TÉCNICO LISBOA

Simulation and Improvement of Inbound Operations in a Pharmaceutical Warehouse

An Alloga-Logifarma Case Study

Ana Sara Guedes da Costa Marques

Thesis to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisors: Prof. Diogo Filipe da Cunha Ferreira

Examination Committee

Chairperson: Prof. Susana Isabel Carvalho Relvas
Advisor: Prof. Diogo Filipe da Cunha Ferreira
Members of the Committee: Prof. Amílcar José Martins Arante

June 2024

Declaration

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

Acknowledgments

Quero expressar o meu agradecicmento ao Professor Diogo da Cunha Ferreira, que aceitou o tema de dissertação que propus e acompanhou todas as importantes decisões tomadas para a tese ter sido possível.
Quero também agradecer ao Eng. João Gomes pela oportunidade e pelos dados disponibilizados, e ao Filipe Pantoja pelo apoio na imersão dentro da Alloga-Logifarma e disponibilidade constante.
Num tom mais pessoal, quero expressar a minha gratidão aos meus pais, Elisa e Humberto, aos meus irmãos, Henrique e Dinis, ao meu namorado, João, à minha avó Deolinda e aos meus tios Carla e Nuno. O vosso apoio incondicional e amor significa o mundo para mim.

Abstract

In the context of warehouse management, there can be a number of details to be studied and improved that can greatly contribute to the daily flow and operations of any activity. The objective of this study is to improve the current state of inbound operations in a pharmaceutical warehouse context, by applying discrete-event simulation to different scheduling scenarios that affect the daily cycle of arriving pallets' flow. The first scenario focuses on the scheduling effort of resources within different activities in the inbound operations scope of electronic reception and storage. The second scenario shifts its focus to outside arrivals of trucks, by imposing a scheduled distribution in order to best control the peak inflow of pallets and best take advantage of working hours and warehouse resources.

The construction of the model was based on the data from Alloga-Logifarma's warehouse. The information was analysed and statistically fitted to be accurately represented within the simulation. The tested scenarios proved there are opportunities for improvement, with both presenting relevant solutions that can decrease total time in the system by over 37% and maximum exceeding area by 14% in scenario 1 and 68% in scenario 2. In the first scenario, this was accomplished with a rescheduling of the electronic reception and of storage activities by focusing on afternoon and night shifts. In the second scenario, the positive impact on the daily flow of inbound pallets was a lot greater, solving the peak arrival problem currently faced.

Keywords: Discrete-Event Simulation, Warehouse Management, Inbound Operations

Resumo

No contexto de gestão de armazéns, existem inúmeros detalhes que podem ser estudados como oportunidades de melhorar o fluxo diário e operações de cada atividade. O objetivo do estudo é melhorar o estado atual das operações *inbound* no contexto de um armazém da indústria farmacêutica, com a aplicação de uma simulação de eventos discretos a diferentes cenários de calendarização que afetam o fluxo diário de chegada de paletes. O primeiro cenário foca-se na programação de trabalho dos recursos em diferentes atividades dentro das operações *inbound*, tanto receção eletrónica como armazenamento. O segundo cenário tem o seu foco direcionado para as chegadas externas do camiões ao impor uma distribuição calendarizada, de forma a manter um melhor controlo no pico de fluxo de paletes e aproveitar melhor as horas de funcionamento do armazém e dos seus recursos.
A construção do modelo foi baseada nos dados retirados do armazém da Alloga-Logifarma. A informação foi analisada e estudada estatisticamente de modo a permitir que os dados sejam representados com precisão dentro da simulação. Os cenários estudados permitiram concluir que existem oportunidades de melhoria, apresentando ambos soluções relevantes que permitiram diminuir o tempo total no sistema em 37% e a utilização máxima da área de excedente em 14% no cenário 1 e em 68% no cenário 2. No primeiro cenário, isto foi conseguido através de ambas as programações de horário da receção eletrónica e armazenamento, com um principal foco nos turnos da tarde e da noite. No segundo cenário, o impacto positivo observado no fluxo diário *inbound* de paletes foi significativamente maior, resolvendo o atual problema do pico de chegadas.

Keywords: Simulação de Eventos Discretos, Gestão de Armazéns, Operações *Inbound*

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Glossary

3PL Third Party Logistics
AIC Akaike's Information Criterion
BIC Bayesian Information Criterion
CDF Cumulative Distribution Function
CMR Convention on the Contract for the International Carriage of Goods by Road
DES Discrete Event Simulation
ERP Enterprise Resource Planning
KPI Key Performance Indicator
KS Kolmogorov-Smirnov
PLP Production Layout Planning
QQ Quantile-Quantile
SKU Stock Keeping Unit
VIMS Visual Interactive Modelling Systems
WIP Work in progress
WI Work Item

Chapter 1

Introduction

The dissertation is described in this chapter, with the objective of understanding the issue at hand, the goal of the study, and the research methodology as part of the structure that this dissertation follows. The important topics of simulation and inbound operations are introduced here and further developed throughout the chapters.

1.1 Objective and Motivation

The pharmaceutical industry, the context in which the warehouse of Alloga-Logifarma is inserted, has a number of unusual characteristics, both in its structure and in the nature of its business operations, which materially affects the process of bringing pharmaceuticals to the patient. A high level of service for medical supplies and effective inventory policies are considered essential objectives for all health care industries, including all entities inserted into logistics, distribution and storage. Medical shortages and improper use of pharmaceuticals can impact, not only the financial side of the industry, but also patients and health providers. As Uthayakumar explores in detail, the problems can be found in all levels of the supply chain, with a significantly greater impact being felt in hospitals that experience difficulties in handling of how medicines are managed and supplied and thereafter used to save lives and improve health [1]. Therefore, studies are essential to understand operations in health care industries and to offer decision support tools that improve health policy, public health, patient safety, and strategic decision-making in the pharmaceutical supply chain.

A crucial cost in the pharmaceutical industry relates to storage and control requirements imposed on warehouses facilities and transportation, as products can be expensive to purchase and distribute. An effective management is required to ensure product availability at the right time, with the right cost, and in good condition [2]. These conditions can entail specific efforts by the warehouse to ensure, for example, appropriate temperature, appropriate humidity, experienced and careful handling of glass vials, supervised handling of controlled substances. Overall, these are several aspects that unwillingly deter optimization attempts within the everyday flow of the warehouse. Nevertheless, constant improvement is what enables warehouses and businesses in general to stay competitive in prices whilst offering high quality services. In today's business environment, organizations need to develop new competitive advantages to keep up with the speed of change in technology, customer demands and global competition. Goksoy states that organizations can benefit from innovation strategies and tools more than ever, as it helps companies to optimise their competing power by increasing their performance and efficiency. One strategically effective way to use innovation for a company is to apply it in warehouse management, as warehousing is becoming more and more a critical activity in companies. The ultimate objective is to respond to customer demand, that forces companies to hold less inventory, react faster to market changes, lead times and overall costs [3].

The motivation behind this thesis is to study the possibility of improving the everyday flow of one of the main activities within the warehouse, inbound operations or, more commonly referred to throughout the thesis as reception, by attempting to take better advantage of current resources available whilst proposing a different organization of activities and schedules.

Inbound operations are a crucial part of any warehouse, with the responsibility of accurately logging information of the product to ensure all entities involved in the supply chain can receive updated product data and accurately make decisions. Within a wider framework for optimization in logistics, there is always a notable necessity for accurately retrieved data, which in turn connects the information collected throughout the supply chain so as to study integrated inventory and transportation system policies [4]. The information logged can be varied, from size, weight and amount of product, to data containing the temperature at which it was maintained throughout its journey, information regarding requirements of specific handling, etc. Within inbound operations, it is also included the arrival, unloading and departure of vehicles carrying the product, all the logistics behind docking and ensuring the load had the correct level of security, and the appropriate storing of products inside the warehouse.

There are several aspects of the warehouse that can be studied and improved, and optimization in general can be studied through several methodologies. Simulation was the selected methodology to study both the flow of activities currently happening in the system, and the possibility of implementing specific changes. Simulation in warehouse optimization helps capture uncertainty in clients' demands, order-picking time, and travel time, leading to more efficient capacity plans and competitive advantages, as studied in the context of distribution network design of 3PLs [5]. Overall the advantages of simulation as an optimization tool, as described by Pidd, focus on the "trial and error" aspect of demonstrating the likely effects of different policies or changes within a system, allowing for a flexibility on study topics without incurring costs on the real system [6].

The simulation was modelled after the actual warehouse, with data retrieved from different systems and cross-checked to create mathematical distributions for every activity and queue in the flow. The initial arrival data were retrieved from the security office, followed by data collected from the platform where clients can schedule arrivals, and the data collected as electronic reception and storing. These distributions allowed for an understanding on the behaviour of arrivals by time and by amount, the effort going into unloading pallets, electronically receiving them and storing them, as well as the time spent awaiting such activities.

1.2 Problem Formulation

An initial analysis of all warehouse inbound data proved an average of 26 hours by pallet is spent within the activities categorised as reception. This feat is clearly not ideal given the daily cycle followed in terms of tasks. This results in a need for overtime. The main focus of the problem is, for that reason, the study of how this daily cycle of activities can be adjusted to ensure the average falls bellow 24 hours. A larger amount of time spent by the pallets within the reception area, also results in a larger need for space utilization, as the flow is slower. The objective is then to both decrease the average time spent in the system, and the utilization of space, measured not in the utilization rate of already existing slots, but measured as how much extra space was needed to manage peaks in arrivals at any given time.

There is a clear focus on the optimization of time and space, as is often the topic in warehouse and resource management in general. The two opportunities identified as hypothesis worth studying by simulation are then:

1. Scenario 1 - The impact of shifting improvement by allocating skilled resources to different time frames more suitable to activity peaks, both for electronic reception and storing of pallets.

2. Scenario 2 - The impact of scheduled and intervaled arrivals in the peak activity of the system, by dispersing arrivals throughout the working hours of the warehouse and allowing the resource currently responsible solely for unloading to be pooled with electronic reception.

Both scenarios are in place to provide a solution to the question: Can appropriate shifting and resource management improve the daily flow of work throughout the inbound operations of a warehouse and decrease average time spent in the system to under 24 hours?

The first study is applied to two different identified types of resources that perform different tasks, excluding the unloading resource, which are electronic reception and storing. The team of resources is distributed in shifts that might not directly reply to the influx of pallets into that specific queue. For this reason, several different combinations were studied so as to best understand where and when each resource team should be focused, whilst maintaining their capabilities, amount and requirements equal. The second scenario goes into scheduled arrivals, given that the hour reservation system was applied some time ago, but there is no correlation between scheduled time and arrivals, resulting in the time reserved being merely suggestive and impairing an appropriate study into resource distribution. An actual distribution of arrivals could present an opportunity for a more even-spread amount of arrivals and therefore lower exceeding space utilization and overall time spent in the system.

To conclude, the improvement of logistical steps and activities within the warehouse can stem from changes performed in a smaller scale, and the motivation behind this study is to test hypothetical scenarios both mathematically and visually. This allows for a better understanding of the situation and flow at hand, aiding on the decision-making process behind operational management, without initially compromising the already working state system at place in the warehouse. The objective is made clear, given the hypothetical situations' focus on the 24 hour cycle happening in inbound operations, to reduce time spent in the system and improve the space at hand, whilst maintaining the same resources, rules and requirements already at place. More concretely, the objective is to lower the average time in the system as much as possible, by only implementing change in certain approved aspects of the warehouse, such as shifting resources and scheduling arrivals.

1.3 Dissertation Structure

The structure of this dissertation follows the methodology through which the study was conducted, so as to best understand the situation and accurately represent the thought process.

1. Introduction - This chapter presents a brief explanation of the context behind what is being studied, the objective of the simulation and the structure behind the dissertation.

2. Literature Review - This chapter presents a broad overview into the utilization of simulation, focusing mostly on logistics and narrowing into supply chain and warehouse management. There is then a shift towards the theoretical concept of simulation modelling, with classifications into the type of data and simulation being analysed. There is also a contextualization into what is required to construct a model and a brief discussion on the selected software.

3. Case Study - This chapter describes the company and its operations, with a focus on the warehouse layout, the natural flow of pallets, and a focus into the area in study and the improvement opportunities identified. This section allows for a detailed description of the current situation and clearly states the objectives and problem formulation.

4. Model and Methodology - This chapter describes the steps taken in the study regarding all handled information and provides a clear distribution of effort and information regarding the steps of the study taken prior to the writting of the thesis.

