Designing In-House Logistics Operations towards Industry 4.0

Volkswagen Autoeuropa Case-Study

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Thesis to obtain the Master of Science Degree in

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Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

ABSTRACT

The automotive industry might be seen as a living organism which is constantly affected by internal and external factors. In a highly competitive business environment, the quest for not missing the 4.0 industry boat is enormous. Therefore, the Portuguese automotive plant, Autoeuropa, from Volkswagen Group, intends to re-design their in-house logistics procedures towards industry 4.0 in order to guarantee high levels of operational efficiency.

The thesis hypothesis gives a contribution to operationalize the implementation of automated guided vehicles and also automated support during the picking procedure in Volkswagen Autoeuropa. In order to figure out the optimal almost full-automated scenario, a static analysis is developed. Afterwards, a more thorough analysis is carried out. For developing the aforementioned analysis, a discrete-event simulation model will be created and used as a digital twin to test those brand-new configurations of the in-house logistics operations, throughout Visual Components 4.1 software.

The major findings are: the obtained results emphasized clear frailties of the simulation software Visual Components 4.1; the new process identifies a potential saving of approximately fifty-eight thousand euros in terms of line feeding (human capital reduction) per year for a specific sequence family of components; awards a contribution to the development of new versions and features in the simulation software industry. It also opens the door and takes the first steps of a long way which culminates into the creation of a digital twin for the entire factory.

Keywords: In-House Logistics; Automotive Industry; Simulation; Supermarket; Line Feeding; Automated Guided Vehicles.

RESUMO

No paradigma atual, a indústria automóvel pode ser percecionada como um organismo vivo que é constantemente perturbado por fatores internos e externos. Num ambiente altamente competitivo, o alinhamento tecnológico com a indústria 4.0 é fundamental. Consequentemente, a Volkswagen Autoeuropa, membro do grupo Volkswagen, procura restruturar e redesenhar os seus processos de logística interna rumo à indústria 4.0, com o intuito de garantir elevados níveis de eficiência operacional. A hipótese da tese contribui para operacionalizar a implementação de veículos automatizados e também o suporte robótico durante o processo de preparação de encomendas (*picking)* na Volkswagen Autoeuropa. Uma primeira abordagem estática foi elaborada de forma a obter uma primeira solução de um cenário de quase total automação. Posteriormente, foi realizada uma análise mais completa e complexa. Para desenvolver a análise previamente mencionada, um modelo de simulação de eventos discretos foi devidamente desenvolvido e usado como um gêmeo digital para testar essas configurações totalmente inovadoras das operações de logística interna, através do *software* Visual Components 4.1.

As principais conclusões são: os resultados obtidos enfatizaram fragilidades claras do *software* de simulação Visual Components 4.1; o novo processo identifica a possibilidade de economizar aproximadamente cinquenta e oito mil euros em termos de abastecimento de linha (redução de capital humano) por ano para uma sequência de componentes específica; concede uma contribuição no desenvolvimento de novas versões e recursos no setor de *software* de simulação. Adicionalmente, constrói os primeiros passos de um longo caminho que culmina na criação de um gêmeo digital para toda a unidade fabril.

Palavras-Chave: Logística Interna; Indústria Automóvel; Simulação; Supermercado; Abastecimento de Linha de Montagem; Veículos Automatizados.

ACKNOWLEDGMENTS

Henry Ford, an undoubted reference in the world of the automotive industry, once said “Coming together is the beginning. Keeping together is progress. Working together is success.”. A timeless message which might be extrapolated to all life and work matters…

The present work does not deviate from the aforementioned conclusion. This dissertation is not exposed as a mere individual work. The teamwork carried out during this project was essential to guarantee added value and add positive outcomes from a personal perspective, as well as for the other participating entities.

First and foremost, a special thanks and a major reconnaissance to my master's thesis supervisor, Susana Relvas, who actively volunteered to help, clarify and support me throughout the realization of this dissertation. In parallel, a tribute of courtesy to Fábio Coelho for the partnership developed with my supervisor to provide a positive direction to the work performed and polish some edges.

Secondly, a vote of gratitude to Volkswagen Group and Volkswagen Autoeuropa for giving me the opportunity to work for an internationally renowned firm and one of the largest Portuguese industries. Internally, the internship took place within the Logistics sub-department of Autoeuropa, thereby, I will obviously have to highlight the name of Hans Holbein for having given me the opportunity to start a pioneering project of such a large scale. Within the aforesaid sub-department, I cannot fail to mention the person who accompanied me throughout the whole internship on a regular basis, who integrated and allowed me to take the first steps and grow inside the firm during the 6 months, Paulo Sousa a huge thank you. In the Volkswagen environment, it would be thankless not to emphasize the entire Assembly Team (Ana Jacinto, Celina Pacheco, José Gomes, Luís Carolino and Pedro Percheiro) as well as to the other members who contributed to this project (Diogo Graça, Mário, Susana Pombo, among others), all of them made me grow professionally, were constantly available to answer my questions and allowed the creation of a relaxed, delightful and pleasant work ecosystem. Undoubtedly, an outstanding team with an excellent atmosphere.

Thirdly, a word addressed to Visual Components that has predisposed to work cooperatively on the present project to improve the results for both parties.

Last but definitely not least, an enormous praise to my parents and my sister for providing me with all the opportunities which got me here and an even greater vote of gratitude for the affection shown in all phases of my life. An expression of affection towards my girlfriend, Maria, for constantly helping me deal with anxiety in the most difficult moments of this journey and for motivating me even in the worst periods. Special appreciation to my uncle, Manuel, who aided me in structuring the document and shed light on the path of this dissertation. Additionally, pleasurable company during a tough journey makes the way seem shorter and easier, therefore, and once again, a vote of gratitude to all my family and friends who shared important moments of happiness during this ride.

Obrigado a todos!

“Now… This is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.” – Winston Churchill

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ACRONYMOUS

AE – Autoeuropa

AGV – Automated Guided Vehicle

BTO – Build-to-Order

BTS – Build-to-Stock

CAD – Computer Aided Design

CPS – Cyber-Physical Security

CSCMP – Council of Supply Chain Management Professionals

EPC – Empty Containers Zone

FLP - Facility Layout Problem

GLT – *Grosse Ladungsträger* (Container Type)

GT - *Gebinde Typen* (Container Type)

HR – Human-Robot

IoS – Internet of Services

IoT – Internet of Things

IRP – Inventory Routing Problem

IT – Information Technology

JIS – Just-In-Sequence

JIT – Just-In-Time

KLT - *Kleine Ladungsträger* (Container Type)

KPI – Key Performance Indicators

LOT – Lot-Wise Components

LOZ – Logistics Optimization Centre

NPC – New Parts Control

PC – Personal Computer

PDF – Portable Document File

POF – Point of Fit

POT – Point of Transfer

SKU – Stock Keeping Unit

SUMA – Supermarket Area

SWOT – Strengths, Weaknesses, Opportunities and Threats

VA – Volkswagen Autoeuropa

VC – Visual Components

VRP - Vehicle Routing Problem

VW – Volkswagen

1 - Introduction

This research falls within the scope of the dissertation in Industrial Engineering and Management at Instituto Superior Técnico. The present chapter purports to introduce the dissertation.

The first section (1.1) comprises an explanation of the context in which the problematic is currently subsumed. Therefore, through a deep understanding of the environment, the motivations for the dissertation are easily perceived. In the following section (1.2), the project in which this thesis is embedded is described in a light way. Subsequently, the objectives of the dissertation are posed (1.3), as well as the methodology used for the development of the research (1.4) and the respective structure of the document (1.5).

1.1 – General Context

The complexity inherent to the entire context of the automotive industry is extreme. Therefore, in order to better contextualize the problem in hand it is crucial to return to the origins of its history. Henry Ford, a reference which cannot be overshadowed when diving into the roots of the modern-days automotive industry, is responsible for a plethora of meaningful inputs and changes which contributed to the initial development of this industry and which are still widely used today (O'Donnell and Batchelor, 2006). Basically, the introduction of inter-changeability of components and the use of the moving assembly line laid out to the foundations for modern-day mass production techniques. This new way of producing cars is clearly in contrast to the craft production presented until then (Holweg, 2008).

However, regardless of the competitive realm and innovation introduced by Ford (not only applicable to the automotive industry), some part of its strategy was rapidly overtaken. This is because the auto industry roughly behaves as a dynamic ecosystem which is constantly evolving according to market changes, competitiveness and technological evolution. Thereafter, General Motors based on Alfred P. Sloan, "introduced a more decentralized organizational structure and offered customers the choice they wanted through a much broader product portfolio but still not totally customized" (Holweg, 2008).

Though, these were not the only modifications. Over the years, due to the fast pace of development and innovation, new concepts were introduced, such as lean production, which blossomed in Japan (Griffiths, 2003), model years and several others. Nowadays, several manufacturers from various industries still exploit some of these approaches from Ford, Sloan and Japanese production culture.

Nevertheless, an extremely small number of firms figured out that the new competitive fight of this new century is not only related to technological development. There was a shift in the firm's mentality and customer satisfaction in a market that was saturated was fundamental. Presently, in a scenario of overcapacity, customers demanding customized products and increasing dynamic variety, the main problem is how to go beyond this new mass production system based on forecast-driven production planning and vehicle supply (Holweg, 2008). Following the evolution, several car producers decided to move from a built-to-stock (BTS) oriented production of standardized cars towards a customized built-to-order (BTO) production (Meyr, 2009). Since the production has turned into customer-oriented, customers were able to savour value-added services which allow them to customize their own vehicle (Boysen *et al.*, 2015). Based on that, the complexity of the in-house logistic processes associated to the huge number of differentiated vehicles is tremendous (Emde and Boysen, 2012b).

The mixed-model assembly lines used in modern days, which relies on producing several different vehicles of the same base product with lower adjustment times and costs, rear a new challenge. The endless number of different parts that must be available on the assembly line at the right time, location and quantity, for the corresponding vehicle, makes the firm's logistical operations seen as the heart of the company (Emde and Boysen, 2012a).

Without an efficient and flexible logistic process, the scarcity of a specific material or component at the assembly line will happen and, consequently, line stoppages will increase the production costs. On the other hand, as a trade-off, if there is a surplus of a component, it will generate idleness of these parts, hence, the holding and handling costs increase (Faccio *et al.*, 2013). Basically, a well-orchestrated in-house logistic at the shop floor based on Just in Time philosophy is fundamental to overcome such trade-offs of line stoppage and parts idleness.

Based on that, by considering the new technological paradigm in which we are subsumed and the increasing level of competitiveness through differentiation, the preponderant role that comes from the introduction of automated robots in the future is reinforced. The cooperation between robots and humans in the shared shop-floor will certainly create a co-working partnership and increase the levels of productivity, flexibility and responsiveness. The use of both will allow exploring the cognitive and logical capabilities of the human being (usually associated with high value-added activities) and leaving more repetitive and ergonomically complex activities with less mental requirements for automated robots (INESCTEC, 2018). By the same token, equipment and machinery cease to be static elements and flexibility is no longer exclusively introduced by factory operators. In this new ideology, centred on the human being, will make use of the flexibility introduced by the automation to reach an optimum level for each productive scenario. One of the challenges is to research how this 4.0 technologies could be applied.

1.2– Brief Case Description: Volkswagen Autoeuropa Project

This research will analyse a real and UpToDate case-study of one of the largest Portuguese automotive manufacturing plants, Volkswagen Autoeuropa (VA). In an environment of high-level complexity, as described, the regular search for the maintenance or increase of the levels of efficiency is immense. On top of that, the emergence of the 4.0 technologies and the growing concern with concepts such as ergonomic and sustainability reinforces changes.

Therefore, there are a broad set of issues which might be improved regarding those topics in Volkswagen Autoeuropa. On this basis, a future-oriented project will be carried out in order to figure out a better in-house logistics structure to overcome some of the above-mentioned problems and challenges. The present project will focus on the concept of supermarket (intermediate storage areas described in chapter 2) as well as the picking and sequencing activities, and line feeding processes.

From a pragmatic perspective, Autoeuropa (AE) purports to introduce automation in its in-house logistics procedures. Essentially, by replacing line feed operators by automated guided vehicles, AE is going to benefit a huge reduction in human capital costs. Additionally, these automated vehicles will allow to withstand some ergonomically problematic tasks for supermarket operators. Therewith, a new paradigm will emerge which will be evaluated later throughout several prior simulation analysis and a discrete-event simulation analysis performed through Visual Components 4.1 simulation software (chapter 4 and 5). In this way, throughout this summary, it is possible to recognize the desire that VA has in integrating automation and robotized components in its internal operations. It was immediately concluded that it intends to follow the novel challenges that are being established by the new industrial revolution (industry 4.0).

1.3 - Thesis Objectives

The objective of this thesis is to provide scientific and practical insights on how to implement efficiently Industry 4.0 concepts in real world case studies. To achieve this main objective, two specific objectives are outlined.

The first specific objective is to shed lights on several concepts directly related to the in-house logistics processes on the automotive industry and to the new-fangled ideas of the recent technological revolution (Industry 4.0). In other words, the goal is to build up a solid knowledge basis which will be valuable for tackling the present research. Additionally, it will try to fill possible gaps in the literature and add value to those areas and industries, namely, through the operationalization of several of those new contents into a real case-study.

The second specific objective is to comprehend and characterize the present case-study problem throughout a far-reaching descriptive and visual explanation of the current and future possible paradigms of the Volkswagen Autoeuropa operational processes.

Based on the challenge presented in this project (section 1.2), the main output of this thesis will be, briefly speaking, to develop an alternative future-oriented scenario for the in-house logistics operations at Autoeuropa and to helping grease the skids for figuring out what would be an optimal in-house structure from the supermarket to the assembly line.

The thesis hypothesis is that is possible to give a contribution to operationalize the implementation of automated guided vehicles and also robotic support during the picking procedure in Autoeuropa efficiently. Essentially, this thesis aims to plant the seed and, subsequently, capitalize one of the largest firms in the Portuguese industry towards industry 4.0. Thus, it represents the first steps on the long road that Volkswagen Autoeuropa has to fulfil until reaching industry 4.0 and implementing it to the whole factory.

1.4 – Overview on the Research Methodology

Analogously to the division performed in the thesis's objectives, the thesis's research methodology is also broken down into several modules. Therefore, the methodology might be portioned into nine parts as denoted in Figure 1. The respective chapter for each of the methodology phases is also identified.

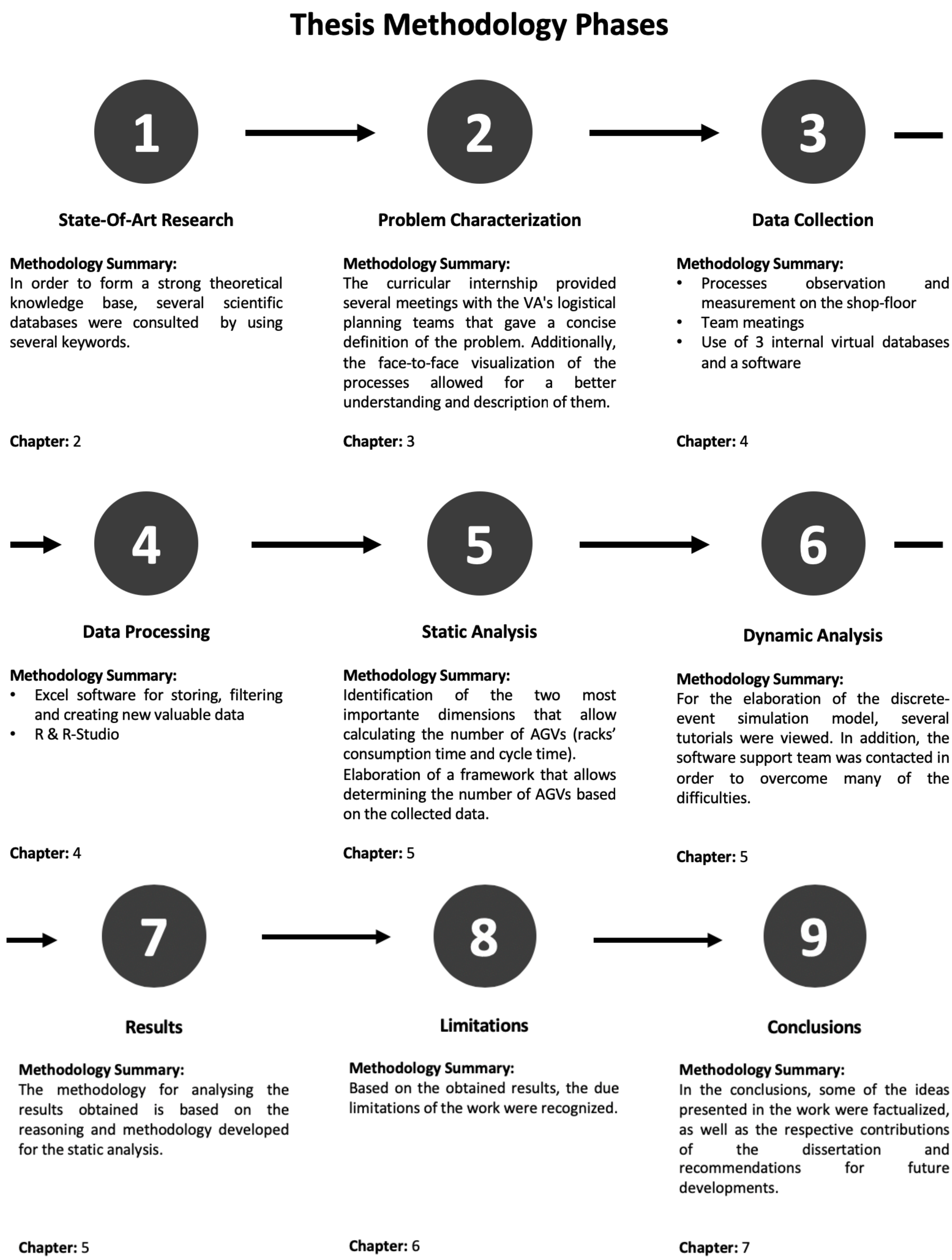


Figure 1 - Thesis Phases and Methodology Summary

Phase 1 – State-Of-The-Art Research Methodology

In order to develop the above-mentioned knowledge base (mentioned at section 1.3), a state-of-the-art research was conducted. For this purpose, keywords were defined to perform the research (logistics, in-house logistics, automotive industry, industrial supermarkets, warehousing, feeding policies, mixed model assembly line, industry 4.0, automated vehicles, simulation). By writing down those words in several scientific published databases (Web of Knowledge, ScienceDirect and others like Google Scholar) several papers, articles and books were encountered. Those documents were thoroughly analysed in order to weave a chronological history of the components from the upstream to the downstream part of the internal logistics operations and to highlight the benefits and adversities of the new trendy concepts of the industry 4.0 and simulation. Apart from all the papers found throughout the keywords, several others were subsequently found by consulting the references of the first papers.

Phase 2 – Problem Characterization

For the problem characterization, a curricular internship at Volkswagen Autoeuropa was undertaken during a period of seven months. Here, the opportunity to characterize and visualize on-site the in-house logistic processes emerged. Through careful observation of the firm's processes and several documents provided by the logistics department, their procedures were duly described. Additionally, several meetings were made with the head of the Logistics Planning department in order to grasp the purpose and objectives of the purposed challenge. Furthermore, in order to expand even more the analysis of the challenge to several other key performance indicators (KPI) that were not discussed during the aforementioned meetings, various analyses were carried out on the factory shop-floor. Here, with the medical and physiotherapy department, it was possible to acknowledge the ergonomic and sustainability issues and include them as a major key performance indicator for the project side-by-side with the others (costs, efficiency, cycle time, makespan, beside others).

Phase 3 – Data Collection Mechanisms

For data collection, intensive work was required within the firm. In addition to team meetings, process observation and time measurements of several processes, it was undoubtedly necessary to use three different virtual databases (LINCS, LISON and AP) in order to collect the necessary data to prepare the proposed analysis (explained in detail in chapter 4). Moreover, an internal architectural software (HLS) was also employed to retrieve the physical measurements of the factory for the digital twin. There was also other data, such as routes, for instance, through team meetings or even meetings with other departments (Industrial Engineering Department).

Phase 4 – Data Processing Methodology & Tools

Concerning data treatment, Excel Microsoft Office was the most used tool in order to store, filter and build new data. Some steps of data processing were analysed through R and Rstudio.

Phase 5 – Static Analysis

The methodology used to obtain the desired results was based on the elaboration of a static analysis and a dynamic analysis (simulation – digital twin). The static analysis might be fragmented in three main steps: gathering the relevant data for the analysis from phase 4, identifying the most important dimensions and how to calculate them (cycle time and rack's consumption time) and developing a framework with all the subdimensions and respective outcomes. This final step was developed in a spreadsheet (Excel) with the assistance of the head of the logistic planning assembly team and with the manager of the planning sub-department. The static analysis allowed to withdraw a first approach and some conclusions that served as basis for the dynamic analysis.

Phase 6 – Dynamic Analysis

For the elaboration of the dynamic analysis Visual Components was used since this software already existed in AE. To get knowledge on its use, several tutorials were visualized from Visual Components Academy. Then, the implementation process went through trial and error approach. It was briefly a self-learning process. However, during the model implementation, several obstacles sprang up. As a way to overcome those obstacles, the software supporting teams were contacted. The following steps might be characterized as a joint development between the candidate, Volkswagen Autoeuropa and Visual Components in order to allow the program to meet the expected needs. Several Skype conferences were taken and, are still being taken, to overcome the aforementioned issues.

Phase 7 - Results

The methodology for analysing the results was self-created and based on the methodology used in phase 5 of the static analysis.

Phase 8 – Limitation

Based on the results obtained, several limitations were recognized (literature, time horizon, data, databases, software, team, besides others) and communicated to Volkswagen Autoeuropa and Visual Components.

Phase 9 - Conclusions

The respective conclusions were drawn, and all the significant findings were factualized. Notwithstanding, a recommendation analysis was prepared for the future developments on this Autoeuropa's project.

1.5 – Thesis Structure

The thesis structure is duly fragmented into seven key chapters. Table 1 represents that division, presenting the content which will be addressed in each of them by order.

Table 1 – Thesis Framework

CHAPTER	1	2	3	4
CONTENT	**Introduction:** 1 – General Contextualization of the Problem In Hand 2 - Case-Study Overview (Description) 3 - Problem Relevance (Why Is it Relevant?) 4 - Main Objectives 5 - Research Methodology (Sequencial Description of the Used Methodology) 6 - Project Organizational Structure (Present Section)	**Theoretical Review:** 1 - Logistics & In-House Logistics Definition, In-House Logistics Importance. 2 - In-House Processes Description, Literature Review, Main gaps and future researches. 3 - Emergency of 4.0 Technologies description 4 – Simulation Definition, Importance of Simulation in Logistics activities, Similar Examples.	**Case Study:** 1 -Volkswagen Group Contextualization (history, geographical dispersion, revenues, production levels, employment, etc.); 2 - Brief History of Autoeuropa (same data provided in 3.1); 3 – AE Organizational Structure (Departments and Functions presentation); 4 - In-House Logistics Processes Description; 5 – Problem Characterization: Motivations for Change, Current Scenario Description, Future Scenarios (Improvements and Adversities).	**Data:** 1 – How data was retrieved and generated 2 – Numerical Functioning of the Factory (Assembly Line & Supermarkets) 3 – Data Treatment (Excel, R & Rstudio)
PAGES	1-6	7-27	28-40	41-54
CHAPTER	5	6	7	Extra
CONTENT	**Model:** 1 – Static Analysis (Structuring, Main Findings, Strenghts & Weaknesses) 2 – Dynamic Analysis (Modelling & Implementation, Simulation on Run, Elaboration of an Analysis Methodology, Results)	**Limitations:** 1 – Literature Gaps 2 – Research Constraints 3 – Software Limitations 4 – Visual Components Problems 5 - Volkswagen Shortcomings	**Conclusion:** 1 – Main Findings & Contributions 2 - Recommendations	**Conclusion:** 1 – References 2 – Software 3 – Databases 2 - Annex
PAGES	55-71	72-77	78-80	81-End

2 – Literature Review

The present chapter represents a review of the existing literature and theoretical concepts regarding the automotive industry. This information is important in order to grasp future analyses that will be developed throughout the research and serve as a knowledge base to feed the study. It is broken down into three major topics. The first one represents an overview of the big picture and tries to define consensual definitions of logistics and in-house logistics (2.1). Secondly, a detailed review of the existing literature regarding all the in-house logistics operations is presented (2.2). Finally, the new trendy concepts of Industry 4.0 and Simulation are examined (2.3 & 2.4).

2.1 – The Essence of Logistics

Before diving into the in-house logistics procedures, it is extremely important to understand the big picture. Thus, this section 2.1 is also split into three main chapters. First and foremost, several different definitions of the logistics concept, which were developed over time, are provided. Secondly, since external and reverse logistics are not the main scope of this research, a zoom in in-house logistics is performed. Finally, in order to comprehend the purpose of this study, the importance of internal logistics in the business world is properly reinforced.

2.1.1 - Logistics Insight

In the current paradigm, the concept of logistics is commonly used within the business world. The majority of distinguished people in this area consider that the logistics poses a fundamental function for the good operation of a business (Deloitte Consulting, 1999).

There is an immensity of well-accepted definitions for the concept of logistics. An extremely famous definition is the “Seven R’s of Logistics” which states that logistics is a fundamental component to ensure a specific product (right product), at the right place, in the right quantity and conditions, at the right time, for the right customer, at the right cost (Shapiro, 1985). Another conception of logistics was postulated at the Council of Supply Chain Management Professionals at 1998, which declare that logistics is a particular part of the supply chain management process responsible for planning, implementing and monitoring the efficient, effective flow and product storage, services, and information from the starting point until reaching the point of consumption in order to meet client’s expectations and requirements (Council of Logistics Management, 1998). According to Langley and Holcomb and also based on the aforementioned definitions, the logistic area of a firm creates value from a customer point of view (Langley, C. John, Jr. and Mary C. Halcomb, 1992). Basically, it is possible to affirm that the concept of customer satisfaction, which is seemingly associated with marketing, can be extended to the area of logistics. In other words, ensuring good customer service is no more an exclusive marketing problem but also a logistics problem (Rutner and Langley, 2000).

All the aforementioned definitions are extremely interesting. However, they are the old definitions and the iterative process to reach a more consensual definition of logistics has continued until today. Nowadays and according to the Council of Supply Chain Management Professionals, logistics and logistics management are “that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information

between the point of origin and the point of consumption in order to meet customers' requirements" (CSCMP, 2019).
Concerning the specific case of the automotive sector, the logistics process might be duly portioned into three main parcels: external, in-house or internal and reversal or return logistics. From a more detailed perspective, it is possible to schematically depict the scope of this process throughout Figure 2.

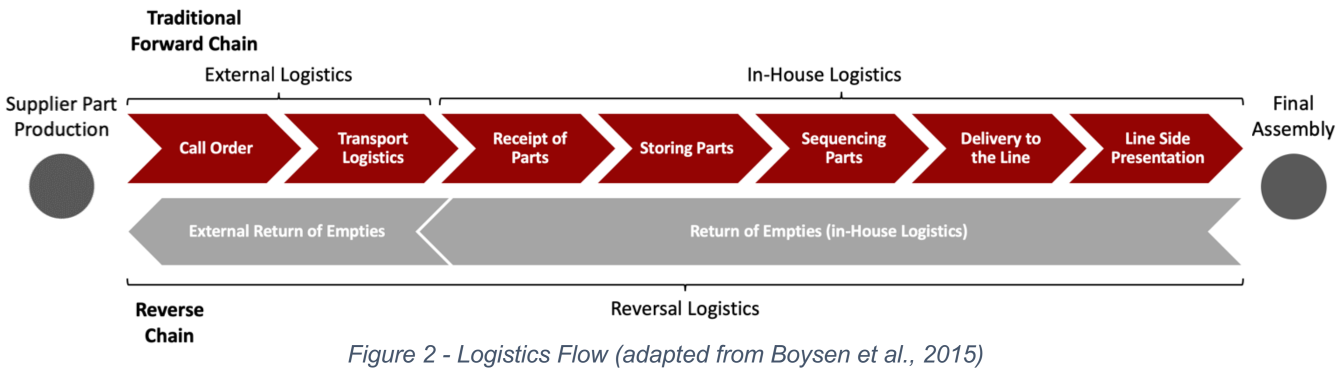


Figure 2 - Logistics Flow (adapted from Boysen et al., 2015)

Essentially, based on Figure 2, the external logistics spans itself to all the processes directly related to supplying parts from an external or internal supplier to the automotive plants. In order to ensure Just-in-Time (JIT) part supply, the firm must have extremely powerful supplier relationships and frame agreements. The in-house logistics entails everything from the components' arrivals to the sequenced and timely delivery of those same components to the assembly line. Finally, reverse logistics is responsible for the return of the empty bins to the upstream part of the supply chain (Boysen *et al.*, 2015). In this dissertation, in-house logistics will be highlighted and further scrutinized.
Obviously, not all the above steps are performed by all the components. There are several pathways based on the sequencing point. This sequencing point represents where the components are sorted (Swaminathan and Nitsch, 2007). In other words, the point where the components are sequenced has an impact on the scheme presented above.
The sequencing process can be done at the supplier and, then, parts are delivered Just-in-Sequence (JIS), according to the production sequence at the line. In those cases, the intermediate warehousing and sequencing of parts are disregarded, and parts jump directly to the assembly line. Several large and valuable parts tend to undergo these steps which reduce holding and handling costs, avoiding extra handling and resource time allocation.
When dealing with JIT parts, these parts will not suffer any significant change in relation to the full course referred above. During their normal course, they will be sequenced inside the logistic facilities of the automotive manufacturer. The previous philosophy, JIS, requires fast and frequent deliveries which leads to a meaningful increase in transportation costs. In those cases, a JIT doctrine is actually more affordable for parts with medium or low variety, value and size.
The distinction between LOT ("parts are delivered LOT-wise to the line in homogenous bins and the assembly worker has to identify and extract the appropriate part as required by the current workpiece from the respective bin.") and JIT parts is tenuous (Boysen et al., 2015). Basically, it depends on the line side space. If there is free space near the assembly line, parts will be forwarded directly to there

(LOT parts). Conversely, if there is no free space, parts will go through an intermediate storing procedure where they await and are sequenced (JIT parts).

Lastly, parts can also be sequenced at the assembly line. In such cases, line workers should carefully extract the components necessary to assemble. This type of procedure obviously does not require the step of “sequencing the parts” prior to arrival at the line. However, since the space near the line is extremely scarce, it only becomes applicable to components of small dimensions, value and variety (Hua and Johnson, 2010).

For better visualization and understanding of those three reasonings, a visual explanation is provided in Figure 3:

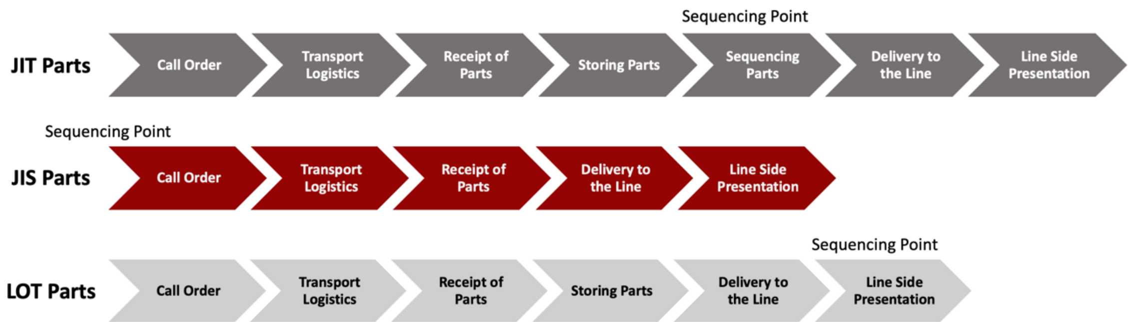


Figure 3 - Sequence of Logistics Processes for Each Part Type (adapted from Boysen et al., 2015)

All the concepts represented schematically above and related to the in-house logistics process will be further analysed in detail throughout this literature review.

2.1.2 - Overview of In-House Logistics Functions

As alluded above, part logistics can be broken down into three structures (external, internal and reverse logistics). The twofold borders of the in-house logistic structure in the automotive industry are “the receipt of parts” in the upstream, and “line side presentation” in the downstream part of the chain (Boysen *et al.*, 2015).

By slowly beginning to scrutinize the in-house logistics concept, there are three main blocks which are transversal to all industries. Having this in mind, in-house logistics can be divided into warehousing, in-house transportation (or shop floor transportation) and line-side presentation (Battini, Boysen and Emde, 2013).

Warehousing encompasses, not only large centralized warehouse dedicated zones but also decentralized intermediate logistics areas throughout the shop floor. Basically, after receiving the parts from the suppliers and before moving them into the line, parts are stored. These components can be warehoused in a central unique warehouse or in one central and thereafter, in several small intermediate storage points. Albeit a unique central warehouse has higher turnover, it ends up being inefficient and untenable due to the long distances to the assembly line. Nowadays, due to the huge size of these automotive factories, the concept of decentralized logistics storage points (logistics supermarkets) is crucial to overcome this problem. However, this new system is not always a flawless solution as it comes with some deprivations and drawbacks, these small points reduce the shop floor area (Battini, Boysen and Emde, 2013) and have several other disadvantages.

