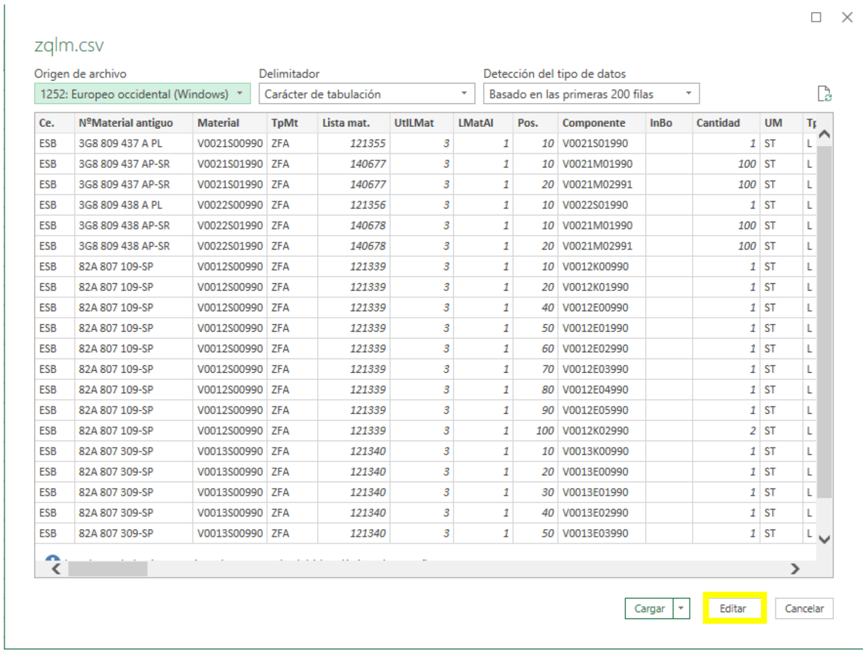
The user must click Load (*Cargar*) for this query to be imported into Excel but can also edit it if desired. When loading, a new sheet will be created with the query (Figure 90) and Excel will indicate that a new query/connection exists with a certain number of rows. This should be done for all three queries.



	Material	PstoTbjo	Cantidad base
2	F0009S00990	S003	320
3	F0010S00990	S003	314
4	F0011S00990	S003	286
5	F0012S00990	S003	286
6	F0018S00990	S003	320
7	F0019S00990	S003	320
8	F0020S00990	S003	286
9	F0021S00990	S003	286
10	F0029S00990	S003	274
11	F0031S00990	S003	274
12	F0034S00990	S002	108
13	F0036S00990	S002	93
14	F0037S00990	S003	227
15	F0038S00990	S003	223
16	F0039S00990	S002	84
17	F0040S00990	S003	193
18	F0041S00990	S002	95
19	F0044S00990	S002	104
20	F0046S00990	S002	95
21	F0052S00990	S003	356
22	F0052S01990	S003	356
23	F0052S02990	S003	356
24	F0079S00991	S028	110
25	F0080S00991	S028	110
26	G0016S00991	S003	413
27	G0016S01991	S003	413
28	G0016S02991	S003	413
29	G0016S03991	S003	366
30	G0016S03991	S003	419
31	L0008S02990	S015	30
32	L0017S02990	S015	32
33	L0017S10990	S015	32
34	L0018S05990	S015	30
35	R0011S00990	S015	44
36	R0014S00991	S015	132

Figure 90 - Sheet created with the query

As an example of editing a query, it is used the ZQLM query (Figure 91). It is possible to observe that this transaction has many fields that are not necessary (in SAP there is no option to export this transaction with a specific layout that limits the fields), so this is possible to be done by clicking on the "Edit" button deleting the non-desired fields.



Ce.	NºMaterial antiguo	Material	TpMt	Lista mat.	UtILMat	LMatAl	Pos.	Componente	InBo	Cantidad	UM	Tp
ESB	3G8 809 437 A PL	V0021S00990	ZFA	121355	3	1	10	V0021S01990		1	ST	L
ESB	3G8 809 437 AP-SR	V0021S01990	ZFA	140677	3	1	10	V0021M01990		100	ST	L
ESB	3G8 809 437 AP-SR	V0021S01990	ZFA	140677	3	1	20	V0021M02991		100	ST	L
ESB	3G8 809 438 A PL	V0022S00990	ZFA	121356	3	1	10	V0022S01990		1	ST	L
ESB	3G8 809 438 AP-SR	V0022S01990	ZFA	140678	3	1	10	V0021M01990		100	ST	L
ESB	3G8 809 438 AP-SR	V0022S01990	ZFA	140678	3	1	20	V0021M02991		100	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	10	V0012K00990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	20	V0012K01990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	40	V0012E00990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	50	V0012E01990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	60	V0012E02990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	70	V0012E03990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	80	V0012E04990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	90	V0012E05990		1	ST	L
ESB	82A 807 109-SP	V0012S00990	ZFA	121339	3	1	100	V0012K02990		2	ST	L
ESB	82A 807 309-SP	V0013S00990	ZFA	121340	3	1	10	V0013K00990		1	ST	L
ESB	82A 807 309-SP	V0013S00990	ZFA	121340	3	1	20	V0013E00990		1	ST	L
ESB	82A 807 309-SP	V0013S00990	ZFA	121340	3	1	30	V0013E01990		1	ST	L
ESB	82A 807 309-SP	V0013S00990	ZFA	121340	3	1	40	V0013E02990		1	ST	L
ESB	82A 807 309-SP	V0013S00990	ZFA	121340	3	1	50	V0013E03990		1	ST	L

Figure 91 - Example of editing a query

Then it will be displayed to the user the window shown in Figure 92. By just clicking on the "Choose Columns" option and a checkbox will appear where the user can mark or not the columns to be deleted. It is also allowed to change the name of the fields. Once this is done, the user must click on "Close and Load" to finish the query creation.