5. Data Collection and Model Construction - This chapter, as the name indicates, goes into the more technical aspects of the study. Firstly regarding the data collected and the statistical modelling behind the distributions applied to the simulation and all activities. There is then a detailed description of how the model was constructed, explaining the common terminologies and entities used in simulation and detailing the different sections of the entire simulation model. Lastly, the chapter focuses on the model validation and set-up, with a study into the warm-up period, the results collection period and the recommended number of runs.

6. Results and discussion - This chapter thoroughly examines the scenarios studied, describing the hypothetical situations and commenting on all obtained results. The scenarios were divided into subscenarios, given that the two scenarios studied presented a large number of hypothesis between them. All scenarios and subscenarios were discussed together, so as to best identify possible improvement strategies.

7. Conclusion - This last chapter focuses on stating all conclusions that were withdrawn from the previous chapter, as well as discussing all limitations and weaker aspects encountered throughout, and suggests future work.

Chapter 2

Literature Review

In this chapter of the project, a thorough literature contextualization of simulation is conducted, along with a specific narrowing into warehouse optimization approaches. Starting with an overview of the definition of discrete event simulation and relevance in certain sectors, the chapter will then discuss types of simulation, warehouse improvement and the application of simulation in warehousing.

Simulation

Discrete event simulation quantitatively represents the real world, replicates its dynamics on an event-by-event basis and generates a report based on its performance, and has long become one of the mainstream computer-aided decision-making tools [7]. The distinction between discrete event simulation and continuous simulation will later on be explained in further detail, but is quite simple to understand. Discrete event simulation is best suited for problems in which variables change in and by discrete times and steps. Continuous simulation, on the other hand, is suitable for systems where variables can change continuously [8]. There have been studies conducted with the intent of comparing the two. A study conducted in 1999 analysed both in regards to problems suitable for both modeling techniques, in which it was pointed out that the major purpose of system dynamics models is behavioural analysis, whilst discrete event simulations are built to analyse particular processes with the aim of estimating parameter values with statistical significance [9]. The study went further into the underlying mathematics of the two approaches, with a conclusion that system dynamics is best suited for problems associated with continuous processes in which their behaviour is significantly affected by feedback, whilst discrete event simulation models thrive in providing detailed analysis of linear processes that model discrete changes.

In order to continue to discuss all aspects related to simulation, it is first important to understand the relevance of simulation against experimentation. Simulations, strongly interconnected with the term of numerical experiments, can be described as attempts to apply scientific theories to systems that fall under the theories' domain [10]. This results in a cost-controlled alternative to real-life experimentation with methods that produce results comparable to the experimental design settings [11]. As Pidd described, there are five pillars to consider as advantages to simulation [6]. **Cost** as, despite simulation relying mainly on skilled manpower, which can be costly, real experiments can be expensive, especially if something goes wrong. **Time** as, in theory, once a simulation is set up, it becomes possible to simulate long periods of time in seconds. **Replication**, as simulation allows a precise repetition of results that cannot be observed in a lot of real experiments, in areas such as military and scientific laboratories. **Safety**, which comes into play in simulation of extreme conditions, ranging from dangerous to even illegal. And, lastly, **legality** mostly in that changes in legislation can greatly affect businesses and so on.

Nevertheless, simulation is not always the most reasonable solution, as found in a study conducted on crash simulations for full passenger cars that took between 36 to 160h to compute, making simulation a more impractical way to optimise the system at Ford Motors Company [12].

2.1 Simulation and Logistics

The vast plethora of attributes given to discrete event simulation as an improvement tool for various sectors can be applied differently given specific requirements. A lot of sectors benefit from the advantages described, such as the healthcare sector, the defence sector and public services. Wild specifies that discrete event simulation can be applied to operations systems, defined as a configuration of resources combined for the provision of goods and services, and later identifies four specific functions of operations systems: manufacture, transport, supply and services [13]. Another author has described somewhat similar but different topics, all within a logistics standpoint, which are in particular interest to this paper and will be further analysed. These are the manufacturing sector, the logistics transportation sector, supply chain planning and warehouse management [14]. Inside each relevant sector, it is important to understand what it is that discrete event simulation brings to the table.

2.1.1 Manufacturing

In the manufacturing sector, simulation can be applied to most processes present, including the study and comparison of alternative designs and control of the model before the initiation of construction of the physical plant [15]. It can also be applied to existing plants to find better ways to operate as a cycle of periodic checks on the running of the system. The task of coordinating all the individual activities required to produce, assemble and deliver a product to the customer involves a multitude of correlated functions together and intensive information exchange. Based on a conceptual model presented by P. Cunha and R. Mesquita in their research work, there are four main information processes that exist inside the manufacturing system, that revolve around the most crucial part, factory operations [16]. The first information flow relates to product design and development where there is the engineering drawing and bill of materials required to present a product. The second information flow that requires attention is the manufacturing planning, where all processes, requirements and capacity must be planned, taking into account master scheduling, production order and inventory management to ensure all aspects of production are appropriately identified and considered. Thirdly there is manufacturing control, where there must be shop floor control, monitoring, as well as quality assurance within the line. Lastly there are business functions also required to ensure proper production, with relevant information coming from sales, accounting, forecasting, marketing and so on. These four pillars of information work around factory operations, representing processing, assembly, material handling and control. All this information is important as a simulation system is able to address almost all exercises in a manufacturing company so long as it shows a deep understanding of the manufacturing system coupled with the capabilities and operation of the simulation system [16].

There are, of course, articles and studies that focus on more specific parts of the manufacturing process and make more in depth observations of how impactful simulation can be. Line balancing, a production strategy that balances the machine time with operator time and requirements in order to best match both can be studied through simulation [17]. Material handling, an important part regarding how material is transported inside the manufacturing plant and storage units, has also been implemented as part of studies into optimising time utilization, space utilization and material handling vehicles [18][19].

Production layout planning, PLP, is another highly studied and important aspect of any manufacturing plant, with studies conducted relating to various types of products, from the aviation industry, to microchips. Several studies thus far have proven that reasonable production layout can reduce production cost but increase utilization rate of equipment and personnel, as approached by Ciu Jing having established a study into the aviation composite material production line, with an aim at improving product quality, managing to efficiently increase production and reduce production cost [20]. The two main focuses addressed by most studies into PLP are to optimise the quantity of process equipment and to conduct quantitative analysis from the aspects of material flow and equipment occupancy [21]. An example of this application is a study carrying out a simulation through the combination of minimum material flow and optimization of downstream flow, managing to solve the optimal sequence of equipment in a ”U” type layout [22]. Layout planning can also fall under warehouse management, a topic that will be discussed further on in this chapter, as it can affect both production and storage in manufacturing or warehouse plants. Overall it is an important takeaway that simulation can be implemented in several layout aspects of manufacturing under the premise that, given a specific space and flow, the objective is to satisfy the restricting conditions whilst optimising resource utilization and enhancing competitiveness [23].

Lastly, production scheduling is an important focus inside the manufacturing sector, with different aspects to consider. Scheduling of a job shop is a push towards automation and flexibility, having led to a number of computed solutions aiming to address specific problems at hand. In a more practical setting, a scheduling system in place can facilitate the reduction of work-in-progress inventory and increase throughput, whilst enabling a faster response to changing demands. This result is directly correlated with an increase in return on investment and market share [24]. In simulation, the scheduling problem has been approached differently depending on the specificities of the situation. Discrete event simulation has assisted in both short-term and long-term scheduling, with studies being conducted into flexible scheduling techniques and their applicability to certain markets [25]. One long-term situation is, for example, the scheduling of maintenance based on predicted machine degradation, which was estimated based on a simulation of machine utilization through longer periods of time and previous conducted studies on safety behaviour [26]. Another approach was taken in regards to the performance of certain rules in manufacturing scheduling, as first-in-first-out, shortest processing time and longest processing time are all valuable evaluation criteria for a new dispatching situation aimed at minimizing total tool set up time [27].

2.1.2 Logistics Transportation

Inside the logistics and transportation sector, there are several relevant and widely studied problems that can be of importance in the study of discrete event simulation applications. Transportation can be construed as its formal Oxford Dictionary definition of a system for carrying people or goods from one place to another using vehicles, roads, etc [28]. This entails a large variety of articles and studies conducted. For example, a recent study applied simulation to a freight operations modelling for urban delivery and pick-up, having mentioned the impact of the pandemic on the increase of necessity for their flexible routing solutions [29]. Another recent example can be applied to the complexity of military operations, that can be cross-functional in the different sectors studied, as simulations were conducted to analyse planning, management and decision making in the implementation of logistical support to deployed units, specifically during the first phase of operations. This paper uses simulation to study implementation of specific technologies [30]. The list of quite specific applications can be infinite, there are however studies previously conducted that can act as pioneers to the implementations to take place today. In the aviation sector, for example, simulation methods have been useful to help plan large passenger terminals, as the passenger and aircraft flow are crucial to understand and evaluate current scenarios. A time-oriented simulation was used by Low to test design concepts relating to size, location, interactions and operation to study operational rules and their impact on the flow of all entities inside the airport [31]. Joustra, more specifically, applied simulation to check-in counters, overall contributing to the study of passengers getting to departure gates on time [32]. Cheng, more focused on aircraft mobility, focused simulation on apron control, which is the control of aircraft to and from airport gates, by evaluating the effectiveness and appropriateness of the proposal in an apron control activity [33]. On the other hand, studies referring to air traffic control systems ensure that the planning of routes and airspace utilization happens both in advance and in real time, to ensure a safer and more cost-effective air traffic control [34]. Still inside transportation sectors, routing takes effect in several industries, like shipping or road transport. In fact, the shipping industry is where the computer simulation programming language CSL originated, with the intention of developing support simulations of the movement of crude and refined oil around the world. This was accomplished by Buxton and Laski in 1962 [35].

The road transport sector can be differentiated in the planning of individual companies' operations or the study of road traffic systems in general. The latter works as a means to generate traffic information by reproducing the flow of whole networks in multiple real time simulations, providing detailed information on the motion of cars and correctly identify various traffic situations such as bottlenecks, intersections and so on, allowing for meticulous planning and road management [36]. Simulation has also been used to, more specifically and in detail, simulate multibody mathematical models, from databases of vehicle and human body data, to analyse driving surfaces and study the occupants' behaviour under different road conditions and different driving regimens, allowing for an investigation into safety, comfort and speed parameters [37]. The first, planning of individual companies' operations, falls under transportation but can also be considered part of the supply chain domain inside simulation efforts, as is discussed in the following subsection.

2.1.3 Supply Chain Planning

Supply chain is generally referred to as the alignment of firms that bring products or services to market, including manufacturer, suppliers, transporters, warehouses, wholesalers, retailers, other intermediaries and even customers themselves [38]. Simulation can take part in any process inside the supply chain, or in it as a whole. An example of a complex supply chain is the world-wide crude transportation, that links upstream and downstream functions of the supply chain management in the oil industry. Simulation was used to represent a decision support system in order to improve and investigate the combined controlled inventory and transportation system happening world-wide, working as a powerful tool to provide insight into the behaviour of various strategies for design and operation of the system. It is, nevertheless, a very complex simulation to achieve given the consideration of a lot of aspects including uncertainties in travel time, crude demand, giving the system overwhelming computational requirements and requiring dynamic programming and approximate methods [39]. In fact, the field of system dynamics was initially known as industrial dynamics, which reflected its origins in the simulation of industrial supply chain problems [40]. There is a literature review that goes in depth into the use of system dynamics or discrete event simulation in the supply chain context, suggesting that there are different patterns of use with respect to the problems being tackled. There is, however, some overlap in the use of both methodologies, suggesting that each methodology is valuable in their specific study. At the end it was suggested that discrete event simulation has been used more frequently to model supply chains, with the exception of the bullwhip effect, which is mostly modelled using system dynamics, given the relevance of feedback in the behaviour [41].

Understanding that supply chain management represents a network of different facilities and related entities, such as suppliers, production sites, markets and so on, is what reflects the problem of investigating a combination of several operational tasks. There are three main distinct optimization points inside supply chain improvement, which are production scheduling, distribution planning and transport planning, often tackled as a mixed-integer linear programming problem, having weights distributed to each associated cost [42]. In this particular study, the optimization of the planning and scheduling decisions in order to determine the global optimal solution proved a great level of complexity, causing problems in the computational load, which was the motivation behind the decision to use simulation as means to capture the behaviour and continue an analysis into the complexity of the supply chain within acceptable times. This is an example into the growing field of combining simulation with optimization algorithms. As described by Amaran, simulation combined with optimization involves addressing various constraints, with various algorithms and applications with simulation features in order to create value and improve directions discussed. In this study there is an in-depth analysis of already proposed approaches in literature that address specific features in the combination of both fields [43].