Since all those components do not go straight to the assembly line, there are several mechanisms to transport those items through the shop floor. There are three main vehicles in that are used in the automotive industry, namely forklift, tow train and feeder line. A forklift is a vehicle commonly used in industries given its relatively cheap cost, operational flexibility and lifting capacity. The downside of the forklifts corresponds to the fact that they have considerable low capacity. On the other hand, the tow train has greater capacity since it is coupled to a handful of wagons for storing parts. These transports can be moved manually or automatically as an automated robot (AGV – automated guided vehicle). When compared to a forklift, a tow train is tougher to handle and poor in lifting capabilities. Finally, the feeder line is not as regular used as the other ones since the associated costs are huge. These gadgetry are only used when dealing with large pieces or rather fragile (Boysen *et al.*, 2015).

Regarding the line-side presentation, it is an extremely important part of in-house logistics. The way parts are placed along the line is crucial, the majority of the value creation is there. Near the assembly line parts and kits (combination of parts) are presented. It is mandatory for a well-structured in-house operation that those kits are presented in an efficient manner and previously sequenced.

Throughout this document, these three main concepts associated with in-house logistics will be explored through an exhaustive analysis of the existing literature.

2.1.3 - Importance of In-House Logistics

According to Battini, Boysen and Emde (2013), the main focus of the actual automotive industry is shifting. The innovation on part logistics, mainly in in-house logistics, is the spotlight for car manufactures. This paradigm shift is due to the increase in several new trends.

Firstly, the pursuit of increasing customer satisfaction and car customization was introduced and, consequently, the number of differentiated vehicles and parts expanded. This vast number of customized car models causes an enhancement in terms of complexity of the shop floor activities, since an extra number of parts must be handled (Pil and Holweg, 2004).

Secondly, the JIT philosophy developed in Japan (Griffiths, 2003) and the recent concept of Just-In-Sequence delivery diminish the delivery cycles and boost the addiction to well-orchestrated and trustworthy logistics operations.

Last but not least, to improve even more the customer-firm relationship, automotive companies allow their customers to modify the composition of their orders a few days before the car's production starts. On one hand, it's an interesting measure to maximize customer satisfaction and increase the revenues per car. However, from a logistic and production perspective, the risk adjacent to these possible modifications makes the organization of the parts as utmost importance (Battini, Boysen and Emde, 2013).

In brief, the evolution of the importance of in-house logistics is extremely important in order to surpass these trends. Each internal logistics process must be working well because a simple failure in one of them will compromise and preclude all the subsequent logistics and production processes, since they are dependent on each other (Kilic and Durmusoglu, 2015).

2.2 - In-House Logistics Processes

After comprehending the overview, this research will analyse the existing literature regarding all the in-house logistics processes presented in the scheme of the previous section (Figures 2 and 3), from the reception of the parts to the feeding of the assembly line (chronological explanation).

2.2.1 - Parts Receiving

Receiving Process

The receipt of parts corresponds to a boundary between the external and internal logistics process. This process may seem seemingly easy to execute but has its complexity.

At the dawn of this process, the trucks arrive at the factory with several components which must be organized. Initially, the registration process of the arriving inbound trucks must be duly realized. Each truck is registered at a specific gate and, afterwards, a dock door is allocated (Boysen *et al.*, 2015). As an alternative, trailers can be removed from the trucks, stored in a trailer yard, and later recovered by a switcher (Yano, Bozer and Kamoun, 1998).

Thereafter, all the product flow entering the factory should be noted and registered in the information system of the automotive plant. This procedure is made throughout most appropriated technological means, such as bar code scanning or completely computerized by radio frequency identification. Depending on the type of components which are being considered, their pathway from here onwards will be different. JIT and LOT components are moved to an intermediate storage point (centralized or decentralized point) and JIS parts are moved directly to the assembly line.

Based on that, in order to optimize the receiving process for the different types of parts, the strategy used is different. For the JIS parts which are critical in terms of time, there are specific unloading docks for those trucks. Basically, when a truck arrives, it has a dedicated dock door in order to easily deliver the merchandise. Several firms use this methodology, such as Volkswagen in Germany, where at each dedicated dock door a certain forklift is responsible for unloads all the JIS components and feeds them into a conveyor system, which delivers those parts to the line. The remaining parts, JIT and LOT, follow the standardized procedure. Each truck has no predetermined dock door. Inbound trucks go through the process of registration and should wait at the parking place. After all the bureaucratic processes are completed, drivers are rapidly informed about the dock door which is available to unload the goods (Boysen *et al.*, 2015).

Regarding the JIS parts, from a logistics standpoint, there are no noteworthy problems. Only a sequencing problem must be solved if two trucks are competing for the same door. Usually, this does not occur. However, if it happens there are several priority rules, such as first-in-first-out. The other parts, since there are no predefined doors, suppliers have the ability to reserve a specific timeslot (fixed and predefined by the receiving company) through a web-based information system. Consequently, the entrance and exit of trucks from each dock is levelled, minimizing the number of congestion and optimizing the efficiency of the discharge process in terms of time.

Obviously, there might be problems related to the unloading of merchandise. In this way, timeslots already have some extra-time to be able to count on such problems. However, if it is found that the problem is a large-scale problem and the liability belongs to one of the parties there are penalty measures.

As it was possible to perceive, the process of receiving the pieces is not so easy. According to Klug (2010), these problems can be aggravated. If firms take into consideration the relationship between the discharge ports and the point of the line where the parts will be used in terms of distances and also considering that the same truck will pre-port several doors, there is an increase in complexity.

Existing Literature on Receiving Parts Problems

The process of receiving parts is quite complex. Associated to this process comes the huge challenge of defining the number and location of dock doors. The existing literature has already tackled those two problems.

According to Kamoun and Yano (2008), with the emergency of JIT systems and policies, the Japanese automotive manufacturers started to use the concept of Decentralized Receiving as a methodology to receive all the components. Basically, in contrast to the past, instead of having only one location to receive the components, there are several locations along the facility perimeter. The growing interest in the decentralized receiving areas has been stimulated by the increase in material handling costs that accompanied the adoption of JIT. Based on that, several firms around the globe are considering the adoption of this new receiving paradigm.

Nowadays, deliveries are much more frequent. The use of multiple areas nested in several parts of the facility creates numerous advantages. The costs of in-house trips might be reduced since the number of congestion and both move distances are blunted. On the other hand, firms cannot build an infinite number of dock doors for loading and unloading. These areas require huge gates to allow the entrance and exit of numerous materials with several different dimensions. It also requires the construction of a specific space to, temporarily, handle and store the material before being moved to the next department. Apart from these fixed costs, the human force required to support all those areas increase and, consequently, an incremental portion in the variable costs would appear. To tackle this problem, a generalization of the facility layout problem (FLP) was developed which entails determining the number and locations for the dock doors (decentralized receiving points). The heuristic algorithm, based on Benders' Decomposition, takes into consideration several intangible factors along with the direct costs and allows to get one or more near-optimal facility layouts (Kamoun and Yano, 2008).

With regard to the truck's assignment to timeslots, the scientific researches on this topic are almost non-existent. This problem can be linked to scheduling researches done for the health sector which was extremely explored by Gupta and Denton (2008). Although there are several similarities, in this case the truck control centre has clear information on who will appear, which components are coming and how long is the unloading process on average. In the health care sector, there is almost no information about the persons that will appear (Boysen *et al.*, 2015), mainly in the emergency areas.

Regarding the process of truck unloading, the literature directly related to this topic is extremely small. However, parallelism can be made with a well-known problem in the world of optimization. Essentially, the unloading process can be seen as tasks/job and the dock doors are the processors, which is quite similar to the *traditional machine scheduling*. This parallelism is easily resolved since the components that are delivered are known in advance (by filling the data into the web-based information system previously mentioned) and it is possible to calculate the approximate "activity" (unloading) time based on historical data (Boysen *et al.*, 2015).

Several other papers were developed to study the truck scheduling problem, mainly in the area of cross-docking (warehousing strategy based on zero inventory). In one of those researches, the main goal is to figure out the best sequencing for trucks at the dock doors. However, it considers inbound and outbound trucks. The objective is to minimize the time or maximize the throughput of the system. Firstly, a mathematical model was used with the objective of minimizing the makespan. However, the model ended up being halted for large size problems. Having this in mind, a heuristic was developed in order to achieve near-optimal solutions for large size problems. The heuristic approach developed has the objective of minimizing the total number of products that pass through the temporary storage (Yu and Egbelu, 2008). Cross-docking problems are slightly different from the truck scheduling problem in a receiving parts context though, is certainly a good starting point for future researches and developments (Boysen *et al.*, 2015).

2.2.2 – Storing Parts

Centralized vs. Decentralized Storage Strategies

As previously mentioned, warehousing is one of the major in-house logistics domains (Battini, Boysen and Emde, 2013). Storage of components in specific zones of the facility works as a way to fulfil the time gap between the reception of the parts and its end use near the production/assembly line (Boysen *et al.*, 2015).

There are two logistics pathways for JIT and LOT parts. In the first path, parts are stored in a centralized warehouse. This centralized storage point is responsible for providing the components to the assembly line. However, an ever-rising number of industries are increasing the size of their facilities in order to meet their current needs. The enormous size of the facilities makes the transport of goods from a central warehouse to a certain location on the assembly line inefficient. These huge distances, which may exceed a few kilometres, end up in an inflexible part delivery in large lots. These large lots will decrease the space near the assembly line, which is notoriously scarce. A completely different approach is the decentralized storage points. These structures occupy an area where space is extremely important (Battini, Boysen and Emde, 2013) and adds an additional phase to the feeding line process (double handling) (Boysen *et al.*, 2015). In the automotive industry, these intermediate points are extremely used and are called JIT-Supermarkets.

Basically, supermarkets are decentralized storage areas subsumed into the shop floor which are closer to the line segments. The concept of only one central warehouse is sunsetting. These new in-house structures prevent frequent and long-distance deliveries from a central store (Emde and Boysen, 2012b), and can be considered as the in-house logistics counterpart of a cross-dock (Boysen and Fliedner, 2010).

Supermarkets are stocked from receiving store (point of storage immediately upon receipt of the parts) through large size internal industrial trucks. On the other hand, from the supermarket to the downstream part of the chain, components are conveyed with small tow trains (Faccio *et al.*, 2013). If it is strictly

controlled, this modern system ensures an exponential increase in terms of flexibility. For instance, unexpected events may arise and due to the small-lot deliveries and extremely short distances, the internal orders can be easily reprogrammed (Battini, Boysen and Emde, 2013). The huge size deliveries and the exceedingly great distances, which were the paradigm of the central warehouse, are much less flexible and, consequently, hardest to reprogram (Emde and Boysen, 2012b).
The aforementioned facts make the supermarket a fundamental and extremely useful concept since the available space near the assembly line is scarce. Additionally, the small-lot delivers bring several benefits in terms of handling. Small-lot deliveries are stored near the line in small racks and workers are able to comfortably handle and access parts. Based on this statement, it clearly diminishes the ergonomic problems and optimizes the makespan (Emde and Boysen, 2012b).

Supermarket Procedure

After figuring out the supermarket concept, it is important to understand the processes which occur inside the boundaries of these intermediate structures. Everything starts where the previous section ended (section 2.2.1).
Basically, after the operations at the dock doors are finished, materials are stored into Decentralized Receiving Areas or in a central warehouse. Afterwards, those materials are carefully transported through industrial trucks to the supermarkets. When the materials reach the supermarket, the workers immediately sort those components into the racks (Emde and Boysen, 2012b).
Parts are stored in the supermarket until an order is established by the assembly line. When an order arises, workers receive a pick list in order to prepare and organize the bins. Some parts must be sequenced according to the assembly line requisites and some others are posteriorly sequenced. When the bins are properly filled and coupled to empty wagons, these wagons will go to a previously determined point in the shop floor where tow trains are stopped (Battini, Boysen and Emde, 2013).
When a tow train arrives, it starts to collect those wagons that are needed to the assembly line. At the assembly line, the driver exchanges the empty bins by the new full bins and place the materials at the racks of the stations (Faccio *et al.*, 2013). Empty bins are allocated into the tow train in order to be refilled in the future at the supermarket area (Battini, Boysen and Emde, 2013). Several automotive industries have already automated these procedures throughout the use of AGVs and shooter-racks (Emde, Fliedner and Boysen, 2012).
Numerically speaking, a supermarket generally supplies 20 to 30 line' stations and a tow train tour varies between 200 to 500 meters. The transportation process between one supermarket to the assembly line is ensured on average by 3-5 tow trains (Emde and Boysen, 2012b).

Supermarket Concept: Literature Analysis

The conceptual idea of a supermarket is quite interesting. Apparently, it seems an extremely simple concept to be implemented with several associated advantages. However, this system is not always a flawless solution as it comes with some implementing complexities.
As a way to ensure the proper functioning of a supermarket, there are 4 main tasks that have to be previously analysed. According to Emde and Boysen (2012), it is fundamental to determine the number

and location of these intermediate logistics structures and allocate line segments, the number of tow trains assigned to each supermarket and their route, the schedule associated to each tow train for supplying parts on its given route and, finally, determine the bins that must be coupled to a tow train per tour.

In 2012, an article was developed to scrutinize the last aforementioned problem related to the bins. In other words, the load of the tow trains is investigated with the objective of minimizing the inventory of parts near the line and ensure that there is no paucity of materials given the capacity constraints of the tow trains. For this, a polynomial-time solution procedure was introduced and the interdependencies with the planning of production were studied in this computational research. Basically, this study allowed to determine the bins that should be loaded for each tour according to the objectives previously mentioned (Emde, Fliedner and Boysen, 2012).

The supermarket localization problem was tackled before. At the dawn of the second decade of the current century, an innovative study was carried out to assist materials management decision-making policies. Essentially, this paper poses a mechanism which helps the decision of when, where and how it is convenient to introduce a supermarket by considering several aspects (assembly systems, demand rate, transportation mechanisms and systems, physical constraints for loading and unloading materials, several costs, etc.). In brief, lines were allocated to supermarkets based on their component commonality and, afterwards, they build the supermarkets as close as possible to the respective lines (Battini *et al.*, 2010).

The location problem was also deepened by Emde and Boysen (2011), where they postulated a mathematical optimization algorithm to figure out the best location for supermarkets in a context of only one assembly line.

Golz et al. (2010) studied a real case-study of a German company where throughout a heuristic methodology tried to tackle several problems. Basically, the heuristic decomposes the entire in-house logistics problem in two different stages. In the first one, transportation orders are derived. Concerning the second procedure, those orders are assigned to specific tours by taking into account capacity constraints, due dates and scheduling problems. By doing this, scheduling, routing and loading problems were tackled, "aiming to minimize the number of vehicles and operators while avoiding stock-outs at the line, where the routing is limited to picking a path from a predefined set" (Battini, Boysen and Emde, 2013).

There is almost no literature regarding routing and scheduling problems in a supermarket context. However, there are several classic problems associated with routing and scheduling that might be seen as a bridge (or as a baseline) for further developments in the supermarket's areas.

Fisher (1995), like many others, struggled to analyse the vehicle routing problem (VRP). This problem is a generalization of the travelling salesman problem, which is based on the optimization of an integer programming model that aims to figure out the optimal route for a certain fleet of vehicles to deliver several customer's orders. Basically, a parallelism with the supermarkets can be considered. The customers represent the stations and the vehicles are the tow trains. However, there are two drawbacks. Firstly, there is no compulsory order in the classic VRP formulation in contrast with the process of stations' feeding. On top of that, the routing problem, which is an integral part of the tow train function,

is not considered. Additionally, these routing problems are single-period problems which neglect temporal horizons.
Several authors (Christofides and Beasley, 1984; Cordeau et al., 1997; Angelelli and Speranza, 2002) attempted to not disregard the time horizons by elaborating a multi-period VRP model. However, it remains an exclusively routing problem, not including the scheduling component.
Similarly, the inventory routing problem (IRP) may also be intertwined with the supermarket problem. The regular distribution of a specific product, from a single facility to a broad set of customers over a predetermined longer time horizon is beheld by the IRP problem. The major advantage of this mathematical approach, when compared to the VRP, is the multi-period consideration. Nevertheless, a constant consumption rate and distribution volumes are used as a baseline (Campbell, 1998). This mindset goes against JIT philosophy, which assumes a quantity variation required by each workstation. The constant rate will surely increase the amount of inventory near the assembly line which eventually obstructs the workers.
Therefore, in these formulations (IRP & VRP), the inventory costs are overshadowed and the transportation costs are emphasized (Battini, Boysen and Emde, 2013). As mentioned, those formulations might be a good starting point but are ill-suited to supermarket deliveries based on JIT ideology.
According to Emde and Boysen (2012), there were only four central problems (location, routing, scheduling and loading). However, a few years later, in 2015, Boysen clearly identified another problem. All the aforementioned problems behold the external boundary of the supermarket. In other words, those problems are only considering the outflow of the supermarket. Another extremely important aspect is the inflow of materials (supermarket replenishment).
The literature closely related to this topic is tiny. Nevertheless, a connection with the forward-reserve problem might be done. In this problem, the number of products to be stored into a distribution centre for fast-moving items and replenished from central storage is determined. The products correspond to the internal components, the central storage point represents the receiving storage areas or the central warehouse and, finally, the distributions centres serve as supermarkets. Based on this parallelism, according to Boysen et al. (2015), the trade-off between the additional space required by the fast picking area by increasing stored items forward and less frequent refuelling is shaped by the forward-reservation problem'. Several authors provided their contribution to fill this literature gap (Frazelle, Hackman, Passy, and Platzman (1994); Van den Berg et al. (1998); Bartholdi and Hackman (2008); Gu, Goetsschalckx and McGinnis (2010)). However, it is important for future researches to deepen the supermarket replenishment topic.

2.2.3 - Introduction to Feeding Policies

According to the initial logistics scheme, the next step would be parts sequencing. Though, before getting to the heart of that matter, feeding policies must be reviewed. Especially because not all parts are sequenced immediately after the warehousing procedure.
One of the major challenges of the automotive industry is to avoid components unavailability at the assembly line. Conversely, the space near the line is extremely scarce. On this basis, the feeding policy

efficiency is fundamental to increase the overall performance of automobile manufacturers. Therefore, the meticulous selection of the right feeding strategy is a complex and important process (Caputo and Pelagagge, 2011).

Obviously, the whole concept of “feeding” is directly linked with the storage and material handling policies. In other words, based on the feeding policy, storage and transportation strategies can change (Kilic and Durmusoglu, 2015).

There are several feeding theories and policies according to previous researches. According to Caputo and Pelagagge (2011), each policy is applied for a specific case based on “qualitative judgements, perhaps influenced by product structure, operational constraints, company-specific practices and tradition”. So, apart from understanding those policies, the selection process of the most suitable policy based on the facility environment it is tremendously difficult. Furthermore, in several cases, a single feeding strategy ends up being unsatisfactory.

Overview of Feeding Policies

Line Stocking

Starting by the oldest one (Faccio, 2014), in line stocking policy, components from the central warehouse are exhibited in several individual bins or containers near the assembly line. It is important to mention that each container holds a huge amount of quantity. As time went on, empty bins are rapidly substituted by new containers.

In this strategy, product variety impacts the quantity that is inside of containers near the assembly line (Kilic and Durmusoglu, 2015). In cases where product variety is expressively huge, the amount of stock near the line is also tremendous. Based on this proportional relation, high product variety directly impacts the ease that workers find out certain required parts. The huge part’ containers which are positioned next to the assembly line will also promote the increase of the holding costs. However, despite these shortcomings, the continuous replenishment of those bins allows to ensure the continuous availability of the components (Corakci, 2008) and, since the transport associated with the JIT philosophy is notably discontinuous, the costs and efforts adjacent to the handling process are smaller (Caputo and Pelagagge, 2011). Moreover, the articulation of JIT philosophy and bulk line storage feeding ideology are not favourable to variable product mixes since it will increment the control activities, the internal complexity and costs. In order to curtail costs, production planning plays a difficult task of assign items to containers and decide the frequency of the movements from the storage points to the assembly line (De Souza et al., 2008).

Kitting

Given the new needs and volatility associated with different industries, new policies have emerged. Kitting is one of the most used and studied policies in the literature. In this policy, parts are arranged along the line inside specific containers. What differs most to the aforementioned methodology is that those containers contain kits that have been previously grouped in a predetermined way (Corakci, 2008).

According to Killic and Durmusoglu (2015), a kit corresponds to a set of parts which are grouped together into a kit container used to support various line operations for a certain product. This process of kit preparation is developed in a stockroom utilizing a pick list (for order picking) based on specific line order. To elaborate on those kits, a process is required which is called “parts sequencing”. This process will be further scrutinized in order-picking and sequencing sections.

Immediately, after kitting the components, those kits must be allocated into kit racks. Afterwards, those kit storage racks will move directly to the assembly line through tow trains. At the assembly line, a distinction has to be extolled. Kits can be distinguished as a stationary kit and travelling kit. The first one represents a kit that is allocated to a certain station of the line and will stay there until depleted. Whereas, the second one follows the product through the various stations (Faccio, 2014).

The control and free-space at the shop floor inherent to the kitting process are extreme. Especially, due to the fact that the number of containers is significantly small instead of having one container for each type of component (Kilic and Durmusoglu, 2015).

This process is also aligned with small batch size deliveries with huge product ranges. Where materials which are becoming to be obsolete are quickly removed from the inventory. Additionally, the kitting process introduces more flexibility and represents a good and advantageous choice when dealing with a high number of total components. Though, when dealing with a low number of components at each workstation or when assemblies are standardized, this policy ends up not being useful due to the extra handling of components (Caputo and Pelagagge, 2011).

In lights of performance, since parts are previously grouped, re-checked and pre-positioned, this increases the throughput and quality. The kits concept allows to reduce time-wasting to search for specific components since they are already properly ordered according to the logistics needs (also improve the ergonomic conditions), reduce operators travelling time to retrieve parts and the process of scheduling kit’s replenishment is easier when compared to bulk replenishments in line side stocking (Limère *et al.*, 2012).

The main drawbacks and deprivations of this methodology are directly related to the time spent preparing the kits, the costs associated to the kit organization, the area occupied to prepare and dispose of those kits and the human requirements to prepare them. On top of that, errors in kit elaboration may also occur and the assembly process will be jeopardized (Battini *et al.*, 2009).

Kanban Feeding Policy

The following feeding policy is characterized by the association of a Kanban card to each supermarket container. Cards contain information directly related to the production and transportation of the component at each stage. There are a transportation card and a production card. The information presented on the transportation card as regards to the quantity needed in the next stage and the quantity which might be withdrawn from the preceding one. The production card determines the quantity to be produced at a station in order to replace what has been withdrawn. The current procedure requires a specific area at the assembly line, not only to exchange empty and full containers but also to collect the Kanban cards. Essentially, these cards are used to control production flow and inventory levels. In the described system, the assembly line is “refilled through the constant replacement of the parts consumed, pulled by the Kanban system” (Caputo and Pelagagge, 2011).

JIS Feeding Policy

All the above feeding policies are developed for JIT and LOT parts. As highlighted in the first two chapters, some parts are delivery Just in Sequence. Basically, those items not only arrive just in time to a specific dock door but are also previously sequenced by suppliers. The warehousing and sequencing processes are evidently not required and products are unloaded and moved directly to the assembly line (Boysen *et al.*, 2015).

The intermediate processes are disregarded which reduces material handling (Boysen *et al.*, 2015). However, its success is strongly supported by the sequencing activity developed by a third party (supplier) which diminishes the control of the process (Belcourt, 2006). In order to succeed, the bullwhip effect must be reduced by a well-articulated flow of information and communication to the upstream part of the supply chain (Lee, Padmanabhan and Whang, 2008).

Hybrid Feeding Policy

By taking into consideration the complexities in a manufacturing environment, the existence of a unique and exclusive feeding policy ends up being meaningless (Hua and Johnson, 2010). There were several studies developed to compare all the existing feeding policies. The main concern was to figure out which is the best policy. Depending on the product characteristics (size, value, vulnerability, etc.), manufacturing environment, etc., different feeding policies will be better for each of the different cases. Therefore, sometimes firms apply multiple different feeding strategies according to the different physical conditions and ranges of components at the facility. This is called a hybrid feeding strategy.

Literature Analysis Regarding Feeding Policies

Decision-makers in all organisations continually face the rough task of balancing benefits against costs and the risk of realising benefits (Costa, 2018). Several authors attempted to simplify the complex decisions of choosing the right line feeding policy through the use of logical methods.

In 2015, Caputo et al. developed an integer linear programming mathematical model to ascribe the optimal feeding policy to each part type. The model concerned enable to choose between kitting, line stocking and just-in-time delivery policies. As an objective function, the above-mentioned model focuses on total cost reduction. The present choice of the right policy is not simple. Various thorough economic comparisons of the alternatives were performed. The main findings of this research are that an extremely well-articulated mix of parts feeding policies (hybrid policy) may be better when compared to a single feeding policy (Caputo et al., 2015). The optimal choice results from an item-by-item analysis which permits significant savings.

Two years later, those same authors deepened their first research and drew up a new analysis. In the second paper, they explored the impact of parts features (for instance, cost and unit size) and scenario variables on the total delivery cost of materials to assembly lines workstations, according to different materials feeding processes (kitting, line stocking and just-in-time delivery). Immediately after building cost models based on parts characteristics, two analysis are performed (sensitivity and parametric) to substantiate the cost-effectiveness of the feeding strategies and figure out whether economic break-even points “exist among available feeding alternatives” (Caputo et al., 2018). On this basis, it was possible to build up an areas map where each feeding strategy is more suitable and to quickly find out the best feeding strategy for each part form an economic perspective (Caputo et al., 2018).

With the emergence of just-in-time principles, supermarkets are emerging as a major warehousing procedure. Consequently, line stocking is unsurprisingly vanishing. Thereby, Kanban and kitting feeding policies are being adopted by manufacturers. A study, developed by Faccio (2014), has the objective to quantitatively analyse both feeding policies, by considering the production mix variation and the assembled models variety influence. Additionally, kitting-Kanban feeding strategy and the related optimization issues are deemed as hybrid. An industrial case-study was used for the present analysis and a “decision-making tool that defines a series of ‘convenience areas’ for the different feeding policies is provided”. In order to figure out the optimal solution for the hybrid strategy at the single component level results into a large-scale combinatorial optimization problem. They presented that the hybrid optimization might be simply resolved by using a classes-based approach, using the cross-matrix for approximately seventy percent of the tested cases with low margin of error.

Although Kanban is emerging in several industries, line stocking and kitting are still the most widely used feeding policies. Over the years, an enormity of researches focused on those two strategies. Hanson and Brolin (2013) invested time and resources on performing qualitative comparisons between those policies throughout two firms’ case-studies. Those comparisons are based on several key performance indicators, such as flexibility, man-hour consumption, product quality and assembly support, inventory levels and space requirements. According to them, kitting benefits man-hour consumption near the assembly line since the assembly operators no longer need to collect and fetch parts (already organised through the kits). In lights of quality, kits allow line operators to increase their throughput by focusing exclusively on the vehicle assembly. Hence, if we assume a negligible number of kitting errors (since kitting procedures are extremely propped up throughout the use of new technologies), the quality of the assembly is evidently superior. Additionally, kitting enlarges the range of parts that might be handled at a single workstation. Therefore, flexibility is strongly boosted. Last but not least, according to the present research, inventory levels may seem to be lower since diminish at the assembly line. However, there is solely a shift in inventory location. More concretely, inventory moves from the downstream (line) to the upstream part of the in-house logistics procedures (kitting area).

Finally, an older study from Battini et al. (2009) is also extremely interesting. Despite being older research when compared to the previous ones, their results ended up being quite up-to-date. First and foremost, the storage problem was tackled. Afterwards, the best feeding policy is assessed (line stocking, stationary kitting, travelling kitting) throughout the multifactorial analysis. In accordance with Battini et al., there are three main features which ascertain the best feeding strategy for each kind of component. Number of components, physical dimensions of the components and the distance between the assembly line to the storage point are the accountable features to determine the feeding policy. The main findings of the presented work state that the lot size (physical characteristic) is the major responsible for the choice. Line stocking fits better for high dimension parts, medium-small parts are allocated to a kit procedure (stationary – medium, travelling – small parts). As above-mentioned, it is extremely up-to-date research since this is roughly the same strategy used by Autoeuropa as will be described later in section 3.4.

2.2.4 - Order Picking and Parts Sequencing

General Conceptualization of Parts Sequencing

Prior to the line's feeding policies, the chronological path of a component was being described from the upstream part of the internal logistic process until it reaches the line. The last-mentioned step was the storage procedure. After the storage process presented in detail in a previous chapter (section 2.2.2), the sequencing parts process takes charge.

Since JIS parts were already sequenced by the suppliers, in-house part sequencing is exclusively applied to JIT and LOT parts. Those parts are properly taken from a central warehouse or from supermarkets and are fully loaded into JIT-containers according to the assembly order.

The conceptual definition of this logistics step can be easily distinguished from the classical and mere order picking. In order picking, parts are retrieved and loaded to a specific container without any order. Conversely, in parts' sequencing, parts are not only picked and loaded into a specific bin but also organized according to the assembly order (Boysen *et al.*, 2015).

As previously mentioned in feeding policies, the organization of parts inside the containers diminishes the time-wasting at the assembly line for searching and identifying components and, consequently, enhances productivity. On the other hand, if there is an error in the process of sequencing parts, this error is only identified at the assembly line (Limère, 2012). In order to overcome this shortcoming and avoid the line from being halted, the wrong parts are inevitably assembled. Subsequently, the wrong parts must be removed and swapped by the right components in the rework area. Undoubtedly, this process increases the number of logistics operations, shop floor complexity and time-wasting. According to Shingo (1986), a poka-yoke methodology should be applied to these sequencing processes. This method raised in Japan, interconnected with the Toyota Production System, and its purpose is to maximize attention to avoid human mistakes as they occur.

Additionally, on top of those drawbacks, there is an associated cost to order picking, sequencing activities and kits preparation. For instance, the order picking costs are roughly 55-60% of the total warehouse operations (Berg and Zijm, 1999; de Koster, Le-Duc and Roodbergen, 2007). The human requirements for those activities are also huge.

Numerically speaking, that is the main reason why firms struggle to figure out the best picking strategy and to introduce productivity improvements (de Koster, Le-Duc and Roodbergen, 2007).

Order Picking and Sequencing Strategies Explanation

Order picking operation is one of the major warehousing activities. Whenever an order is presented, the requested components must obviously be retrieved from the warehouse or from the JIT-supermarkets. This is where the order picking procedure starts.

There are two generic types of picking operations. Less-than-case picking, single items are picked up from storage position and in pallet-picking operations, pallets are moved in and out of the storage points. It is clear that picking strategy is directly linked with the typology of warehousing systems. There are three distinct systems according to the degree of automation: manual warehousing systems (picker-to-product), automated warehousing systems (product-to-picker systems) and automatic warehousing systems. Those structures will be subsequently scrutinized in the next paragraphs.

In picker-to-product system (manual), a vehicle driven by the order picker moves along all pick locations. The order picker contains a pick list which includes all the materials quantities of different SKUs (stock keeping units – a unique item of supply) that must be collected. Inside the manual order picking two methodologies can be highlighted: single-order-picking and batch-picking. The first one corresponds to an approach where the order-picker is accountable for picking a complete order. In contrast, the second approach suggests that each order-picker is responsible for several and multiple orders at the same time. In this approach, the order-picker activity is normally constrained to a certain area (zoning). Basically, batch picking reduces travelling time when compared to single-order but orders must be sorted afterwards. Wave picking corresponds to a hybrid strategy where batching and zoning are applied together. Order-pickers starts the activity in their areas simultaneously and, afterwards, when all pickers finish their tours, the second wave begins (Berg and Zijm, 1999; de Koster, Le-Duc and Roodbergen, 2007).

Product-to-picker is inversely correlated with picker-to-product. Here, instead of the order picker being in constant motion, the operator occupies a fixed position and the components move to that location automatically. The order-picker travelling time is efficiently minimized which allows increasing their time for “sorting, packaging and labelling of the retrieved components”. Sometimes, pickers are allocated to more than one zone. So, each time that a picker is unloading items from one zone, another order is starting to be processed in the other zone. When picker finishes the first zone, the second one automatically arrives, and the process is repeated. Essentially, by assigning several zones to each picker improves their throughput and diminishes the waiting time of this activity (Berg and Zijm, 1999; de Koster, Le-Duc and Roodbergen, 2007; Boysen *et al.*, 2015).

Finally, the automatic order-picking system is a totally automated system. Basically, not only the picking process is performed automatically as well as product-to-picker but the order picker (which is responsible for receiving, sorting, packaging, etc.) is a robot. This cutting-edge technology is mainly used to small and medium-size non-vulnerable items and it is performed at extremely high speed (Berg and Zijm, 1999; de Koster, Le-Duc and Roodbergen, 2007; Boysen *et al.*, 2015).

Based on those methodologies, normally, product-to picker is more applied to small and low-value LOT parts. These parts are generally stored in automated storages. Regarding JIS parts, those ones are previously sequenced and do not go throughout these processes. JIT parts are “delivered only right before consumption”. Essentially, JIT and big and valuable parts are associated with the picker-to-product ideology (Boysen *et al.*, 2015).

2.2.5 - Line Side Presentation & Value Creation

Line Side Presentation Overview

Immediately before parts are correctly assembled, line side presentation takes place and corresponds to the final step of the in-house logistics procedures.

The material deposition next to the assembly line is not carried out completely randomly. Existing space is limited, and operators need room to work. Additionally, it is important to assure uninterrupted components' availability. However, material surplus ends up not being effective.

