Designing In-House Logistics Operations towards Industry 4.0

Volkswagen Autoeuropa Case-Study

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Abstract - The paper 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.

1.Introduction

1.1 – Contextualization

Historically, the automotive industry has undergone a process of technological evolution as well as mentality evolution. Anciently, a mindset centred on mass production prevailed. Henry Ford, a reference which cannot be disregarded 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.

Since this industry roughly behaves as a dynamic ecosystem which is constantly evolving according market changes, competitiveness and technology evolution, several other policies and brand-new configurations were evidently introduced.

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, 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, the majority of those transformations are focused on technology and mass production.

By taking into consideration the highly saturated market, the golden key undergoes a change in mentality. The modern days competitive advantages are no longer focused on volume of production. Customer satisfaction sprang up as fundamental factor. 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 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. 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 automotive production based on a mixed-model assembly lines, which relies on producing several different cars 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 – Case-Study Introduction

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. On this basis, a future-oriented project was 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 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. In this way, 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).

The paper 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 paper 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.

2 – State-Of-The-Art

Before diving into the research problem, several theoretical concepts are covered in order to grasp future analysis which will be developed in the subsequent chapters and serve as a knowledge base to feed the study.

2.1 – Logistics

The majority of distinguished people in this area consider that the logistics poses a fundamental function for the good operation of a business. Through the years, several definitions were stated until today. Nowadays, and according to the Council of Supply Chain Management Professionals, 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). It comprises external, internal and reversal logistics (return of empties) (Boysen et al., 2015).

Actually, this concept became one of the main concerns of several automotive firms. 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 (Pil and Holweg, 2004). Secondly, the JIT philosophy developed in Japan 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.

2.2 – In-House Logistics Processes

In-house logistics encompasses all the logistical procedures which are performed internally from upstream (reception of the components) to downstream (use of the components).

First and foremost, the receipt of parts corresponds to a boundary between the external and internal logistics process. 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). Thereafter, all the product flow entering the factory should be noted in the information system of the automotive plant. Depending on the type of components which are being considered, their pathway from here onwards will be different.

The second step embraces the warehousing of components. There are two logistics pathways. 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).

After the storage process presented in detail in the previous paragraph, the sequencing parts process takes charge. Since Just-In-Sequence parts were already sequenced by the suppliers, in-house part sequencing is exclusively applied to the other 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 organization of parts inside the containers diminishes the time-wasting at the assembly line for searching and identifying components and, consequently, enhances productivity (Limère, 2012).

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 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. 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. 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 (de Koster, Le-Duc and Roodbergen, 2007). 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 (de Koster, Le-Duc and Roodbergen, 2007). Based on those methodologies, normally, product-to picker is more applied to small and low-value parts.

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).

2.3 – Industry 4.0 and Simulation

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) (Hermann et al., 2015). 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. 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 previously mentioned, 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. 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.

As previously mentioned, 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 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. 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).

3. Volkswagen Case-Study

3.1. Motivations

The Volkswagen Autoeuropa corresponds to an automotive production plant from Volkswagen Group, nested in Palmela, near Lisbon, Portugal. As shortly stated in chapter 1, there are four main trends which oblige the firm to change its in-house logistics procedures.

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.

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.

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.

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.

3.2. Current and New Paradigm

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 activities are executed by operators (Figure 1).

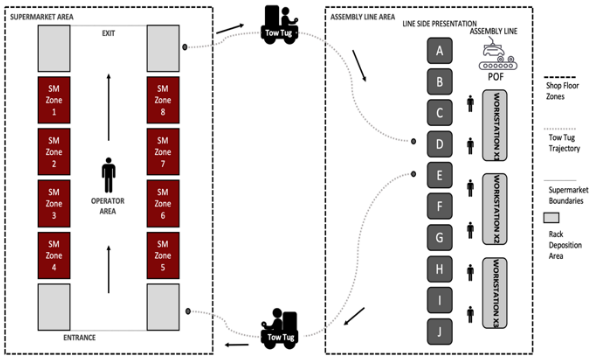

Figure 1 – Previous Paradigm

Basically, 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 an industrial vehicle 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). According to Autoeuropa, the introduction of automated vehicles in the process is to be considered the next generation of their supermarkets' and line feeding operation.