2.1.4 Warehouse Management

Warehouses are usually situated between manufacturers and customers, within the supply chain, as they provide a secure and organised space to store products until they are needed for distribution. Warehouse management includes inventory management and order management. These include control of available internal resources and supply resources to the needed activity. Thus, the management process is in charge of 6 crucial activities [44]:

1. Reception and inventory management of inbound products into the warehouse;
2. Replenishment of dynamic picking zones;
3. Inventory allocation - assigning stock to orders;
4. Order assignment - assign orders to resources and/or work stations;
5. Load balancing and control of picking posts or order picking resources;
6. Consolidation of orders and dispatch labelling.

There are numerous recent technological advances within the warehouse automation field that propose different tackles to all activities aforementioned, and simulation can be utilised in several steps of warehouse design and planning, and warehouse optimization. This necessity arises from the state of current markets, with requirements for a higher degree of flexibility, adaptability and velocity to cover customer demands, whilst maintaining reasonably reduced costs. In such degree, the distribution industry requires that the warehouse be configurable and optimisable according to market changes [45].

Within warehouse design, it is an important step after the definition of the target throughput, warehouse capacity and organization, to understand how the warehouse daily functions might be conducted. This can be studied in key performance indicators (KPIs) such as build-up of work in progress (WIP) at any point in the warehouse [46]. By analysing the rate through which WIP travels through the system, it is possible to tell how unstable a system is by its build up. This study suggests that these observations are important in order to identify if there is a current bottleneck and help develop means to identify where it is by defining overworking limits in resources and recording the utilization function of the simulation.

Warehouse activities, after design configuration or analysis, can be detailed individually in order to study all aspects worth improving. Simple studies conducted into the behaviour and efficiency of each warehouse management activities are, for example, resource utilization, resource allocation, flow of working items, jobs performed under a set limit of time, and so on. One quite important area of study, approached by almost all warehouses, is inventory allocation and management. This is, of course, interconnected with logistics associated with how picking activities take place and the replenishment of such specific areas. Order picking involves determining a sequence in which to visit unique location where each part of the order is stored. This can entail different areas to assemble different order quantities and batches. For example, some orders might require full pallets of a single item, whilst others might require a variety of one single unit of each item. With computer tracking of inventories, it is now possible to make decisions based on order fulfillment methodologies, so that assigning a location to specific items and optimising collection routes can be as efficient as possible, whilst reducing overall warehouse traffic and order fulfillment time [47].

A final aspect of warehouse management worth mentioning is operations related to reception and inventory management of inbound products into the warehouse. Inbound operations are more commonly studied as part of cross-docking mechanisms, that require a harmony between arrivals and departures from the system in record time. Cross-docking is a concept in which items delivered to a warehouse are immediately received, sorted and organised according to customer orders, routed into outbound trucks and loaded for delivery, all within a 24 hour period. The optimal scheduling of inbound and outbound trucks in cross-docking systems can reduce total operation time and improve system performance [48]. Nevertheless, this option is not feasible for all warehouses, as most are utilized for storage, rather than order redistribution alone. A problem related to inbound activities, that is mostly retrieved from cross-docking facilities but can be extrapolated, is the assignment of available docking stations to arriving trucks. This problem is usually affected by the arrival and departure window of each truck, the operational time for cargo unloading among docks, and the total capacity available on a daily basis for collection and processing. The objective is ultimately to find an optimal assignment of trucks that minimises the operational cost of unloading and trucks awaiting processing. This problem can be formulated as integer programming [49]. Another aspect of inbound warehouse management that can be borrowed from studies referring to outbound movements has to do with staff shifting utilising queuing theory. The first comparable aspect has to do with considering the time distribution of order arrival and fulfillment necessities, so that all activities related to picking, packing and sorting can be executed properly and in a timely manor. Another is the capacity with which resources can perform tasks and the requirements behind it. Overall, staff management using queuing theory, and simulation as means to evaluate the solution, shows adequate approximations in the optimal number of skilled resources (pickers and packers in this study) and a consequential improvement in processing efficiency and service quality [50]. Finally, an aspect that is not only important within the realm of inbound operations, but that requires special attention given its importance, is accurate information registration into the warehouse system. This step takes place within inbound operations and can greatly impact how all other activities within the warehouse flow. Appropriate information management, within all levels of the supply chain, can help companies significantly improve service levels, as decisions made by retailers, production managers, suppliers and so on, are based on correct levels of inventory and information regarding the product [51]. For this reason, inbound activities require attentive care and thorough information reviews throughout the entirety of the process.

To conclude, within the warehouse management sector there are numbers of detailed problems that require attention and planning to tackle, and can be resolved or studied more in depth with the utilization of simulation to best understand where problems exist and visualise certain theories before being physically tested. Within specific warehouse aspects, receiving operations have very few formal models developed, and most literature that is available addresses receiving operations coupled with shipping in strategies designed for cross-docking warehouses, leaving some room for improvement in what Gu references as traditional warehouses [52].

2.2 Simulation Modelling

Modeling of any system begins with the understanding that there was previous consideration differentiating experimenting with the actual system, as opposed to experimenting with a model of a system. This consideration is usually into the possibility of studying a system by physically altering it, followed by the cost-effectiveness of this decision and the relevance of the results. It is, nevertheless, rarely feasible to apply direct changes to an already established system, even more so changes that can not be fundamentally proven to increase productivity or decrease costs. The same can be construed even for non-existent systems, so as to study various proposed alternative configurations to see how the system should be built in the first place [7]. After the establishment of the study as a computational study, rather than a physical alteration of a system, it is also relevant to understand the desired output. A study that can be resolved via an analytical solution, where the system can be represented in a mathematical model and a numerical and simple answer to the question at hand can be obtained, simulation might not be required or of interest. It is in the instance of more complex situations of models that require a number of output measures of performance and the mathematical model itself being too complex for a valid analytic solution, that simulation becomes of interest. This brings us to the understanding of in what situations it is appropriate and not appropriate to utilise simulation, or a simulation model, to study a specific problem. Overall, the objective of simulation aligns with the appropriate situations. Firstly, simulation enables the study of complex internal interactions of a system or subsystem, and therefore can be applied as means to test informational, organizational and environmental changes in the effect or alterations caused in the model's behaviour. Simulation should be considered if the knowledge gained during the designing of the model could add great value towards suggesting improvement, as well as if changing simulation inputs and observing the resulting outputs can produce valuable insight into which variables interact and what are the most important interactions. Simulation can also be used as a pedagogical device to reinforce analytical solutions, or even verify the legitimacy of such solutions. Simulation can also help experiment with new designs or policies to study possible effects before implementation, or determine requirements in terms of capability of resources and, lastly, given that modern systems can be thoroughly complex, it is important to use simulation in the eventuality that its internal interactions can only be treated and understood via simulation [53].

On the other hand, simulation should not be used when the solution to a specific problem can be obtained by applying common sense, or even if the problem can be solved analytically. Simulation should also not be considered if performing direct experiments is easier and more cost-effective, as well as if the costs at which a simulation is built exceeds the possible savings resulting from implementing new solutions. Time constraints should also be considered, given the time effort going into the creation of a simulation study might outweigh the necessity for a solution. Lastly, and most importantly, the aspect of available data. Simulation, or a lot of studies, can only be conducted if the data available are relevant and can somewhat accurately describe the system, and if the behaviour of the system can be verified and validated through either data or behavioural observations [53].

2.2.1 Model Classification

Upon consideration of simulation as the correct and appropriate approach to tackle a specific situation, it is important to understand the diversity of simulation models and its three dimensions of proposed classifications. These classifications stem from different books that overall address the dimensions with the same approach and describe the aspects pertaining to the differences identified. For this reason, this subsection references Pidd, Braislford, Fishmand, Law and Banks in what is commonly shared as dimensions to consider [6] [54] [55] [7] [53].

Deterministic vs Stochastic Simulation Models

A system is deterministic if its behaviour is entirely predictable. In more detailed terms, the system needs to be perfectly understood and is, therefore, possible to precisely predict what will happen. An example is a cycle of operations on an automatic machine, which can be deterministic in the sense that each cycle can be repeated identically and will take the same length of time unless certain conditions influencing the cycle times are altered. This means that, if there are no probabilistic or random components affecting the model, it is called deterministic. A stochastic system, on the other hand, is a system where its behaviour cannot be entirely predicted. These systems tend to be more complicated to replicate, though some statements can be made about the likeliness of certain events to occur, or specific outcomes that are possible. Many systems must be modeled as having at least some random input components, as most queuing and inventory systems are modeled stochastically. These models produce outputs that are in themselves random, and must therefore be treated as only an estimate of the true characteristics of the model. Nevertheless, it is important to note that the stochastic nature of most simulation models, in the dealing with distinct entities, scheduled activities, queueues and decision rules, is what allows the model to compare scenarios based on prediction and optimise specified performance criteria so as to best validate options given the large amounts of quantitative numerical data provided. Ultimately, the distinction between stochastic and deterministic systems is artificial, as it is more a statement of the amount of knowledge about a system, or the amount of control over that system that can be exercised by an observer.

Static vs Dynamic Simulation Models

A static simulation model is a representation of a system at a specific and particular time, or one that may be used to represent a system in which time plays no role. Static simulation models specify parameters and inputs necessary for the model to be constructed, disregarding factors that can be identified as possible disruptions, and calculating the solution by providing the basic required parameters and addressing them. Dynamic simulation, on the other hand, represents a system as it evolves over time. This allows the system to account for possible disruptions, events and so on, and evaluate the changes these components have on the system over time as information regarding various aspects can be taken into account.

Discrete vs Continuous Simulation Models

As the name indicates, continuous simulation refers to change as being continuous, and discrete simulation refers to change as being discrete, when referring to how state to state alters through time. Discrete change can be viewed as when one or more phenomena of interest change value or state at discrete points in time, rather than continuously. Mathematically speaking, the system can change only at a countable number of points in time. These points in time are the ones at which an event occurs. An example is to consider a railway system in which trains move from station to station, travelling with passengers that wish to enter and exit at specific points. Visualising this model with discrete change entails understanding that there are 4 steps in the train event list: train stops at station, doors open, doors close and train leaves station. The time it takes between events can be known (deterministically or sampled with appropriate distribution) so, between train leaves the station and train stops at the next station, there is a journey time that is considered. Considering discrete changes, all the changes happening in the system take place with the events, and the variables are only of interest when they point to a change in the state of the system. Considering a continuous change simulation, the variables would be continuously changing as the simulation process. For example, if the train is traveling between stations and we consider the locomotive to be electrically powered, then the speed will increase smoothly from rest until cruising rate. The speed does not change by discrete amounts, rather in a continuous way. However, continuous change cannot actually be occurring in a typical computer, as they operate only with discrete quantities, which entails that in system dynamics, the apparent continuity is achieved by allowing variables to be inspected or changed at a multitude of fixed points in simulated time, providing an approximation of continuous change. Furthermore, the decision whether to use a discrete or continuous model for a particular system depends mostly on the specific objective of the study, rather than actual properties from the system at hand.

2.2.2 Model Construction

The steps taken in the assembly of a simulation study are not universal, but different studies tap on relevant subjects relating to what aspects need to be considered and relevant parts of the process. The first information considered important pertains to **Problem Formulation or Structuring**. This comes as an attempt to understand the issues which are being addressed in the project, in an effort to decide what detailed operational research methods will be appropriate. This can be merely preliminary to the study itself, but identifies a lot of important information whilst working towards a detailed understanding of existing linkages and complexities [6]. Within the formulation of the problem, it is important to set objectives and a project plan, so that the questions that desire answers are clear throughout the study. Such plan can also be of interest in terms of expected cost and time of the study, and if it is viable for the entity [53].