Two pathways are deemed for components line side presentation. Large carriers of large components or subassemblies (cockpits, wheels, seats, etc.) are stored on the ground near the assembly line. On the other hand, smaller bins are efficiently housed in racks as close as possible to the assembly line. Preferably, those smaller bins are stored in gravity flow racks which encompass tilted shelves "to be replenished by logistics workers from the back and depleted by the assembly worker from the front". According to the line operators, rack storage is better from an ergonomic standpoint. Nevertheless, this second way enlarges the logistics effort of the workers (double-handling) (Limiere, 2011).

Basically, the major problem which might be solved is the placement of the components. Here, the perfect balance between the location of each bin (ground or rack) and the scarce space at each station is desired. Operator walks are taking up a considerable portion of the total time at each workstation. Wherefore, unproductive walks might be minimized. Ergo, the optimal location for bins is the one that minimizes those distances and, consequently, minimizes the total time at each workstation.

However, a simple bins location problem will absolutely result in an overlap of bins positions. On this basis, a different dimension bins placement problem with scarce space emerges. Moreover, some areas are forbidden which are occupied by walls, pillars, unmovable equipment, etc. (Boysen et al. 2015).

Line Side Presentation & Value Creation: Literature Review

The complexity of line side components presentation is huge. In order to guarantee flexibility and that space at the line is well used (to preclude material surplus or paucity) problems regarding the strategic positioning of the components have to be considered. A research developed by Klampfl, Gusikhin and Rossi (2006) attempted to solve this placement problem. The prime objective was to figure out the perfect way to allocate components within the workcells in order to minimize non-value-added activities (walking and waiting). In brief, these authors tried to deal with a placement and layout optimization problem at the workstations. Their paper presented three different non-linear optimization approaches, with different levels of sophistication. However, overlapping of bins and crossing of stations are allowed in two of those three models. Finally, the different models are evaluated, and an optimized layout is presented (Klampfl, Gusikhin and Rossi, 2006).

At the same data frame, another relevant study directly related to this topic was elaborated by Bukchin and Meller. The purpose was extremely similar to the previous one. However, the major objective was to find out the maximum line fill-rate. More specifically, the probability of zero-line stoppages "due to a lack of components between consecutive replenishments". In order to calculate the line fill-rate, the model is embodied into a design algorithm which determines the space allocation. Here, a myopic procedure is considered to generate an initial feasible solution. The final result appears as a near-optimal result.

Over the years, the ergonomic concept emerged. Since the beginning of this century, a plethora of researches directly related to this topic has been appearing. More recently, in 2011, Finnsgård et al. studied the impact of racks positions from an ergonomic perspective. This impact is easily identified through empirical measures of the ergonomic efforts (Finnsgård et al., 2011). Likewise, there are several other studies stemming from other authors directly related to this subject.

However, plenty of space for further researches is still available. There are an immensity of real-world requirements which are not being considered, such as: "the possibility of storing bins on both sides of the line is not considered; typically multiple workers jointly assemble in a station; different storing policies for the same part family (e.g. high runner variants in original carrier load, low runners in bins in racks); different car models with varying part demands are produced; forbidden areas restrict the bin locations; and workers may be able to collect multiple parts per walk to the storage area." (Boysen et al., 2015).

2.3 – Industry 4.0 (AI, Automated Robots, Internet of Things, Renewable Energies, VR, etc.)

Presently, the industrial requirements and complexity, together with the technological development opened up a huge spectrum of opportunities. New concepts and catchwords sprang up, such as internet of things (IoT), internet of services (IoS), digitalization, simulation and digital twin, automation, artificial intelligence (AI) and cyber-physical systems (CPS).

The benefits which are going to come along with this 4th Industrial Revolution result in an increase of mass production flexibility, optimization of value chains, costs reduction and allow real-time coordination. Unsurprisingly, the benefits of 4.0 era are not barely applicable to the production and product development departments. The logistics area undergoes through several noteworthy possibilities of improvements. It allows having real-time tracking of material flows, improved transport handling as well as accurate risk management.

According to Hermann et al. (2015), there are four preeminent components in 4.0 Industry: CPS, IoT, IoS and smart factories.

CPS comprises a system which brings up the physical and virtual world together (Akanmu et al. 2015). Here, physical and virtual systems are duly intertwined, and these mechanisms are controlled by computer-based algorithms. From an industry angle, physical shop floor information and the virtual world are strongly synchronized (J. Lee et al. 2014). Both networks (virtual & physical) are integrated throughout the use of manifold sensors, actuators, control processing units and communication devices. Hence, the levels of control, surveillance, transparency and efficiency enhance exponentially.

The second one is the IoT. This concept represents a world where essentially all physical stuff can turn into so-called "smart things" by featuring small computers that are connected to the internet. The knowledge and communication level became tremendous.

Additionally, IoS corresponds to services that are available throughout a wide range of web technologies, allowing everyone to create and offer novel value-added services.

Those three core components of the 4.0 Industry are directly linked together. Basically, CPS communicate over IoT and IoS basis. The concept of smart factory emerged from the combination of all those components. The full-fledged internet and virtual environment combined with the idea of decentralizing production systems, in which humans, machines and resources are working together in a natural way, is basically the idea of a smart factory. This recent paradigm allows to reach out a whole new level of linkage and communication between products, machinery, transport systems and humans. Under this new virtual and computerized era, automated robots and artificial intelligence are also concepts which are undoubtedly "in the mouths of the World". The ergonomic benefits and their capabilities to perform extremely repetitive activities make them remarkably valuable. As mentioned in section 1.1, those robots are also responsible to introduce flexibility on the shop floor (since machines are no longer fixed components) and vanish human requirements for low-value- and low reasoning activities.

Beyond the key components defined by Hermann et al. (2015) and the automated robots' introduction, several new structures such as exoskeletons, smartwatches, glasses and gloves, augmented reality, autonomous vehicles (for instance, AGVs, drones, etc.), distributed ledger systems (e.g. the blockchain) or big data analytics were created to intelligently help humans performing an enormous broad set of activities (Hofmann et al., 2017).

The in-house processes of order picking, which represents one of the main elements of this research, are generally supported by automated guided vehicles. However, the majority of order picking procedures are elaborated by humans, mainly because, hitherto, automated systems are still extremely slow, adamant and unsafe (Relvas et al. 2018). Obviously, it is possible to envisage that the future trend is to integrate collaborative robots with humans by creating a partnership between both. However, there is a plenty of studies which does not consider two arms collaborative robots (Relvas et al. 2018). Kimura et al. (2015) is one of the studies that have considered two arms automated robot, nevertheless it is not a two arms collaborative robot.

2.4 – Simulation in Automotive Industries

2.4.1 – Simulation Definition

As mentioned in chapter 1 and section 2.3, in the current modern days, the competitive environment is tremendous. Firms are constantly facing new market challenges. Customers are always searching for novel products. Each product is kept on the market for an extremely short period. Furthermore, the globalization and decentralization of industries make the flow of information in real-time, across the various steps of the product development life cycle, a highly important point. On this basis, this new dawn of mass customization, globalization, logistics complexity and turbulence make simulation an important component (Mourtzis, Doukas and Bernidaki, 2014).

This technology represents an important tool for implementing successfully digital manufacturing. Basically, it enables to develop and test several new scenarios and policies, novel concepts or systems with no need for physical implementation. In other words, the aforementioned technology allows to experiment and validate various configurations before applying them in the real world. Additionally, it also permits to fathom a lot of hidden knowledge, perhaps invisible to the un-aided eye, gather information without destabilizing the actual system (Mourtzis, Doukas and Bernidaki, 2014) and allow to achieve a completely new level of productivity (Rosen *et al.*, 2015).

An interesting fact which reinforces the importance of simulations is the number of publications regarding this topic. Before 1970, the number of studies directly related to this was extremely low (Figure 4).

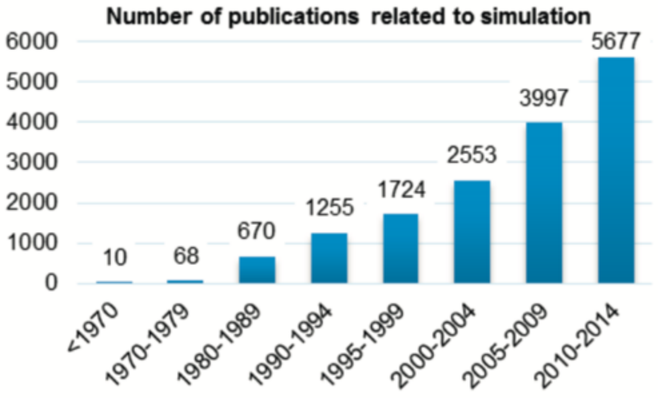


Figure 4 - Evolution of Simulation Studies in Factories (adapted from Mourtzis, D., Doukas, M. and Bernidaki, D., 2014)

Another aspect which is responsible for the ever-rising use of the simulation software's and tools are the autonomous systems. Autonomous systems comprise a system with automated and intelligent machines which exert activities without any human assistance and being capable of making decisions. In order to improve the quality of those decisions, the autonomous robots should have access to realistic digital models.

This conceptualization is typically called the Digital Twin, a replication of physical components into a digital software which presents the previously mentioned advantages for the future of manufacturing industry towards 4.0 Industry. Essentially, it can be seen as a digital replica of the real physical world (El Saddik, 2018).

2.4.2 – Simulation in Similar Challenges: Literature

Henceforth, firms are struggling to implement those simulation tools in order to validate their new-fangled processes before, actually, introduce them. In the present section, several examples are provided. Essentially, examples of case studies and researches which attempted to apply various layout and procedures modifications and evaluate those changes according to some indicators (which are similar to the ones that will be used in this research) through the use of simulation.

Chryssolouris et al. (2017) attempted to apply to a real-life automotive case-study a simulation model. The major objective was to automatically generate a human-robot (HR) partnership by allocating tasks as efficiently as possible. Typically, simulation researches are solely focused on cost-effectiveness. However, this one is concerned with developing an automatic design of a hybrid layout and HR coordination. "Multiple criteria evaluation based on both analytical models and simulation modules have been integrated in the HR coordination task planner.". Both analyses were used to the estimation of the criteria values. Therefore, the evaluation of the different alternatives was performed.

Apart from costs and robot's integration, a simulation software is also crucial to evaluate the ergonomic conditions. A research, powered by Solomon et al. (2017), assessed ergonomic issues of an existing scenario in various factories shop-floors and attempted to “come up with user-friendly designs of workstations, processes, layouts and operation sequences with the intention of improved occupational health, safety and productivity.”.

More recently, a study was conducted in 2019 by Sharma in order to analyse all the possibilities of increasing production capacity with minimum increase in infrastructure. The study was driven under several different production scenarios. This research contributed for acknowledging the importance of simulation in shop-floor control decision making in a scenario of high level of logistics complexity and globalization.

Concisely, as proved in various studies, simulation is vital tool to evaluate physical plants reorganization. It allows to duly evaluate several different outcomes from different scenarios such as ergonomic issues, costs, automated robot’s integration, efficiency and design, etc. Additionally, it is also used for industrial manufacturers in scenarios of high complexity. Consequently, it is crucial to use a simulation software to perform the present research.

3 – Volkswagen Autoeuropa Case Study

This chapter is responsible for bridging the gap between theory and practice. In other words, all the processes and theories previously described during the literature review, which are directly related to the in-house logistics operations in the automotive industry, will presently be described from practical standpoint.

First and foremost, a brief chronological introduction to the Volkswagen group and Volkswagen Autoeuropa will be stated. Thereafter, all the relevant internal logistics operations and procedures will be scrutinized from upstream to downstream (receiving, warehousing, packaging and line feeding). Ultimately, after the awareness of how internal logistics is orchestrated at VA, the Volkswagen Autoeuropa project is portrayed in more detail. In addition to the aforementioned project's detailed description, several advantages and shortcomings are also acknowledged and discussed.

3.1 – A Brief Context of Volkswagen AG

The appearance of Volkswagen AG requires rewinding about 80 years. Rightly before the 2nd World War, more precisely at 28th May 1937, Volkswagen was officially founded in Berlin. The commercialization of the Volkswagen car was duly backed by the German politician and leader Adolf Hitler. The main purpose was to create a car which was affordable for common German people. The engineer in charge of developing the model was Ferdinand Porsche (1875-1952), although much of his drawing was inspired by the cars developed by Hans Ledwinka for the firm Tatra (Volkswagen Autoeuropa, 2018). At a drop of hat, Volkswagen has become a reference automotive brand which cannot be disregarded in German and worldwide. The tremendous trade-off between quality and price drove the rise of its market share and brand loyalty. Nowadays, the Volkswagen Group encompasses not only the Volkswagen brand but also another well-referenced brands such as Audi, Lamborghini, Ducati, Bentley, Bugatti, Porsche, Scania, Seat, Skoda, TRATON and Here.

Numerically speaking, in 2018, the group presented a revenue of around 235.000 million euros, which translates into about 11 million cars sold. For this to be effective, the firm presented production levels of approximately 44 thousand cars per day and 365 different models (Volkswagen AG, 2019).

Geographically, the company is dispersed throughout the various continents of the globe. Therefore, it has 122 production plants around the world employing around 600 thousand employees (Volkswagen AG, 2019).

3.2 – Chronological Evolution of Volkswagen Autoeuropa

The Volkswagen Autoeuropa corresponds to an automotive production plant from Volkswagen Group, nested in Palmela, near Lisbon, Portugal. The history of Autoeuropa began in 1991 with a joint venture agreement between Ford Motor Company and Volkswagen AG for the production of multi-purpose vehicle. Thereby, it forced a capital raising of roughly 1,970 million euros (1.282M€ - factory implementation; 479M€ product development; 209M€ formation and launch). This financial investment decision was made in half by both parties.

Afterwards, in 1995, the production plant was inaugurated, and the cars were officially presented in Genève. At the dawn of 2000, the Volkswagen Group takes over 100% ownership of Autoeuropa. Hitherto, Volkswagen AG continues to have full ownership of the assembly plant.

Since the beginning, several car models have been produced at the shop-floor of the factory, as shown in Figure 5.

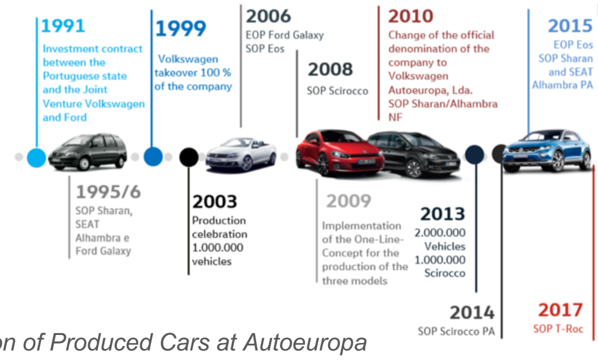


Figure 5 - Evolution of Produced Cars at Autoeuropa (adapted from Volkswagen Group Academy, 2015)

From the outset, the Portuguese Government propped up Autoeuropa. The vision was to expand and modernize constantly in order to maintain high standards and become a benchmark for the Volkswagen Group. These investments were aimed at deploying new infrastructures, modernizing equipment and training employees over time, in order to make production lines and methods more efficient. In 2015, Autoeuropa was elected as the best factory of Volkswagen brand under the "Macth18.FACTORY" program, which aims to improve the production units in several areas such as efficiency, team spirit, competence, quality, innovation and product launch.

Nowadays, Autoeuropa represents one of the most efficient group's assembly plant. It produces roughly 900 cars per day. Additionally, the factory includes in eight departments about 5800 employees, specialized in the most diverse areas.

3.3 – Volkswagen Autoeuropa Internal Departments

The efficient functioning of the firm over the years is thoroughly dependent on its organizational structure. In this way, Autoeuropa is evidently divided in eight departments which can be schematically represented as shown in Figure 6.

Figure 6 – Volkswagen Autoeuropa Organizational Chart (adapted from Volkswagen AG)

Each of those departments works in a co-working environment with the objective of increasing plant's efficiency in terms of time, quality and costs, without jeopardizing the production. Although all departments are of utmost importance, only the logistics department is part of the universe of this study. The functions inherent to the logistics department are mainly related to planning, implementing and monitoring the efficient, effective flow and product storage, services, and information from the starting point until reaching the point of consumption in order to meet client's expectations and requirements.

The logistics department itself might be clearly scrutinized and subdivided into several sub-departments or teams, as shown in Figure 7.

Figure 7 - Volkswagen's Autoeuropa Logistics Sub-departments

The case study in hand will be inserted at the logistics planning sub-department, more precisely at the assembly team. This department is responsible for planning all the logistic processes of the components from the upstream part of the in-house logistic process (receiving of the parts) until the line side presentation of those same components. It is extremely important for them to ensure that each component is feeding the assembly line at the right time, quantity, location and quality.
The assembly team, inside the logistics planning sub-department, is responsible for several in-house logistics activities which mainly goes from the supermarkets to the assembly line.

3.4 – In-House Logistic Procedures Description

From a theoretical point of view, the in-house logistics activities were already covered in the literature review. In this chapter, the in-logistic procedures will be further analysed in a more practical way.

3.4.1 – Generic In-House Logistic Numbers

The Volkswagen Autoeuropa production plant occupies an area of roughly 2.000.000 m^2. The production area comprises only 1.100.000 square meters and 900.000 are considered to be the industrial park. This giant factory encompasses four main stages of production: presses, body, painting and assembly.
The press zone comprises the area in which aluminium plates are pressed, cut and moulded. Thereafter, all the aluminium plates, which were previously pressed, are welded and unified in order to build the car's skeleton (Body section). Consequently, the car undergoes throughout several painting and varnishing procedures (Painting zone). Ultimately, the assembly area is where all the components (engine, steering, wheels, cockpit, windows, etc.) are assembled and where several functional and quality tests are performed. Each car must go through all those 4 stages without exception. It also incorporates 3 warehouses (LOZ Body, Assembly & Paint) as well as two areas for empty containers (EPC & EPC Canopy B).
In order for these four production areas to function properly, the right components must be delivered to the factory at the right time, quantity and location. In this way, this factory has about 4,000 components coming from about 653 suppliers (646 European and 7 from the rest of the world).
Since the present research is devoted to the assembly part, the processes that will be described in the immediately following sections concern this area of the plant.

3.4.2 – Assembly Central Warehouse

Warehouse Areas Description

The in-house logistics chapter sets in at the assembly central warehouse. Recently inaugurated, this logistics structure is called Logistics Optimization Centre or *Logistics Optimirung Zentrum* (LOZ). With an area of approximately 20,000 square meters, it houses the vast majority of storage activities which are properly managed and executed by a third party (logistics operator - outsourcing). In order to preclude line stops this logistics structure operates continuously, i.e., 24 hours per seven weekdays.

The LOZ is visibly divided into eight distinct areas: truck unloading area, empty containers loading zone, shelving area, NPC (new parts control), cage zone, storage area (Blockstorage), empty containers cleaning zone, repackaging zone, packaging inspection zone and *Bahnhof* (Annex I). Those areas will be hardly scrutinized in the following paragraphs.

The border between in-house and external logistics occurs when the trucks arrive at the unloading zone. Here, there is a single entrance gate through which access is made to the interior of the warehouse. Along the various unloading places, the trucks parked, and the merchandise is rapidly unloaded into a specific location. Finally, the unloaded components are verified, and trucks leave the plant throughout the exit door. Additionally, the empty containers loading zone is clearly subsumed into the previously mentioned unloading zone. This zone stores the empty containers, previously cleaned, in order to send them back to the respective suppliers.

The second major area of the LOZ is called shelving area. The defined region encompasses 21 aisles, each having about 9 levels of height (1 meter/level). Essentially, in this location small dimension boxes and components are palletized. The material is stored according to its assembly line feeding routes. However, extremely high-value components are carefully stored in a specific location, near the shelving area. Hence, for security reasons the access to the aforementioned zone is restricted.

Containers of high dimensions are hosted in the Blockstorage area. These same containers are warehoused by type and stacked according to their characteristics. The stacking factor varies according to the weight, size and shape of the container.

There is an area for cleaning all types of durable (reusable) containers. In this location, all labels and protections of material (plastic bags, cardboard separators, etc.) that may exist inside and outside the packaging are removed. The boxes are palletized by type (dimension) and then sent back to the different suppliers. Collapsible containers are also scrapped at this location to optimize the transport of empty containers.

All packages which are not shipped by suppliers according to the packaging specified by Volkswagen must be decanted into the correct packaging. This process occurs in the settling or repackaging zone. It is only after repackaging that the containers are properly stored on the Shelf or Blockstorage areas. The prime reason for this procedure is to have standardized packaging for the components.

Following the repackaging zone an area for packaging inspection emerges. Whenever the packages present damage due to transport, they are segregated to the inspection zone where an inspection is made to the material. The major objective is to analyse if the inspected material is in perfect conditions to be used. If it is not, a document is developed in order to return the material to the supplier. This

verification procedure is carried out by the logistic operator. However, the quality department of Autoeuropa is the one which is responsible for the aforementioned process.
The material storage process ends with material picking according to orders scheduled for the production day. The picking operators rapidly receive the information on their equipment (HHT), which indicates where the components are nested and their reference. After collecting, operators leave the material at the transfer points (POT's), from which all the material supply routes to the production line of the assembly left. This area is called *Bahnhof* zone.

Parts Receiving & Storage Processes

The trucks unloading procedure sets in with the arrival of the various trucks to the ordonnance of Volkswagen Autoeuropa. Immediately afterwards, the drivers park in the truck park, next to the Autoeuropa gate, and go directly to the Traffic Control Centre (the team responsible for capturing and examining the trucks/material). In this locus, the truck drivers are assigned an electronic equipment (Telematic) that gives them the exact guidelines of “when, how and where” to start the unloading procedure. When the driver receives the aforementioned information regarding merchandise unloading, enters the Autoeuropa gate and moves directly to the central warehouse, where he parked at the unloading dock indicated by the Telematic.
The material is unloaded from the truck by a forklift and placed in a properly identified area in front of the unloading dock, where the material is carefully inspected. Thereafter, all the collected material is obviously registered at the Volkswagen AE system. Thus, a label is generated in order to streamline future processes. This label has a reference number (part number), the point of transfer at the *Bahnhof* (POT) and the point of usage at the assembly line (POF). Subsequently, the “put away” operators store all the components according to the label description (Blockstorage/shelving area).
On the shelving area, either in the picking or in the “put away” process, the picker uses cab equipment that operates up to approximately 9 meters high. In the specific case of the order picking, the picker uses a mobile rack (hardware) with about 3 levels where it places the boxes. In the vast majority of cases, this procedure includes the collection of approximately 25 boxes. When the picking process is over, the operator places the rack in the POT (Point of Transfer) according to its box supply route. The Supply Operator ties the Hardware to the motorcycle and moves rapidly to the assembly line to fill the material.
In the “put-away” and picking operations in the Blockstorage area, forklifts with different tonnages and types of forks work according to the weight and dimensions of the containers they move. The picking operator receives the information on the electronic equipment (HHT – handheld device used in picking activities for giving locations information) of the next material to be collected, collects the material with the stacker, and delivers to the POT indicated on the label.
The process of storing of small or large components ends up with the influx at the transfer zone (*Bahnhof*).

3.4.3 – Packaging Value

One of the previously mentioned activities is the repackaging procedure. It represents an activity of utmost importance for the firm. The value of the standardized package is tremendous.

All the group processes and activities are intertwined. Wherefore, the existence of normalized packages is crucial for the efficient exchange of components between the group and also with the suppliers. Another important point to be highlighted is the line side restrictions, the existence of standardized and optimized packages reduces the line side space usage which is extremely tight. After the assembly, the packages will return to the suppliers throughout the reversal logistics process. A standardized package facilitates, secures and streamlines the return process.

However, obviously, not all components reach the assembly plant in normalized packages. Here, the repackaging procedure springs up in order to switch the package to a standardized one. Essentially, it reduces logistics complexity.

Grosse Ladungsträger (GLT) and *Kleine Ladungsträger* (KLT) are the two types of standard boxes utilized. The first one corresponds to large dimension boxes. Conversely, KLT corresponds to small dimension packages. Importantly, there is not solely one type of GLTs nor KLTs.

Therefore, GLT's and KLT's have remarkably different routes. In order to foster in-house cost reduction, the KLT's are enclosed into a cube denominated *Gebinde Typen* (GT). In other words, GT is a complete pallet of homogeneous KLT's or other small boxes.

Those cubes are treated as GLT's. This betokens that only one warehousing and line feeding label is to be used from the warehouse until the POT's, at *Bahnhof*. Obviously, the KLT's, from a specific GT, must be organized in an optimal route delivery, by a tow tug, in a synchronized and stable mode. This must be done to minimize waste due to unnecessary stoppages on the loading and unloading areas, as well as traffic.

Finally, all the packages must be duly covered during transport to avoid quality concerns. At the supermarket's area, those components must be presented with lids and covers removed, cardboard boxes and plastic bags opened to provide unimpeded access to the material by the logistics outsourced partner.

3.4.4 – In-House Logistics Transportation Vehicles

Even though transportation is sometimes acknowledged as a non-value-added activity, it is thoroughly indispensable for the proper functioning and circulation of the components between the various stages of the logistics and production processes. In order to ensure the appropriate functioning, three vehicles are typically used (Annex IV).

First and foremost, the forklift corresponds to a short distance powered industrial truck which is used to lift materials. The present vehicle is mainly utilized at the central warehouse (LOZ) to retrieve parts from the suppliers (new merchandise which arrives at the factory), store them into the Shelving and Blockstorage area and take them to the *Bahnhof* transfer zone. They are fully flexible since are able to rapidly move through all possible paths along the warehouse aisles. At times, forklifts are also used into the shop floor to aid in the transportation of high weight parts to the assembly line. For all these operations, those vehicles are human-dependent (not automated).

Secondly, AGV is an abbreviation for the automated guided vehicle. Those vehicles follow along marked long lines at the shop floor and use lasers and magnets to limit their actions. They are mainly used for kitting and line feeding activities of racks and trays, and several other activities. Automation represents a huge advantage since it is no longer dependent on the human being. On the other hand, once it is automated and follows the marked lines, its operational flexibility is quite tiny.

Finally, the tow tug (or tow train) is the most widely used vehicle at the AE production plant. In line with the forklift, it is not automated which gives a greater human being dependency however, on the other hand, it presents greater flexibility of routes. From a capacity perspective, it clearly dependents on the rack size (trolley). Different parts have different specific racks.

3.4.5 – Supermarkets Structure at AE

As aforementioned in chapter 2, supermarkets are decentralized areas or intermediate points at the shop floor to strategically warehouse components near the point of usage at the assembly line. These structures are responsible for avoiding the existence of material surplus and idleness along the line and minimizing distances faced by operators.

At the AE shop-floor, there are about 9 assembly line zones (A, B, C, E, F, G, H, J) fed by 14 supermarket areas (SUMA) as proven at Annex II & III. Those locations are efficiently shared by logistics operator (8 supermarket areas) and the production department of the firm (6 supermarket areas).

Those 14 locations might be broken down into more than 25 supermarkets which feeds 277 workstations at the assembly line. Herein, the procedure of picking and sequencing takes place based on picker-to-product philosophy (manual order picking & sequencing). Some of the supermarkets are propped up by AGVs, which are also responsible for feeding the line. On the supermarkets which are not supported by AGVs, which are the majority of the supermarkets, racks are handled by the operators. They move along the supermarket to collect the components and full those racks. When they are completely full, racks are placed at a specific location and, afterwards, tow tugs catch them in order to deliver the material to the assembly line.

3.4.6 – Autoeuropa Line Feeding Policies

All the cited in-house logistics structures are relevant. Nonetheless, not all the components are embroiled in all those steps. This essentially depends on the need to be sequenced or where the sequencing point occurs. The production procedure embraces JIS, LOT and JIT parts. Therefore, each kind of parts has a specific pathway according to the sequencing point.

As seen in the literature, JIS parts are preliminarily sequenced by suppliers. Broadly, those components arrive at the receiving area and are directly forwarded to the assembly line. In general, at Autoeuropa, it comprises high value, upmarket and unhandy components such as cockpits, seats, wheels, airbags, etc. As previously mentioned, Autoeuropa must guarantee a well-articulated relationship with its suppliers in order to not jeopardize the assembly process.

Alternatively, JIT and LOT parts will go through a different channel. The components are rapidly unloaded at the receiving area. Afterwards, the repackaging procedure is realized due to the existence of non-standardized packages or space restrictions. Thereafter, two possible paths must be considered.

In both paths, components are effectively stored at the central warehouse (LOZ). However, some of them will move directly to the assembly line (line stocking) to their POF and others will go first to the supermarkets area (kitting and sequencing line feeding policy). The distinction between these two pathways is based on line-side space restriction and component complexity. In a utopian scenario, all the components would go straight to the line. However, since space is not infinite, some of those components are housed at the supermarket in order to make some time for the space to be freed.

For supermarket components, kitting and sequencing processes are conducted. Here, components are carefully taken from their packages and dispatched to racks and kit containers according to the aforementioned philosophy (section 3.4.2). When the order picker completes the procedure, those organized components wait for a tow tug to dislocate them to their particular POF zone at the assembly line.

On this basis, it is possible to conclude that the line feeding policy is a hybrid feeding policy since multiple policies are used. All those line feeding policies are schematically described in Figure 8.

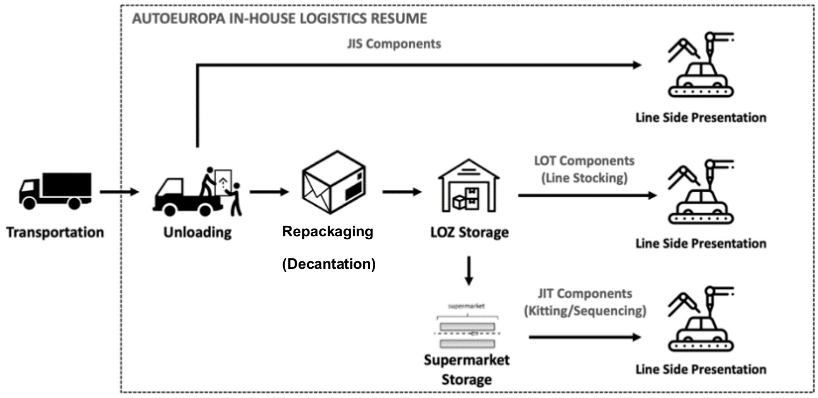


Figure 8 - In-House Logistics Feeding Strategies Scheme

3.5 – Problem Characterization: Project of Volkswagen Autoeuropa

The challenge posed by Volkswagen Autoeuropa is described in the present sub-section. Here, the main shortcomings of the current in-house logistics paradigm are provided and the motivations for changing. Afterwards, the fields of improvement and gaps are recognized, and the possible future internal structures are described. Finally, all the possible adversities and improvements of the alternative scenarios are described and the key performance indicators to evaluate those scenarios are duly identified.

3.5.1 - Main Shortcomings and Motivation

As shortly stated in chapter 1, there are four main trends which oblige firms to change.

First and foremost, the new mass customization era, where Autoeuropa is firmly subsumed, has increased the complexity of the logistics of their procedures. On this basis, the vastness of different components that must be efficiently available at the assembly line is massive. In this way, it is from the utmost importance to articulate, constantly update and optimize the in-house logistics processes in order to avoid line stoppages or, conversely, material surplus near the line.

Additionally, irrespective of human mental ability to make well-considered judgements and rational decisions, much evidence has been accumulated that there are several actions where humans are not performing well. Some of the activities performed by human beings are susceptible to several forms of inconsistency. Humans, undoubtedly, have concentration problems and physical limitations which, consequently, generates an enormous amount of possible errors and ergonomic problems (Davison, R. and French, S., 2007).

Thirdly, the emergence of new state-of-the-art technologies (already mentioned in sections 1.1 and 3.4) will bring up an extremely new paradigm of production. As aforementioned, the use of technology and automated robots has the capability to introduce flexibility inside the logistics processes, diminish the number of human errors, decrease complexity, perform several repetitive tasks, reduce human requirements and reduce ergonomic problems without compromising production. Essentially, in this new paradigm of full-fledged automated environment, a role change can be performed. With automated and mobile robots, the flexibility range is enlarged. Humans tend to be more static and robots start to perform more exhaustive duties.

Fourthly, picking and sequencing activities are extremely expensive activities as seen in the literature. It comprises roughly 55% of the in-house costs (Le-Duc and Roodbergen, 2007). Thereby, this represents a motivation to change the current structure since there is potential for cost minimization.

Last but not least, the possibility of change and introducing the aforementioned modification is evidently spurred by the tremendous search for efficiency. Basically, this opens the door to a radical change and to review all the current in-house procedures.

3.5.2 - Current Paradigm and Fields of Development

The scope of this research focuses on the in-house logistics operations concerning the supermarket areas until reaching the POF at the assembly line. The great majority of the in-house procedures is strongly dependent on humans. The order picking and sequencing/kitting activities are executed by operators. Basically, as mentioned in the previous section, a manual picker-to-product philosophy is developed. The order picker receives a picking list, moves a rack along with the supermarket stations and collects all the necessary components. Afterwards, the rack is placed on a predetermined space where a tow tug (not automated and driven by an operator) takes it to the assembly line. It is possible to claim that the current procedure is highly dependent on human labour (supermarket and line feeding operations). The current status leaves plenty of space for future improvements. According to Autoeuropa, the introduction of automated robots, or in other words, automated vehicles such as AGVs in the process is definitely to be considered the next generation of their supermarkets' and line feeding operation. Figure 9 represents the present-day paradigm.