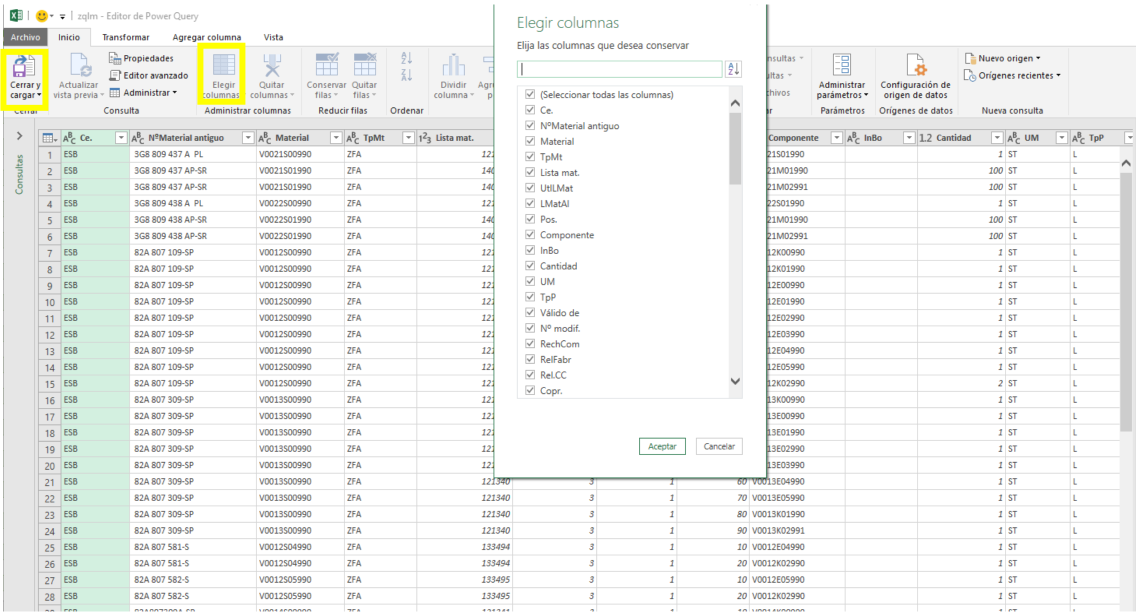


Figure 92 - Choose columns in the query

With all the queries created it is possible to proceed to the "**Combine Queries"** function referred to at the beginning of this chapter. Within this option select the sub-option "Merge"(Figure 93) and the window represented in Figure 94 will appear.

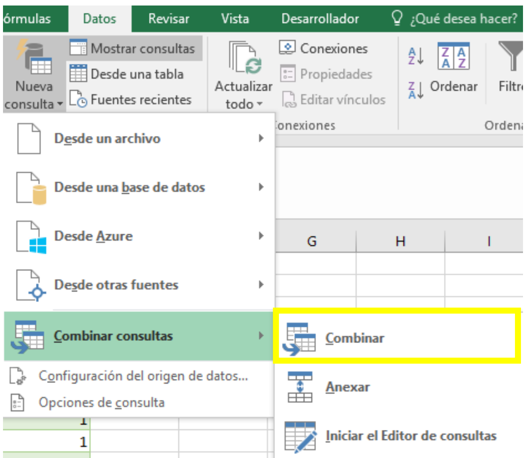


Figure 93- Combine queries (Merge)