The next step comes as the actual modeling of the project. **Modeling** can have a sequential behaviour of model conceptualization, followed by data collection and analysis, computer implementation, verification and validation of the model and, finally, result collection [56]. Model conceptualization is an activity in which the analyst tries to capture the essential features of the system that is being modelled, identifying the features deemed necessary, or, in more discrete event simulation related terminology, identify the main entities of the system and they ways they interact. After the understanding of how it is the system overall functions, there is an interplay between the construction of the model and the collection of needed input data, given that the complexity of the model can change with how the data are organised, as well as the necessity for specific data can arise from implementation processes [57]. Following conceptualization and data collection, it is possible to design the program at hand, by means of actual programming or with the utilization of VIMS, visual interactive modelling systems, which are computer packages that enable the modeller to develop the computer model by selecting and linking items together in logistical interactions that make up the model. VIMS are not suitable to all simulation systems, given the complexity of some studies that require proper and complex logic, and can be considered an investment to apply a specialist software in the eventuality that there is already considerable expertise in computer programming within resources [58]. It does, however, bring various benefits, which will be discussed further on. After an assembled model, it is important to validate, a process that allows the modeller to ensure that the model is suitable for use within its defined experimental frame. Validation takes many forms and can be a process tailored to the model at hand. Balci suggests that there are a number of validation aspects to consider before validating the model itself, including data validation, experimental design verification, system and objectives definition verification, and so on. Model validation can take the form of subjective validation techniques or statistical techniques, which are applied to models built under the pretense of being completely observable, partially observable or unobservable. The subjective validation can only be applied to completely observable systems, whilst statistical validation should be applied more thoroughly to models built mostly as completely unobservable. There are several steps and criteria that can be followed in each case, as well as a suggested interpretation of simulation results, which indicates that, since results can be descriptive, a validation of the model can depart from the judgement of how the solution fits under the study objectives and if it makes sense or is reasonable [59]. Result collection, as the last step of modeling, refers to understanding how best fitted the system is to retrieve the predefined measures of performance, entailing a planning of the experiments to be performed, whilst considering the appropriate results collection period and the confidence interval within which the information should fall into.

Implementation and Documentation are the lasts steps of the study, already falling outside the modeling category, which entail the implementation of the results in the system being studied, as well as documenting all the studies that were performed in order to guarantee possible replication and ensuring no information is lost [53].

2.3 Simulation Software

Following possible discussions on the utilization of a general purposed programming language versus a simulation package software, it is necessary to discuss advantages or disadvantages of each software in order to select the most appropriate. Despite programming languages possibly offering more flexibility, require less execution time and being generally less costly than a simulation software, they require extensive knowledge and potential problems that a simulation package can work around. These are providing a natural framework, as the construction is more closely akin to the simulation at hand and significantly more visually representative, they are easier to modify and maintain, and they require less efforts in ”programming” time given most feature already available and error detection capabilities [7]. There is further distinction made between types of simulation packages, with object-oriented and application-oriented simulation packages. Overall it can be argued that there are numerous classifications of software choices, through the discussion of modeling approaches, modeling elements, software features, user-friendliness with support, documentation and pedigree, and so on. It is, nevertheless, important to note the existing software packages before performing any analysis on which to select. The first specialist software simulation packages to appear were around the 1960s with the introduction of SIMSCRIPT[60], GPSS[61] and SIMULA[62]. There were then advances on powerful computers that allowed for the development of the aforementioned VIMS software. A variety of recent papers has begun to compile all the VIMS simulation packages available, which are still considered up to date, to begin to discuss choice criteria and hierarchical decision-making on which software to select. The most commonly mentioned and compared software packages and the respective website to access are the following: Arena, by Rockwell Automation, AnyLogic, by The AnyLogic Company, Enterprise Dynamics, by InControl Enterprise Dynamics, ExtendSim, by Imagine That, Inc., Flexsim, by FlexSim Software Products, Inc., Plant Simulation, by Siemens Digital Industries Software, Pro Model, by ProModel Corporation, SimCAD Pro, by CreateASoft, Inc., Simio, by Simio LLC, Simul8, by SIMUL8 Corporation and ShowFlow, by Webb Systems Limited.

Fumagalli suggests an evaluation framework to select the most appropriate simulation software, that consists of generating hierarchies in terms of research approach, industrial application and integrated. Integrated hierarchy takes into account both the former hierarchies and generates a process with which decisions can follow a guideline in order to understand the best option for each company [63]. Dias, on the other hand, tackles the issue with an approach mostly focused on the usage, or ”popularity” as described, by cross-referencing the incidences of each software and simulation tool with the amount of articles and overall scientific publications that exist [64]. Overall the decision to utilise Simul8 as the simulation software stems from, not only the agreement of student license with Instituto Superior Técnico, but with the presence of Simul8 in most discrete event simulation books and subject manuals, such as

Pidd, 2004 [6], Brailsford, 2014 [54], Banks, 2010 [53]. Simul8 offers an interactive and practical experiments methodology to be implemented as a set of computer program modules that are not specific to a particular simulation model and provide an interface that lets the modeller construct an efficient simulation experiment. The methodology and program modules are illustrated with a practical simulation model, and the results show how they can improve simulation response with negligible increase in computational effort. Simul8 also offers a large selection of statistical distributions and options for modelling that can accurately represent the study at hand.

In literature, Simul8 is considered to be a relevant planning and scheduling tool that can intelligently sequence product flow whilst combining order planning with production modeling. As found by Hindle, Simul8-Planner generated production schedules that satisfied delivery objectives within capacity limits, answering the complex scheduling problem of sequencing part requirements through a composites manufacturing center [65]. The process through which the study was conducted relied on firstly creating a production model replicating the current state of plant processes and flow. This allowed the flow of planned production to be simulated, based on the existing schedule, and to analyse each area of the facility and apply global and local sequencing rules to deal with interdependencies of different operations. Once again, the analysis is coupled with a visual interpretation of the system, which is not feasible using algorithm-based optimization. The second part of the problem is focused on experimenting with the available scheduling rules, to test the capacity of the system to generate efficient production schedule options that not only satisfy manufacturing constraints, but also maximise the objectives of the composites manufacturing center. Ultimately, the efficient scheduling and understanding of the system allowed the system to effectively apply a pull production system, allowing the line to be supplied with work based on necessity and tackle overproduction.

Concannon also describes advantages on the utilization of the Simul8 tool, once again the version of Simul8-Planner that was introduced specifically to adequately study production planning and scheduling. The tool allows, in addition to the model visualization capabilities and incorporation of programming languages that enable the creation of accurate, flexible and robust simulations rapidly, Simul8-Planner links directly to the organizations' ERP system (Enterprise Resource Planning) [66]. This allows for a connection between the internal data of the company, with the simulation tool addition. Simul8 as a tool still allows for data to be inserted, however it does require expertise and data treatment before studies can be conducted, perhaps losing some information in the process. Concannon goes on to describe all the approaches and steps that turn Simul8 into a simulation tool that is highly focused on production and warehouse management, in aspects that will be later on studied in this thesis. Time management, which can be for both schedule planning in the long run, but also scheduling of maintenance and down-time requirements, uses start time features, calendaring facilities, job assignment, etc. In order to search routines, the tool allows for the scanning and sorting of indexed data, with Gantt chart displays on any suitable KPI and data sheets. Gantt charts allow a visual recognition of patterns, which can, simultaneously with the specific picking of KPIs, provide all relevant information to the decision making process.

Chapter 3

Case Study

In this chapter of the project, it will be presented an overview of Alloga-Logifarma as a company dedicated solely to logistics and distribution within the healthcare industry. Starting with an overview of the positioning and relevance within the field, the chapter will then discuss warehouse operations and layout, and finally contextualise in detail the identified problem and proposed challenge.

3.1 Alloga-Logifarma

Alloga-Logifarma was founded in 2019 as a fusion of Alloga and Logifarma, both previously well established logistic names in the Healthcare Industry. Logifarma was founded in 1997 as a partnership, stemming from two groups: Group IBERFAR and Group JABA. The necessity to provide services of elevated quality in storage and distribution to its users, all within the high standard regulations of the pharmaceutical industry, was met with Logifarma as a solution, functioning as a wholesaler acting in primary distribution for the companies.

Alloga Portugal is a 100% owned subsidiary of Alliance Healthcare, present in the wholesaler industry since 2000. Alliance Healthcare Portugal is the result of a 51% *Associação Nacional de Farmácias* (ANF) stake partnership with 49% stake Walgreens Boots Alliance. The market positioning of Alliance Healthcare is the offer of innovative and global solutions for activities related to pharmacies, the pharmaceutical industry and its supply chain management.

Alloga-Logifarma works with a portfolio of 120 companies and in 2023 reached 450 thousand orders, 110 million units shipped to over 115 thousand delivery locations. The services provided are Reception, Storage, Order Preparation and Distribution, whilst also ensuring the clients' needs are met in terms of psychotropics and narcotics handling, returns and recollections, waste disposal and destruction, delicate transportation, co-packing and product labelling. The workforce is of around 200 employees and the distribution fleet is comprised of 30 vans and 3 trucks, allowing a rapid response to eventual emergency situations, and resorts to *Torrestir* to ensure extra sporadic deliveries and deadlines. The fleet covers continental Portugal with dataloggers and alarms, to ensure both a temperature adequate and safe environment. Temperature requirements can be of 2ºC to 8ºC or 15ºC to 25ºC, with a possibility of negative cold.

3.2 Warehouse

The warehouse, present in Sintra, Portugal, is a facility comprised of over 24 thousand squared meters, with a capacity of 27 thousand units of storage. The units are divided into three categories: Ambient, Cold Chain and Controlled Drugs/Narcotics, with a capacity of 24 500, 1 800 and 700 respectively. All these categories require specific treatment and follow regulations to ensure the appropriate handling and quality, with emphasis on temperature control and appropriate and safe management of controlled substances. This requires specific certifications and data tracking to ensure constant supervision of all relevant external factors. Appropriate institutions, including Infarmed - *Autoridade Nacional do Medicamento e Produtos de Saúde*, DGAV - *Direção Geral de Alimentação e Veterinária* and SGS, are responsible for such certifications.

The warehouse can be divided into three main areas: Reception, Storage and Order Assembly. Reception is comprised of every activity between the entrance of the truck in the premise, until all pallets have been electronically registered and are stored. Storage, which takes up most of the warehousing space, is where the pallets are strategically arranged and await collection. Order Assembly contains processes from collection of the stored SKU, until the complete shipment is ready to be sent out. There are also auxiliary areas, such as the co-packing and relabelling areas, as well as different areas within Order Assembly, given that different orders might require *Unit picking*, *Box picking* or *Pallet picking*. These different types of orders heavily depend on requirements and order size by both client and the geographic location to which the product will be shipped, and are processed differently.

3.2.1 Flow

To better understand the intricacies and different possible flow problems within a warehouse, it is first crucial to visualise the product's main flow. In Figure 3.1 is represented a simplified flow of products with possible side flows that affect daily workings.

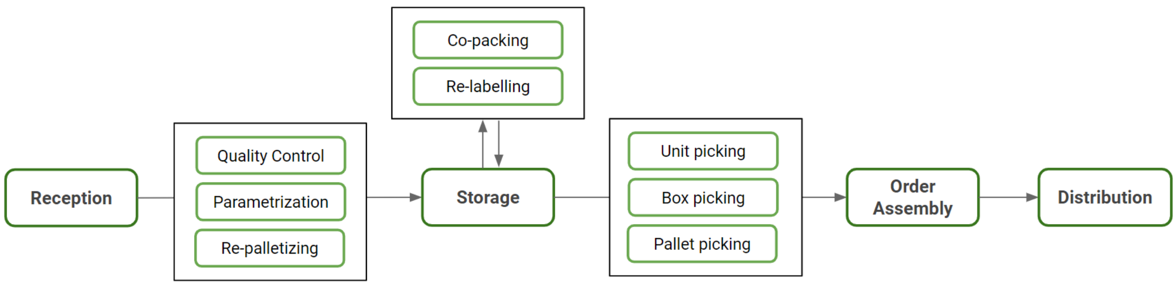

Figure 3.1: Warehouse Flow Diagram

Alloga-Logifarma works with both large and small pharmaceutical companies, which results in different inbound situations. The trucks and vans that arrive on a daily basis can carry from 1 to over 66 pallets, consisting of uni or multi-product loads. These are unloaded in appropriate docks, depending on vehicle size, checked for possible damage, and electronically received. This reception ensures the system has record of all products that arrive, as well as the exact quantity. The system is able to determine amounts with precision through physical measures, as all new products received are parameterised and logged. Most arrivals are of products already in the system. Nevertheless, new arrivals happen with some frequency and require extra resources. A second situation has to do with pallet size. An Europallet has a standard size of 800$\times$1200$\times$144mm, and the storage display is strategically designed in accordance to these measures, as well as the load's height. For this reason, some deliveries require re-palletizing to optimise the utilization of storage space.