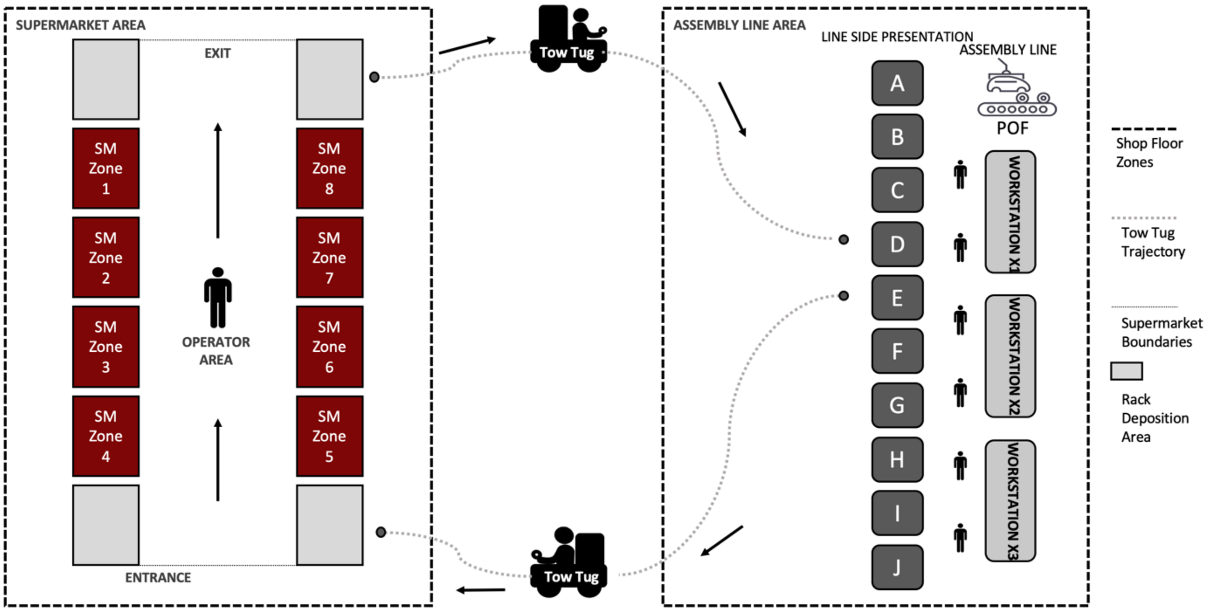


Figure 9 - Present-Day Paradigm

3.5.3 – Big Picture of the Future Environment

In order to better explain the new ideology, a visual scheme is provided in Figure 10:

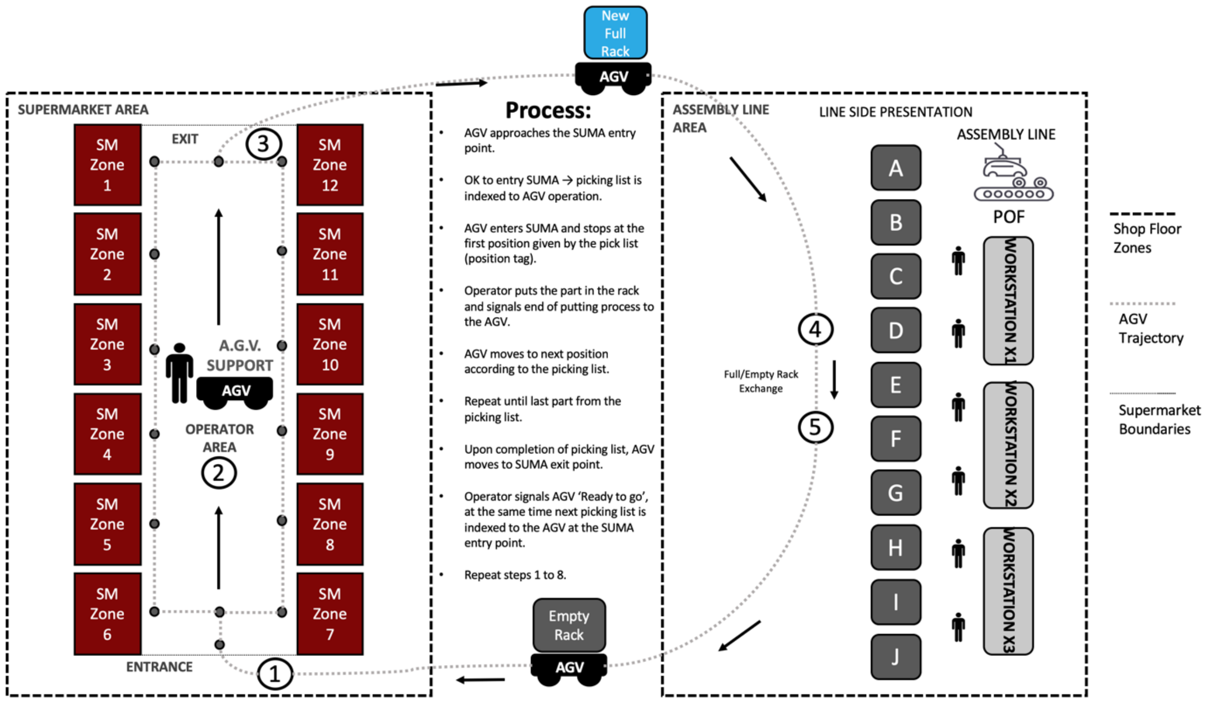


Figure 10 - Future Paradigm

This visual scheme represents a roadmap associated with a single supermarket. It corresponds to a general overview or a basis of all the possible alternative scenarios. Here, we are considering only one circuit and only one sequence.

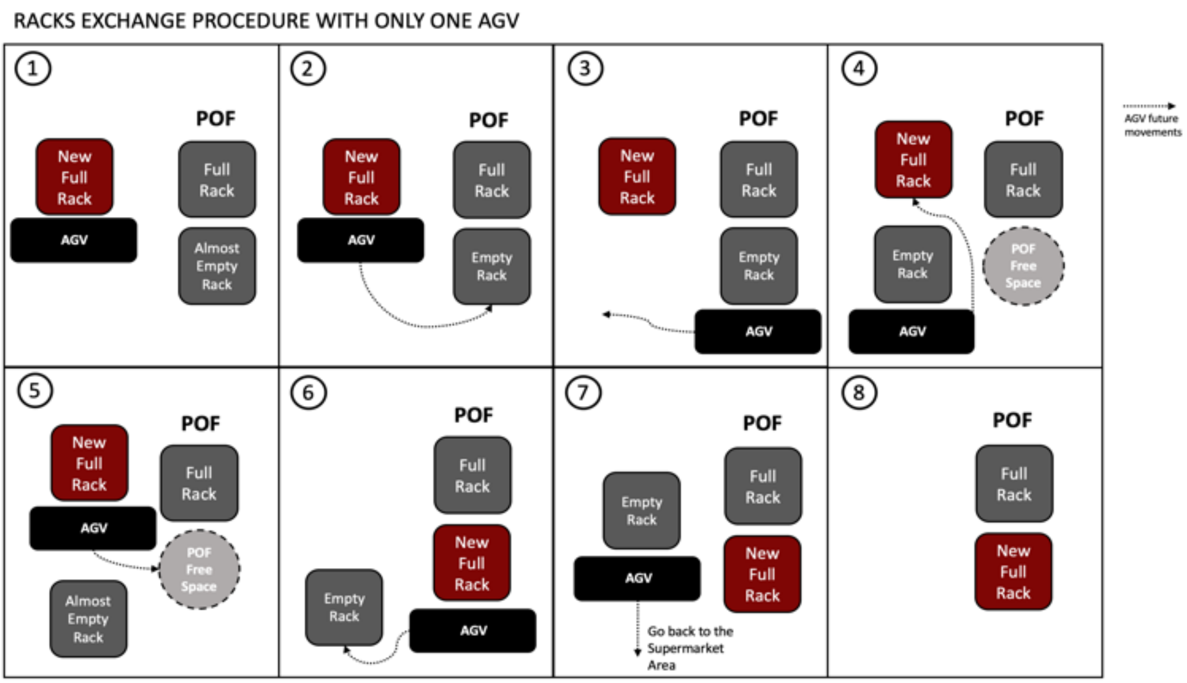
In order to make it easier to grasp the process, numbers were assigned to the various areas and stages of the procedure. The initial condition (1) is represented by an AGV on the verge of entering the supermarket with an empty rack. When the supermarket logistics operator provides permission to enter, a picking list is indexed to the AGV system and, evidently, stage (2) takes place. AGV receives information on the picking list and the position of the components throughout a geo-referencing technology and stops at the first position. Hereinafter, the robot-human partnership arises. The operator inserts the component(s) into the rack and signals end of the "putting" process to the AGV. Thereafter, the automated vehicle efficiently moves to the next position according to the picking list. In the aftermath of this procedure is accomplished, the AGV moves directly to the supermarket exit point (3). The operator signals "AGV Ready to Go", and at the same time, a picking list is indexed to the new AGV at the entrance point. The first AGV moves straight to POF destination (4), upon their parts are placed on POF rack. Finally, the reverse procedure begins. The empty racks are carried to the supermarket (5). This procedure is realized in an iterative way.

It is extremely important to highlight that this process is still not being implemented in the Volkswagen Autoeuropa.

3.5.4 – Operational Adversities and Improvements of the New Scenario

It is important to highlight that this novel system is not a perfect solution. Amid all this bright, there are several associated disadvantages and deprivations. Apparently and according to the scheme provided in section 3.5.3, the process is seemingly done through the use of a single AGV for a single sequence. However, the present strategy is extremely risky since the entire operation is fully dependent on a single machine. Furthermore, the number of manoeuvres to exchange the empty/full racks at the assembly line with only one AGV is huge, as presented in Figure 11 (up part).

Thereby, the use of more than one AGV clearly benefits the number of manoeuvres and minimizes the risk of the internal operation, as can be seen in Figure 11 (down part).



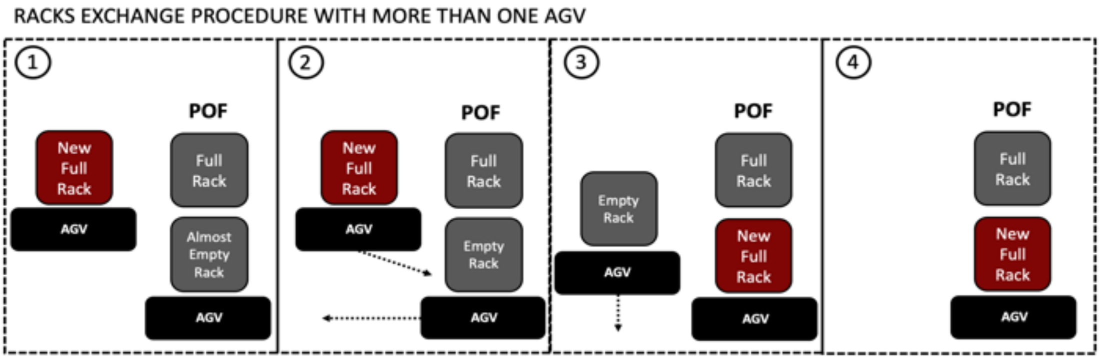


Figure 11 - Manoeuvres Comparison

According to Figure 11, it is possible to claim the number of moves is evidently reduced (from top to the bottom).

On top of the manoeuvre's optimization and dependency, the use of automated robots perhaps presupposes an impact in terms of electricity consumption. The continuous use of those vehicles in all the aforementioned areas of the shop floor will unsurprisingly consume their battery in a glance. Obviously, it will be important to balance those costs with human capital reduction. But regarding battery consumption, it will be important to think about a way and a place to recharge and replace them (recharging places, possible use of battery substitutes, etc.).

However, painting a picture of gloom misses the point. With the brand-new logistics practice, a plethora of meaningful aspects are improved. First of all, there is clearly a space for human capital reduction. The components and racks transfers between the supermarket and the assembly line are no more human dependent. In other words, the majority of in-house logistics routes will be evidently performed by an automated vehicle. Those vehicles will follow the predetermined marked lines on the shop floor without any driver. Staff expenses will be unmistakably slashed.

From a different standpoint, the process will be plainly more automated. On this basis, ergonomic and efficiency issues will be overcome. The supermarket operator is duly propped up by an AGV. The ergonomic problem related to the physical effort of pulling the rack will not be further called into question. Additionally, the AGV also has information regarding components collection (picking list). Thereby, the number of human errors will decline.

Obviously, the use of an AGV inside the supermarket has several ergonomic and errors minimization benefits. However, the gains in lights of efficiency are not tremendous.

In brief, all of these new practices and possible scenarios will have several impacts (benefits and adversities) which must be duly measured, before implemented, throughout several key performance indicators related to operations (operators/human occupation rate, AGVs occupation rate, area gains, makespan inside the supermarket, number of realized sequences per specific amount of time), finance (long-term viability of the project, initial investment, potential financial savings in terms of human capital reduction, differences in terms of energy expenses), ergonomic issues and sustainability (CO_2 emissions and energy consumption), which will be closely defined with Volkswagen Autoeuropa. Essentially, the major objective is to figure out the optimal number of AGVs per sequence to perform those activities, the in-house design and maximize results in terms of the aforementioned KPIs. Since, it is not an effortless answer, a research question is stated. Obviously, the perfect model would be to introduce the whole factory into the analyses. However, due to the different timeframes of this master thesis and the Volkswagen project (5 years) and also due to the complexity of the project, this thesis aims to achieve the first advances. For this purpose, a smaller sample ends up being extremely representative, effective and less time-consuming. Hereupon, a group of supermarkets was selected for the present research, which is defined as SUMA G Left Area. Numerically speaking, this area represents 5 supermarkets, 20 distinct component's families, more than 200 part numbers and respective containers, feeds 2 out of 8 workstations zones of the shop-floor.

In order to analyse the abovementioned area, the subsequent chapter is responsible for describing all the steps that were undertaken to retrieve, treat and process the data needed for analyse the feasibility of the new paradigm.

4 - Data Processing and Future Paradigm Design

A digital twin of a present or future reality requires an enormous variety of data in order to create the perfect parallelism and ensure accuracy and thoroughness of the model. The present chapter provides a consistent description of how data was retrieved and why it was collected to support the simulation model. The collected data were grouped in order to easily grasp the information and, each of those groups, will be thoroughly scrutinized in the subsequent subchapters.

As stated in section 3.5, the analysed area represents one of the largest supermarket areas (SUMA G13-G09 or SUMA G Left Area – Annex II) with 5 supermarket aisles, 10 queues of containers, 20 distinct component's families, more than 200 part numbers and respective containers and feeds 2 out of 8 workstations zones (Zone B and Zone E – Annex III) of the shop-floor. Moreover, some of the routes which will be performed by the AGVs responsible for feeding Zone E and B, will intersect some routes that will be performed by the AGVs responsible for feeding Zone A and C. By following this reasoning, the purposed project will be directly related to 2 out of 8 workstation zones nevertheless, it will affect half of the assembly plant's zones.

Gathering such a hefty amount of trustworthy data and, simultaneously, so detailed was solely possible through a regular presence at Volkswagen Autoeuropa shop-floor, as well as throughout an assiduous use of the group's internal virtual databases and software. This exhaustive data collection process was extremely time-consuming however, it fosters a better understanding of all the different important parts of the system. The data collection and processing process took almost 3 months (June-August 2019).

As will be observed in subsequent subchapters much of data retrieved from their platforms was unstructured data. On that basis, several data underwent through a process of skimming and screening with the aim of extracting hidden data and removing non-relevant details for the simulation model.

Some software, such as R, R-Studio and Excel, spurred and propped up the data treatment, allowing a better comprehension and easing its manipulation.

It is important to emphasize that some data presupposes irregular behaviours, such as non-automated tasks performed by humans, which hinders the accuracy and robustness of the data. Additionally, a timer was used to take several temporal measurements. Since there are no sensors associated, there is a slight percentage of error associated with the obtained figures. Although, several observations were performed in order to surely depicts those behaviours and reduce the amount of error.

Finally, it is important to highlight the fact that all the data described in this chapter served as input for the Visual Components 4.1 software. The present simulation software allows to performing 3D manufacturing simulations to design, test and validate new cost-effective, simple and incredible solutions for several industries (Visual Components, 2019). It represents one of the newest simulations software's in the market, it was released in 2016. The main reason for selecting the present software is based on an existing collaborative partnership between AE and Visual Components.

All the relevant data for the analysis is summarized in Table 2 and presented in the following sections.

Table 2 - Data Summary

Data Type	Sampling Time + Treatment	Requirements (Collection, Storing and Treatment tools)	Department Supplier	Responsible for Data Collection and Treatment
Physical Environment & Measures	1 day (June)	**Collection:** HLS Software	Logistics Planning	Author
Supermarkets Functioning, Sequence Families & Part-numbers Collection	15 days (July)	**Collection:** On Site Observation **Storing Data:** HLS layout printed sheets & Microsoft Office Excel	--	Author
Containers Information	3 days (June)	**Collection:** LISON virtual data base **Storing Data:** Microsoft Office Excel spreadsheet	Logistics Planning	Author
Resource Allocation	1 day (June)	**Collection:** On Site Observation **Storing Data:** HLS layout printed sheets & Microsoft Office Excel spreadsheet	--	Author
Supermarket Administrative Activities	(August)	**Collection:** AP software **Storing Data:** Printed Sheets from AP software	Industrial Engineering	Author + Industrial Engineering Department (Supermarket Responsible)
Picking Data	33 days (July/August)	**Collection:** LINCS virtual data base **Storing Data:** Microsoft Office Excel spreadsheet **Treatment:** Microsoft Excel and R & R-Studio	Logistics Planning	Author
AGVs Routes	3 Team Meetings (3 hours each) (July)	**Design:** Team Meeting + HLS PDFs and Microsoft Office PowerPoint	Logistics Planning	Author + Assembly Team
Assembly Line Information	1 day of observation (May) 1 workshop (July)	**Collection:** On Site Observation **Storing Data:** Microsoft Office Word	--	Author
3D CADs	(August)	**Collection:** E-mail **Storing Data:** PC	Volkswagen Suppliers	Author
Financial Data	1 meeting	**Collection:** Meeting **Storing Data:** Microsoft Office Excel	Logistics Planning	Author + Specialist from the Assembly Team

4.1 – Physical Data

The major basis of a simulation model dwell on the physical environment. Thereby, the physical structure corresponding to the layout of the assembly line and supermarket area was obtained throughout an internal firm's software, which is called HLS. This software has architectural characteristics which enables to develop accurate layouts.

Essentially, the aforementioned software allowed to acquire two-dimensional representations of the assembly plant layout. In other words, the output of the software is a 2D factory drawing in which supermarkets can be viewed with their containers and racks, the assembly line with their respective workstations and also the physical thresholds of the factory as well as its possible paths.

Moreover, the presented layout is sized according to reality. Therefore, it was possible to retrieve all the distances between the physical components of the space under analysis. The various locations of the factory were printed using PDFs format obtained from the HLS software and the distances were recorded manually on the printed sheets based on the information available on the computer software (Annex VII and VIII).

As an example, the following figure (Figure 12) presents the layout of 5 supermarket aisles, namely G13 to G09, extracted from the HLS where it was possible to draw distances as well as the physical organization of all system components:

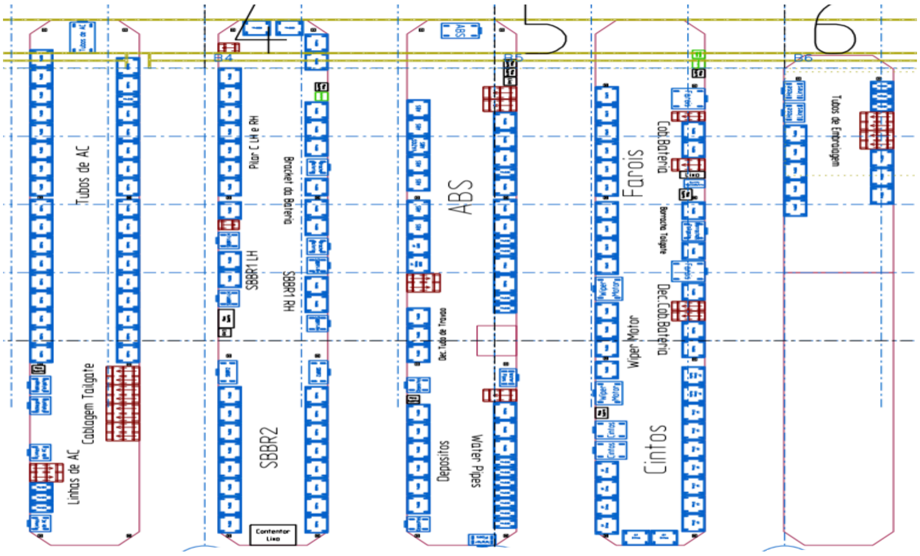


Figure 12 – Bidimensional Representation of Supermarkets G09-G13 (extracted HLS file)

4.2 – Supermarket Data

4.2.1 – Sequences Families and Part Numbers Locations

The above-mentioned software enabled to absorb the physical world. In essence, it was possible to acknowledge, for instance, the space occupied by the supermarket containers and racks, their distances and locations. However, the HLS did not allow to grasp and conceive which component (part number) corresponds to each of the blue containers represented in the two-dimensional representation, nor the type of container where parts are inserted and not even the family of parts corresponding to each area of the supermarket. In this way, extra work was needed to achieve those key points.

Each supermarket comprises several different components families (or sequence families), each family has several distinct part numbers (or picking locations) which are allocated inside a specific type of container.

In order to streamline the explanation, a concrete example will be picked up. In Volkswagen Autoeuropa, the supermarket G13 (Figure 13) is composed by three different areas and each of those areas is allocated to a family of components (in this specific case: AJA1, AIA1 and AKA1). Each of those families have several different part numbers. For example, in the case of the AJA1, there are 36 different types of AJA1 (part numbers) that are able to perform this task. All of those 36 components belong to the AJA1 sequence family but have slightly different specifications that may change according to the customer request.

Each of those part numbers are stored in a specific container on the supermarket and each container has several components that have the same part number.

First and foremost, areas corresponding to components families were properly identified (Figure 13).

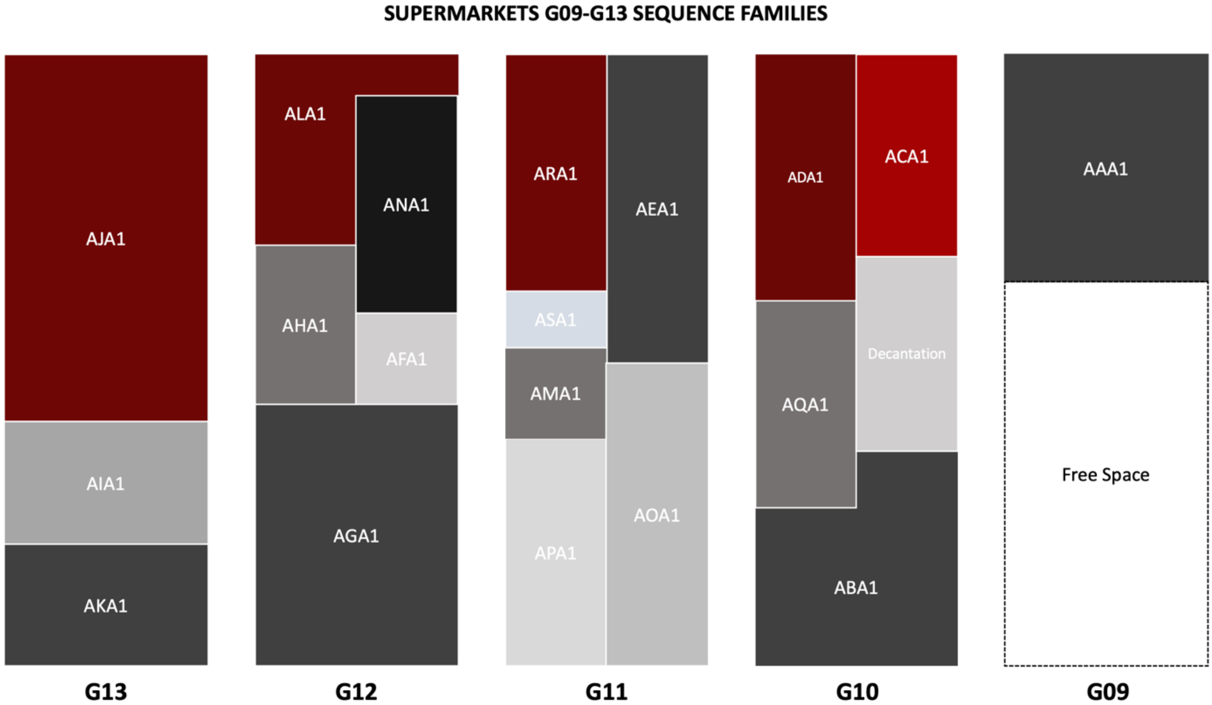


Figure 13 - Supermarkets G13-G09 Areas & Components

In order to retrieve the information regarding the part numbers location on the supermarket several tours around the shop-floor had to be performed. Objectively, throughout on-site observation of the supermarkets the part numbers were manually registered on the printed sheets of the HLS software (Figure 14 – as an example - and Annex V and VI). In this way, about 200 part numbers were located and registered manually during several staged periods that totalled about 6 hours over the several days.

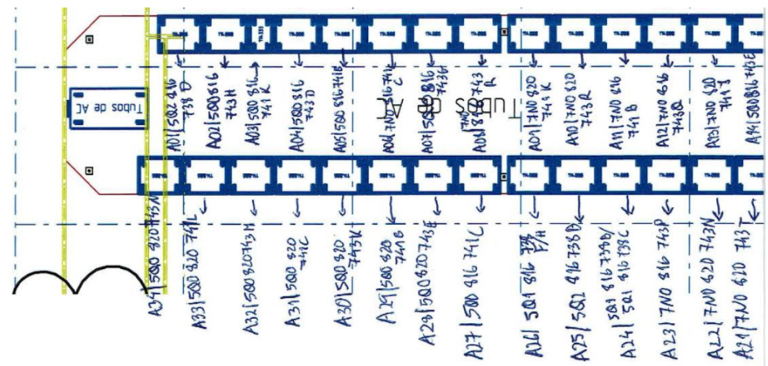


Figure 14 - Exemplifies How Part Numbers Were Manually Collected (scanned file)

In Figure 14, it is possible to verify that for each container (blue box) there is an associated visual description (such as “A34”) in order to help out the logistics operator to find out the picking location of a specific part number separated by a slash from its respective part number. The aforesaid method was repeated for all the supermarket containers as presented in the Annex V and VI.

4.2.2 – Containers Information

Concerning the containers where each part number is allocated a distinct procedure was undertaken. In the aftermath of the attainment of the part numbers and their respective locations an internal online information system and data based was consulted. This virtual database, called LISON, has meticulous information regarding the containers type and reference on which each part number is allocated at the facility. All the 200 part numbers were inserted, one by one, in LISON in order retrieve the container information. On the basis of this data and the information retrieved in the previous subchapter, an Excel worksheet was developed with all the knowledge regarding the supermarket, sequence families, part numbers and their respective sort of containers.

Basically, all the manually collected part numbers were written down in LISON and the type of container was retrieved. Afterwards, all this information was gathered in an excel worksheet for each supermarket (Table 3).

Table 3 - Example of Organized Data from LISON

PART NUMBER	ALPHANUMERIC DESIGNATION	CONTAINER REFERENCE	CONTAINER TYPE	NUMBER OF COMPONENT	SEQUENCE FAMILY	PART TYPE	SUPERMARKET
5Q2816738D	A01	114888	GLT	170	AJA1	AJA1	G13
5Q0816743H	A02	114888	GLT	260	AJA1	AJA1	G13
5Q0816741K	A03	114333	GLT	40	AJA1	AJA1	G13
5Q0816743D	A04	114888	GLT	260	AJA1	AJA1	G13
5Q0816741B	A05	114888	GLT	100	AJA1	AJA1	G13
7N0816741C	A06	114888	GLT	110	AJA1	AJA1	G13
5Q0816743G	A07	114888	GLT	260	AJA1	AJA1	G13
……..	……..	……	…..	…..	…..	……	……

Table 3 shows part of an Excel worksheet with all the information regarding the components of Supermarket G13 (part numbers, alphanumerical designation, container type and reference, number of components per container and sequence family). The present information regarding the containers types is crucial. Each container reference has specific standardized measures which are fundamental for a realistic construction of the supermarkets in the digital twin.

4.2.3 – Resource Allocation, Workload and Supermarket Operator Trajectory

The simulation model might be clearly fragmented into three key sections: the supermarket sequence activity, the AGV journey from the supermarket to the assembly line and vice-versa (line feeding), and the delivery of the material at the assembly line.

It is from utmost importance to figure out which activities are incorporated in those sections. The section which explicitly encompasses more activities is the supermarket sequence activity.

Once again, on-site observation was the fundamental mechanism to attain those figures. Basically, by visualizing the work performed by the supermarket logistics operators it was possible to apprehend the tasks which they must execute when they are sequencing a family of components (workload). Additionally, from a cost optimization standpoint, Autoeuropa strives for minimizing the number of supermarket logistics operator. Consequently, and in general, each operator is liable for more than one sequence family of components. Therefore, a table was developed with all the sequences that each operator is accountable for (Table 4).

Table 4 - Resource Allocation

Operator	Sequence Family	Supermarket Area	Supermarket
Operator A	AKA1	G	G13
Operator A	AIA1	G	G13
Operator A	AJA1	G	G13
Operator B	AMA1	G	G11
Operator B	ALA1	G	G12
Operator B	ANA1	G	G12
Operator B	AFA1	G	G12
Operator C	APA1	G	G11
Operator C	AOA1	G	G11
Operator C	AGA1	G	G12
Operator C	AHA1	G	G12
Operator D	AEA1	G	G11
Operator D	ARA1	G	G11
Operator D	ASA1	G	G11
Operator E	AAA1	G	G09
Operator E	ACA1	G	G10
Operator E	ADA1	G	G10
Operator F	ABA1	G	G10
Operator F	AQA1	G	G10

In a nutshell, table 4 allows to acknowledge how many logistics operators are needed to perform all the sequences in supermarkets G13-G09 and their respective workload. As stated, 6 workers can be identified with their respective sequence tasks.
Ultimately, a roadmap was developed with the logistics operator trajectory inside the supermarket aisle.

4.2.4 – Supermarket Activities

In the same line of thought, the supermarket activities were highlighted as of high relevance. Those activities might be duly portioned into two main fields: moving activities and non-moving activities.
Regarding the moving activities, it is extremely simple to incorporate that into the simulation model inasmuch as it is possible to retrieve the time it takes based on the average speed of the human worker or mobile vehicle and the distance covered (through the HLS and based on the travelled space).
The non-moving activities corresponds to a broad set of the activities where the logistics operator or the mobile vehicle are stopped. Thereby, since there is no movement, the elapsed time during the operation cannot be achieved based on distance and speed (as it was on the aforementioned activities). For this purpose, several meetings with the Industrial Engineering department of Volkswagen Autoeuropa, more particularly with the responsible for the supermarket areas, were made. The above-mentioned department has the function of fathoming the workload of the human workers at the facility. Throughout

several analysis made in the past, by observation and with the aid of an internal software (AP software), a list of all the activities performed by the supermarket operators with their associated times was provided by the Industrial Engineering Department (these files are not reported in this document due to confidentiality requirements).

4.2.5 – Picking Data

Historical Data

Replicating the operator behaviour while picking a particular sequence is quite complex. The picking activity of a specific sequence is almost always different. Basically, when an operator is performing a sequencing activity, the operator will pick the components according to the picking list. Wherefore, the picking list is evidently intertwined with the assembly line orders which, in turn, are based on customer orders. Therefore, the part numbers collected in each picking activity are not always the same. However, since they are dependent on customer orders, patterns and bias might be identified.

By following this line of reasoning, those trends might be observable by looking into the historical data of pickings. Each operator possesses a Tablet PC which record several information, including all parts numbers which have been picked. Afterwards, the present information is swiftly sent and stored, for a specific period of time in a virtual database (LINCS).

During an entire month (which corresponds to approximately 10% of an annual sample), the Tablet PC information was extracted to an Excel Sheet on a daily basis. Twenty-five Excel worksheets were elaborated for each sequence, which corresponds to 425 spreadsheets. Thereafter, all the daily Excel Sheets were gathered into a single worksheet (Table 5).

Table 5 - Part of a Tablet PC Information Retrieved

DATE	VALUE1	VALUE2	VALUE3	SESSION_ID	TERMINAL	OP_ID
2019-07-01 23:59:04:5836503	Battery	MAIN	Battery Level Charge Changed to 63%	E535173A-6F83-42EA-8CF8-C8E35A3243B5	10.81.119.79	7941
2019-07-01 23:59:04:5836503	Battery	MAIN	Battery Indicator Color: Color [Green]	E535173A-6F83-42EA-8CF8-C8E35A3243B5	10.81.119.79	7941
2019-07-01 23:56:48:7074116	Battery	MAIN	Battery Level Charge Changed to 64%	E535173A-6F83-42EA-8CF8-C8E35A3243B5	10.81.119.79	7941
2019-07-01 23:56:48:7074116	Battery	MAIN	Battery Indicator Color: Color [Green]	E535173A-6F83-42EA-8CF8-C8E35A3243B5	10.81.119.79	7941
2019-07-01 23:55:19:3660547	Info	FAMILY	Generating FAMILY Buttons	E535173A-6F83-42EA-8CF8-C8E35A3243B5	10.81.119.79	7941
.....	.....	.....	....	....	.....	.....

The information was filtered in order to rule out all the non-picking data (other activities performed by the tablet that are not directly related to picking activities) and, consequently, the part numbers were drawn throughout a blend of Excel functions (Table 6).