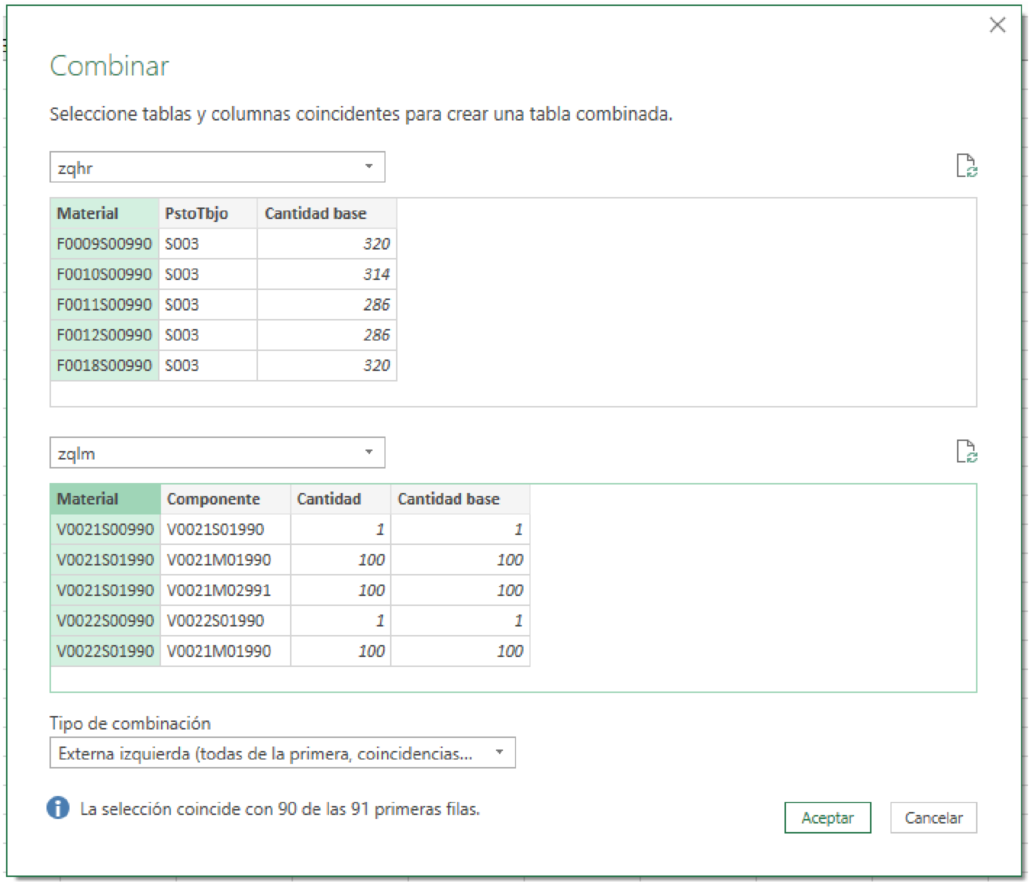


Figure 94 - Way to combine queries

In the Merge function it is only possible to combine two queries at a time, so the user must select from the available queries the ones that he intends to join first. The example combines ZQHR and ZQLM queries transactions. The type of join must be as indicated in the figure and the first query to select must be the one that the user choses to delimitate the future database, in order for the match to be well processed. It is also necessary to indicate which column will be connecting the two queries (marked green in Figure 94). These must have the same data to connect. Clicking "accept" will display the window represented in Figure 95.