Following the electronic reception and subsequent storage, some products might require alteration by request of the company or changing national regulations. Both are at the responsibility of different teams, however they require some resources shared with the reception area. One such activity is Co-packing, which is the result of, for example, a promotion a client is looking to implement and requires different products to be packed together. This results in a substantial difference in terms of number of products in stock, as the SKU at the end of Co-packing is the new package containing all different products combined. Re-labelling, on the other hand, is a necessity that stems from different pharmaceutical products' need for an updated price. A large percentage has to do with the constant update on the prices of state contribution on specific medications, and the fact that these prices are printed on the box. This does not change the amount of SKUs in stock, but does interfere with the main flow.

Lastly, the distribution is mainly organised by regions where the different orders were placed. The orders can, nevertheless, have different amounts of specific products. For this reason, and to best package all orders, there are different logistics going into order assembly. Orders that require small amounts of different products are processed with Kardex machines, that optimise space and deliver the exact product the collaborator requires. These need to be stocked in order to function, hence Box Picking being a responsibility of a supply sourcing team. These carry products that have a higher turnover, which still leaves Unit Picking required for less common circumstances. Pallet Picking, lastly and as in implied in the name, is resorted to as to fulfill orders that contain greater amounts.

3.2.2 Layout

The layout of the warehouse is a crucial part in the understanding of what study is being conducted and the reason behind it. The warehouse can be seen in picture 3.2. The flow can be visualised entering in the unloading area, highlighted in green, where all pallets are also received. They are then stored inside the warehouse, in all areas in grey. Once required, pallets, boxes or units are picked and the orders are assembled in the purple section, before being loaded and distributed.

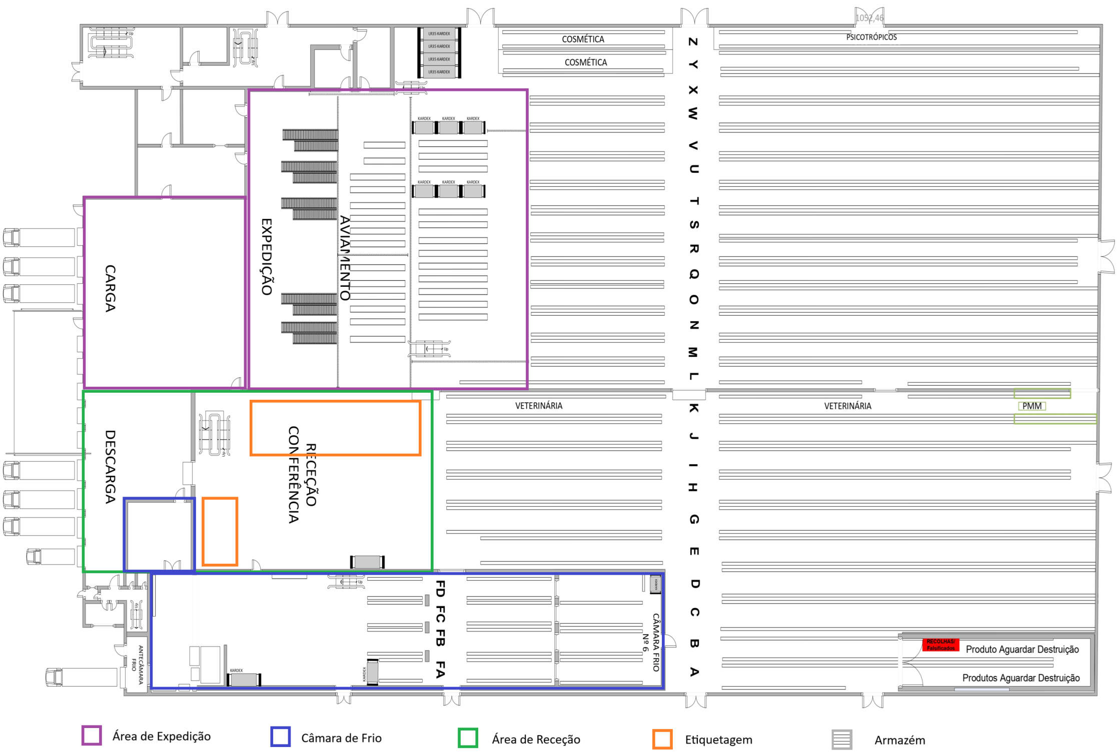

Figure 3.2: Alloga-Logifarma Warehouse, adapted from the facility's plant

There are two areas important to point out, that are the cold chamber in blue and Re-labelling area in orange. The cold chamber is much like a regular warehouse in smaller proportions and inside the warehouse, with the only difference being the temperature at which everything is stored. Re-labelling area might be misleading, as the action of re-labelling takes place on the floor above. The need for collecting pallets, transporting them up and bringing them down is what requires the space presented. The cold chamber can be supplied to via a specific vehicle unloading dock, or through a door from the reception area when vehicles bring mixed temperature chambers.

3.2.3 Problem Formulation

Improvement Approaches

Given the main areas present in the warehouse, it is important to note vast existing studies in terms of storage optimization, order assembly and distribution. These three activities present significant impacts in how a warehouse is perceived by clients and ensures that an order placed can be matched with extreme accuracy. Warehouse layout and storage methodologies, such as flow planning warehouses in U-shape, V-shape or Straight-Through, and aisle configuration such as cross-aisle or angled-aisle, are a few well documented and relatively studied possibilities, which can impact the translation of area into actual storing space. Order assembly is a sensitive process that requires a methodology ensuring that the information received is treated in the shortest time possible, with minimal error. Distribution is also a widely studied field within logistics, with several softwares in the market.

Alloga-Logifarma currently has a rate of over 99.9% orders dispatched and a 97.5% arrival rate within contractual time, which is the result of studied distribution routes and a smoothly operated order assembly. This is made possible with high levels of organization within the system, as all SKUs are regularly studied. Storage collaborators are given suggestions on where to best store each pallet, and the supply sourcing team ensures all auxiliary machines are properly stocked and ready for order assembly. Storage is also at a consistent rate of around 85% resource utilization, with fluctuations corresponding to seasonality of certain products. Nevertheless, an area that is often overlooked as it does not directly impact the daily order shipment is the reception area. Currently the area has an average turnover rate of slightly over 26 hours, which means that a larger amount of pallets arriving in a day, or some minor setbacks, can impact the natural flow and result in having to turn to exceeding area or extra time in order to fully receive, log and store all products.

Area in Study

As mentioned above, a crucial part of any warehouse or storage facility is the reception area. Unloaded products require proper handling and efficient system registration, in order to ensure that all SKU are identified, the correct number, weight and volume are parameterised, and both temperature and fragility are taken into account. A mistake in the electronic reception of products can cause multiple different problems in terms of amount in stock, storage space, missing items, and proper identification of damage. For this reason, there is a team of 12 collaborators in shifts covering the entire day, that ensure the unloading of products, control quality, electronically receive the orders and check all documents, parameterise if needed, re-palletise if needed, and store them. These activities tend to be performed by different collaborators, and in different shifts.

In Figure 3.3 is illustrated the flow which every load that arrives in the warehouse has to go through.

As can be observed, vehicles arriving can be categorised into different types, that require different unloading methodologies and spaces. Average trucks can dock at Dock 9, Dock 10 and Dock 11 if the temperature corresponds to 15ºC-25ºC, and Dock 13 for 2ºC-8ºC or negative cold, as it leads directly to the Cold Chamber. Larger vans, or smaller trucks, fit specifically in Dock 12 and often carry their own

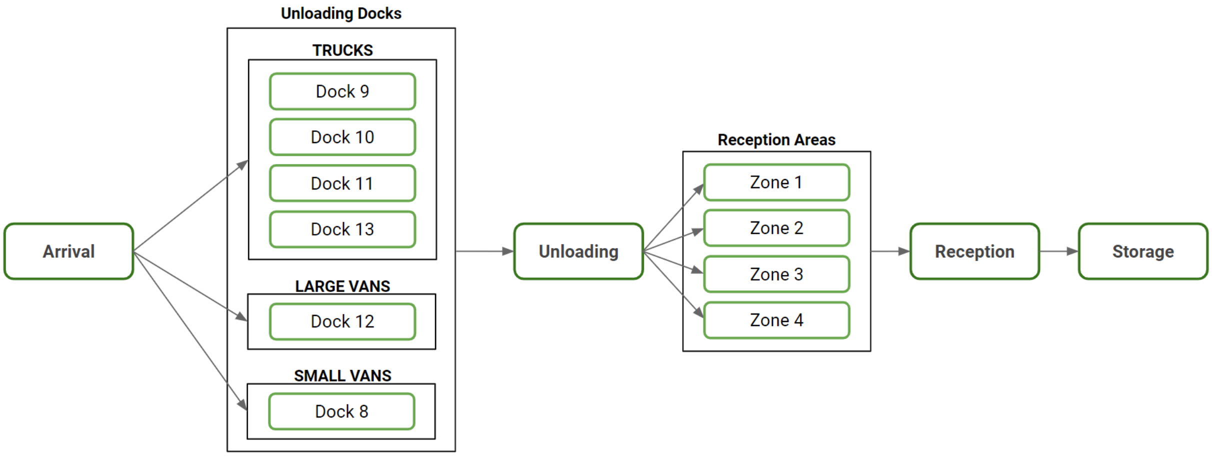

Figure 3.3: Reception Flow Diagram

hand pallet jacks given that some electric pallet jacks are too heavy. Lastly, small vans dock at Dock 8 and can either be unloaded by hand, in case of boxes, or require pallet stackers, in case of pallets that cannot be removed any other way.

All trucks are required to have been scheduled in order to be unloaded, and bring with them CMR's and temperature tickets. Drivers wait in line for instructions on which dock to proceed to, once the team is available to unload.

Once being unloaded, pallets are set down in one of four zones. It is important to note that this zone distribution is merely for organizational purposes, and given the positioning of walls and barriers. There is no actual distinction between areas in the normal functioning of the warehouse, only a tendency to unload in certain areas first. Trucks are usually unloaded onto zone 3, 1 and then 2. Smaller trucks and vans, which naturally bring less cargo, tend to unload in zone 4, as it is the nearest to Dock 12, and the smallest. Trucks that unload in Dock 13 are no longer part of the regular reception and are the responsibility of a specific team at the Cold Chamber.

In figure 3.4 is represented the reception area, where all inbound activities occur. Zone 1, as represented, is often a shared resource, with not so linear bounds with the re-labelling area.

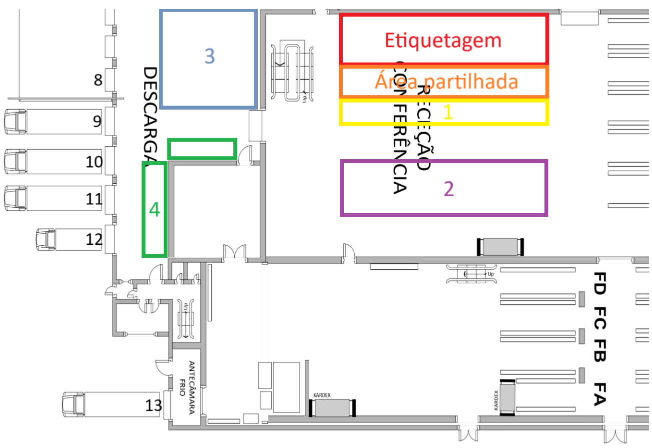

Figure 3.4: Alloga-Logifarma Warehouse Inbound Zoom-in

Current Situation

In Figure 3.5 is represented the time distribution that takes for each step to take place, with a line representing the average. All values were calculated without the consideration of weekends, as that would deeply influence times that do not reflect each activities duration.