In order to have a better idea of the amount of data collected throughout LINCS virtual database regarding the picking process, Table 7 is presented.

Table 6 – Part of Tablet PC Filtered Data (Only with Pickings)

DATE	VALUE1	VALUE2	VALUE3	SESSION_ID	TERMINAL	PART NUMBER	P.N. VALUES
2019-07-01 23:39:27:1796121	Processed Info	PICK	BAY_NO: 1019 , STATE: 2 , PARTNUMBER: 2GA 971 147 A , DESC: A01 , QTY: 1 , BARCODE: A7A , BCVALID: 1 , POS: 2 , SEQUENCE: 333	7E333DFA-5B91-4ED1-BCDA-10FD4F6A170D	10.81.119.79	2GA 971 147 A	2GA971147A
2019-07-01 23:39:27:1796121	Processed Info	PICK	BAY_NO: 1019 , STATE: 2 , PARTNUMBER: 2GA 971 147 A , DESC: A01 , QTY: 1 , BARCODE: A7A , BCVALID: 1 , POS: 8 , SEQUENCE: 340	7E333DFA-5B91-4ED1-BCDA-10FD4F6A170D	10.81.119.79	2GA 971 147 A	2GA971147A
2019-07-01 23:39:27:1796121	Processed Info	PICK	BAY_NO: 1019 , STATE: 2 , PARTNUMBER: 2GA 971 147 J , DESC: A05 , QTY: 1 , BARCODE: A7J , BCVALID: 0 , POS: 1 , SEQUENCE: 331	7E333DFA-5B91-4ED1-BCDA-10FD4F6A170D	10.81.119.79	2GA 971 147 J	2GA971147J
2019-07-01 23:39:27:1796121	Processed Info	PICK	BAY_NO: 1019 , STATE: 2 , PARTNUMBER: 2GA 971 147 J , DESC: A05 , QTY: 1 , BARCODE: A7J , BCVALID: 0 , POS: 12 , SEQUENCE: 345	7E333DFA-5B91-4ED1-BCDA-10FD4F6A170D	10.81.119.79	2GA 971 147 J	2GA971147J
2019-07-01 23:39:27:1796121	Processed Info	PICK	BAY_NO: 1019 , STATE: 2 , PARTNUMBER: 2GA 971 147 S , DESC: A09 , QTY: 1 , BARCODE: A7S , BCVALID: 0 , POS: 11 , SEQUENCE: 344	7E333DFA-5B91-4ED1-BCDA-10FD4F6A170D	10.81.119.79	2GA 971 147 S	2GA971147S

As an example, the Excel Function (Equation 1) used to extract the part number from VALUE3 was:

Equation 1 - Excel Formulation to Extract Picked Part Numbers

(1) MID(Tabela2[@VALUE3]; FIND ("PARTNUMBER"; Tabela2[@VALUE3]) +12; FIND ("DESC"; Tabela2[@VALUE3])-FIND ("PARTNUMBER"; Tabela2[@VALUE3])-14).

Table 7 - Amount of Data Retrieved for Each Sequence Family

SEQUENCE FAMILY	COLLECTION PERIOD (DAY)	Tablet PC Amount of Data
AIA1	25	1,114,088
AKA1	25	1,114,088
AJA1	25	1,114,088
AGA1	25	1,165,730
AFA1	25	620,149
AHA1	25	1,165,730
ANA1	25	620,149
ARA1	25	1,499,098
AMA1	25	620,149
AEA1	25	1,499,098
AOA1	25	1,165,730
APA1	25	1,165,730
ACA1	25	879,656
ABA1	25	955,660
AQA1	25	955,660
ADA1	25	879,656
AAA1	25	879,656

In the wake of this soft data treatment, a more complex treatment was applied. The historical picking data table was, consequently, used to generate a probability distribution of picking for each sequence family. Thus, the picking behaviour will be based on those probability distributions.

Data Treatment

Throughout the use of Excel, the raw data was filtered, the picked part numbers were withdrawn and, finally, a pivot table was generated in order to obtain the absolute frequency of pickings associated to each part number for each sequence family.

Afterwards, based on the absolute frequency of pickings a probabilistic distribution was generated for each sequence family of components.

For this purpose, R and Rstudio software's were used in order to figure out which probabilistic distribution might fit to the obtained data. R encompasses a programming language with a specific free software environment for statistical computing, data treatment and analysis, as well as for graphic visualization. The Rstudio corresponds to an integrated development environment and allows to get graphical user interfaces. One of the R's greatest strengths is that the R community develops active contributions in terms of providing packages. Those packages which corresponds to pre-programed functions that allows the user to reach out certain findings without the need of intensive programming. For the present purpose, the *fistdistrplus* package was employed. This general package aims at helping parametric distributions to censored or non-censored data. There are two major functions associated to the aforementioned package. *Fitdist* is used for fitting on non-censored data and *fitdistcens* for censored data. However, before estimating the probabilistic parameters, the distribution function that better fits the set of data must be envisaged. The choice of candidate probabilistic distribution may be helped by the use of *descdist* and *plotdist* functions. The *descdist* function computes descriptive parameters of an empirical distribution for non-censored data and provides a skewness-kurtosis plot. The second one plots an empirical distribution (non-censored data) with a theoretical one if specified.

However, after obtaining the results of the probability distributions that best fit the absolute frequency data obtained, it was possible to acknowledge that these distributions could not be applied (Morais, Manuel, 2010). This finding was based on the fact that the discrete dataset composed of part numbers is a dataset from which no order can be retrieved. In other words, part numbers do not have a specific order (such as ages, weight, height, dates, etc.). Thus, the developed probability function was not a predefined probability distribution (normal, binomial, poison, etc.). The probability function describes the behaviour of a chance-dependent phenomenon based on the relative probabilities of part numbers.

Therefore, the relative probabilities of each part number of each sequence were obtained through the absolute frequencies of the generated pivot table.

Thus, the probability distribution function conforms to a discrete function that assigns to each part-number its relative frequency during the observation period.

Table 8 displays a pivot table with the respective absolute and relative frequencies associated with each part number of AJA1 sequence family. This pivot table seems quite simple, however it should be noted that for setting up those figures, data from 25 days of activity (600 hours) were collected. Consequently, those numbers translated into about 1,114,088 occurrences on the operators' tablet PCs. These occurrences were filtered, and, as an example, for the AJA1 sequence family 39,880 pickings were obtained. Ultimately, the pivot table was created and plotted (Table 8).

Table 8 - AJA1 Picking Probabilistic Distribution

PART NUMBERS	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY
5Q0816741B	6199	15.54%
5Q0816741C	3337	8.37%
5Q0816741K	3522	8.83%
5Q0816743D	4356	10.92%
5Q0816743E	1026	2.57%
5Q0816743G	3491	8.75%
5Q0816743H	4167	10.45%
5Q0820741C	1	>0.00%
5Q0820743M	1	>0.00%
5Q1816738F	6750	16.93%
5Q2816738B	1	>0.00%
5Q2816738D	1106	2.77%
7N0816741B	77	0.19%
7N0816741C	2173	5.45%
7N0816743M	42	0.11%
7N0816743N	38	0.10%
7N0816743Q	754	1.89%
7N0816743R	1424	3.57%
7N0820741K	707	1.77%
7N0820743N	21	0.05%
7N0820743R	673	1.69%
7N0820743S	14	0.04%
Total Geral	**39880**	**100.00%**

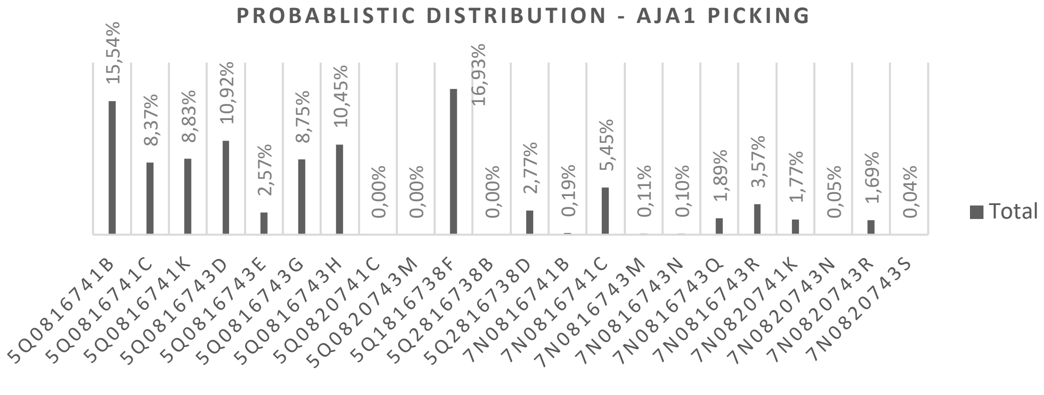


Figure 15 - Graphical Representation of the Probabilistic Distribution of the AJA1 Picking Activity

In order to introduce those probability distributions into the simulation software, it was mandatory to elaborate a Python code which will be subsequentially explained in chapter 5. However, this Python code receives, as input, those probabilistic distributions in a cumulative way. Thus, based on the individual probabilities, a second table was created with the accumulated relative frequencies (Table 9).

Table 9 - Cumulative Probabilistic Distribution of AJA1 Sequence Family

PART NUMBERS	RELATIVE FREQUENCY	CUMULATIVE PROBABLISTIC DISTRIBUTION
5Q0816741B	15.54%	0.1554
5Q0816741C	8.37%	0.2391
5Q0816741K	8.83%	0.3274
5Q0816743D	10.92%	0.4367
5Q0816743E	2.57%	0.4623
5Q0816743G	8.75%	0.5499
5Q0816743H	10.45%	0.6544
5Q0820741C	~0.00%	0.6544
5Q0820743M	~0.00%	0.6544
5Q1816738F	16.93%	0.8237
5Q2816738B	~0.00%	0.8237
5Q2816738D	2.77%	0.8514
7N0816741B	0.19%	0.8534
7N0816741C	5.45%	0.9078
7N0816743M	0.11%	0.9089
7N0816743N	0.10%	0.9099
7N0816743Q	1.89%	0.9288
7N0816743R	3.57%	0.9645
7N0820741K	1.77%	0.9822
7N0820743N	0.05%	0.9827
7N0820743R	1.69%	0.9996
7N0820743S	0.04%	1

4.3 – Line Feeding Data

4.3.1 – AGVs Routes

One of the two major objectives is to minimize the process time. In order to propped up this objective, the AGVs routes were sized as a way of minimizing the distance travelled by the mobile vehicles. Once again, HLS software was from utmost importance fostering the efficiency of collecting this data. First and foremost, all the possible and feasible pathways were identified. Consequently, all those trajectories were analysed with the assistance of the Logistics Planning Department, more specifically the Assembly Team, so as not to generate an ill-advised decision.

Since for each route only less than 3 possible paths were found, it was not necessary to make an optimization model to find the route that minimized the distance the most. Based on temporal efficiency and benefit in terms of internal logistics (avoiding possible bottlenecks, difficulty in supply, difficulty in manoeuvring, etc.) the route was chosen. Figure 16 shows some of the routes defined with the help of HLS for 8 sequences belonging to the supermarkets under analysis.

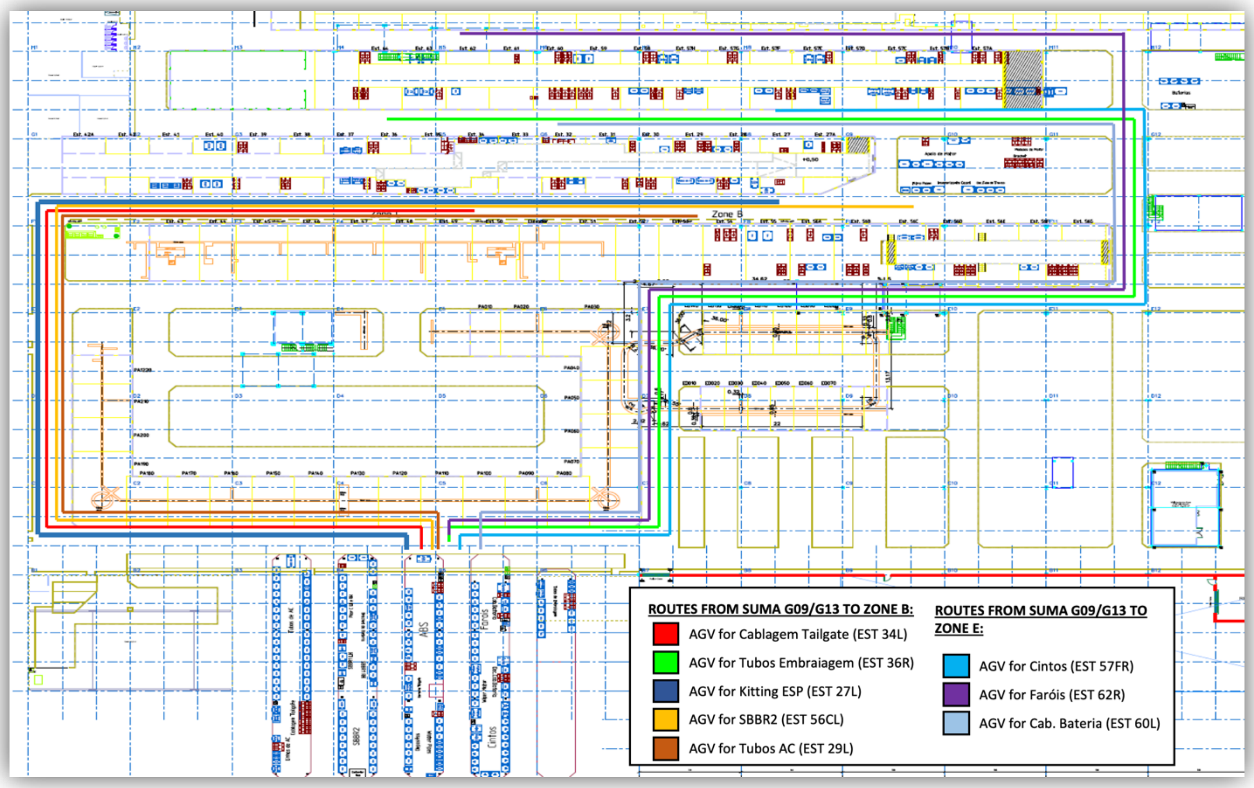


Figure 16 - Routes Designed Together with the Assembly Team (Layout Retrieved from HLS and Lines & Subtitles Added Through PowerPoint)

Additionally, it should be emphasized that for the above-mentioned procedure (line feeding) is not necessary to measure the length of time this path may take. This is due to the fact that it corresponds to a moving activity, based on the distance travelled and the speed that the AGV which will be introduced in the simulation, in the most varied aspects (straight line, curves, manoeuvres, etc.), the elapsed time will be automatically attained.

4.4 – Assembly Line Delivery & Consumption

4.4.1 – Assembly Line Delivery & Consumption Functioning

Comparatively to the supermarket, the amount of data regarding the assembly line functioning is considerably lower. However, regardless of the volume of figures, it is highly important to figure out how it operates.

Generically, most of the workstations under analysis work as follows. Basically, at each workstation a task has to be performed, more specifically, the assembly of a particular component must be properly done. The assembly line operator has the components at his disposal in the sequence racks and is assembling them as the cars pass through the station.

The bulk of those workstations work with a specific strategy called Alternating/Alternative POF. Here, two sequence racks are duly arranged at each station as shown in :

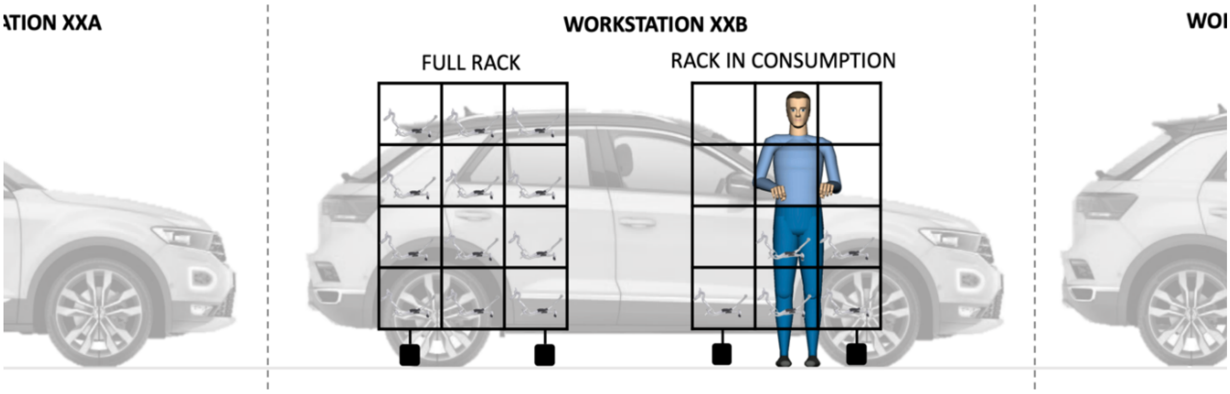


Figure 17 - Assembly Line Functioning

Essentially, one rack is under consumption and the other one is full. The assembly line operator picks up the components, which were previously sequenced, from the consumption rack and assembles the cars. Simultaneously, the other rack is set aside in order to serve as a buffer, and, additionally, to not jeopardize and secure the production when the "rack in consumption" runs out.

Hereinafter, the empty rack might be gleaned and replenished by a new previously sequenced full rack (which will suit as a new buffer for the new rack in consumption). Subsequently, the operator will start collecting material from the rack that was initially full. The present fact represents the reason why is called an alternative POF. In a simplistic way is because the operator switches between two positions (depending on the rack being consumed).

4.4.2 – Numerical Evaluation of Assembly Line Procedures

In the aftermath of a lightweight description of the assembly line functioning, it is surely possible to dive into a more analytical depiction.

First of all, each operator does not have unlimited time to execute a specific task at each workstation. In other words, it would obviously be ludicrous if each operator does not have limited time to assemble each part numbers. Unsurprisingly, the assembly line has a predetermined steady speed. Numerically speaking, per hour (considering only uninterrupted working hours) 45 cars are produced on average. In other words, in the hourly time frame about 45 cars pass on each workstation. Therefore, from a mathematical standpoint, this means that each car spends 1.33(3) minutes (1 minute and 20 seconds) at each workstation. It is important to highlight that sometimes there are delays in the performance of certain tasks. On this basis, the assembly line has several buffer zones. However, as a way of simplification, those delays and buffer zones will be considered out of the scope of the present dissertation.

In accordance with the abovementioned information, the production operator has 1.33(3) minutes to perform its task and assemble the component.

The aforesaid numbers are not an end in itself. Those numbers enable to evaluate the cycle time. Basically, it allows to compute the amount of time that a rack takes to become empty (racks consumption time), which simultaneously corresponds to the maximum amount of time for the logistics operators to create another full rack (which includes the picking and sequencing procedure, several administrative procedures and the line feeding – cycle time). Thus, the rack consumption time corresponds to the product of the rack size by the quotient between the minutes per hour and the volume of cars produced per hour. The cycle time is critical for the subsequent analysis. For instance, if the picking, sequencing, administrative and line feeding procedures take more time than the consumption rack time the number of AGVs and racks must be higher.

4.5 – 3D CADs

Conversely to several simulation software's, in Visual Components 4.1 building a three-dimensional scenario which turns out to be extremely similar to the actual scenario is quite important for more reliable results. In order to enhance even more the realism of the simulation model and ensure successful results 3D Solidworks CADs were provided by Volkswagen Autoeuropa suppliers. Those 3-dimensional computer aided designs have the actual dimensions which facilitates the structuring of the layout. 3D CADs have been made available for some of the racks, containers and also container support bases.

4.6 – Financial Data

The operational dimension is a fundamental area of analysis. However, if the operational benefits are not financially bearable, the project will not be viable. Thus, a complementary financial analysis would be performed.

From a supermarket and assembly line standpoint, it is estimated that there are no significant amendments in the scope of the present investigation. Therefore, financial data regarding the line feeding activity was properly retrieved. Costs in line feeding encompass a fixed and variable component as they depend on sequence families, rack sizes, production volume and also a priori fixed contractual issues. For the sake of simplicity, all of those tranches were correctly gathered in order to obtain a cost per car produced per route.

Antagonistically to the future AGV's scenario, where each AGV is indexed to a specific sequence, the current industrial tow tugs on their routes take more than one sequence family to the line. Following this reasoning the actual routes were determined and analysed in terms of costs (Table 10).

Table 10 - Line Feeding Routes Cost Analysis

Line Feeding Routes (SUMA G09-G13)	Sequence Families	Cost per Car
1	ADA1+ AHA1 + AFA1	0.229 €
2	ALA1 + ACA1 + ABA1 + AQA1	0.362 €
3	AIA1 + AJA1 + AKA1	0.234 €
4	ANA1 + AMA1 + AEA1 (including ARA1) + AOA1	0.364 €
5	AAA1 + APA1 + AGA1	0.301 €

To obtain the annual values for a temporal analysis simply multiply the value per car by the annual production level (251,874 cars). The above figures represent the potential savings which will be achieved with the new scenario without operators doing line feeding. Conversely to the aforementioned financial gain, a large investment in tangible fixed assets will be required given the number of AGVs. Each of the AGV entails an investment of approximately 25,000 euros. There is also a cost or benefit associated with differences in energy consumption between AGVs and industrial motorcycles which will be disregarded for the present analysis.

5 – Modelling, Results & Implications

Forthwith upon data collection and processing, the model started to be developed. In the present chapter, two analyses are examined. Firstly, a static analysis was designed. This first analysis is more easily constructed, allowing to quickly understand some important concepts which were fundamental for the dynamic analysis, to understand how the collected data was articulated and to develop an analysis methodology which will be, consequently, used for the simulation outcomes. The second one comprises a dynamic analysis which overcomes some of the shortcomings of the static analysis.
In both analyses, a description of the reasoning and how they were implemented is conducted. subsequently, the analysis methodology was described, the results were evidenced, as well as the respective limitations of each of the models.

5.1 – Static Model

The word "static" in this analysis comes out from the fact that it represents an analysis in which there is neither movement nor variability. Basically, the cycle performed by AGV was broken down in the various activities. To each of those activities was allocated an average time obtained from the data collection carried out in the previous chapter. Then, the times were summed up in order to obtain one of the most important dimensions of the analysis, the cycle time associated to each sequence family. By comparing the cycle time with the consumption time of each rack in the assembly line, it was possible to determine the number that would be considered ideal for AGVs and racks. All the aforementioned reasoning is explained with more detail in the subsequent subsections.

5.1.1 – Modelling

Prior to the dynamic analysis, a theoretical analysis was developed in order to have a first basis of forecasting regarding the number of AGVs.
As previously mentioned in section 4.4.2., the cycle time is a vital component in the present analysis, and it is also the basis of reasoning for the simulation itself. With this in mind, all the times related to the activities which influence the cycle time were estimated (Figure 18 and Equation 2).

Equation 2 - Cycle Time Equation

$$(2) \quad \boldsymbol{Cycle\ Time = Administrative\ Procedures + Transportation + Picking + AGV\ Manoeuvers + Waiting\ Times + Buffer}$$

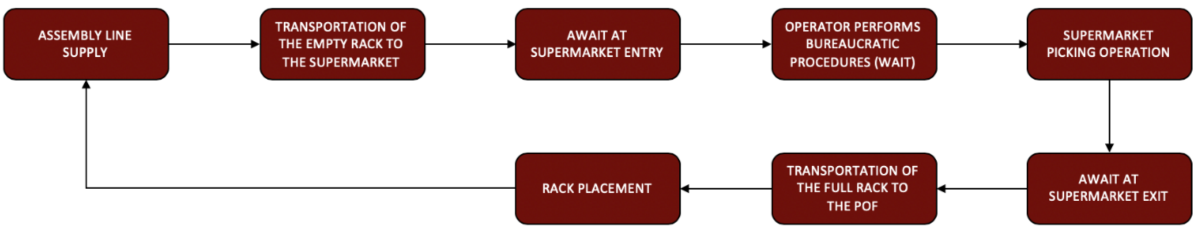


Figure 18 - AGV Cycle

The picking and sequencing times were withdrawn from the Industrial Engineering Department of Volkswagen AE, as well as the administrative procedures.

The line feeding/transportation times were computed based on the predetermined routes, the distance travelled by the AGV and its average speed. Additionally, when arriving at the supermarket or at the assembly line, the AGV must perform several couplings with the racks in order to exchange them. This time was obtained throughout the observation of some already implemented AGVs, with the aid of a timer. Finally, a buffer time was added at the entry of the supermarket. Afterwards, all those times were summed up in order to get the total cycle time.

Simultaneously, the rack consumption time was calculated. On this basis, the rack sizes were multiplied by the time each car takes in each workstation (1,33(3) minutes). This time comprises how long a rack takes to be empty at the assembly line, which is called consumption time. With those two important dimensions it is possible to draw several conclusions regarding the number of AGVs and racks.

Essentially, if the cycle time is longer than the time a rack takes to become empty, the number of AGVs responsible for this sequence must be greater than one. In other words, this means that the time it takes for a rack in consumption to be empty is shorter than the time it takes for an AGV to cycle all the way back to a full rack, meaning there will be a shortage of material at the assembly line. Thereby, the number of AGVs allocated to each sequence will be given by rounding up the quotient between the cycle time and the rack consumption time. However, it is important to highlight that the POF strategy will influence the number of racks. The number of racks when using a "same POF strategy" (i.e. only one rack) is equal to number of AGVs, otherwise by using an "alternating POF strategy" (2 racks – one in consumption and another one full) a rack should be added to the aforementioned quotient calculation.

5.1.2 – Static Results

Within this framework of thought, Table 11 was developed with all the above reasoning to estimate the number of AGVs and racks according to the rack sizes, times and type of POF at the assembly line.

Table 11 - Static Analysis Results

Sequences	SUMA	POF reference	Sequence Process	Cars / Hour	Parts/ Rack	Distance SUMA – POF (m)	Distance POF – SUMA (m)	SUMA Waiting Time (min)	Sequence Time (min)	Rack Change Time SUMA (min)	Transport SUMA – POF (min)	Rack Change Time POF (min)	Transport POF – SUMA (min)	Cycle Time min (min)	Cycle Time max (min)	Material / Transport (min)	Qty / AGV / Circuit	Qty / Racks / Circuit
AAA1	G	L1-36R	1	45	12	275	275	3.00	6.223	0.81	7.64	0.81	7.64	26.12	32.65	16	3.0	4.0
ABA1	G	L1-57FR	1	45	24	285	285	3.00	19.780	0.81	7.92	0.81	7.92	40.23	50.29	32	2.0	3.0
ACA1	G	L1-60L	3	45	12	250	250	3.00	3.773	0.81	6.94	0.81	6.94	18.51	23.14	16	1.4	1.4
ADA1	G	L1-62R	1	45	12	295	295	3.00	5.677	0.81	8.19	0.81	8.19	26.69	33.36	16	3.0	4.0
AEA1	G	L1-27L	1	45	12	210	210	3.00	11.192	0.81	5.83	0.81	5.83	27.48	34.35	16	3.0	4.0
AGA1	G	L1-56CL	1	45	12	265	265	3.00	5.883	0.81	7.36	0.81	7.36	25.23	31.53	16	2.0	3.0
AIA1	G	L1-34L	1	45	24	185	185	3.00	4.303	0.81	5.14	0.81	5.14	19.20	24.00	32	1.0	2.0
AJA1	G	L1-29L	1	45	12	190	190	3.00	6.427	0.81	5.28	0.81	5.28	21.60	27.00	16	2.0	3.0
AKA1	G	L1-56CR	1	45	24	175	175	3.00	4.352	0.81	4.86	0.81	4.86	18.69	23.37	32	1.0	2.0
AFA1	G	L1-57CL	1	45	24	240	240	3.00	5.724	0.81	6.67	0.81	6.67	23.68	29.60	32	1.0	2.0
AHA1	G	L1-57CR	1	45	24	250	250	3.00	5.658	0.81	6.94	0.81	6.94	24.17	30.21	32	1.0	2.0
ALA1	[redacted]																	
AMA1	[redacted]																	
ANA1	[redacted]																	
AOA1	G	L1-41L	1	45	12	172.5	172.5	3.00	1.432	0.81	4.79	0.81	4.79	15.64	19.54	16	2.0	3.0
APA1	G	L1-32L	1	45	12	430	430	3.00	4.87	0.81	11.94	0.81	11.94	33.38	41.73	16	3.0	4.0
AQA1	G	L1-57DL	1	45	24	235	235	3.00	3.306	0.81	6.53	0.81	6.53	20.98	26.23	32	1.0	2.0

It represents a static mathematical analysis and certainly a satisfactory starting point in order to begin to comprehend the functioning and articulation of supermarkets in a future scenario, as well as to understand which data are relevant for the AGV analysis. To briefly summarize the present idea, this table shows the number of AGVs and racks that will be appropriate for the average time values of certain activities.

By looking on the positive side first, the present estimations allowed Volkswagen to fathom an approximation of the investment required for changing the in-house paradigm concerning this particular part of the assembly plant. Another way to say, it was possible to have a numerical approximation of the number of AGVs and racks. One further point worth mentioning is that with the performed analysis it was possible to acknowledge that there are some sequence families (red) of components will not be included into the present study since those components will not be sequenced when the project is implemented. Likewise, there are even other sequence families of components that might not be continued as a sequence (yellow). By this reason they will not be a priority for Volkswagen.

Albeit it is based on real data and it is not simply an eye assessment, it represents static representation of reality without any kind of oscillations. Notwithstanding the aforementioned times were gathered from real processes, they correspond to average times for each part of the cycle (transportation, manoeuvring, etc.). In other words, it may not work for the extreme values that occasionally occur. It turns out to be a slightly simplified analysis of the project's complexity. Basically, with this, it is being assumed that each cycle is always performed in the same way and takes always the same amount of time for each sequence. Undoubtedly, this represents a fallacy.

In addition, in this present analysis, not only the average times are considered. The speed attributed to AGVs, to travel from the supermarket to the assembly line and vice versa, is also an average value. This reality turns out to be a quite minimalist. Conversely, in a digital twin, it is possible to assign to the AGV a maximum speed in a straight line, average speed, turning speed, reverse speed, rotation speed, acceleration and deceleration, etc.

Moreover, it also treats each sequence family as self-contained of each other (box-to-box approach). Essentially, several sequence families of components use the same supermarket operator (same resource). From a practical standpoint, this operator may not always be available when the AGV arrives at the supermarket. Concisely, it ends up being ill-advised to treat those sequences as independent processes since they have a common resource (same human operator).

Furthermore, it does not consider several events that might occur, such as the need to load AGVs or some traffic during the route travelled by the vehicle.

Finally, in view of the above analysis, several of the average times found in that framework were evidently retrieved throughout the observation of the current reality. Since with the new paradigm there will be changes, mainly, in the picking process and also in the line feeding, handling of the racks, etc., it ends up not being thorough to use the times of the current processes. The aforesaid facts are visually explained through Figure 19. The blue activities speak for the activities that will be performed differently in the new backdrop.

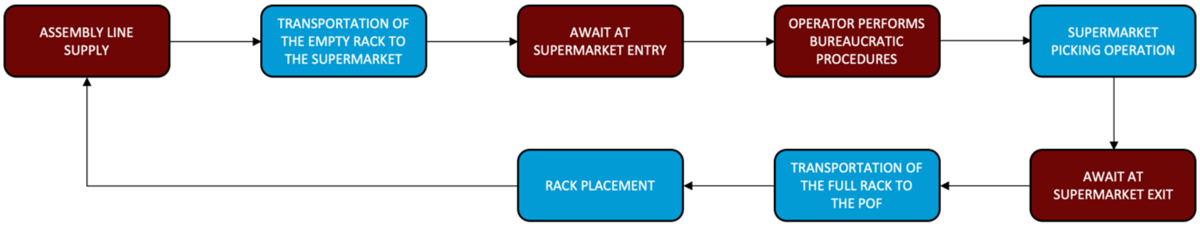


Figure 19 - AGV Cycle. Blue Activities Represent the Ones that Will Be Performed Differently in the Novel Paradigm

On the whole, on top of the present mathematical static analysis a more complementary dynamic analysis closer to reality will be necessary. This is undoubtedly achieved throughout a simulation model which will allow to have better trustworthy results.

5.2 – Dynamic Analysis

In order to develop the proposed analysis, a discrete-event simulation model will be built and used as a digital twin to test those brand-new configurations of the in-house logistics operations. The use of simulation allows to model stochastic processes which end up being important in systems with high level of uncertainty and complexity. It also permits to fathom the final outcome of several changes without the need for pausing the current production paradigm (section 2.4).

The current paradigm (as-is) will be used as a first basis and, afterwards, changes will be implemented into the model (to-be configuration) to perform the comparisons. As stated in chapter 4, the simulation software used is called Visual Components 4.1.

Henceforth, the master dissertation will continue with a depth-description of the implementation. Afterwards, the simulation operation will be described. The methodology for analysing the number of AGVs will be emphasized and the results of the first sequence family will be thoroughly highlighted. Ultimately, the results and shortcoming of the implementations will be pointed out.

5.2.1 – Modelling and Implementation

Basis of The Simulation

The process of implementing and modelling the digital twin inside the software will be laid out in the present section. All the major steps will be examined in order to beam all the knowledge regarding the implementation.

First and foremost, the first step towards the digital twin underwent through the introduction of the factory plant. The factory plant file was supplied in CAD version by Volkswagen. This file corresponds to a two-dimensional representation. Concisely, it conforms to a file which contains the marks of the different areas of the shop floor (assembly line workstations, supermarket areas, buffer zones, warehouse aisles, factory thresholds, etc.) and reflects a replication of the layout viewed by using the HLS architectural software (Figure 20).