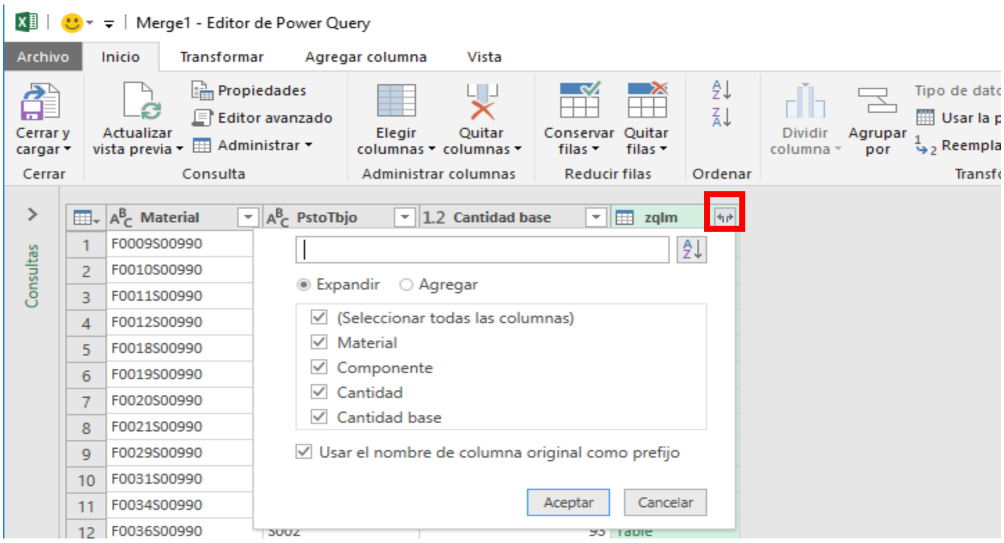


Figure 95 - Choose columns to keep in the merge

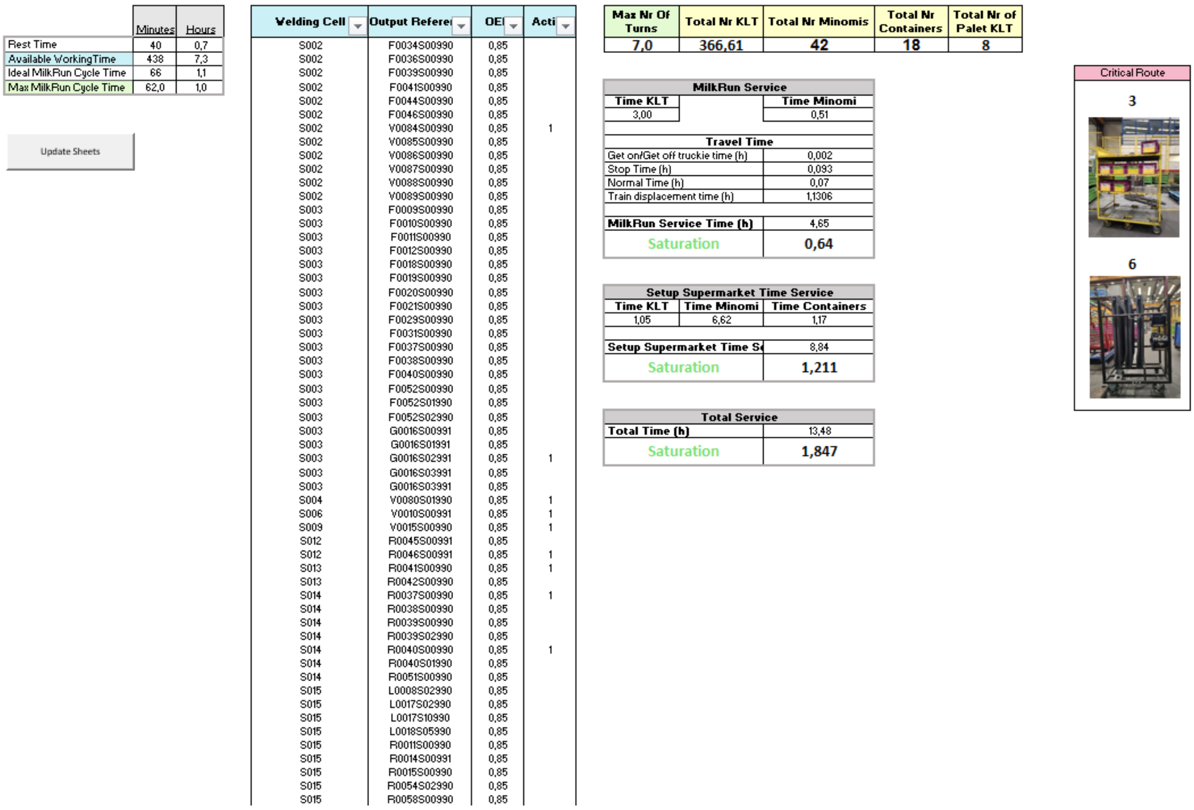
It is noted that the first query that has been selected has the columns expanded, so it is necessary to expand the columns of the second query by clicking the button underlined in red. A checkbox will appear to allow the user to select which columns to be shown from the second query. Once this is done, the user has to click on "Close and Load" and the merge will be available in another Excel sheet. The same steps must be done to combine the previous merge with the third query (ZQNE).

NOTE: The table that results from the second combination was used as the basis of the tool that will be presented in the next chapter and must be updated with recourse to the "Refresh *All*" button presented in the Excel "Data" separator, in case of changes in the data source (SAP). Query sheets can be hidden as they will also be updated.

Presentation of the tool and its options for use

This tool aims to manage the resources needed to perform the components feeding system to the welding cells. Taking into account the variations in demand existing in the automobile industry and the mix of products existing in the company, it provides the user with the possibility of simulating and creating instances relatively to the cells in operation as well as to the products to be produced in a given shift. This will allow a better management and documentation of the necessary resources (human and material) through the different possible scenarios both in a real situation and in an experimental and test context.

After the entire tool is created and programed based on the combination of queries explained in the previous chapter, the user will display the following Excel sheet *(interface)* (Figure 96).



	Minutes	Hours
Rest Time	40	0,7
Available WorkingTime	438	7,3
Ideal MilkRun Cycle Time	66	1,1
Max MilkRun Cycle Time	62,0	1,0

Update Sheets

Velding Cell	Output Referei	OEI	Acti
S002	F0034S00990	0,85	
S002	F0036S00990	0,85	
S002	F0039S00990	0,85	
S002	F0041S00990	0,85	
S002	F0044S00990	0,85	
S002	F0046S00990	0,85	
S002	V0084S00990	0,85	1
S002	V0085S00990	0,85	
S002	V0086S00990	0,85	
S002	V0087S00990	0,85	
S002	V0088S00990	0,85	
S002	V0089S00990	0,85	
S003	F0009S00990	0,85	
S003	F0010S00990	0,85	
S003	F0011S00990	0,85	
S003	F0012S00990	0,85	
S003	F0018S00990	0,85	
S003	F0019S00990	0,85	
S003	F0020S00990	0,85	
S003	F0021S00990	0,85	
S003	F0029S00990	0,85	
S003	F0031S00990	0,85	
S003	F0037S00990	0,85	
S003	F0038S00990	0,85	
S003	F0040S00990	0,85	
S003	F0052S00990	0,85	
S003	F0052S01990	0,85	
S003	F0052S02990	0,85	
S003	G0016S00991	0,85	
S003	G0016S01991	0,85	
S003	G0016S02991	0,85	1
S003	G0016S03991	0,85	
S003	G0016S03991	0,85	
S004	V0080S01990	0,85	1
S006	V0010S00991	0,85	1
S009	V0015S00990	0,85	1
S012	R0045S00991	0,85	
S012	R0046S00991	0,85	1
S013	R0041S00990	0,85	1
S013	R0042S00990	0,85	
S014	R0037S00990	0,85	1
S014	R0038S00990	0,85	
S014	R0039S00990	0,85	
S014	R0039S02990	0,85	
S014	R0040S00990	0,85	1
S014	R0040S01990	0,85	
S014	R0051S00990	0,85	
S015	L0008S02990	0,85	
S015	L0017S02990	0,85	
S015	L0017S10990	0,85	
S015	L0018S05990	0,85	
S015	R0011S00990	0,85	
S015	R0014S00991	0,85	
S015	R0015S00990	0,85	
S015	R0054S02990	0,85	
S015	R0058S00990	0,85	