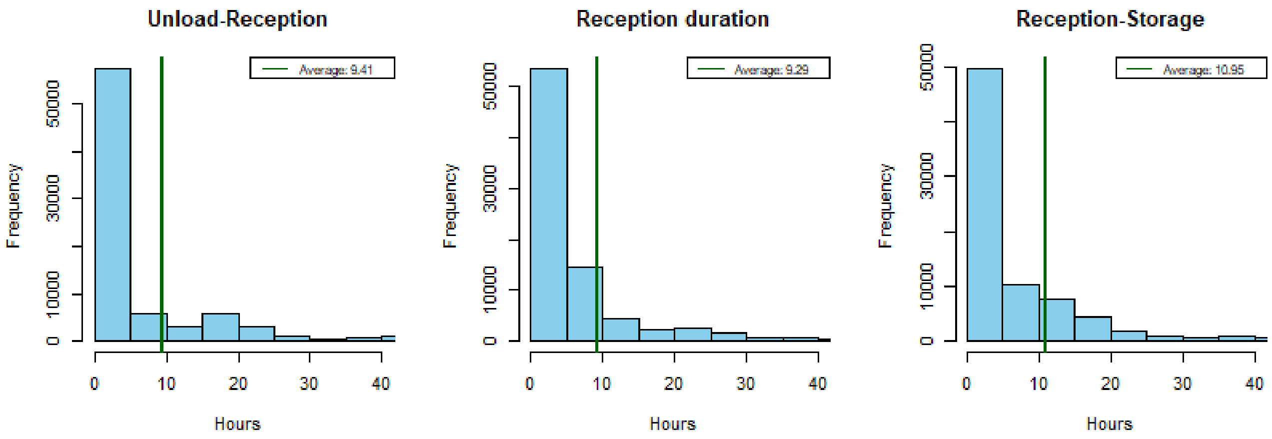

Figure 3.5: Duration of Activities

Pallets, following their unloading, await electronic reception. Some pallets have the property of being stackable, which allows for space optimization as two pallets require the same ground area as one. Nevertheless, pallets take up a specific area that is only available again once they are stored. Electronic reception always entails the confirmation that order was delivered correctly, both in terms of amount and in terms of specific product, and printing of tags specific to the internal software so as to insert all data in the system. As previously mentioned, some orders require re-palletizing and parametrization, which is done at this stage and requires an extra amount of time and resources.

Lastly, pallets await storage. These pallets have a specific hallway assigned to them, which is studied by the system, and are transported there so that a trilateral stacker crane can place them in the racks and insert in the system where exactly the pallet is located and at what time it was stored. The whole endeavour takes, in average, a bit over 24 hours, as pictured in Figure 3.6.

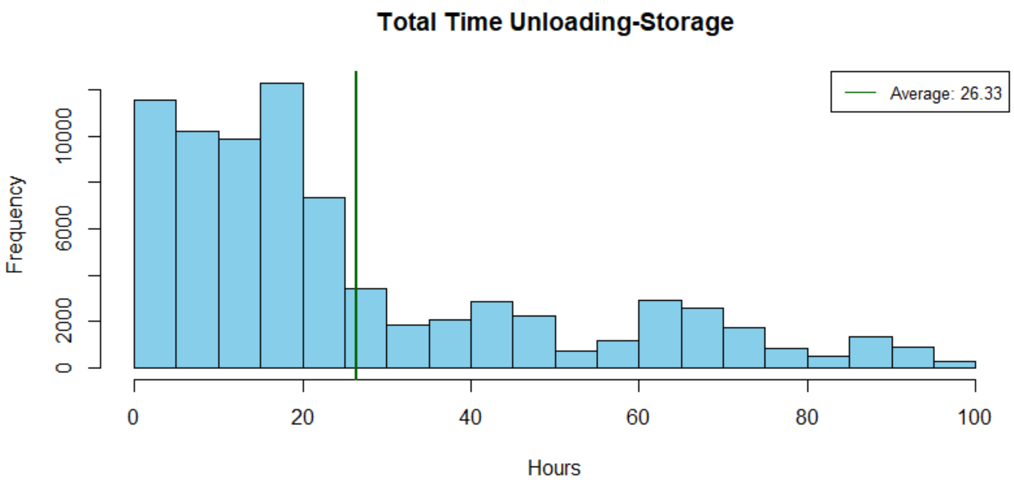

Figure 3.6: Time in System

An average of over 24 hours can pose a certain risk in terms of pallet flow, as reception operations function in a daily format and in limited space. In other words, a workspace that is confined to a specific area and has a numbered amount of resources, if working in turns of 24 hours should strive to ensure that all received pallets are stored in less than a day's time. This allows the cycle of unloading-reception-storage to fully close before initiating a new one the next day. Given the current situation, it is not a rare occurrence for days with heavier flow to require pallets to be unloaded onto extra space.

Important Entities

The relevant entities in this study have specific behaviours associated, as well as schedules or time constraints. Within the system there are four types of resources: unloading docks, reception areas, personnel and warehouse machinery. The only resources that require additional specification on how they operate are personnel and warehouse machinery. The team can be divided into three different functions and skill set: Reception, Storage and Unloading. In figure 3.7 is visible how the current distribution of human resources is made. Warehouse machinery, despite having specific battery life, mostly does no pose a constraint to how daily operations occur. The only possible exception are the trilateral stacker cranes, that require an 8h/8h cycle of usage versus charging.

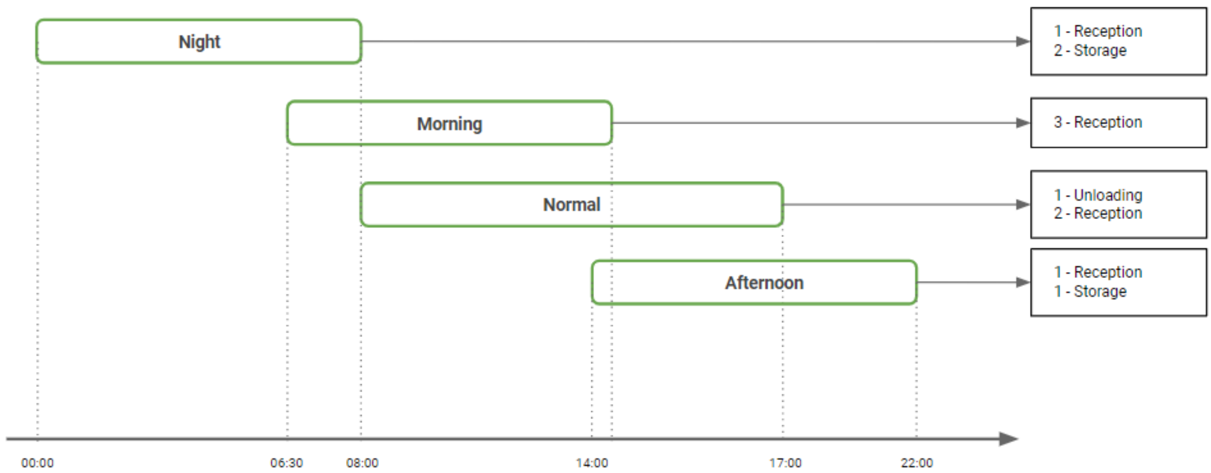

Figure 3.7: Reception Team Shifts

Outside the system is the arrival of trucks, which theoretically occurs with specific date and time scheduling, from 5am to 3pm. In reality, most arrivals do not meet their own scheduling, with only 26% arriving within a 1 hour interval. This results in both an unpredictability of when to expect the first and last truck to arrive, and a longer waiting time for most that arrive between 10am and 12pm. Despite the objective of scheduling said arrivals, the arrival by hour distribution from January to March 2023 represented in figure 3.8 clearly depicts such tendency. Nevertheless, when contrasted with figure 3.9, which reflects the average time a truck is inside Alloga-Logifarma, there are two main takeaways. Firstly, that the response time to the peak that happens between 10 am and 12 pm does not necessarily translate into the highest processing time, but rather that the most concerning times are those between 5am and 7am. It is important to note that the specific resource specifically working in unloading is part of the normal 8am to 5pm shift, represented in green. The task of unloading before 8am falls to the resources in Reception. Secondly, that the arrival concentration between 10am and 12pm impacts not only arrivals within that time interval, but the processing time of most subsequent arrivals, given their significant amount.

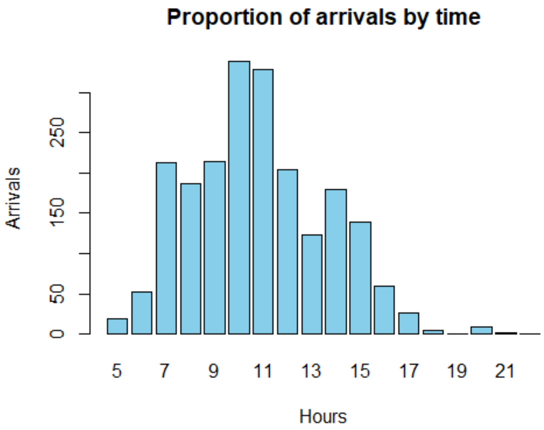

Figure 3.8: Arrival distribution by hour

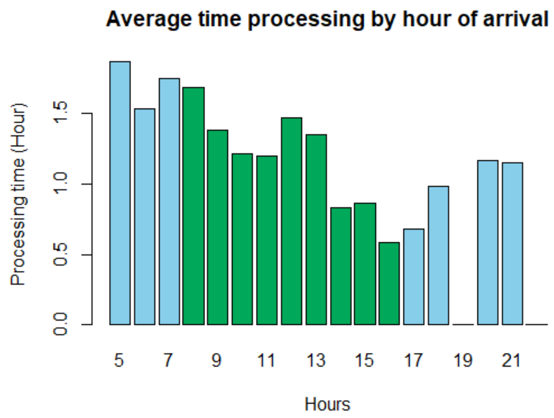

Figure 3.9: Processing time by hour of arrival

An important note to add to the observations is that international arrivals, despite representing only 29% of all arrivals, represent around 50% of incoming pallets and about 56% of international trucks arrive by 10am. This means most arrivals before then might take longer on average due to a higher amount of pallets. Nevertheless, the discrepancy between average processing times is still worthy of attention.

3.3 Problem Statement and Objectives

Throughout the description of the area in study and current situation, it has been contextualised the inner workings of Alloga-Logifarma, focusing mainly on the reception process. The challenges mentioned are of significant importance given the high level of efficiency present in the company, as well as all demands given by specific products that arrive on a daily basis. To understand what changes can better impact the reception area, the main KPIs are time in system, area utilization and exceeding area, human resource utilization, dock utilization and truck waiting times. For this reason, a model must be designed to accurately study all KPIs, given an input of shifts, resources and arrival times in the system. The ultimate goal is to study possible changes and their positive impact in the reception area, and the system in general.

Chapter 4

Methodology, Data Collection and Model Construction

In this chapter, the process through which all data were collected is introduced. Firstly, the methodology followed in this study will be divided into main steps regarding all provided information. Secondly, there are two main important takeaways throughout the data collection section of the chapter, one refers to the data distribution itself, and the other refers to all the intricacies and details that impact not only the statistical distributions, but how the model is built to be representative and accommodating to all relevant characteristics. For the data distribution, all relevant data for the model were fitted into statistical models present in the Simul8 software. To best understand the process, before the data are described and analysed, it is also relevant to understand the statistical model fitting and choice criteria. This is presented beforehand as it is applicable to all models studied.

The data were initially studied with Excel, as it was the original format retrieved from the company's system and allowed for flexible structuring and handling. The statistical tests and distributions were later retrieved from R, a tool better suited for statistical data processing.

Model construction is the third focus of the chapter. This part discusses the important details relevant to the aspects in analysis, and how they were translated into the model. This pertains to all resources and shifts that impact how the day-to-day operations run, as well as the order in which activities take place. Lastly, the model validation and simulation parameters are studied, so that the scenarios that are to be studied can be properly evaluated and ensure the results are relevant.

4.1 Methodology

The most relevant steps in the methodology, in accordance with the literature review presented in Chapter 2 and the case study presented and described in Chapter 3, pertain to the overall information provided and contextualization of the situation, the data collection processes and analysis, the construction of the simulation model and its validity, a discussion regarding the results and comparison of all simulations and a conclusion with further recommendations for further work.

1. Problem description and contextualization - The current situation requires description of all relevant information and a clear statement regarding the objective of the study conducted, the measurements through which the improvement can be measured. The contextualization of the study is more focused on the literature aspect of simulation whilst the description relies on the information pertaining to details and logistical factors for the model to be constructed.