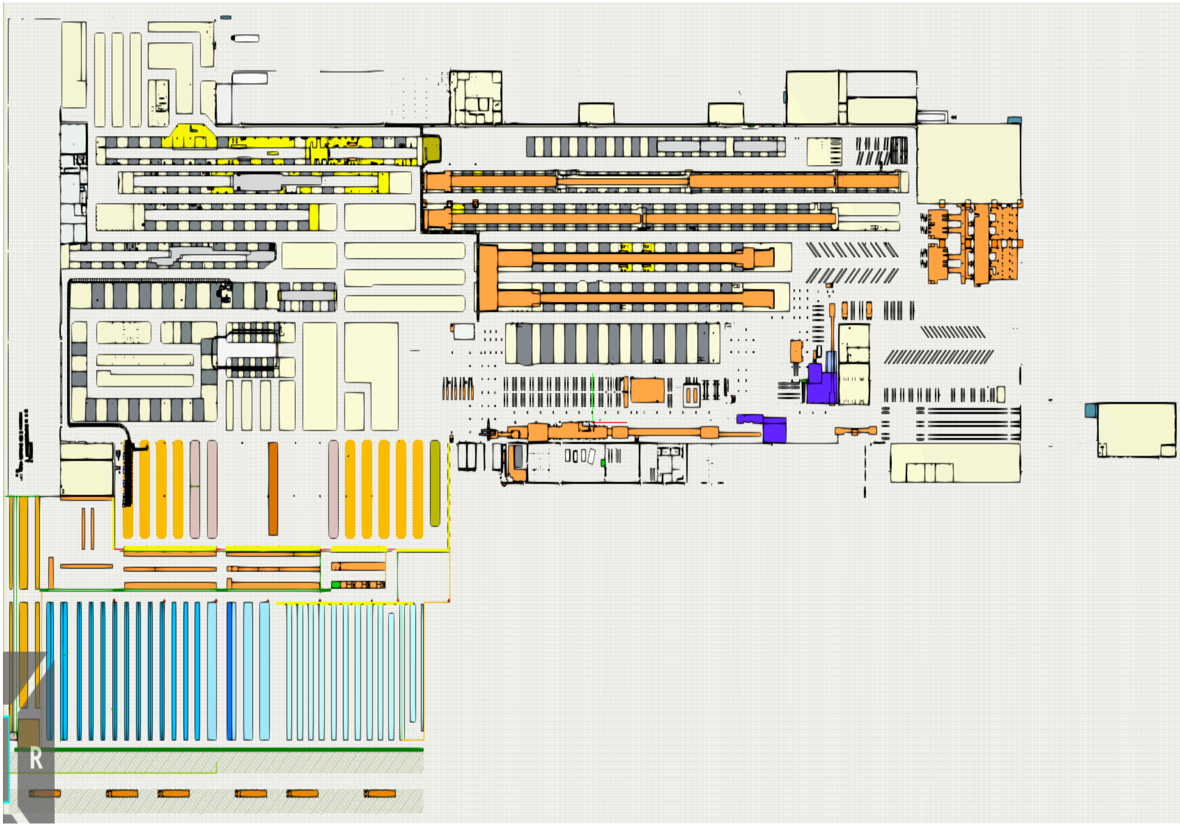


Figure 20 - Factory Plant Implemented Inside Visual Components 4.1

Apart from the factory zones, an area was created where several essential prior simulation activities were carried out. For the sake of simplicity, this area was called Control Area/Zone (Figure 21).

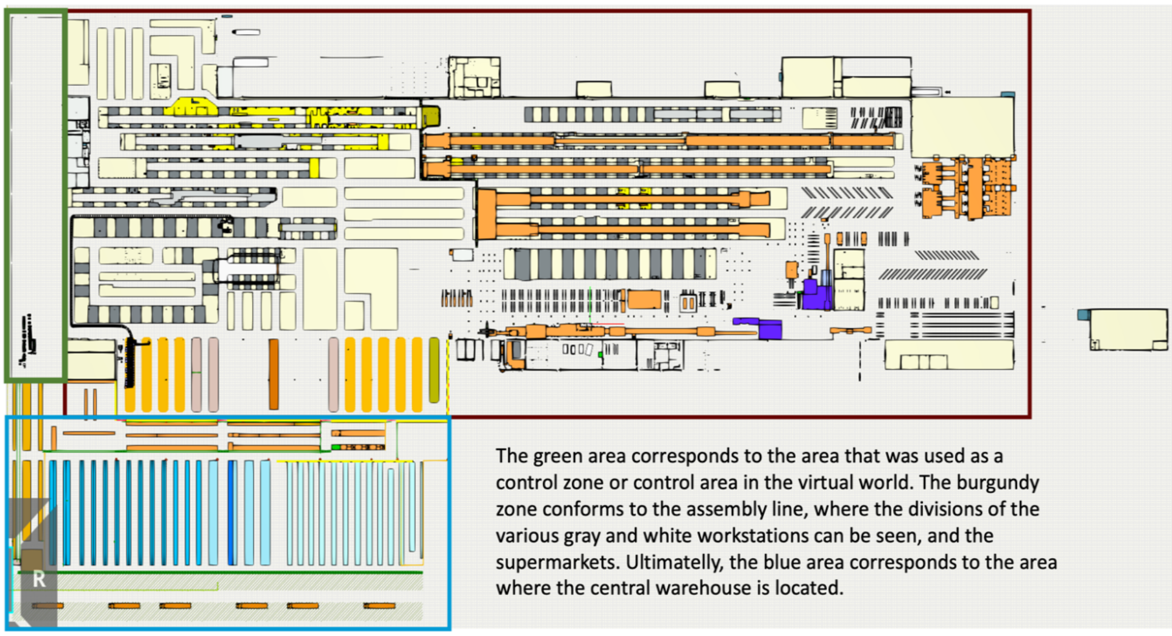
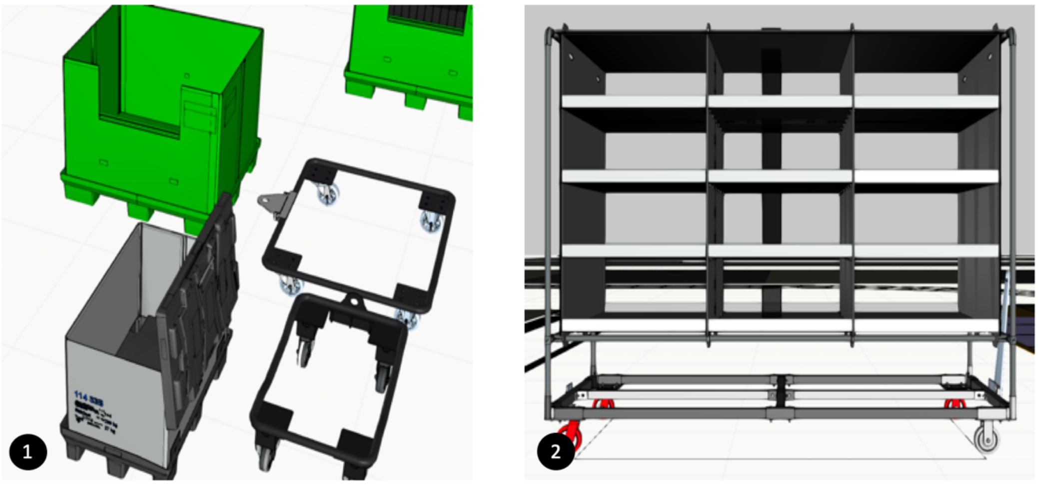


Figure 21 - Virtual Factory Plant with the Marked Zones

The first exercised step spans to importation to the control area of the three-dimensional CAD's of the containers, trolleys (containers support) and sequence racks that are used in the first implemented sequence (Figure 22).



1 – Two Types of Containers and their respective Trolleys

2 – AC Pipes Sequence Rack

Figure 22 - Examples of 3D CADs

Afterwards, the geometry of the containers had to be shaped. The imported containers were closed and, obviously, inside the supermarket they are opened in order to streamline the picking process. Therefore, a face trimming procedure was performed. The 3D CAD faces and edges corresponding to the container lid have been removed (Figure 23).

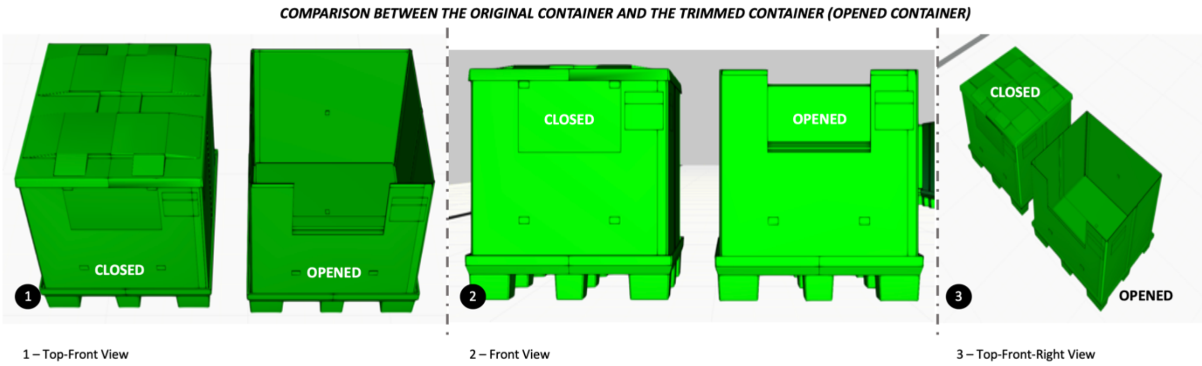


Figure 23 - GLT Container 114888 Before & After Comparison

Subsequentially, all the components were conceived. Since 3D CAD components were not provided, they were represented as blocks. To these blocks a respective part numbers were assigned in the components features (Figure 24).

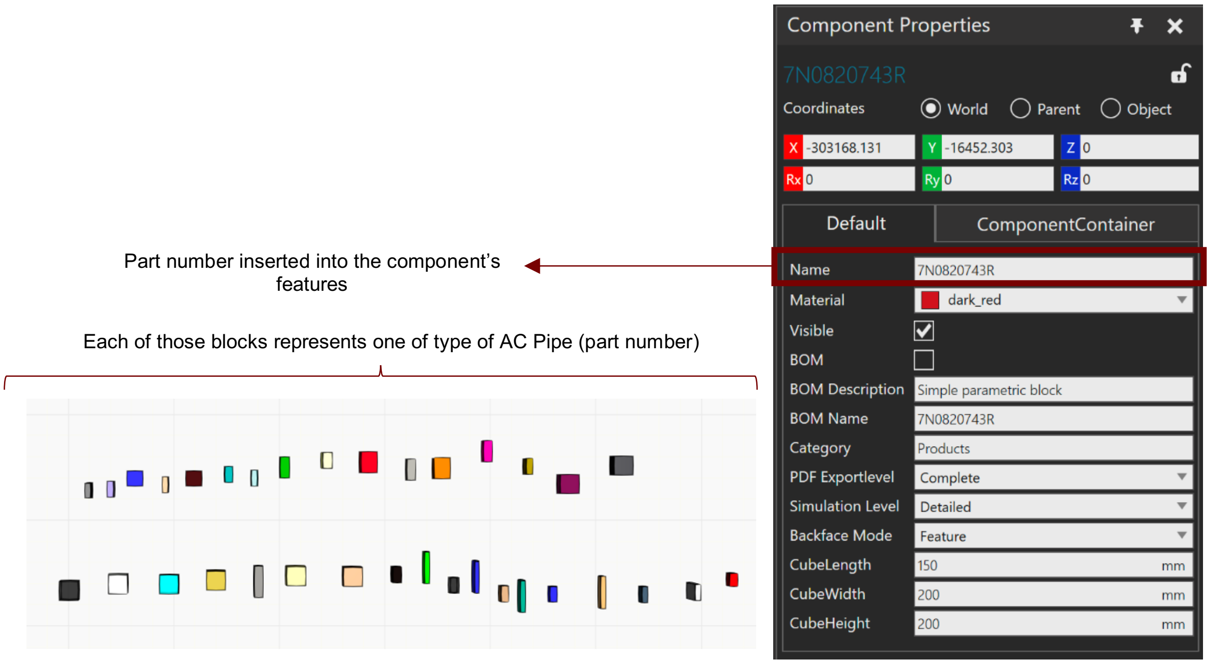


Figure 24 - On the Left Side - Blocks Representing the Components; On the Right Side - Control Panel Where the Part Number of the Components is Inserted

Still in the control area, all containers were filled with the respective components (always according to the collected data in relation to the number of parts each one takes). In order to streamline the filling process, a new component was created at the control zone. To the brand novel component, properties have been added in order to enabling to palletize other components. Herewith, the user solely has to select a parent component (in this case, a container) and a child component (a part number). Afterwards, it is only necessary to mention the number of components that must be placed along the three spatial coordinates (x, y and z).

All of these containers that were filled (Figure 25) will later be generated and nested at the beginning of the simulation in the correct location of the supermarket. The control zone is used to "assemble" what will be generated and used in the simulation.

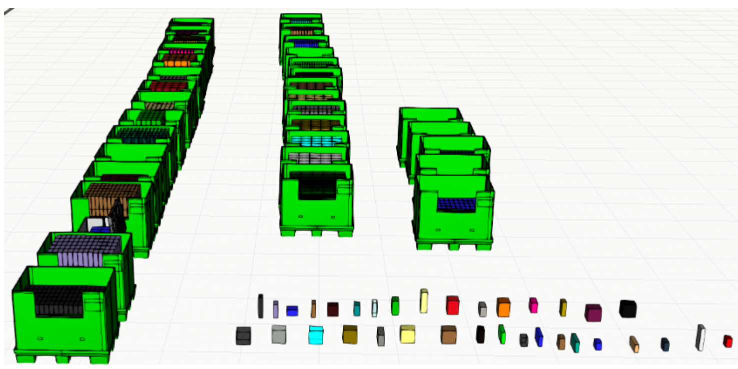
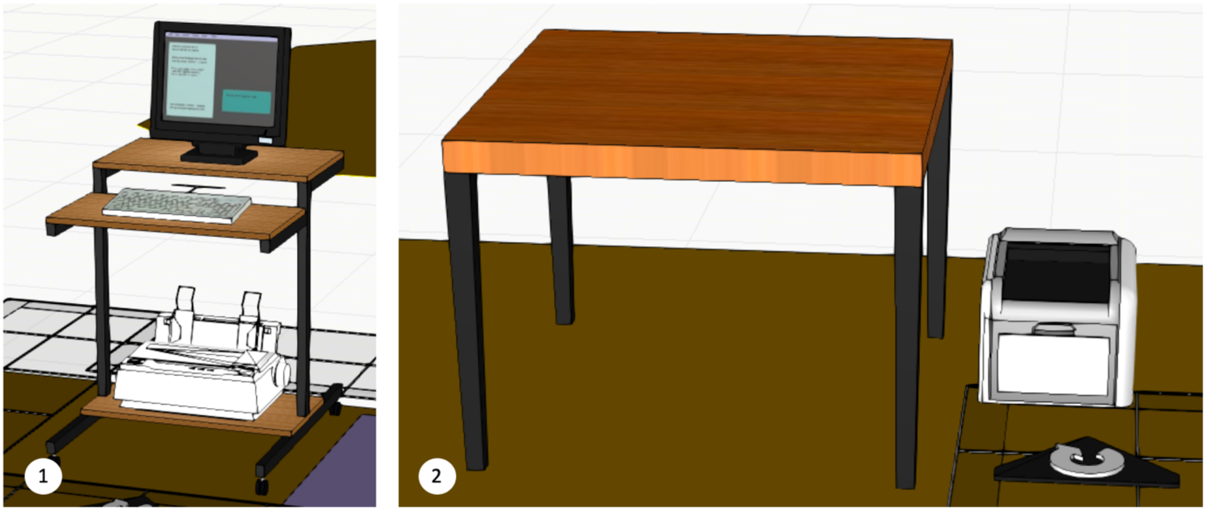


Figure 25 - Filled Containers at the Control Zone

Building the Virtual World: Entities & Tasks

The following steps have already taken place outside of the control zone of the virtual world.
From a straightforward perspective, the number of entities in Visual Components might be efficaciously portioned into three distinct sorts: the non-interactive components, the interactive components and the resources.
The non-interactive components embrace all the physical entities which do not have any kind of Python script associated and are fixed in space and time (do not disappear, move, transform and tasks are not performed on them). Essentially, those components merely constitute physical parts of the environment. In this connection, those entities range from side tables, desks, printers, computers, waste bins, etc. In a very broad simplistic terms, those entities might be perceived as less relevant features of the simulation. Typically, they are responsible for ensuring the correct layout of the virtual world. Those components were the first ones to be set. The Visual Components library was exploited in order to retrieve those items (Figure 26).



1 – Computer & Desk at Supermarket G13 2 – Table & Printer at Supermarket G12

Figure 26 - Examples of Non-Interactive Components from Visual Components

Conversely, the interactive components are the ones where activities are performed. These are generated, move, perform tasks, disappear, etc. Transversely, those components have an associated Python Script which allows them to perform those tasks. The Python scripts can be written by the Visual Components' user or, alternatively, there are some components with already prepared Python scripts. Those components are called "Work Process Components". Basically, these components are already incorporated with Python code so that the user does not have to program them from the source. Those Python scripts enable the components to perform easily several classical tasks. The user solely has to select the task from a list at the control panel (Figure 27). In other words, these solutions do not have to take a lot of time, require subject-matter expertise, nor be difficult. The user can simulate several different aspects of industry using a library of ready-made components executing sequences of tasks.
Those Work Process Components were placed at the shop-floor of the supermarket, as bidimensional entities, and a list of tasks will be enforced to them (Figure 27). They will generate the trolleys and

containers with the respective components, that were created in the control zone, when the simulation starts.

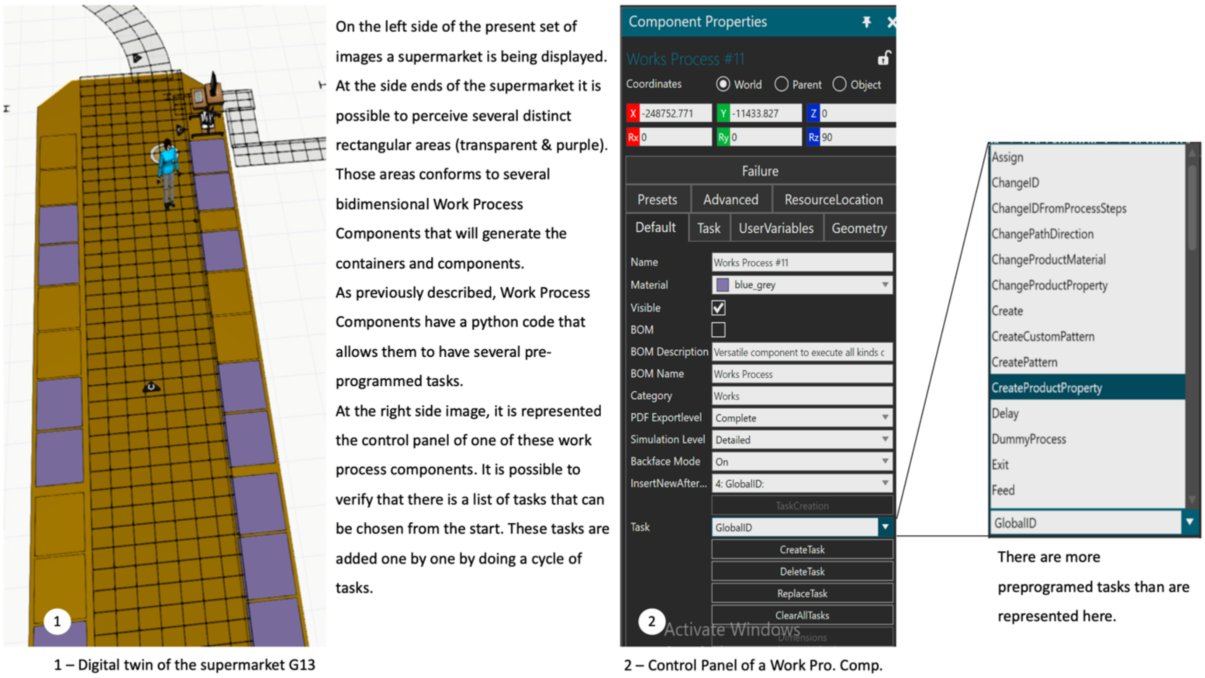


Figure 27 - Work Process Components at the Supermarket and Its Respective Control Panel

All the tasks that are attributed to a specific component are performed in a loop. In other words, when several distinct tasks are awarded to a component, it will execute them cyclically (Figure 28).

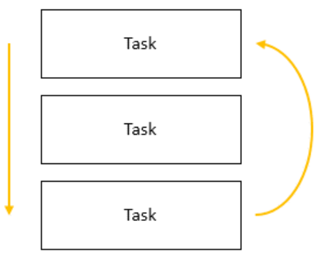


Figure 28 - How tasks Are Performed in Visual Components 4.1

Since the generation of the containers should only be performed once, a "WarmUp" task must be added. "WarmUp" task allows you to execute preceding tasks only once during a simulation (Figure 29).

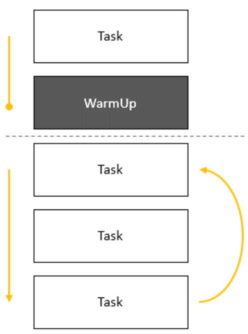


Figure 29 - WarmUp Task: Visual Explanation

After the “WarmUp” task, all the other tasks are performed subsequentially as a regular loop during the simulation.
By continuing the previous line of reasoning, after creating the trolleys, containers and part numbers, the task that will proceed is basically a feeding task related to the picking procedure. A Feed task allows you to request a resource to pick up and delivery components to other Works Process Component (Figure 30).

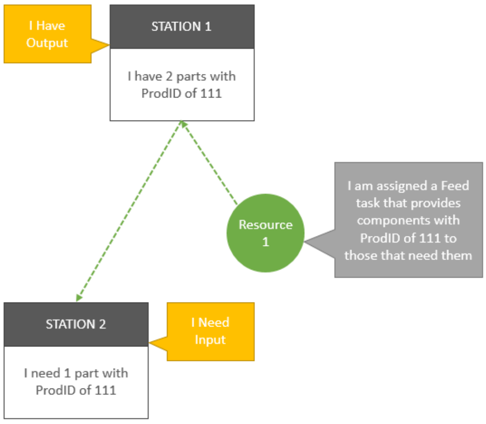


Figure 30 - Feed Task Explanation and Bridge to Resource Explanation

Another additional feature of the Work Process Components, apart from the preprogramed Python script, is that it is possible to transpose a physical geometry for these components. Instead of having a bidimensional component, the 3D CAD of the sequence rack can work as a Work Process Component. It turns out to be extremely useful because instead of writing Python code to create the tasks performed by the rack, several of them end up being pre-written (in the Python Script of the Work Process Component). Afterwards, the tasks applied to the rack began to be chosen.
Finally, the resources are the entities which are missing. The primary function of resources is to carry out tasks that are allocated to interactive components. For instance, when a feed task is allocated to the containers and a need task is applied to the sequence rack, the element responsible for performing the picking is the resource. Robots and humans are generally used as robots to perform picking activities, tasks that take some time at a given location (administrative processes) and also to transport several components from a location to another (Figure 31).

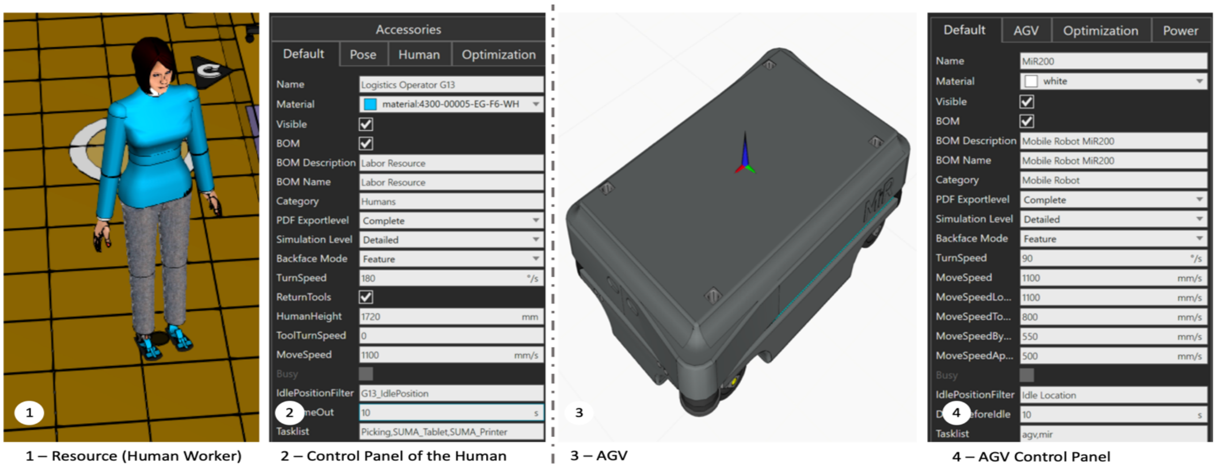


Figure 31 - Examples of Resources and Their Respective Control Panel

At this point, the set of virtual elements of the simulation was portrayed and outlined. Based on those terms, it seems quite simple to build up a simulation. However, not all the required tasks are preprogramed on the Work Process Components. For example, to attach and detach the AGV to the sequence rack, a Python code had to be developed (Figure 32).

```python
def WT__AttachTrolley(attachToCompName):
  if attachToCompName == 'Reserved':
    attachToCompName = autoReservedResourceProp.Value
  # Move mtx to new parent
  attachToComp = app.findComponent(attachToCompName)
  invMtx_attachToComp = attachToComp.InverseWorldPositionMatrix
  mtx_comp = comp.PositionMatrix
  mtx_resLocFrame = comp.findFeature('ResourceLocation').FramePositionMatrix
  mtx_resLocFrame.invert()
  invMtx_comp= comp.InverseWorldPositionMatrix
  invMtx_attachToComp = attachToComp.InverseWorldPositionMatrix
  parentComp = comp.Parent

  # If comp is already attached
  if not parentComp.Name == 'ROOT':
    mtx_parentComp = parentComp.WorldPositionMatrix
    mtx_toWorld = mtx_parentComp*mtx_resLocFrame
    comp.PositionMatrix = invMtx_attachToComp * mtx_toWorld
    attachToComp.attach(comp,False)
  else:
    comp.PositionMatrix = mtx_comp * invMtx_comp * mtx_resLocFrame
    attachToComp.attach(comp,False)
  comp.update()

def WT__DropTrolley():
  app.SelectionManager.setSelection(comp,False)
  drop_action.execute('Detach')
```

Attach Code

Detach Code

Figure 32 - Python Code for Attaching and Detaching an AGV to a Rack

Additionally, the orders from the assembly line are based on probabilistic distributions. In order to do so, a component was created at the control zone. A random component with a random geometry. A Python script was developed in this component in order to generate signals to the Work Process Component that is present at the POF of the assembly line and, afterwards, this signal is transmitted to the sequence rack. The Python scrip is presented on Figure 33.

Python Script

```python
from vcScript import *

app = getApplication()
comp = getComponent()

def OnSignal( signal ):
  if signal == GenSignal:
    name, prodCount, propName = signal.Value.split('|')
    prodCount = int(prodCount)
    process = app.findComponent(name)
    prods = []
    if process and prodCount:
      for i in range(prodCount):
        hit = comp.Random
        for product,propability in products:
          if hit < propability:
            prods.append(product)
            break
      process.getProperty("UserVariables::"+propName).Value = ",".join(prods)

def OnStart():
  global GenSignal
  GenSignal = comp.findBehaviour("GenerateProdList")

def OnRun():
  pass

products = [
  ("5Q0816741B",0.155441324), #0.155441324
  ("5Q0816741C",0.239117352), #0.083676028
  ("5Q0816741K",0.327432297), #0.088314945
  ("5Q0816743D",0.43665998),  #0.109227683
  ("5Q0816743E",0.462387161), #0.025727182
  ("5Q0816743G",0.549924774), #0.087537613
  ("5Q0816743H",0.65441324),  #0.104488465
```

Pseudo-Code/FlowChart

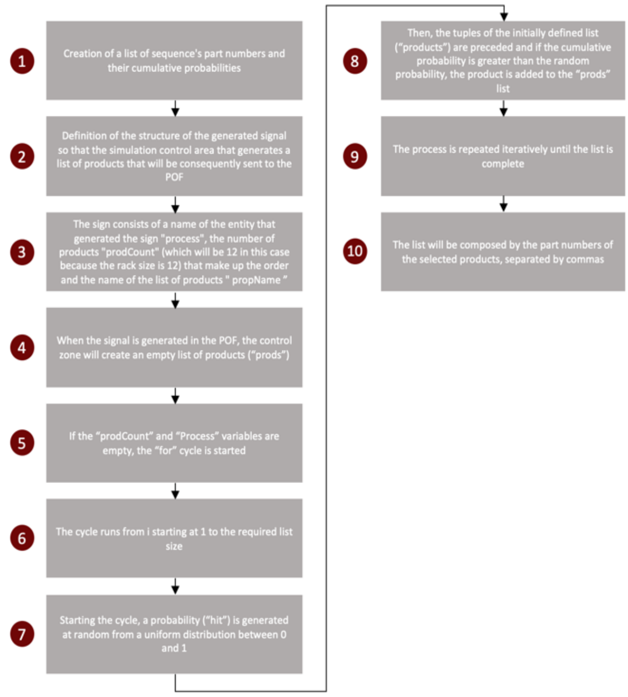


Figure 33 - Python Code and Flowchart/Pseudo-Code for Generating Orders Based on Probabilistic Distributions

One of the major important factors for Volkswagen is to avoid line stoppages. Therewith, another Python code was totted up to this random component at the control zone. In order to effectively understand the function of this Python code we will have to rewind. Firstly, by looking at the workstation, the components arrive in the sequence rack and will be added at the assembly line after 1.33(3) minutes. Thereby, this Python code is responsible for erasing the components from the simulation after 1.4 minutes. Thus, if the present Python script will delete the components and if another component is not yet being delivered after 1.33(3) minutes, the assembly line will have no components at the workstation. Based on that, the present Python code not only phase out the components but also provides a message saying, “Point-of Fit Out of AJA1!!!” and the simulation will be halted. In this way, there is a possibility to comprehend if the scenario that is being tested with a certain number of AGVs and racks is not compromising the line production. The objective of the aforementioned Python code is clearly twofold and is presented on Figure 34.

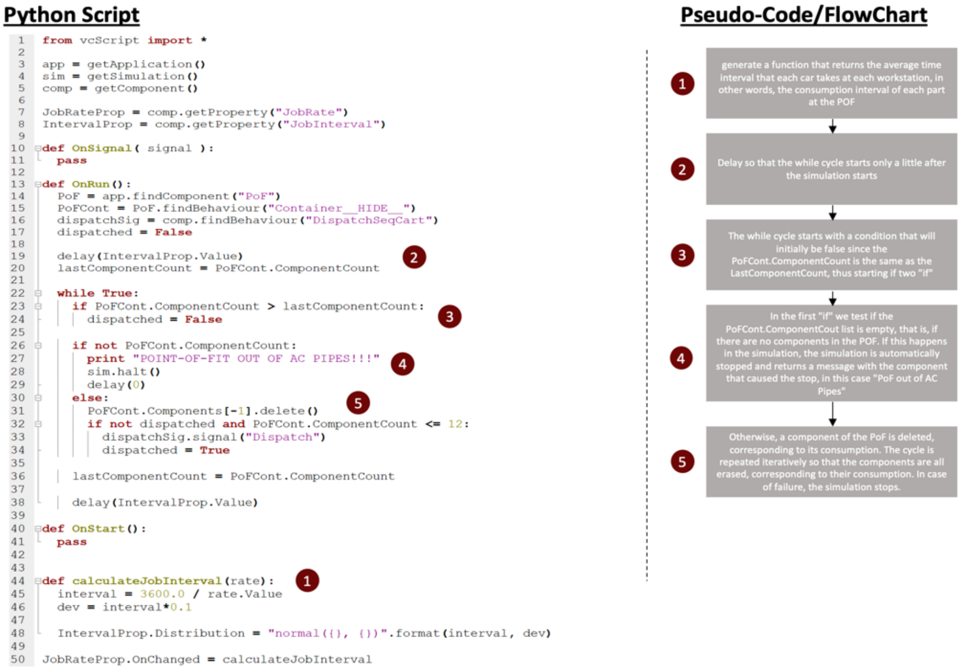


Figure 34 - Python Script and FlowChart Regarding Deleting Components and Warning Messages

Pathways

Before creating the pathways in the virtual world, a Work Resource Pathfinder must be added from Visual Components library. A Works Resource Pathfinder calculates routes for resources using a network of pathways. In other words, a pathfinder must be in the 3D world in order for resources to use pathways and avoid collisions. The component itself can be hidden, and the user only need to have one into the layout (Figure 35).

Figure 35 - Work Pathfinder Component

Obviously, the present component will be incorporated into the "control zone" where all the simulation control mechanisms are found.

A pathfinder calculates the shortest route for a resource to go from point 1 to 2. This calculation can be done manually using the "CalculatePathway" property. By default, "AutoCalculatePathway" is enabled to do this for you during a simulation. A route is based on several factors: connected pathways and their area ids, obstacles, traffic, bypassing, resource locations.