Max Nr Of Turns	Total Nr KLT	Total Nr Minomis	Total Nr Containers	Total Nr of Palet KLT
7,0	366,61	42	18	8

MilkRun Service		
Time KLT		Time Minomi
3,00		0,51
Travel Time		
Get on/Get off truckie time (h)		0,002
Stop Time (h)		0,093
Normal Time (h)		0,07
Train displacement time (h)		1,1306
MilkRun Service Time (h)		4,65
Saturation		0,64

Setup Supermarket Time Service		
Time KLT	Time Minomi	Time Containers
1,05	6,62	1,17
Setup Supermarket Time Se		8,84
Saturation		1,211

Total Service	
Total Time (h)	13,48
Saturation	1,847

Figure 96 - User interface sheet

- The maximum number of turns that the train will make in the available time, the total number of KLT and *Minomi* s to be supplied in a shift and the total number of containers and pallets to be changed/handled (empty/full).
- The saturation (in number of operators) of the in-plant milk run service, of the setup supermarket service, as well as the saturation of both two services, once they are intrinsically related.
- The maximum saturation in handling units that the tow-train will transport (either KLTs or *Minomi* s) in the critical turn.

In addition to this global information, the interface can also analyze in more detail the times spent per shift related to the handling of each packaging to be supplied (KLT / *Minomi*) or packaging to be changed (Pallets/Containers) as well as the time spent on trips during the entire shift.

If the user moves to the sheet "MilkRun and Supermarket Tasks" he will find information of all the Tasks, Activities and Technical Actions performed in the two services (In-Plant milk run and Setup Supermarket) (table on the right of the Figure 97). In the table on the left the user will find the study of times made resourcing to chronometer or MTM referring to the activities of the two services, and in the tables in the middle the user can consult data referring to the route performed by the tow-train as well as the unit handling times (KLT and *Minomi*) and the times needed in the preparation of each one of the *Minomi* s currently existing in the plant.

This sheet can be edited and maintained at any time management desires.

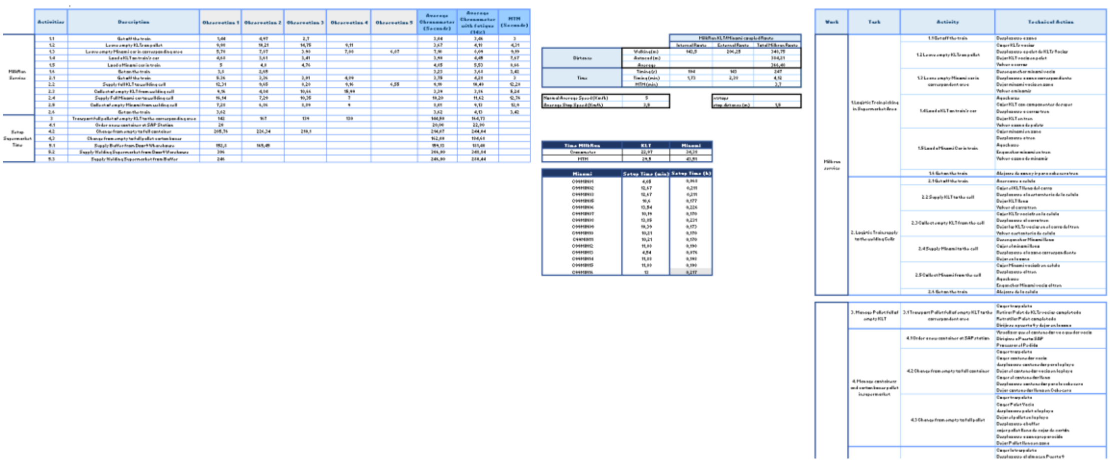


Figure 97 - Study of times sheet

The user will also be able to move around the "*Saturation*" sheet (Figure 98). In this sheet is presented the table filled in green which is the result from the merge done between the three SAP transactions (ZQHR, ZQLM, ZQNE) and it is used to make all the calculations related to the saturation of human resources for the two services. It is also possible to consult the master data regarding the products and parts, the intermediate calculations, the saturation of the various activities as well as the percentage of each one of them in each one of the services (left table and graphs).