This visual scheme (Figure 2) 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 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 takes place. AGV

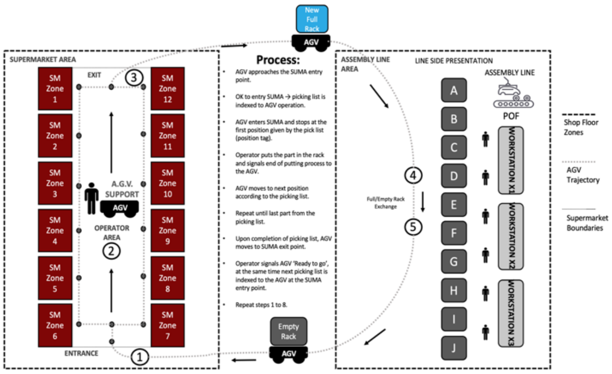

Figure 2 – Current Paradigm

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. 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, upon their parts are placed on POF rack. Finally, the reverse procedure begins. The empty racks are carried to the supermarket. This procedure is realized in an iterative way.

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.

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.

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, etc.), 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 (CO2 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.

4. Data Collection

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. 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. The second step compromises the components sequence' family and part number location identification. 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. In this way, about 200 part numbers were located and registered manually during several staged periods.

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 database 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.

Regarding the resource allocation, there is no operator allocated to each component family. 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. Six workers were identified with their respective sequence tasks. Ultimately, a roadmap was developed with the logistics operator trajectory inside the supermarket aisle.

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 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).

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. 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 information was extracted to an Excel Sheet on a daily basis. 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. 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 (Figure 3).

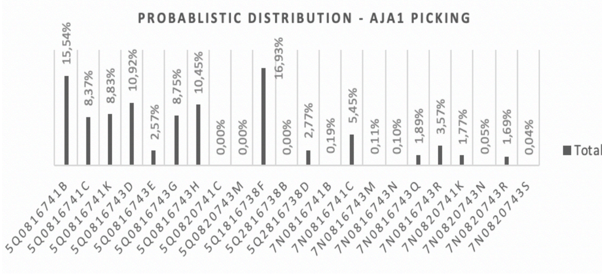

Figure 3 - Relative Frequencies of AJA1 Sequence Family

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. 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.

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. 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).

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 assemble the component.

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 time the number of AGVs and racks must be higher.

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.

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 1).

Table 1 - Transportation Costs per Car

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 and Results

5.1 Static Analysis

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.

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. One further point worth mentioning is that with the performed analysis it was possible to acknowledge that there are some sequence families 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. 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.

5.2 Dynamic 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. The simulation software used is called Visual Components 4.1.

First and foremost, the first step towards the digital twin underwent through the introduction of the factory plant. 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.

The first exercised step spans to importation to the control area of the three-dimensional CAD's of the containers, trolleys and sequence racks that are used.

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. Subsequentially, all the components were conceived.

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. 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. 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.

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. 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.

After preparing the whole environment the simulation starts. 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.

By following the logic of Figure 4, 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

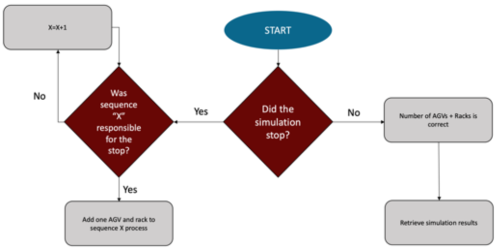

Figure 4 - Number of AGV reasoning

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.
The outcomes obtained by a single AGV regarding AJA1 sequence family of components is presented on Table 2.

Table 2 - Overall Outcomes

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

These results would be relevant for Volkswagen and the remaining sequences would be implemented in the exact same way. The steps described previously 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.

6. Limitations

In the aftermath of the elaboration of the present project it is possible to acknowledge its limitations.
Firstly, the existing literature regarding industry 4.0 and simulation 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. Additionally, no simulation studies and scientific articles were found using Visual Components.
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. 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. 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.
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, 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.
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).
The software also presented capabilities limitations. One activity was not possible to incorporate into the simulation as expected. According to the new Volkswagen 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. Obviously, this behaviour will have a tremendous impact in terms of operator workload, AGV occupation rate and cycle time optimization.

7. Conclusions and Future Work

The paper provides a synopsis on part logistics realm in the modern days of automotive manufacturers.

Incrementally, it is possible to evidence a real case study where the theoretical concepts are reviewed and have practical applicability.
Throughout the problem characterization it was possible to evidently recognize Volkswagen's ambition to follow the 4.0 industry train.
This paper 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.
Despite the thresholds presented by the software, the present research made it possible to highlight a gap between Volkswagen's simulation desires and the program's capabilities. 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.
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.
Apart from extending the future paradigm described in the present dissertation, it would be extremely useful to explore alternative future scenarios. 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.

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