However, by default, when in the simulation a specific displacement task is applied to a component, this component will proceed with the displacement process by taking the shortest possible path. There being no obstacles, the component will then follow a straight path.

Initially, the AGV took the sequence rack in a straight line to the supermarket. However, with the implementation of Work Pathfinder in the "control zone" and library' components that allow defining a trajectory, it was possible that AGV performs exactly the trajectories that were defined during the team meetings (Figure 36).

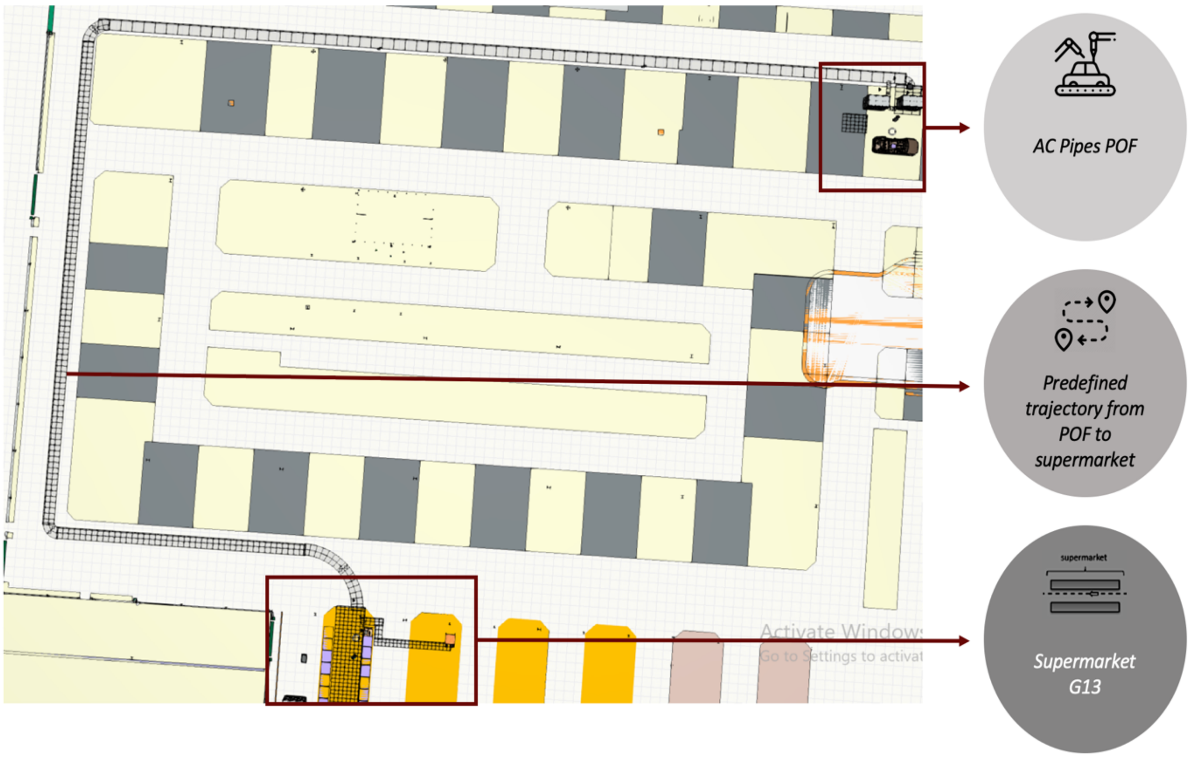


Figure 36 - Trajectory Followed by AGV From the Supermarket to the POF and Vice-versa

5.2.2 – Running Simulation & First Test

In order to decipher the number of AGVs and racks needed, the simulation started off with the smallest possible number of racks and AGVs in an alternating POF strategy scenario. An alternating POF strategy, as mentioned in chapter 4, requires at least two racks: one in consumption at the assembly line and another one full. On this basis, the simulation of the first sequence family began with one AGV and two sequence racks.

Forthwith upon the start of the simulation, two events spring up. At the supermarket all the interactive components arise (trolleys, containers, part numbers) from the bidimensional Work Process Components (Figure 37). At the assembly line, one rack initiates the supply of the POF throughout a human operator (resource) and another rack just got empty.

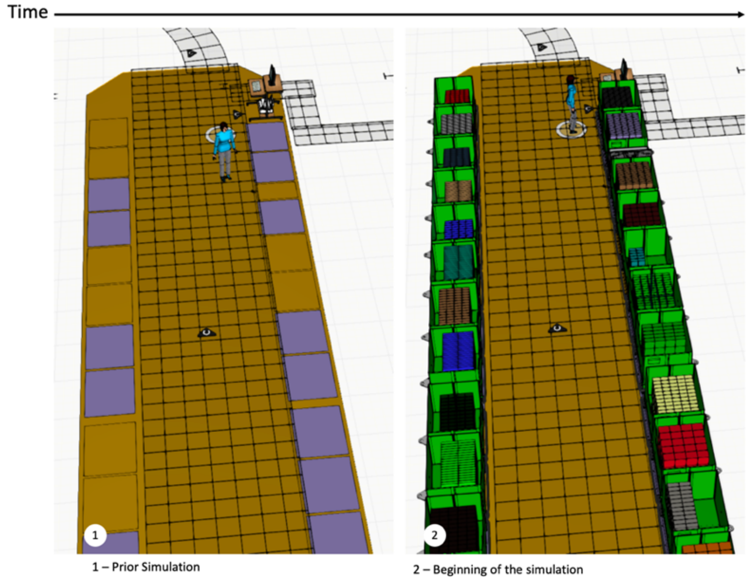


Figure 37 - Generation of the Containers

Afterwards, a signal is spawned from the control zone and reaches the Work Process Component at the POF. With regards to the content of the signal, it comprises a list of 12 part-numbers (due to the storage and transport capacity of the sequence rack) generated based on the probabilistic distributions (historical data). Subsequentially, the present signal is transferred to the sequence rack which will be responsible for the rest of the process. After this, the nearest AGV (in this case there is only one AGV) will connect with the sequence rack and follow the predetermined path until reaching the supermarket (Figure 38).

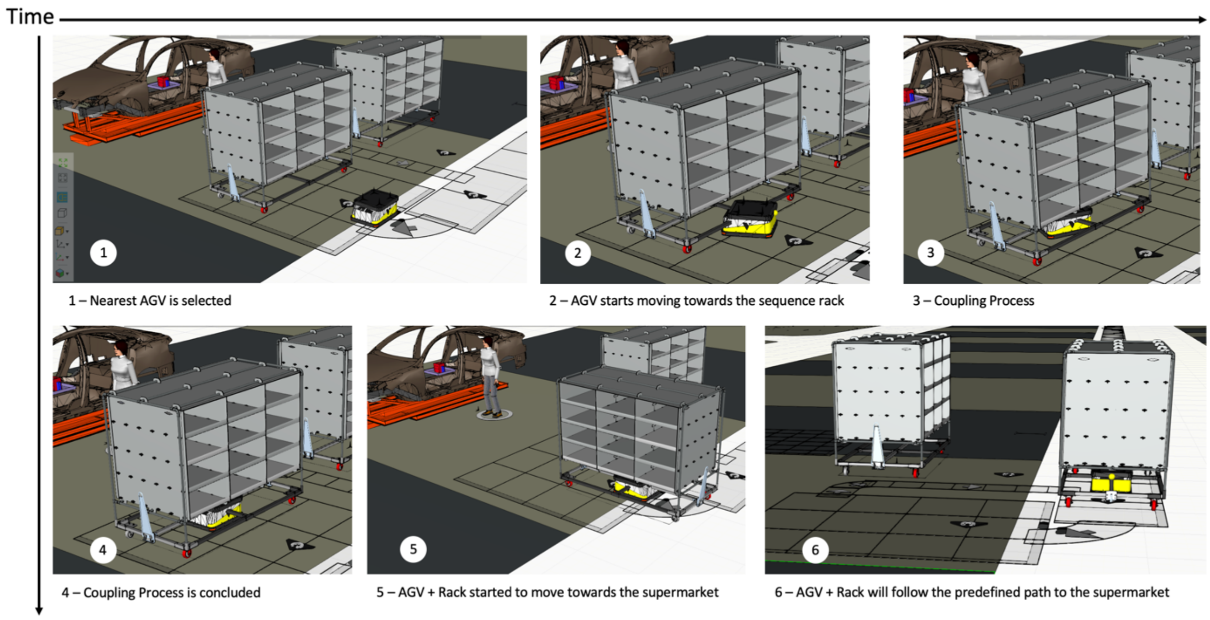


Figure 38 - AGV Coupling and Moving Process

When the rack arrives at the supermarket, if the supermarket operator is available, the administrative procedures will take place (records on the tablet PC, printing, writing, etc. – Figure 39). Thereupon, the picking activity starts based on the order brought by the rack (Figure 39).

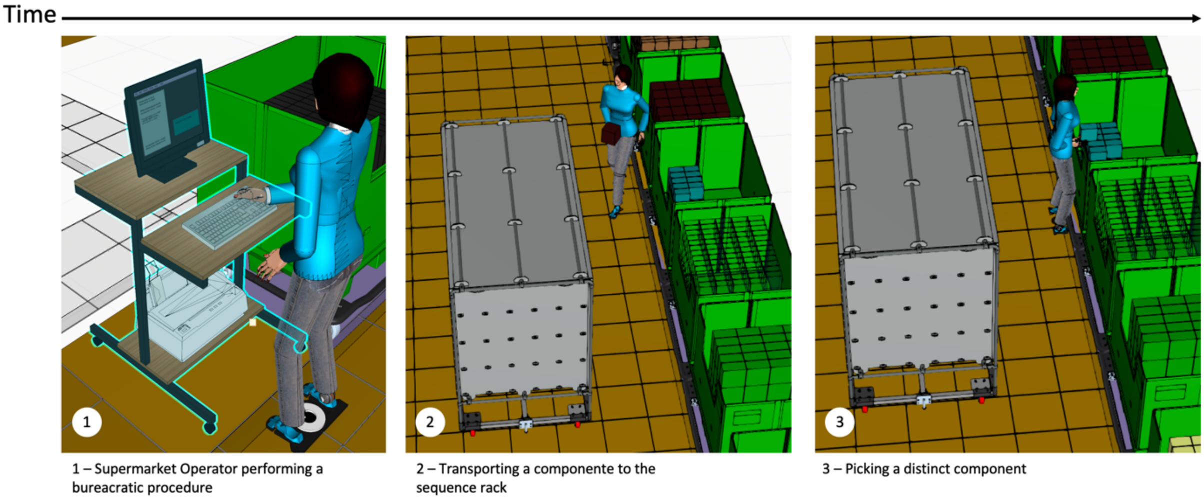


Figure 39 - Supermarket Procedures in Visual Components 4.1 Simulation

Since there are solely two sequence racks, there is always an available place at the workstation for the full rack. As a result, when the picking procedure is finished the sequence rack will move directly to the assembly line.

The pathway taken will be the inverse of the initial. Finally, the assembly line is reached, the cycle ends, and an equal cycle arises with the other sequence rack. The process persists in an iterative way.

5.2.3 –AGVs Analysis Methodology

According to the previous chapter, it is being assumed that the number of AGVs is tuned and the cycle will continue smoothly and iteratively. However, in the present case the number of AGVs is not enough since the simulation halted.

The present section has the aim of shedding lights on how to act if there is a shortage of material at the assembly line. The reasoning for finding out the ideal number of automated guided vehicles is efficiently illustrated into the flowchart presented on Figure 40.

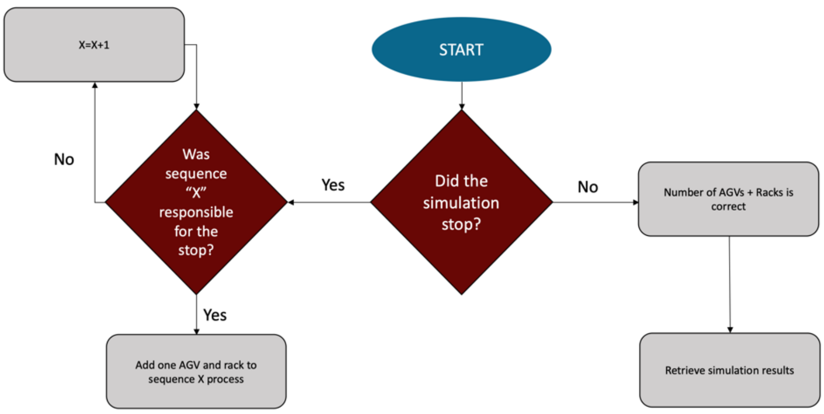


Figure 40 - Methodology for Finding the Ideal Number of AGVs

By following the logic of Figure 40, if the simulation is suspended, the first step is to figure out which sequence is responsible for the line stoppage. Immediately after finding the responsible sequence, the number of AGVs and racks must be incremented by one unit. The process is always replicated until ascertaining the correct number of entities.
The cycle procedure is applied and the number of AGVs is discovered and everything starts to work properly. Nevertheless, when more sequence families are added to the simulation, the cycle time might change since several sequences use the same human resources and waiting times might increase.

5.2.4 – AGV Results Analysis for AJA1 Sequence

The AJA1 was the first sequence to be deployed. By following the abovementioned reasonings, the simulation of the cycle started with only one AGV. As already expected by static analysis, the sequence in question does not succeed with merely one AGV. The output panel returned the message "Point-Of-Fit Out of AJA1!!!".
Based on the methodology previously stipulated, an AGV and a rack must be introduced. However, before another automated vehicle is added, part of the Python code that pauses the simulation when there is a shortage of material on the line was erased. Therefore, it was possible to notice the discrepancy between the cycle time and the rack consumption time. Basically, the simulation always stopped when the first rack that was in consumption became empty. It was not possible to perceive the cycle time. By removing the Python code regarding the scarcity of material at the assembly line, it allows to acknowledge that the cycle time was approximately 23 minutes (Figure 41).

Figure 41 - Simulation Stop Time Example

Based on this cycle time, it is possible to ascertain the number of AGVs that are needed. Since the number of AGV is given by rounding up the quotient between the cycle time and the rack consumption time, the number of AGVs needed will be equal to two. As aforesaid, if another sequence is added the cycle time might be changed due to resources availability (supermarket operators).
With a single AGV, there is a lack of material on the line during approximately 6.85 minutes per cycle (difference between cycle time and rack consumption time). This causes line stoppages for almost three times an hour, 63-day stoppages, 431.68 minutes lost per day which corresponds to almost 22,995 stops over the course of a year, which consequently represents 157,563.2 minutes of breaks. Since there are 256 stations and an average of 1 or 2 workers per workstation would correspond to roughly 256 to 512 human resources which are being wasted for almost 2,626 hours during one year. In addition, a loss in terms of production levels becomes evident.
By taking losses into consideration, using the right amount of AGVs maximizes production level and minimizes capital losses. In this way, the second AGV was added to the simulation in order to flow everything without halts.
Furthermore, the use of two AGVs represents an investment of 50,000 euros. However, as mentioned in section 4.6, the line feeding cost per car for the present sequence is roughly 0.234 euros. Since

Autoeuropa annual production level comprises 251,874 cars, it represents a save of 58,939 euros. Obviously, there will be complementary costs, nonetheless, in almost a year, Autoeuropa recoups the investment. It represents a positive operational outcome and also a return on investment. All the aforesaid facts are duly summarized in Table 12.

Table 12 - Outcomes Summary Table

Operational Drawbacks of a Single AGV						
Cycle Time (min.)	**Rack Consumption Time (min.)**	**Difference (Cycle Time – Rack Consumption Time)**	**Number of Assembly Line Stops per day**	**Number of Assembly Line Stops per year (365 workdays)**	**Daily Duration of Breaks (min.)**	**Annual Duration of Breaks (min.)**
22.85	16	6.85	≅63	22,995	432-431	157,563.2
Operational & Financial Outcomes of a Right Number of AGVs						
Line Stops Duration (min.)	**Number of AGVs**	**Cost per AGV (Euros)**	**Total AGV Investment (Euros)**	**Line Feeding Cost per Car (Euros)**	**Annual Production Levels (2018 – no. cars)**	**Expected Savings Value (Euros)**
0	2	25,000	50,000	0.234	251,874	58,939

5.2.5 – Simulation Shortcoming Resume

These results would be relevant for Volkswagen and the remaining sequences would be implemented in the exact same way. The steps described between sections 5.2.1 to 5.2.4 would be replicated and Volkswagen would have the exact number of AGVs that would be required for one of the company's largest intermediate storage areas.

However, the picking procedure is not implemented as expected by the novel paradigm. This holds an impact on cycle times and, consequently, on the number of required AGVs. The symbiosis between the supermarket operator, the AGV and the sequence rack was not accomplished due to software limitation and high computational requirements.

The aforementioned limitation is better and visually explained in section 6.3 regarding the project limitation.

6 – Limitations

In the aftermath of the elaboration of the present thesis it is possible to acknowledge its limitations. Hereinafter an appreciation of those limitations will be conducted. Due to the different characteristics and nature, those limitations will be grouped and scrutinized in different subchapters. The present chapter is of paramount importance in order to, not merely, recognize the work shortcomings but also to emphasize some points that might be improved (if possible) in the future with the help of new tools that may exist.

6.1 – Literature Gaps

The review of the existing literature regarding the in-house logistics operations at the automotive industry was extremely fruitful. It has positively contributed to incorporate those fundaments before the curricular internship have begun. Basically, it is possible to profess that those concepts are broadly and thoroughly reviewed in the existing literature.

However, there are two more critical concepts that are from utmost importance in the present thesis. The concept of 4.0 industry and simulation. The existing literature regarding both concepts is weaker when compared to the more classical notions, especially regarding the term of simulation. It was remarkably difficult to find out relevant papers that could bring valuable contributions for the present research. Scientific articles on the use of AGVs in supermarkets were also few. In most articles AGVs are merely used in a transport context and not as ergonomic supporters.

The keywords used to find out significant papers related to the software in question were also not effective. No simulation studies and scientific articles were found using Visual Components. Within this framework of though, the way in which the present problem could be tackled could have been optimized if there were more literature regarding the aforementioned topics.

6.2 – Data Retrieved

6.2.1 – Observation Time

One of the major constraints of this research is the time horizon. Much of the data collected was gathered throughout a daily observation of their virtual databases. The records of the collected components by the operators were withdrawn every single day, during an entire month, in order to obtain the probabilistic distributions of the picking procedure. In other words, that data was fundamental to generate the probability of picking a certain component of a certain sequence family at the supermarket and, afterwards, incorporate it into the simulation file (as already explained in chapter 4). Obviously, it would be beneficial if more data was retrieved (and not only one month of data), since the generated probabilities would be closer to the reality. However, due to time constrains one month ended up as a considerable good sample (roughly 10% of a working year). Unequivocally, it would be interesting to continuously sharping those probabilities by including more data.

Firstly, not all part numbers have been recorded by the tablet's PC during the period of data collection. Consequently, it ended up being impossible to attain probabilities for them. Presumably, those components are patently linked with quite specific customer' requests. However, it would be interesting to have all components registered for the simulation. Table 13 illustrates the aforesaid facts, 14 part-numbers were not observed.

Table 13 - Registered Part-Number from AJA1 Sequence Family

Part Numbers	Occurrence	Part Numbers	Occurrence	Part Numbers	Occurrence	Part Numbers	Occurrence
5Q2816738D	Registered	5Q0820741L	Not Registered	7N0816741B	Registered	7N0820743N	Registered
5Q0816741B	Registered	5Q0820743E	Not Registered	7N0816741C	Registered	7N0820743P	Not Registered
5Q0816741C	Registered	5Q0820743K	Not Registered	7N0816743M	Registered	7N0820743Q	Not Registered
5Q0816741K	Registered	5Q0820743M	Registered	7N0816743N	Registered	7N0820743R	Registered
5Q0816743D	Registered	5Q0820743N	Not Registered	7N0816743P	Not Registered	7N0820743S	Registered
5Q0816743E	Registered	5Q1816738B	Not Registered	7N0816743Q	Registered	7N0820743T	Not Registered
5Q0816743G	Registered	5Q1816738C	Not Registered	7N0816743R	Registered		
5Q0816743H	Registered	5Q1816738F	Registered	7N0816743S	Not Registered		
5Q0820741B	Not Registered	5Q1816738H	Not Registered	7N0820741J	Not Registered		
5Q0820741C	Registered	5Q2816738B	Registered	7N0820741K	Registered		

Secondly, it is possible to verify that in a group of almost forty thousand observations, several part-numbers were registered less than 50 times. Table 14 shows that about 7 of the 21 registered part numbers have an extremely small number of records.

Table 14 - AJA1 Records

Part Number	Count	Part Number	Count	Part Number	Count	Part Number	Count	Part Number	Count
5Q0816741B	6199	5Q0816743G	3491	5Q2816738B	**1**	7N0816743N	**38**	7N0820743R	673
5Q0816741C	3337	5Q0816743H	4167	5Q2816738D	1106	7N0816743Q	754	7N0820743S	**14**
5Q0816741K	3522	5Q0820741C	**1**	7N0816741B	77	7N0816743R	1424		
5Q0816743D	4356	5Q0820743M	**1**	7N0816741C	2173	7N0820741K	707		
5Q0816743E	1026	5Q1816738F	6750	7N0816743M	**42**	7N0820743N	**21**		

Additionally, another shortcoming directly related to the observation time horizon is due to the fact that the database that warehouses the information of tablet PCs can solely store data for a maximum period of 5 days. Thus, when data started to be retrieved, beyond the day itself, information could only be retrieved from the previous 5 days.

6.2.2 – Average Data

An evident advantage of the dynamic simulation when compared to the static analysis is the possibility of fluctuating the times associated with certain tasks. In other words, the picking activity will not last always the same time in the simulation. It depends on the items that must be collected and their respective locations. Plainly, this overcomes one of the deprivations of the static analysis presented in section 5.1, since the extremes are also analysed.

Nevertheless, the dynamic simulation also has some activities that will not fluctuate overtime. Those activities are called the bureaucratic/administrative procedures. In other words, they represent all the activities that are not dynamic. For those activities an average time, based on measurements and observations, was attributed.

6.2.3 – Historical Data

An extremely common way of drawing up a simulation layout is by using historical data for several measurements. In this case, excluding physical data related to the factory environment, the majority of the data included into the simulation is based on observation (historic records). This, essentially, represents an assumption. According to this same reasoning, the simulation of a future scenario is being developed based on past measurements. For the purpose of this project, the impact of this reality will not be tremendous and turns out not to be absurd. However, it would be interesting and more reliable if some measurements are based on future data.

For instance, when Volkswagen receives the orders, those orders would be directly intertwined and connected with the simulation and the software would work based on real orders and not based on historical data and probabilistic distributions of the components. In a nutshell, the use of historical data does not represent the future no matter how similar it may be.

6.3 – Volkswagen Team

During the elaboration of this project several loopholes were noted.

First and foremost, the team was not aware of the steps that would have to be taken in order to develop a simulation project. Therefore, the majority of the methodology used for elaborating the overview scenario, collecting the data and implementing it into the software was outlined by the author.

Secondly, several team members were acutely unwilling regarding the implementation of the AGVs into the factory. Basically, those members do not totally believe in a full-fledged automated scenario. Due to those facts, it is possible to acknowledge that Volkswagen is trying to move to a scenario where not all the workers believe, what ends up hampering the process.

Ultimately, Volkswagen has a partnership with Visual Components. However, none of the logistics planning workers is truly an expert in simulation software in general. This makes it difficult to comprehend why this software was chosen. Furthermore, in case of any difficulty with the use of the software there is no one who can help out, except the supporting team headquartered in Finland. This greatly limits the elaboration of the simulation model. Since, when there is a doubt, it can hardly be clarified immediately and, therefore, the project is halted.

6.4 – Software Limitations

6.4.1 – Capabilities & Implementation

Generally, a 3D simulation software enables moving around and interacting with several components in a virtual world. During the simulation a far-reaching number of activities can be performed over time. Components are able to move on their own, disappear, appear new components, etc.

The majority of this classical activities related with the manufacturing world are already preprogramed. In short, the user solely has to select some features in the control panel and the activities will be executed when the simulation starts.

However, since each firm has its own way of working and, additionally, this project is directly related with new conceptualizations (industry 4.0), there are several functionalities that are not incorporated into the control panel of the software. Therefore, in order to conceive and implement those particular activities, it is necessary to program them.

This software enables the user to create new functionalities for the components and robots. It is possible to write a script by using Python programming language in order to calculate, record and simulate an entire robot. There were several activities, such as create orders based on probabilistic distributions, signalling if there is not enough material at the assembly line, attach and detach the AGVs to a rack, that were not preprogramed. For those activities a Python script was required.

However, one activity was not possible to incorporate into the simulation as expected. According to section 3.5, in the new Volkswagen AE paradigm, the supermarket operator must be propped up by the AGV. In short, instead of having the operator pulling the rack and placing the components, the AGV would be attached to the rack and move together with the operator along the supermarket. Additionally, the rack + AGV and the operator must follow a specific path in order to minimize the journey depending on the supermarket structure.

On the AJA1 sequence the whole process is implemented as expected with all the collected data. Only the picking process is not implemented according to the new paradigm philosophy. Basically, when the rack + AGV arrives at the supermarket, instead of following the operator along all the picking locations, the rack and the AGV stop at the centre of the supermarket and the operator collects all the items from all the containers until the rack is full.

Obviously, this behaviour will have a tremendous impact in terms of operator workload, AGV occupation rate and cycle time optimization. In order to better grasp what is being described a visual representation is given in Figure 42.

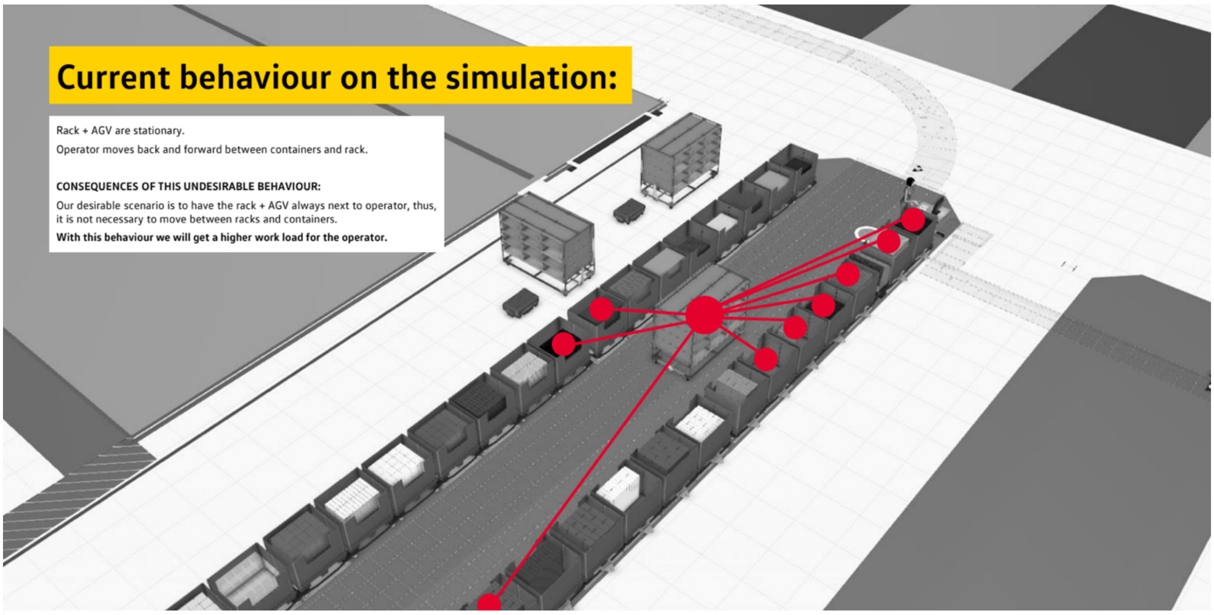


Figure 42 - Current Behaviour of the Symbiosis Rack + AGV + Operator (retrieved from Visual Components simulation file

Basically, Figure 42, the red lines represent the number of moves that the supermarket operator is performing with the current simulation in order to pick all the components from the left and right containers. The figure is self-explanatory, the current behaviour on the simulation is counterproductive. The desirable scenario would be, not only the rack + AGV following the human operator, but also performing a U-shaped path or a straight-line back and forth (Figure 43).

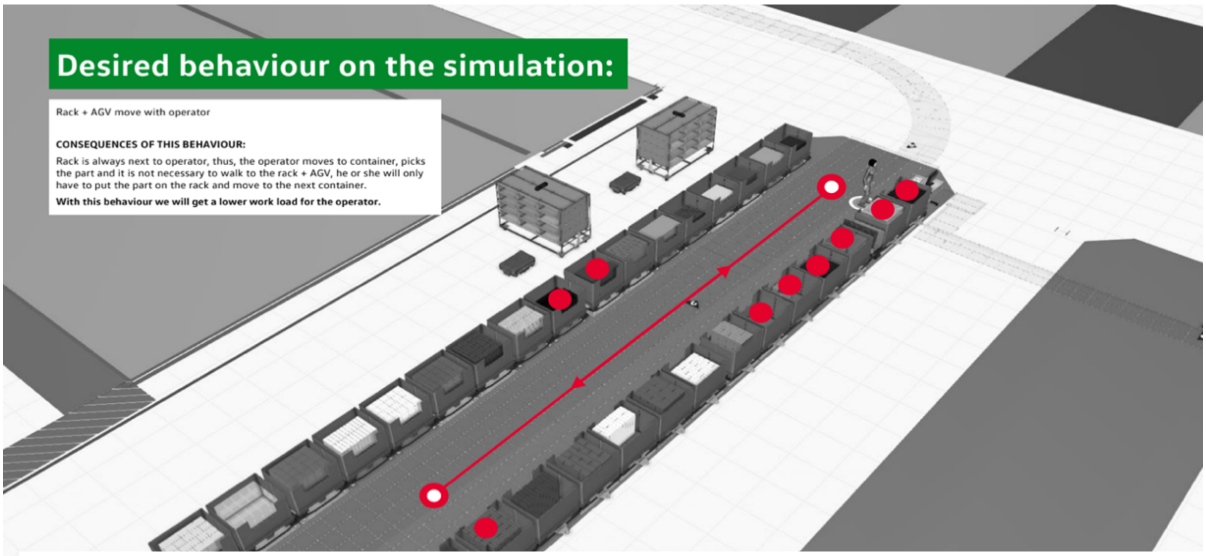


Figure 43 - Desired Behaviour (retrieved from Visual Components simulation file)

Once again, the red line represents the trajectory performed by the human operator. Actually, it is possible to acknowledge that the distance covered by the human operator is evidently reduced. This will have an obvious impact on the makespan of the present activity and, consequently, the whole cycle will benefit. In sum, the symbiosis between the operator, AGV and rack is not being accomplished. The software does not have capabilities to depict that immediately and it requires a huge amount of programming requirements to implement it throughout a Python Script.

6.4.2 – Software Developers

With the purpose of overcoming the aforementioned bottlenecks, the software's supporting team was contacted. Their developers were from Finland, which corresponds to firm's headquarters. By this reason, it was quite difficult to get in touch with them. It was impossible to carry out any kind of face-to-face development during the curricular internship. The contact was fundamentally made via e-mail.

Thereby, it turned out to be extremely convoluted to explain the processes that need to be implemented. Basically, despite having a partnership, the firm showed that they did not have a clear knowledge of Volkswagen's industrial processes.

According to them, programming the picking process would be really time-consuming, even for IT experts and software owners. Essentially, they were always postponing the resolution of the problem. Only after the completion of the internship was possible to schedule several videoconference sessions for clarification and joint work.

Eventually, they recognize that it would be necessary to reprogram some features of the program and probably launch them in the new version (4.2) in order to be capable to easily simulate the required tasks. Therefore, the limitations faced within the context of the thesis turned out have positive outcomes: i) to promote a true collaboration between Autoeuropa and the Software Company and ii) suggest and outline new features for a new version of the software.

6.4.3 – Software SWOT

Based on sections 6.3.1 and 6.3.2 a SWOT analysis was performed regarding the software and the producing firm (Table 15).

Table 15 – Visual Components SWOT Analysis within the context of Autoeuropa's Project

Strengths	***Weaknesses***
• Extremely developed in terms of visual effects; • Provides a wide range of website tutorials; • Allows to incorporate all the 3D CADs. Easily distinguishes features of CAD files imported into the 3D world. Uses a 3D geometry engine to analyse any imported CAD model and provides well-structured data of geometry surfaces, curves, and curve loops. • Allows to edit components geometry; • Enables to add additional physical characteristics to AGVs and their operation; • Plan robot paths faster using the curve-teaching tool. This feature automates robot path planning by analysing object geometries, making paths predictions, and suggesting robot paths; • The library is composed by a wide range of pre-defined components. It has more than 1400 robots from more than 40 of the largest industrial automation brands. Components are added regularly; • It has components with Python code previously elaborated in order to simplify the construction of some tasks for the user (Work Process Components); • Possibility of extracting statistical data automatically; • Streaming.	• User tracking could be optimized taking into consideration the existence of a partnership; • The available website tutorials cover only the basic components of the software and are not very comprehensive. Not having such support slowed the development and implementation of Autoeuropa case-study; • When certain tasks that are not pre-programmed have to be implemented, the software requires enormous knowledge of Python from the user; • Few videos explaining how the program's programming language works; • Some key details are not explained in the tutorials such as the possibility of giving a specific geometry to the Work Process Components, changing the geometry of imported 3D CADs by cutting faces and edges, creating a control zone, etc; • Visual Components has little knowledge regarding Volkswagen Autoeuropa operational processes; • Don't expect to use two resources to perform two different tasks using the same interactive component at the same time (e.g., the symbiosis between the rack, AGV and human operator); • The present software is from a Finnish company and is not deeply rooted in Portugal. Impossibility of face-to-face contact.
Opportunities	***Threats***
• Alignment of both industries; • Possibility of introducing new features; • Partnership Intensification.	• Existence of alternative software; • The appearance of new software and new versions; • Volkswagen seeks a new partnership if Visual Components fails to match in the short term.