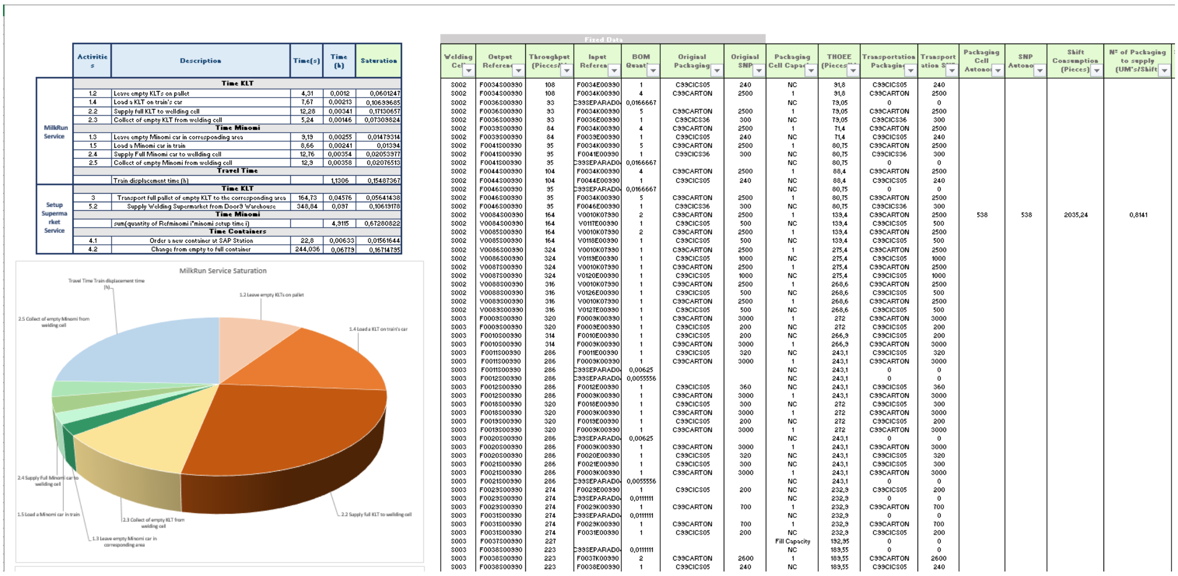


Figure 98 - Saturation calculation sheet

NOTE: The table filled in green should not be altered once it contains formulas and a change could affect the outputs of the "*Interface*" sheet.

All the formulas used in these calculations as well as in the "Interface" to obtain the outputs can be consulted in the "Glossary" sheet (Figure 99).

GLOSSARY

$$Ideal\ MilkRun\ CycleTime = \frac{Min(Packaging\ Cell\ Autonomy)}{2}$$

$$Max\ nº\ of\ turns = Roundup(\frac{Available\ Work\ Time}{Ideal\ MilkRun\ CycleTime})$$

$$Max\ MilkRun\ CycleTime = \frac{Available\ Work\ Time}{Max\ nº\ of\ Turns}$$

$$Available\ Work\ Time(Min) = 8 - Rest\ Time$$

$$Packaging\ Cell\ Autonomy\ (Min) = \frac{Units\ SNP * Packaging\ Cell\ Capacity}{THOEE * BOM\ Qnt.} * 60$$

$$SNP\ Autonomy(Min) = \frac{Units\ SNP}{THOEE * BOM\ Qnt.} * 60$$

$$Shift\ Consumption\ (Pieces) = Available\ Work\ Time\ per\ Ref * (THOEE * BOM\ Qnt.)$$

$$Nº\ of\ Packaging\ to\ Supply = \frac{Shift\ Consumption}{Units\ SNP}$$

Milk Run Time

Time per KLT + *Time per Minomi*

Leave empty KLT on Pallet + *Load a KLT on train's car* + *Supply full KLT to welding cell* + *Collect empty KLT from welding cell*

Leave empty Minomi car in corresponding area + *Load a Minomi car in train* + *Supply Full Minomi car to wellding cell* + *Collect of empty Minomi from welding cell*

+

$$tdt\ (train\ displacement\ time)(h) = (t.normal + t.stops) * \text{max nr of turns}$$

$$t.normal\ (h) = \frac{total\ time\ route\ (s)}{3600}$$

$$t.stops(h) = \text{nº Stops} * (\frac{stop\ distance\ (m) * 0{,}001}{v.stop\ (km.h)} + (tgetin(h) + tgetoff(h))$$

Figure 99 - Glossary sheet

The tool also contains a sheet called "Maintenance Tables" containing maintenance tables that can be edited as desired by the user according to the rules that will be mentioned in the next chapter.

Tool handling

When the user opens the tool file the first thing to do is to click on the "Refresh All" button in the "Data" menu to update all the queries and merge done, since the data in SAP may have been updated, such as: changings on product/component name, addiction to the system of a new product/component or removal from the system of a product/component.

Once this is done, the user must click on the "Update Sheets" button presented in the "Interface" sheet (Figure 100) in a way to update the formulas in the sheets, since depending on alterations in the system the tables may be larger or smaller since the last opening of the tool.

	Minutes	Hours
Rest Time	40	0,7
Available WorkingTime	438	7,3
Ideal MilkRun Cycle Time	66	1,1
Max MilkRun Cycle Time	62,0	1,0

Update Sheets

Figure 100 - Update formulas in the Excel sheets

In addition to having been informed of any change in SAP (incorporation or elimination of workstations, products or components BOM, the user itself must be aware of whether there was any alteration to these levels and update the different maintenance tables of the sheet "Maintenance Tables" according to the following rules:

AuxTable-OEE (Figure 101)

- If there is an elimination of a workstation or/and a output material (product) in the system, when doing the "Refresh All", the input table (1 or 0) with blue header of the "Interface" sheet will decrease in size as well as the table with green header of the "Saturation" sheet. Consequently, in the "Maintenance Tables" sheet, the table called "AuxTable-OEE" will show that this workstation or product does no longer exists in the system because "Not Found" will appear in the column "OEE Exist?". The user is suggested to delete this line so that this table keeps maintained.