7 – Conclusion

7.1 – Conclusions & Contributions

The thesis provides a synopsis on part logistics realm in the modern days of automotive manufacturers. Firstly, a general overview of part logistics is presented and, subsequently, each process is intensively covered in detail. In other words, all the in-house logistics procedures were described, the existing significant literature was revised, the recent discoveries and researches were mentioned and, finally, the future research fields were acknowledged. Thereafter, the same occurs for the concepts of industry 4.0 and simulation. Several articles, where 4.0 concepts and simulation were applied to the automotive industry, were reviewed. The number of researches regarding those two topics are slightly less.

From a practical standpoint, the Autoeuropa case-study allows to grasp the inherent complexity of all the in-house logistic procedures described in the literature. On this basis, the internal processes and layout structure of the manufacturing plant were briefly scrutinized. Those descriptions allow to spawn a robust basis for the problem characterization. Therefore, the present thesis presents a systematization of Autoeuropa in-house logistics procedures.

The challenge proposed by the Planning Logistics department was stated. Herein lies the crux of the matter. First and foremost, the current paradigm was outlined as well as all the motivations for change, the main strengths and adversities. Building on that, the generic view of the possible future scenario was set forth. Once again, since there are no flawless solutions, advantages and drawbacks of the alternative scenario sprang up. Several deep issues arise with the increased detail of the future paradigm (number of automated guided vehicles (AGVs), introduction of novel in-house logistics areas, feeding mechanism, etc.). Throughout the problem characterization it was possible to evidently recognize Volkswagen's ambition to follow the 4.0 industry train.

Additionally, with the work developed, a detailed analysis of one of the larger supermarket areas of AE was elaborated. All data collected in this area were provided to the company and are currently being used as a basis for future interns and people who will be incorporated into this project.

This thesis identified and drew up an effective methodology to retrieve and treat relevant data in order to elaborate the simulation model. Consequently, this methodology will be used at Volkswagen Autoeuropa for the future developments of the present project. Besides this, it was not only created a methodology for data collection and model creation, but also a methodology for data analysis and how the number of necessary AGVs would be evaluated.

During the internship period, a static and dynamic analysis were performed. Although simpler, the static analysis fosters less rigorous results. The digital twin ends up being an extremely better alternative due to the possibility to analyse all sequences in a real and dynamic way.

Despite the thresholds presented by the software, the present thesis made it possible to highlight a gap between Volkswagen's simulation desires and the program's capabilities. Thereby, efforts are still being made to align the wishes of the automotive industry and the manufacturing process simulation software industry. Consequently, this project and this thesis is responsible for developing new features for a new version of the software (Visual Components 4.2). Basically, it allowed to identify points of improvement in the software and also have a strong impact on two different industries at the same time in order to intensify the collaborative partnership and make sure that both are moving in the same direction.

As general information, Process Modelling is one of the new features in Visual Components 4.2 which was presented in the last video meeting. It represents a plain, straightforward, and visual way of distributing products, procedures, and process flows in a virtual 3D layout. This feature streamlines the layout planning and optimization process with a quick simulation setup in Visual Components software. Basically, several features that required resorting to preprogramed tasks from the Work Process Components or writing new Python code to perform certain tasks are no longer necessary. It is possible to create a flow of any kind of component with certain associated processes.

7.2 – Recommendations & Future Work

7.2.1 – Volkswagen & Visual Components Recommendations

First and foremost, it is from utmost importance for Volkswagen, whether it wants to develop this process rigorously without resorting to outsourcing, to give training sessions to its workers. Basically, sessions directly related to the topics of industry 4.0, simulation and some of the automated vehicles used.

The present simulation was drafted throughout a self-learning process. Essentially, this turns out to have an extremely negative impact on the learning curve. Therefore, it would be interesting for Volkswagen to have training sessions directly with Visual Components in order to optimize the software learning curve and, consequently, minimize the time for the project elaboration.

Another point to note is the fact that the company should have a team of workers working with the software in order to model the entire plant as efficiently as possible.

Additionally, it would be extremely useful for Volkswagen to make the virtual database LINCS able to store data beyond a period of 5 days. Therefore, a greater storage capacity would guarantee a larger amount of data to "draw" the probability distributions of each sequence family of components.

Regarding Visual Components, since it is a firm concern with the development of a software for simulating manufacturing procedures, including processes of the automotive industry, it would be interesting to have a direct contact with those industries. The efficiency with which they solve the problems that arose was hardly satisfactory. This is due to the fact that they are not thoroughly aware of the Volkswagen's processes.

7.2.2 – Future Project Work

Concerning the project, as a future work, it would be highly noteworthy that Visual Components could overcome the problem of the picking process. Afterwards, the simulation model developed for that sequence family should be replicated for the rest of the factory plant. Basically, all the sequence families of components must be embroiled into the simulation. Ultimately, all the results must be analysed from a financial, operational, ergonomic and sustainability perspective.

Apart from extending the future paradigm described in the present dissertation, it would be extremely useful to explore alternative future scenarios. The future scenario described in the present document corresponds to a scenario where each AGV is indexed to a specific sequence family. In other words, the AGV is performing a cycle of a specific sequence family. During the curricular internship, an alternative scenario was beginning to be devised. Basically, instead of having an AGV thoroughly dedicated to specific family of components, there would be two islands of AGVs (buffer zones), where they were parked. When something was required one of the available AGVs would be signalled and would perform that task. As a first impression, this alternative scenario would increase the factory complexity in terms of routes and AGVs coordination. On the bright side, there would be an increase in terms of flexibility. Essentially, it would be interesting to examine this scenario (Figure 44).

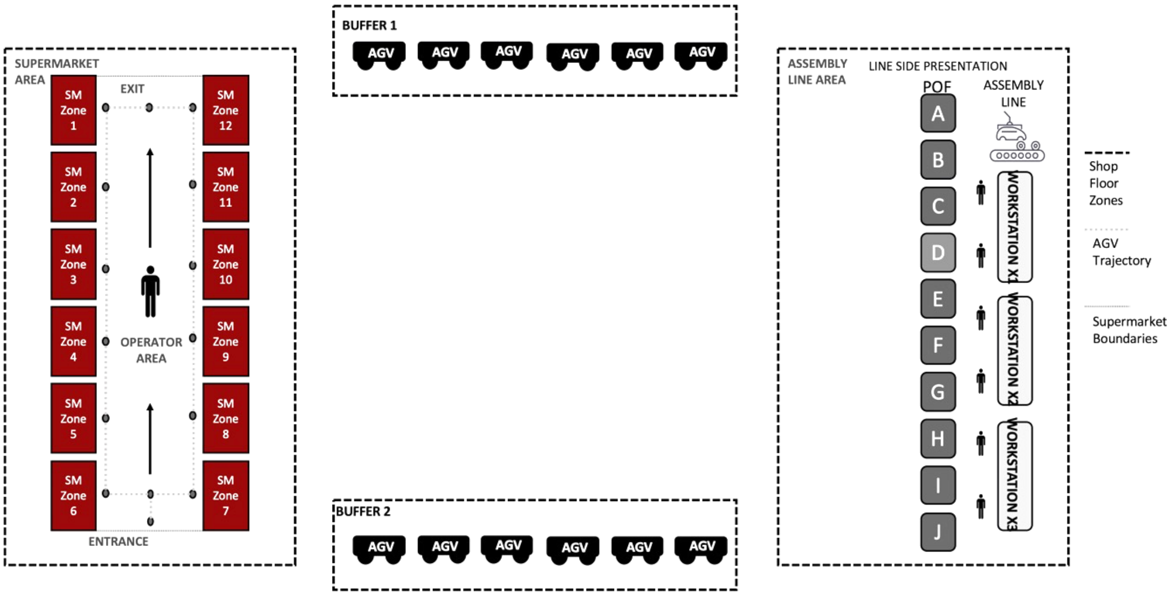


Figure 44 - Hypothetical Future Scenario

Ultimately, it would be crucial to associate to a project of this dimension a multifaceted team. Not only people specialized in logistics and operations, but also people specialized in programming. This is mentioned in order to overcome the obstacles related to the Python language more efficiently. The development of joint theses with different people from different areas of engineering and management would clearly be essential and benign for such a project and, consequently, for Volkswagen Autoeuropa.

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Software, Programming Languages and Databases

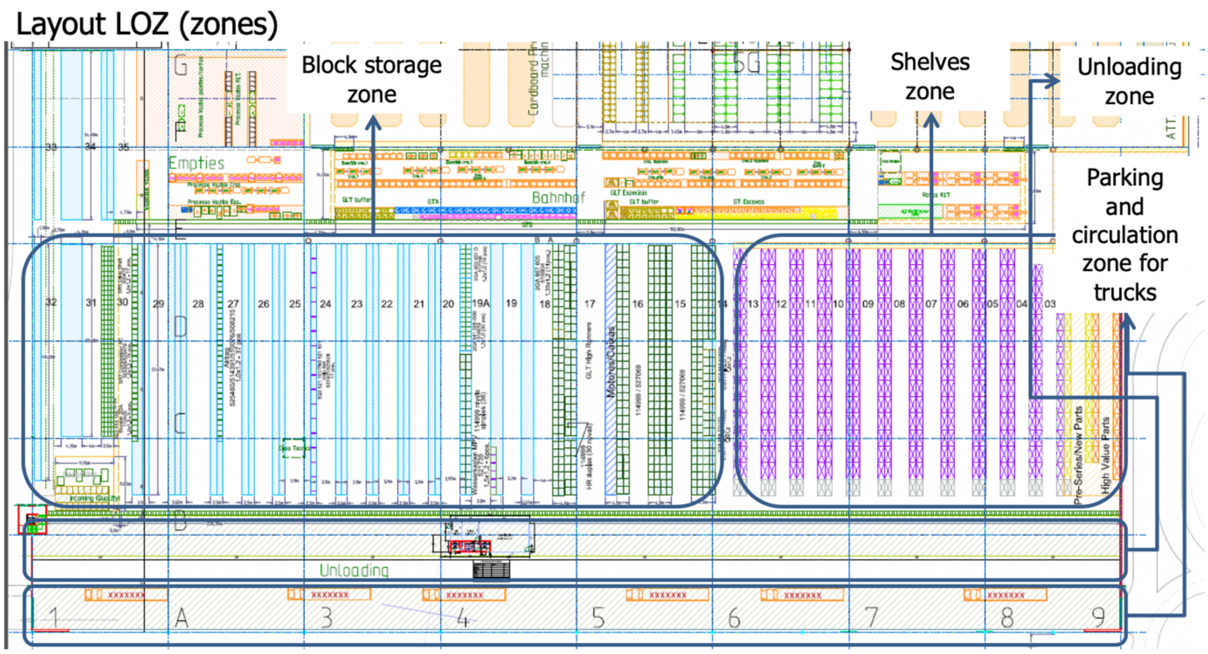
Software:
Visual Components 4.1
R and Rstudio
Excel Microsoft Office
HLS software
AP software

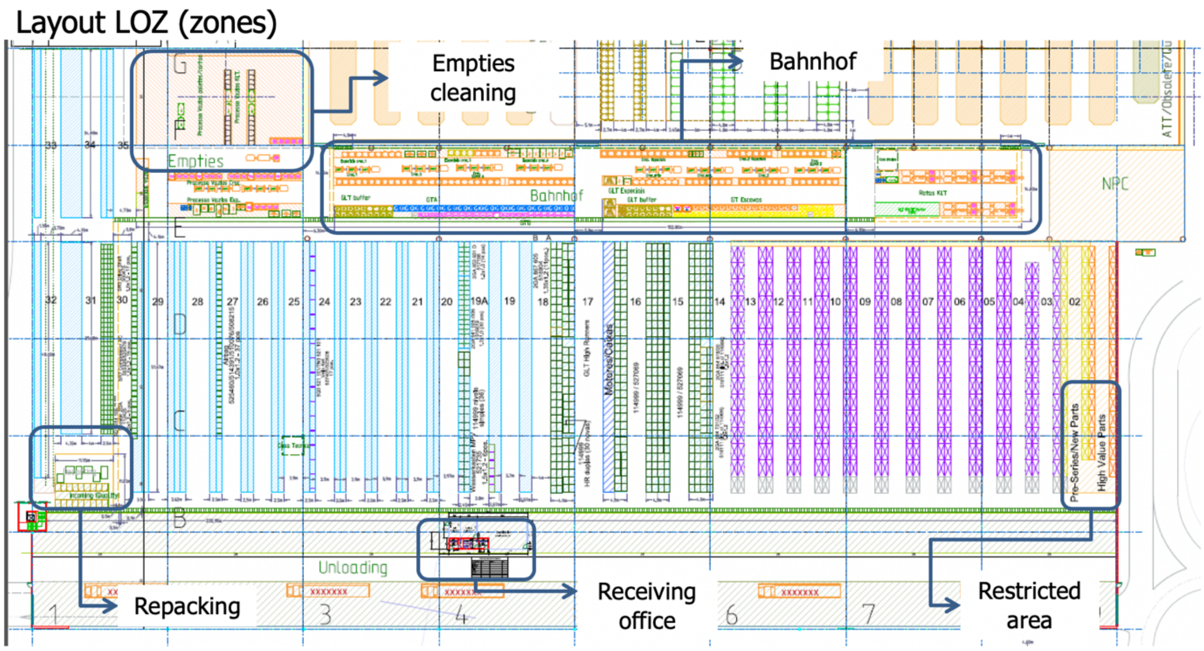
Virtual Databases:
LINCS
LISON

Programming Languages:
Python
VBA

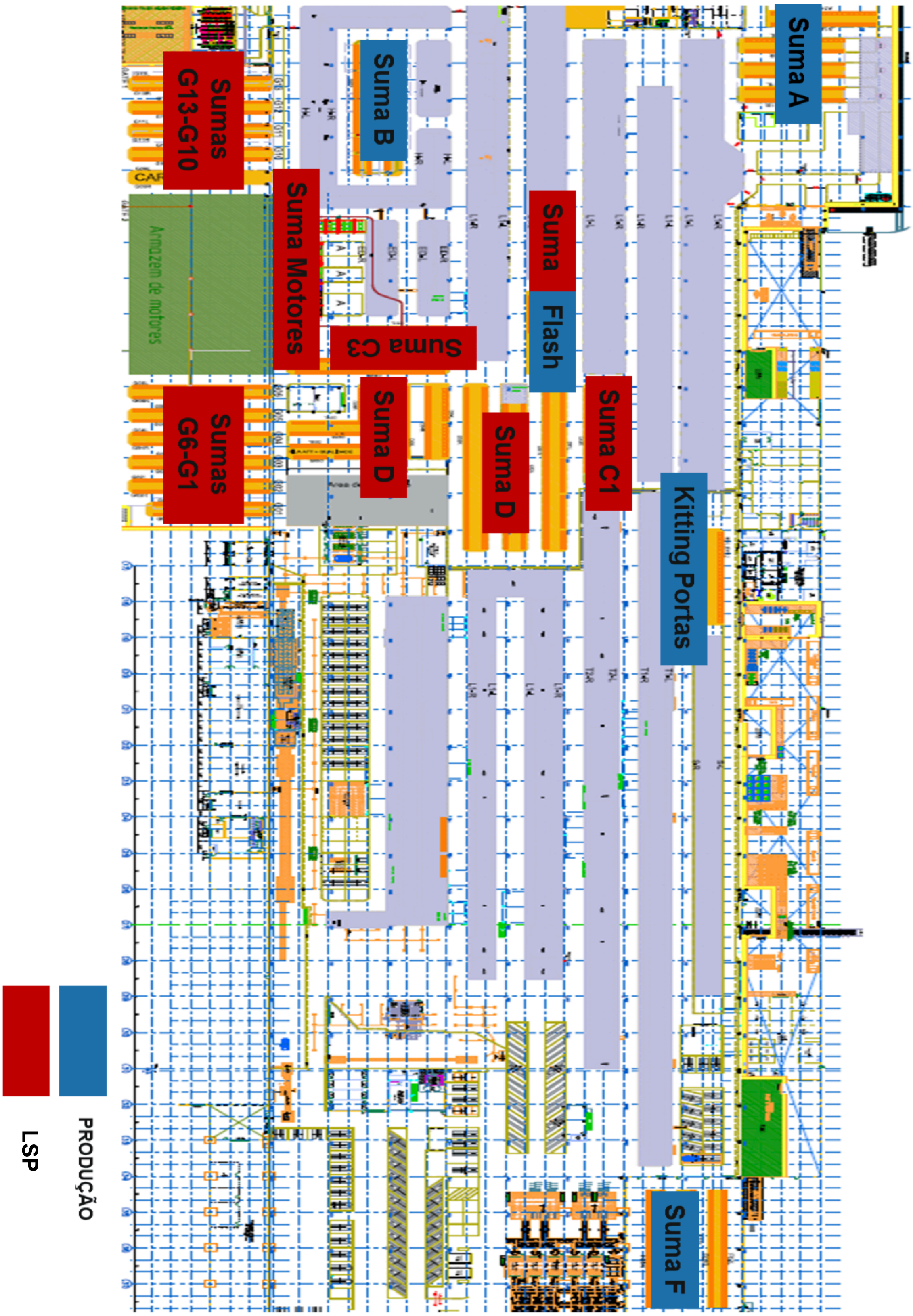
Annex

Annex I – Central Warehouse Layout & Regions

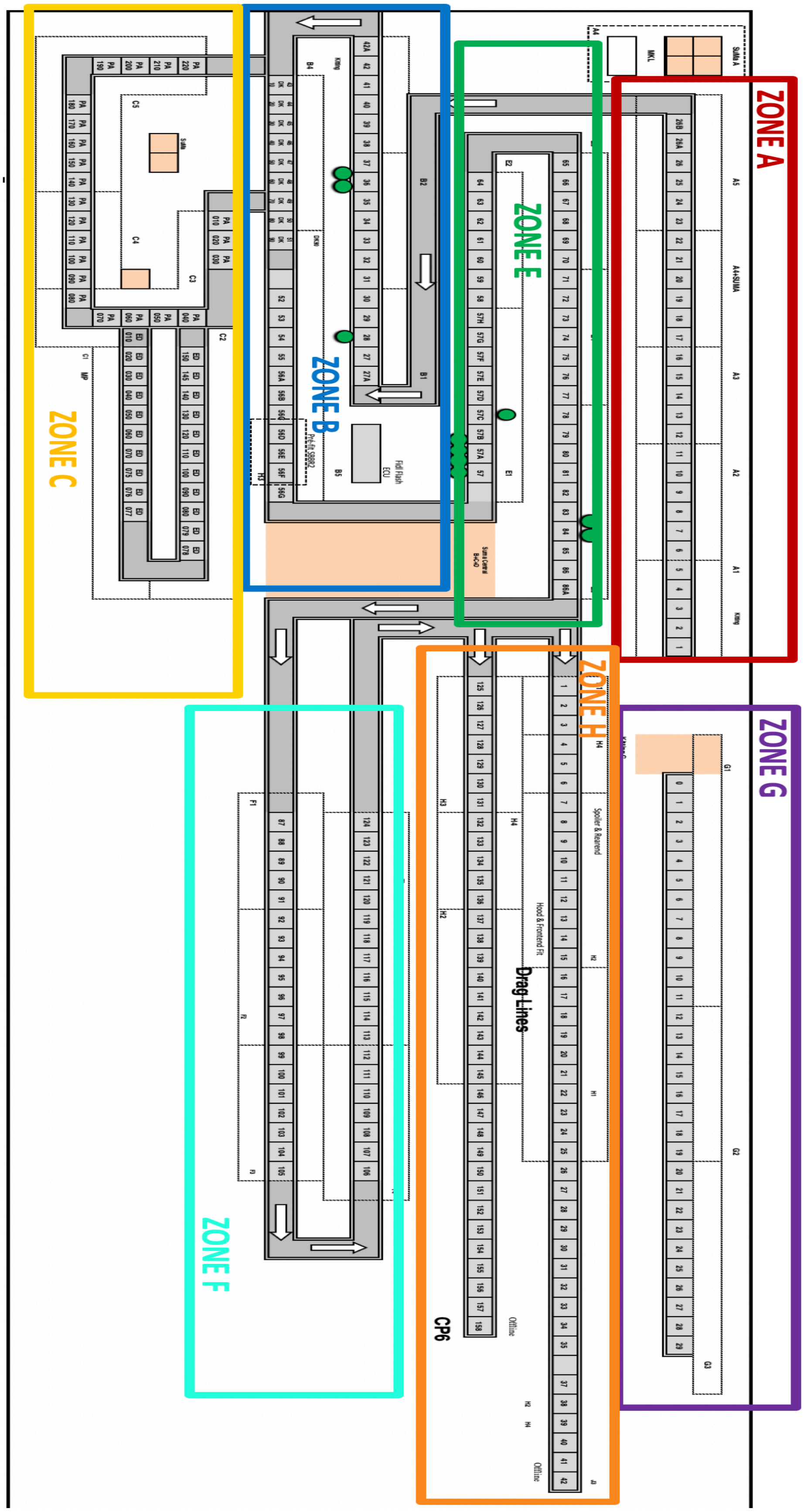




Annex II – Supermarkets Structure



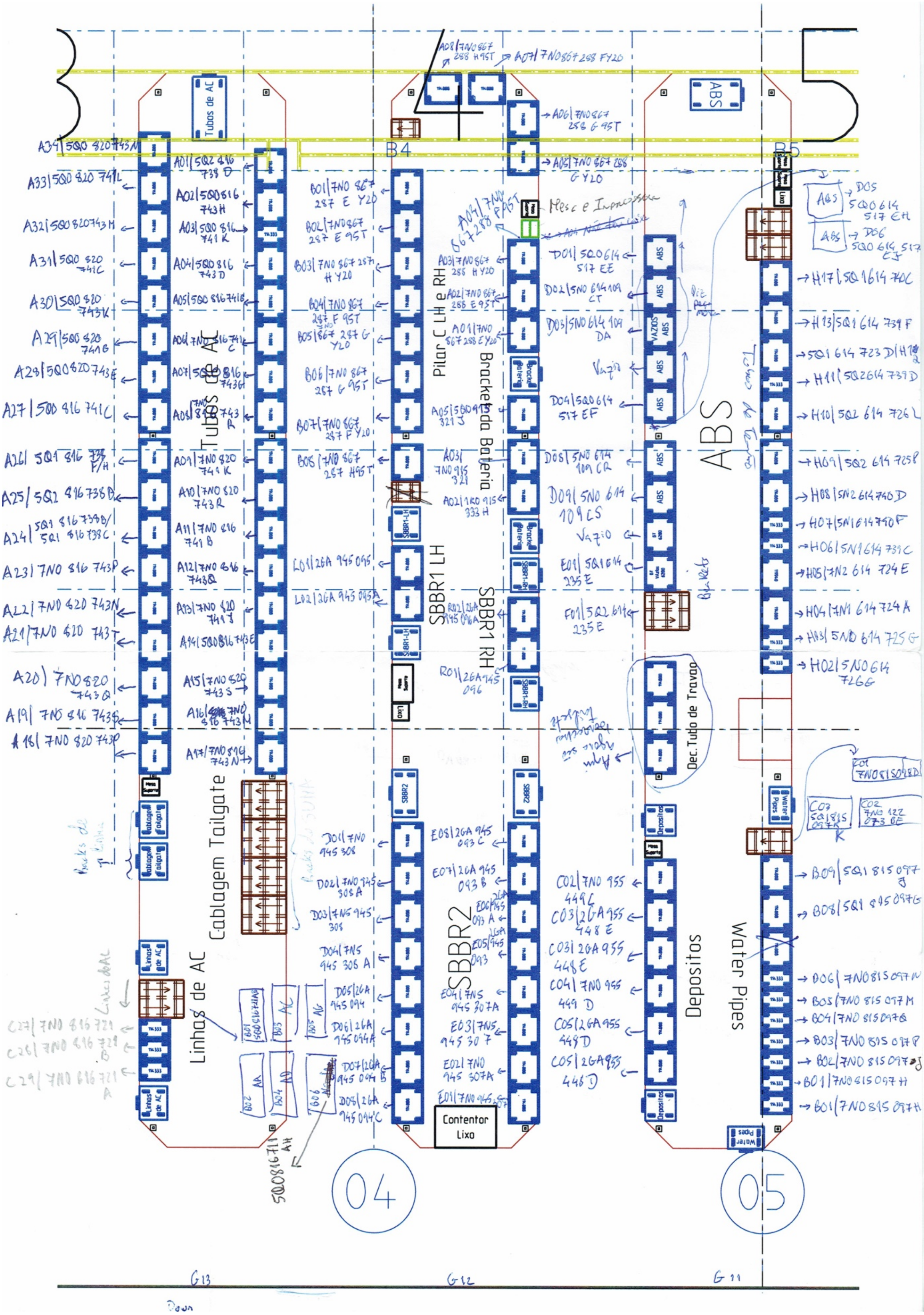
Annex III – Workstations and Shop Floor Zones (Same Orientation of Annex II)



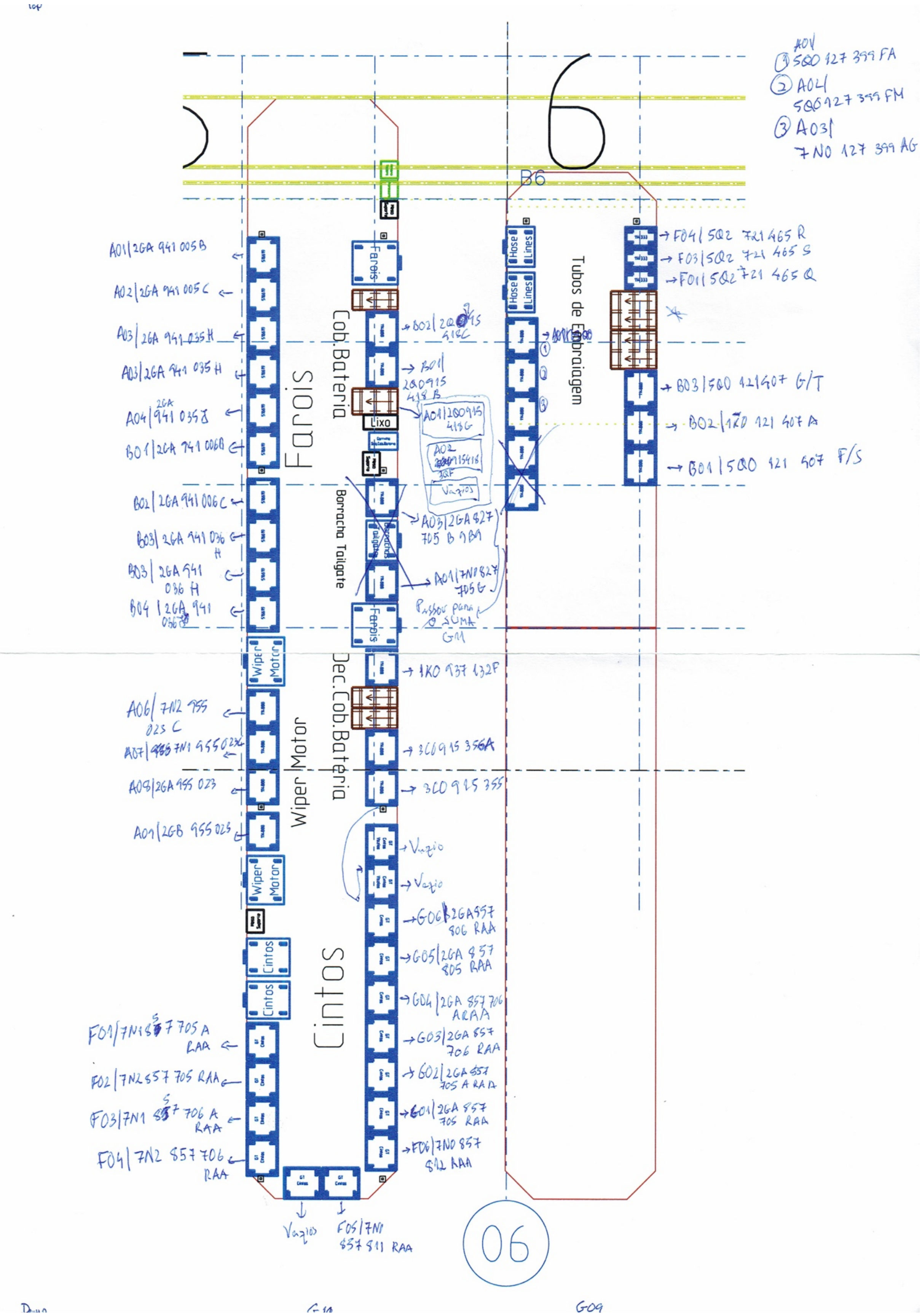
Annex IV – Vehicle Summary Table (AGV, Tow Tugs, Forklifts)

Vehicle	Capacity	Zone of Usage	Flexibility	Driver Need	Main Activities
Forklift	----	LOZ	High	Yes	Retriving parts from Suppliers & Storing at LOZ
AGV	Extremely Limited	Shop-Floor	Low	No (Automated)	Kitting & Line Feeding
Tow Tug	~5 GLT's (Depends on Rack Size)	Shop-Floor & LOZ	High	Yes	Line Feeding

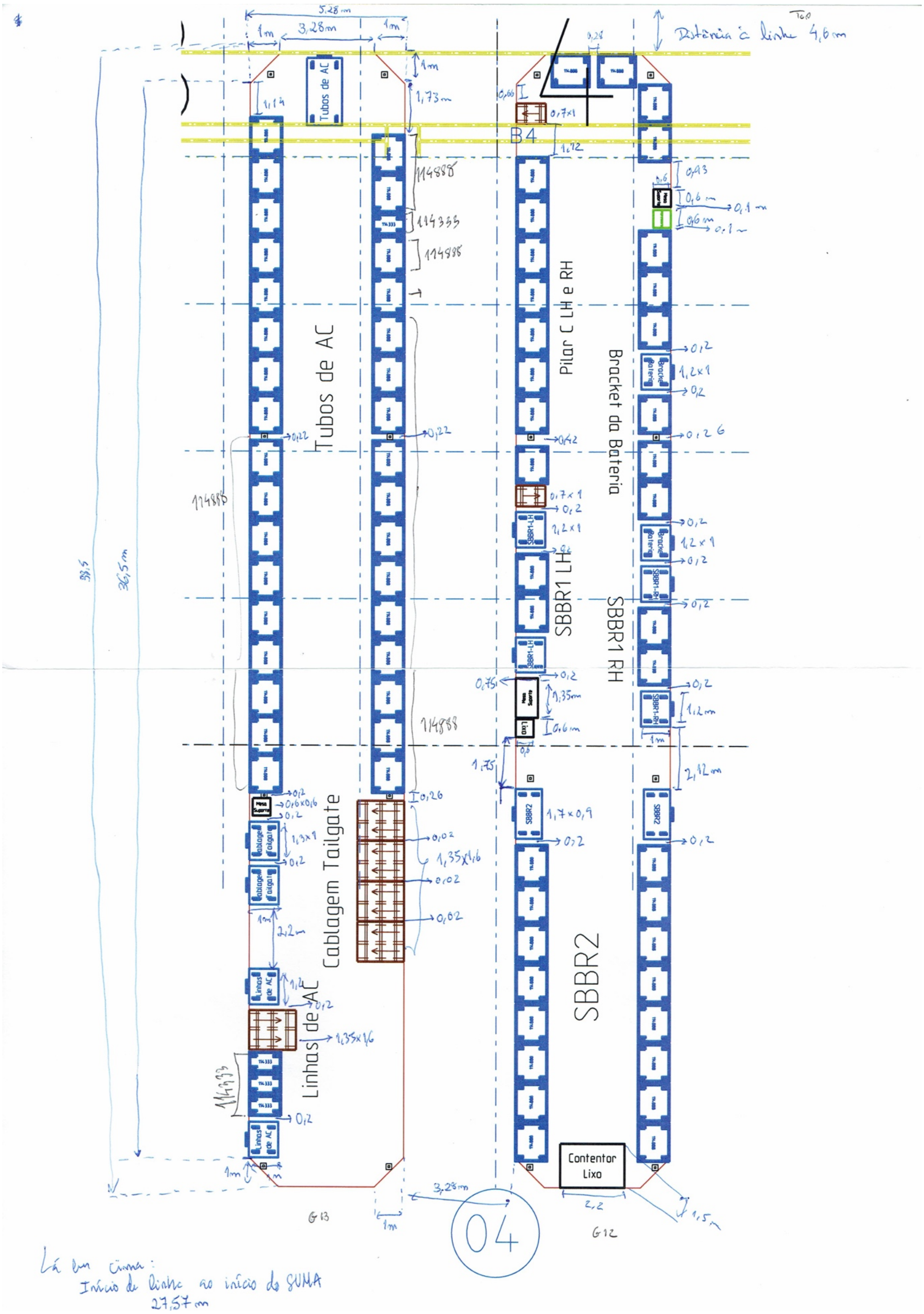
Annex V – HLS Representation of SUMA G11-G13 with Part Number Manually Written



Annex VI – HLS Representation of SUMA G11-G13 with Part Number Manually Written



Annex VII – Distances G12-G13



Annex VIII – Distances G11-G09