	AuxTable-OEE			
Concatenated_Cell_Ref	Welding Cell	Output Reference	OEE	OEE Exsist?
S004V0080S01990	S004	V0080S01990	0,85	ok
S006V0010S00991	S006	V0010S00991	0,85	ok
S009V0015S00990	S009	V0015S00990	0,85	ok
S012R0045S00991	S012	R0045S00991	0,85	ok
S012R0046S00991	S012	R0046S00991	0,85	ok
S013R0041S00990	S013	R0041S00990	0,85	ok
S013R0042S00990	S013	R0042S00990	0,85	Not Found
S014R0037S00990	S014	R0037S00990	0,85	ok
S014R0038S00990	S014	R0038S00990	0,85	ok

Figure 101 - Auxiliary table (OEE input by workstation and output reference)

NOTE: The table in the previous figure is used for the user to inform the tool of the OEE indicator in which a certain workstation is working while producing a certain product.

- If a workstation or/and a output material is added to the system, after clicking on the two refresh buttons ("Refresh All" and "Update Sheets"), the user must manually add in the AuxTable-OEE the new data in the three fields marked red (Figure 102). Automatically, the fields at the ends of the table will be updated once there are assigned Excel formulas.

	AuxTable-OEE			
Concatenated_Cell_Re	Welding Cell	Output Reference	OEE	OEE Exsist?
S004V0080S01990	S004	V0080S01990	0,85	ok
S006V0010S00991	S006	V0010S00991	0,85	ok
S009V0015S00990	S009	V0015S00990	0,85	ok
S012R0045S00991	S012	R0045S00991	0,85	ok
S012R0046S00991	S012	R0046S00991	0,85	ok
S013R0041S00990	S013	R0041S00990	0,85	ok
S013R0042S00990	S013	R0042S00990	0,85	Not Found
S014R0037S00990	S014	R0037S00990	0,85	ok
S014R0038S00990	S014	R0038S00990	0.85	ok

Figure 102 - Fields with need of maintenance

AuxTable - Packaging Cell Capacity (Figure 103)

- If there is an elimination of output material (product) in the system, consequently, there was elimination of assigned components. Thus, in the sheet "Maintenance Tables" the table called "AuxTable-Packaging Cell Capacity" will prove that this component no longer exists in the system because "Not Found" will appear in the column "Packaging Exist?". The user is suggested to delete these lines so that this table keeps maintained.

AuxTable - Packaging Cell Capacity							
Concatenated_Ref_Cell_Ref	Welding Cell	Output Reference	Input Reference	Original Packaging	Transportation Packaging	Packaging Cell Capacity	Packaging Exist?
V0080S01990S004V0077K00990	S004	V0080S01990	V0077K00990	C99CARTON	C99MIN16	NC	ok
V0080S01990S004V0094E00990	S004	V0080S01990	V0094E00990	C99C00H6MEVCN	C99MIN16	NC	ok
V0080S01990S004V0021K00990	S004	V0080S01990	V0021K00990	C99CICS10	C99MIN16	2	ok
V0010S00991S006V0010K06990	S006	V0010S00991	V0010K06990	C99CARTON	C99CARTON	4	ok
V0010S00991S006V0010E00991	S006	V0010S00991	V0010E00991	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K01990	S006	V0010S00991	V0010K01990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K05990	S006	V0010S00991	V0010K05990	C994314ESB	C994314ESB	3	Not Found
V0010S00991S006V0010S05990	S006	V0010S00991	V0010S05990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K03990	S006	V0010S00991	V0010K03990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K02990	S006	V0010S00991	V0010K02990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010E04990	S006	V0010S00991	V0010E04990	C99CICS05	C99MIN07	NC	ok
V0010S00991S006V0010E02991	S006	V0010S00991	V0010E02991	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K04990	S006	V0010S00991	V0010K04990	C994314ESB	C994314ESB	3	ok
V0010S00991S006V0010S04990	S006	V0010S00991	V0010S04990	C994322ESB	C994322ESB	3	ok

Figure 103 - Auxiliary table (input of border of line capacity in holes, by component)

NOTE: The table presented in the previous figure serves for the user to inform the tool of what is the capacity (holes) of the FIFO shelves in the workstations (in case of KLT) and the available spaces in the floor (in case of *Minomi*). When the user fills in the "Packaging Cell Capacity" column, he must do so with a number or with "NC" (Do Not Consider). The user must fill in "NC" if:

- The component is in *Minomi* but its autonomy (replenish lead time) is not to be considered, since one of the components stored in *Minomi* has already been considered;
- When they are components produced continuously from one cell to another and therefore have no packaging (CINESP) and its SNP is 1;
- When there are components in the BOM that are not supplied by the KLT and *Minomi* s in-plant milkrun;
- When there are consumable components (packaging that appears in the BOM).

- If an output material was added to the system, consequently its assigned components were added to the BOM. After clicking on the two refresh buttons ("Refresh All" and "Update Sheets"), the user must manually add the new data in the five fields marked in red in the AuxTable - Packaging Cell Capacity (Figure 104). Automatically, the fields at the ends of the table will be updated once there are assigned Excel formulas. To facilitate this filling, simply copy what has been added in the "Saturation" sheet with the master data and paste in these fields at the end of the table.

AuxTable - Packaging Cell Capacity							
Concatenated_Ref_Cell_Ref	Welding Cell	Output Reference	Input Reference	Original Packaging	Transportation Packaging	Packaging Cell Capacity	Packaging Exist?
V0080S01990S004V0077K00990	S004	V0080S01990	V0077K00990	C99CARTON	C99MIN16	NC	ok
V0080S01990S004V0094E00990	S004	V0080S01990	V0094E00990	C99C00H6MEVCN	C99MIN16	NC	ok
V0080S01990S004V0021K00990	S004	V0080S01990	V0021K00990	C99CICS10	C99MIN16	2	ok
V0010S00991S006V0010K06990	S006	V0010S00991	V0010K06990	C99CARTON	C99CARTON	4	ok
V0010S00991S006V0010E00991	S006	V0010S00991	V0010E00991	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K01990	S006	V0010S00991	V0010K01990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K05990	S006	V0010S00991	V0010K05990	C994314ESB	C994314ESB	3	Not Found
V0010S00991S006V0010S05990	S006	V0010S00991	V0010S05990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K03990	S006	V0010S00991	V0010K03990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K02990	S006	V0010S00991	V0010K02990	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010E04990	S006	V0010S00991	V0010E04990	C99CICS05	C99MIN07	NC	ok
V0010S00991S006V0010E02991	S006	V0010S00991	V0010E02991	C994322ESB	C994322ESB	3	ok
V0010S00991S006V0010K04990	S006	V0010S00991	V0010K04990	C994314ESB	C994314ESB	3	ok
V0010S00991S006V0010S04990	S006	V0010S00991	V0010S04990	C994322ESB	C994322ESB	3	ok

Figure 104 - Fields with need of maintenance in the table

AuxTable – References Transported in *Minomi* (Figure 105)

For this table to be updated the user must be informed if any *Minomi* has been added/removed in the plant related to the KLT/*Minomi* s train, or if there was any SNP change in the components.

- When a *Minomi* and its components are deleted, the user will only need to delete the corresponding lines in Excel;
- In case a new *Minomi* is added, the user must fill in the 5 fields marked in red with the new data and drag the Excel formulas of the fields pointed to yellow (Figure 105);
- You must click on the "Refresh" button so that the "1" in front of the components with less autonomy (small code made in VBA) can be updated;
- Finally, in the field "Component from Container", the user must fill with 1 in front of the components that in original packaging come in a container.

References Transported in Minomi — Refresh

Concatenated_REF_CELL_REF	Concatenated Key au	Output Reference	Input Reference	Welding Cell	Transportantion Packaging	SNP	SNP Autonomy((min)	Setup Time (h)	Consider	Component from Container
R0045S00991S012R0045E01990	R0045S00991S012	R0045S00991	R0045E01990	S012	C99MIN01	45	151,3	0,07	1	1
R0045S00991S012R0045E00990	R0045S00991S012	R0045S00991	R0045E00990	S012	C99MIN01	45	151,3			1
R0046S00991S012R0046E01990	R0046S00991S012	R0046S00991	R0046E01990	S012	C99MIN01	45	151,3	0,07	1	1
R0046S00991S012R0046E00990	R0046S00991S012	R0046S00991	R0046E00990	S012	C99MIN01	45	151,3			1
R0041S00990S013R0041E00990	R0041S00990S013	R0041S00990	R0041E00990	S013	C99MIN02	27	90,8	0,21	1	1
R0041S00990S013R0041E01990	R0041S00990S013	R0041S00990	R0041E01990	S013	C99MIN02	27	90,8			1
R0042S00990S013R0042E00990	R0042S00990S013	R0042S00990	R0042E00990	S013	C99MIN03	27	90,8	0,21	1	1
R0042S00990S013R0042E01990	R0042S00990S013	R0042S00990	R0042E01990	S013	C99MIN03	27	90,8			1
V0012S00990S020V0012K00990	V0012S00990S020	V0012S00990	V0012K00990	S020	C99MIN05	55	114,2	0,18	1	1
V0012S00990S020V0012K01990	V0012S00990S020	V0012S00990	V0012K01990	S020	C99MIN05	55	114,2			
V0013S00990S021V0013K00990	V0013S00990S021	V0013S00990	V0013K00990	S021	C99MIN06	72	154,0	0,23	1	1
V0013S00990S021V0013K01990	V0013S00990S021	V0013S00990	V0013K01990	S021	C99MIN06	75	160,4			
V0013S00990S021V0013K02991	V0013S00990S021	V0013S00990	V0013K02991	S021	C99MIN06	300	641,7			
V0010S00991S006V0010K00990	V0010S00991S006	V0010S00991	V0010K00990	S006	C99MIN07	45	186,9	0,17	1	1
V0010S00991S006V0010E04990	V0010S00991S006	V0010S00991	V0010E04990	S006	C99MIN07	45	186,9			1
V0015S00990S009V0015K00990	V0015S00990S009	V0015S00990	V0015K00990	S009	C99MIN08	80	352,9	0,23	1	1
V0015S00990S009V0015K06990	V0015S00990S009	V0015S00990	V0015K06990	S009	C99MIN08	80	352,9			
V0014S00990S021V0014K00990	V0014S00990S021	V0014S00990	V0014K00990	S021	C99MIN09	51	105,9	0,17	1	1
V0014S00990S021V0013K01990	V0014S00990S021	V0014S00990	V0013K01990	S021	C99MIN09	75	155,7			
V0014S00990S021V0013K02991	V0014S00990S021	V0014S00990	V0013K02991	S021	C99MIN09	300	622,8			

Figure 105 - Minomi s auxiliary table

After all the necessary maintenance (in case there is this need), the user will already be able to fill in the input table of the "Interface" sheet according to the cells and references in operation and thus obtain reliable results.