2. Data collection and analysis - All data required to fit the simulation are collected from the operating systems present at Alloga-Logifarma, with the objective of a deep understanding of all aspects that can affect quality and details that require attention to better replicate the current scenario.
3. Construction of the simulation model and validity - The model's construction required specific steps and processes to ensure it represents, to the best of its ability, the current scenario happening daily at the warehouse. In this step, the model is described with all specifications in order to best approach the defined problem and the previous studied data are applied to the distributions built within the model. The model was then validated and studied to ensure an appropriate number of runs and results collection period.
4. Results and discussion - In this step of the process, all simulations are conducted and analysed, whilst being grouped in specific scenarios that are of interest to study. This analysis and comparison is made in accordance to the results obtained by the models with specifications pertaining to each situation. The section is divided into two main parts, after the study of the current scenario, scenarios pertaining to shifting mechanisms and pertaining to scheduling of vehicle arrival are examined and later discussed together.
5. Final conclusions and future work - It is important to conclude this study with an objective view of what it accomplished and all the improvement points possible, with room for recommendations as a proposal for future work, as well as insight into the impacts the implementation of such scenarios can have on the strategic approach of the company.

4.2 Statistical Modelling

Statistical Modeling, is defined to be an internally consistent set of probabilistic assumptions aiming to provide an idealised probabilistic description of the stochastic mechanism that gave rise to the observed data. In other words, it is the process of using statistical techniques to develop models that can be used to make predictions or estimates about a given phenomenon.

The first step taken in the process was to ensure all data were in the correct format, with valid and relevant values. This was achieved with ensuring there were no evident outliers or non-existent values. It was also useful to run a histogram for all data in order to understand intervals and the overall behaviour of the data. In order to compare already existing distribution to the data, it was necessary to perform goodness-of-fit tests and examine the criteria to best choose which distribution is more adequate. It is important to note that, despite some of the data being considered discrete in theory, given the better fit of continuous distributions and the fact that the model simulation can be made using only integer numbers, some discrete data will later be parametrised as continuous distributions.

The tests performed as goodness-of-fit statistics were the Kolmogorov-Smirnov (KS), Cramér-von Mises, Anderson-Darling and the chi-squared test. The first three calculate a test statistic based on differences between the empirical and the theoretical cumulative distribution function (CDF), whilst the chi-squared's test statistic is based on the differences between observed and expected frequencies in categorical data. In other words, the first three models were used in establishing how much the observed data's pattern deviates from the expected pattern under the assumed distribution. Cramér-von Mises and Anderson-Darling are refinements derived from the KS test and present a higher sensitivity towards the extremities of the distribution. The first utilises the squared differences between the two CDFs and the latter utilises the same strategy with the reciprocal of the expected values of the theoretical distribution [53]. All four tests were performed with the objective to establish which distributions reject the null hypothesis, indicating that the observed data do not fit the specified distribution.

The tests performed as goodness-of-fit criteria were Akaike's Information Criteria (AIC) and the Bayesian Information Criteria (BIC). These measure the relative quality of the statistical models for the given set of data. Taking into account the results observed by the previous tests, an AIC and BIC is calculated and the lowest value represents the distribution which is best fitted for the data at hand. The difference between the two lies on the relevance given to the complexity of the model, as BIC has heavier penalties [67]. In all tests performed, both the AIC and the BIC were in agreement in terms of the best fitting distribution, and therefore no in depth situational analysis between the two was necessary. The histograms and theoretical densities, along with the Quantile-Quantile (QQ) plots for all distributions can be found in Appendix A.

4.2.1 Arrivals

Representing the entry of outside entities into the system, arrivals accounts for the distribution of trucks and vans entering the premises and unloading cargo. The data collection was made through the security office, which controls all vehicle entries. This data includes, amongst other information, the license plates of both the truck and the trailer, company name, arrival time and departure time. It was then possible to retrieve significant inputs for the future model.

Weekly distribution

Despite the scheduling effort to regulate at what time arrivals happen, in order to avoid unnecessary queues and larger waiting times, there seems to be a tendency for arrivals to happen in specific intervals and with a higher influence in certain days of the week. The daily distribution is present in Figure 3.8. The high affluence of arrivals previously pointed out for the interval 10am-12pm can still be observed throughout the week. Nevertheless, it is important to note a higher number happening on Tuesdays, followed by a substantial decrease on Wednesdays, as seen in Table 4.1.

Table 4.1: Weekly average distribution of arrivals

Interval	Monday	Tuesday	Wednesday	Thursday	Friday
6h - 9h	4.3	5.4	4.3	4.5	5.2
9h - 12h	8.8	9.7	8.1	10.0	9.8
12h - 15h	5.8	5.7	5.0	5.3	4.9
15h - 18h	3.2	2.9	2.1	2.1	1.7
Total	22.2	23.8	19.5	21.9	21.5

Daily distribution

The time in system for the trucks is also a distribution to consider. It is common for some deliveries to occur that are not necessarily products from clients, but rather products returned to be destroyed, products with problems or even personal packages. These usually arrive in certain carriers, such as UPS, CTT or DHL, which were all excluded from the entries, so as to not skew the results, given that these deliveries take substantially less effort and time. In Figure 3.9 it was established that the average of processing time is substantially greater in the earlier hours of the day, which may lead to a bottleneck that delays most subsequent arrivals. The arrival of trucks and larger loads also tends to happen simultaneously. In Figure 4.1 can be seen a tendency for the amount of pallets to be proportionately larger than the number of unloadings until 12 pm, where a slight shift occurs towards a larger number of unloadings, in comparison.

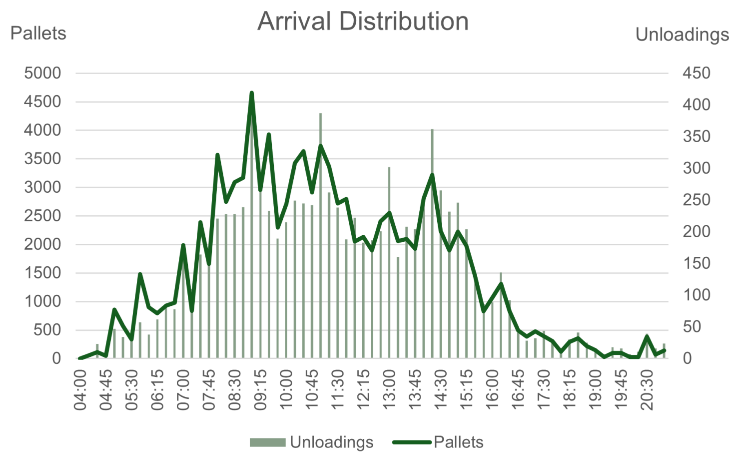

Figure 4.1: Arrival Distribution

4.2.2 Unloading

The first activity performed by the system, following the arrival of entities, is the unloading. The effort can be split into the unloading of trucks, large vans and smaller vans, with special attention to trucks that carry positive of negative cold. The activity is mainly performed, as previously mentioned, by a specifically allocated resource between 8 am and 5 pm. The vehicle, after awaiting instructions and availability, is attributed a dock dependent on size. The data collected initially reflects the amount of pallets in the vehicle, as well as the dock and the time stamps of docking and undocking. However, the docking authorization tends to happen in batches, where the orders are given for trucks to dock at one time and, once docked, they are unloaded separately. In other words, vehicles are ordered to dock in groups of 3/4, are unloaded one by one whilst the others await in the dock, and are only ordered to dock once the previous batch has been finished. This means that, if there are trucks in dock 9 through 12, even if dock 9 is the first to be unloaded and the truck is ready to leave, the next truck to be unloaded is in dock 10 and so on. Only once the already docked trucks are finished, do new ones get to dock. This logistic is due mainly to the necessity for authorizations in terms of temperature tickets and CMR signatures. For this reason, the data collected in terms of time spent docked does not accurately represent the time effort for each vehicle, and times were subtracted from each other in order to account only for the actual time the vehicle took to be unloaded. The remainder time was accounted for as waiting in dock.

Time

The duration of the unloading effort, as mentioned, is only taking into account the time it takes the resource to remove all product from inside the vehicle. This time is naturally impacted by the amount of product. This relationship is, however, not linear. The organization of the pallets inside the gallery, in case of not being directed towards the entry, can represent a substantially increased effort as pallets are removed sideways, aligned and then stored inside. The same goes towards galleries with 2-level loads that are not stackable, which require pallet stackers to align pallets outside the galery, for the electric pallet jacks to store them. For this reason, the amount of time was not directly related to the amount of pallets the vehicles bring, but rather only related to the type of vehicle. Table 4.2 portrays an approximate, albeit not very detailed, representation of average unloading time and average amount present in vehicles.

Table 4.2: Unloading data by dock

Dock		Frequency	Average Time	Average Amount
Trucks	9	43	27:53	24
	10	33	22:20	18
	11	14	09:56	9
	13	4	18:15	22
S. Vans	8	10	12:03	2
L. Vans	12	28	06:12	2

In order to fit the time duration more accurately in the simulation model, this continuous data were more adequately adjusted to a lognormal distribution for trucks and an exponential distribution for vans, as determined by both BIC and AIC. The parameters are as follows:

- Lognormal Unloading Truck Distribution

$$\mu = 2.706$$

$$\sigma = 0.925$$

- Exponential Unloading Van Distribution

$$\lambda = 0.172$$

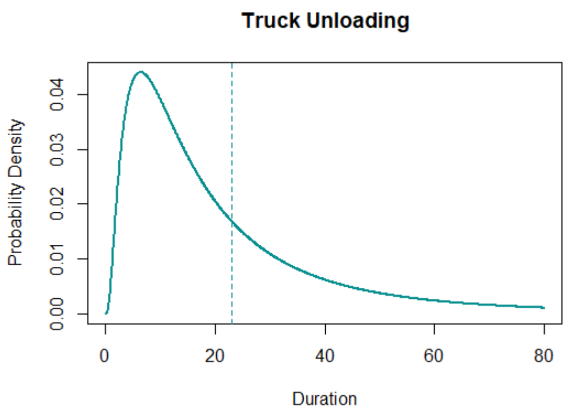

Figure 4.2: Lognormal Unloading Distribution

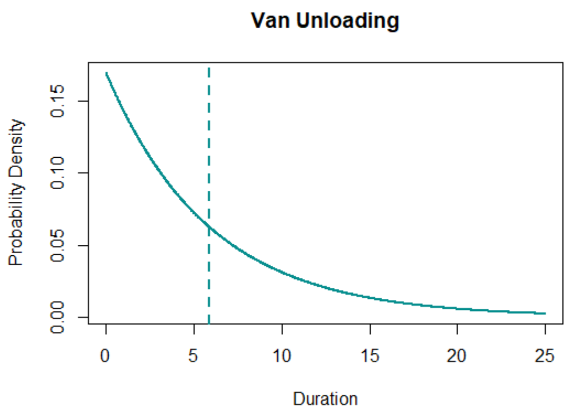

Figure 4.3: Exponential Unloading Distribution

Quantity

In a further study, the average amount does not accurately depict the mechanism through which products arrive. The most common values for trucks reflect their capacity and routes planned by the company itself, which results in most trucks carrying either under 5 pallets, 30 to 33 pallets, representing a full truck, or 60 to 66 pallets, representing a full stackable truck. The quantity distribution is, therefore, crucial to the model construction. The distribution that best fits the quantity each truck unloads is exponential. For each vans, however, the most adequate distribution is discrete, with better results in a geometric distribution. The parameters are as follows:

- Exponential Truck Quantity Distribution

$$\lambda = 0.037$$

- Geometrical Van Quantity Distribution

$$p = 0.310$$

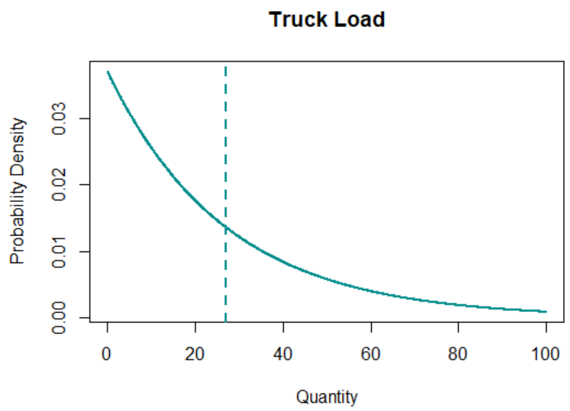

Figure 4.4: Exponential Quantity Distribution

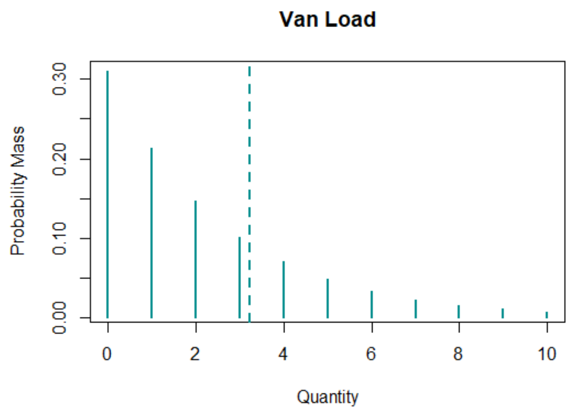

Figure 4.5: Geometric Quantity Distribution

4.2.3 Electronic Reception

The process of electronically receiving each product, as previously mentioned, can entail different efforts. The occurrence of re-palletizing and parametrization is registered independently in each client. To take this into account, however, it is not necessary to establish proportions, as the occurrence directly impacts the time needed to receive such products. In other words, the time effort calculated in association to the electronic reception already accurately depicts any event that might take place. The distribution was calculated resorting to internal data of the log system. The stamps include when the truck was unloaded, the beginning of the electronic reception, the end, and other information pertinent to location, client, etc. The information is organised by pallet, and not by batch of arrival. The time stamps, nevertheless, correspond to the different processes the batch went through. For this reason, it was necessary to either group all pallets by batches and retrieve information by dividing amounts, or to map the hourly efforts throughout the year and cross reference with the resources estimated to have been available throughout. The latter was chosen given the unreliability on the amount of pallets scheduled in comparison with the actual arrivals. A daily count of all receptions was made, divided by the considered active hours and resources available on such shifts. The daily averages were then studied as to determine effectively how long it takes to receive a single pallet. It is important to note that there are naturally a lot of discrepancies, as it is possible that x pallets of the same product were handled in a short period of time, and later one pallet of x products required a much larger amount of effort and time. The studied values best fit a gamma distribution and has parameters as follows:

- Gamma Reception Time Distribution

$$\alpha = k = 5.983$$

$$\beta = \frac{1}{k} = 1.341$$

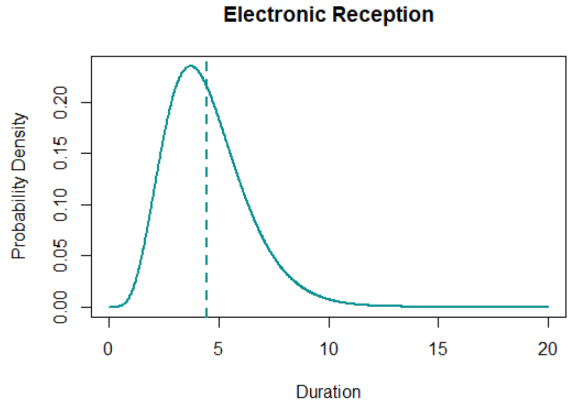

Figure 4.6: Electronic Reception Distribution

4.2.4 Storage

Storage data entailed time stamps only pertaining to when and in which location a specific pallet was stored. Through matching pallet numbers, it was possible to establish a connection between the electronic reception data and the storage data. This allowed an estimation of the current waiting time a pallet goes through after being received and before being stored. To determine the time effort related to storing each pallet, the same methodology as the electronic reception was applied. The hourly effort was contrasted with the available resources throughout the day, resulting in an estimate of how long it took on average, everyday, for a pallet to be stored. The better fitting distribution obtained was a lognormal and has parameters as follows:

- Lognormal Storage Time Distribution

$$\mu = 1.161$$

$$\sigma = 0.925$$

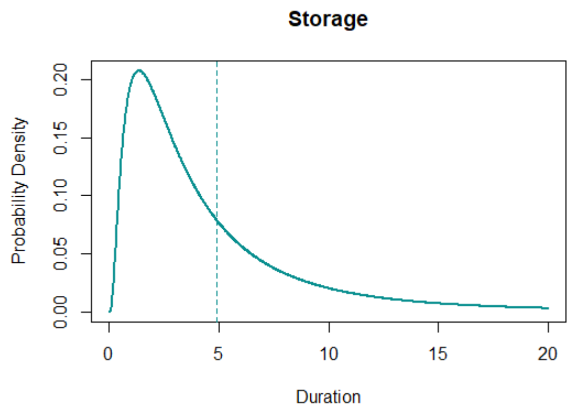

Figure 4.7: Storage Distribution

4.3 Model Construction

Model construction entails all details inserted into the software with the objective of recreating real-life events and studying the possibility for change. The selected software, Simul8, works with a Work Item (WI) that travels through the structure with certain controls in their flow. Work items are a very broad concept that can represent a plethora of situations, i.e. patients in a hospital, products in a factory or pallets in a distribution center.

The main objects responsible for the rules applied to the WI are the start points, queues, activities, resources and end points. As the name indicates, start points are where the WI enters the system, and can control the properties of such arrival. This information can be given as time interval between arrivals, or amount of arrivals within a time period. Once the WI has entered the system, it will go through queues and activities. Queues are an auxiliary system set in place to better organise activities and ensure all required entities are present. Activities, on the other hand, are where the work in the WI takes place. This usually entails a certain amount of time and resources to happen, and can result in certain changes to the WI, such as different label, or quantity. Activities also help understand where resources are being utilised. Resources are items required by an activity for it to take place. Resources can represent various types of situations, such as labor, physical resources. Most resources are shared resources as they can be required by different activities and can move between them. Finally, end points are the place where work that is complete, or otherwise finished, leaves the simulation. After the establishment of the process through which WI go through, it is equally important to recognise what aspects are the main focus of the study, as well as the relevant results collection period. The KPIs selected can be emphasised in the study, through the KPI Summary. These entail certain aspects of activities, queues, resources or any entity of recognised importance. Queues' KPIs can range from total WI, average number of WI at a given time, average queuing time (all and non-zeros), maximum queuing time or even percentage of queuing time within a set time limit. The same applies to activities and resources. Following the identification of relevant KPIs, the results depend on how accurately those KPIs can be obtained. This is done by setting up a simulation with a certain amount of runs that randomly generates all numbers sampled for the distributions.

The relevant aspects to consider once the simulation is designed are the results collection period, along with the warm-up time, and the recommended number of runs given a required precision. The warm-up time is the time that the simulation will run before starting to collect results. This allows for entities such as queues and resources to achieve what is considered normal running conditions, instead of starting at 0, before the results are recorded. The results collection period is best fitted to the defined objective, as it does not require a specific number, but is rather up to the situation at hand to entail a specific time interest. This time can range from minutes, to hours, days or even months. Lastly, the recommended number of runs is estimated based on the required precision of the confidence intervals around the estimate of the mean for the selected KPIs. This is usually of 5% to 10%, ensuring that the confidence limits will each be within 95% or 90% of the estimate of the mean.

The results of the specified KPIs can be relevant numbers, but can also be examined via graphic representation, that help better understand tendencies and behaviours of the system. For this reason, all relevant KPIs also produce graphics over time, obtained during the results collection period, as part of a visual representation of events. Nevertheless, it is also crucial to understand how the model was built, to better interpret all results.

In Figure 4.8 is the structural diagram present in Simul8 that allows for a flow that represents all relevant activities taking place in the area in study. There is a division of 4 areas, in order to better organise and logistically distinguish all events happening simultaneously. The first area A refers to the arrival and distribution of trucks. Area B refers to the unloading of the trucks and placement in the specific areas dedicated to reception inside the warehouse. Area C refers to the electronic reception and area D refers to storage, solely as an activity. It is important to note that some resources are shared between areas and that the WI at hand is not always the same. The entry is counted as vehicles, as that is the studied distribution in relation to time and effort. After unloading, inside section B, is a batching out that takes this into account and switches the WI to pallets. It is finally important to note that, within this construction, only the resources considered as constraints to the system and can impose any type of limit. Resources that are abundant and clearly do not require further study, are not illustrated or mentioned.

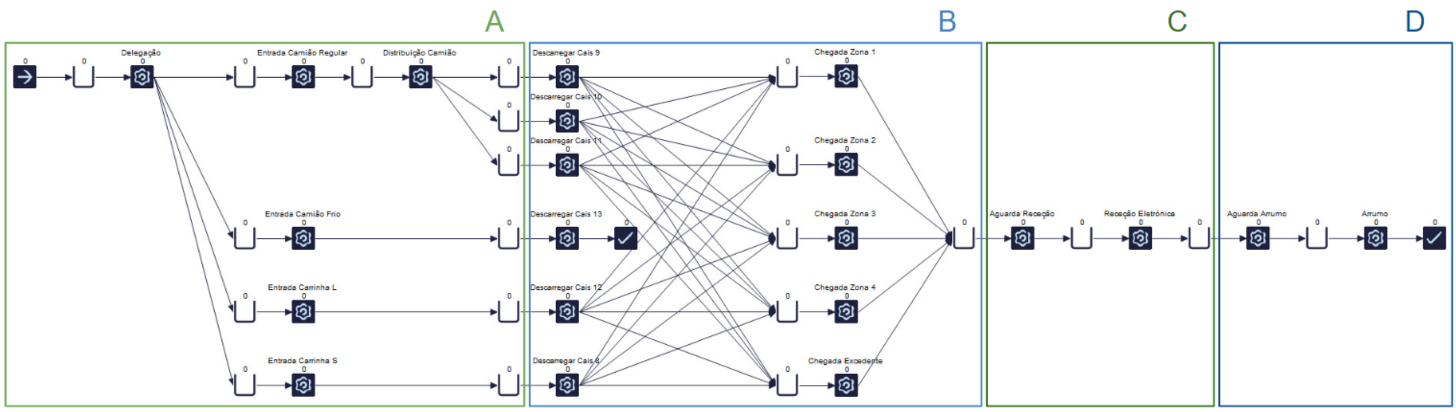

Figure 4.8: Final Diagram of the System in Simul8

4.3.1 Arrivals

The data for the only starting point of the system were retrieved from Table 4.1, with distinction within time intervals and days of the week. After entering the system, in this section the vehicles, both trucks and vans, are then attributed a dock. The objective of these auxiliary activities is to ensure the correct proportion of vehicles and arrivals. The time that takes a vehicle to dock was arbitrarily attributed an average of 5 minutes. No other extra time was added.

Resources

The resources utilised are the aforementioned team member responsible for the attribution of docks and unloading of the vehicles.

Flow

Following the scheme pictured in Figure 4.9, portraying only activities, the WI enters the system and is then split into the four categories by percentage. Regular trucks represent 70%, and large vans, small vans and cold trucks represent 21%, 7% and 2%, respectively.

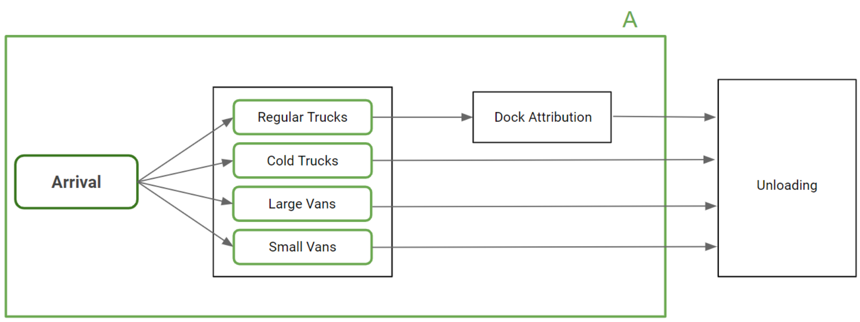

Figure 4.9: Area A Diagram

Regular trucks then await distribution into dock 9, 10 or 11. This distribution is made in terms of priorities, and is made when the resource is free, which means that trucks await dock delegation until previous trucks and vans have been unloaded, and are attributed to docks once those are freed. If there is only one truck waiting, that truck goes into dock 9, if there are two then dock 10 is also used, and so on. This activity is lower on the priority of the resource that unloads, as dock delegation tends do happen in cycles once all already docked vehicles take priority in finishing. On the last column of queues is where trucks await for a free dock after authorization.

4.3.2 Unloading

The data previously described in Statistical Modelling for Unloading 4.2.2 are directly applied to this specific area. The time pertaining to the unloading of trucks was applied to dock 9, 10, 11 and 13, and the unloading of vans was applied to dock 8 and 12. The batching out size was also carried out with the same logic, with truck unloading quantities being applied to WI that came through dock 9, 10 and 11, and van unloading quantities for dock 8 and 12. It is in this area that the initial concept of WI unit being a vehicle shifts into a pallet as unit. Finally, as mentioned, there are truck arrivals that are specifically in the cold chamber area, or sometimes regular trucks that carry singular pallets that require such storage. The unloading still falls under the responsibility of the reception area resources, therefore they are still taken into account in the unloading area as means to represent the occupancy of the resources, even given that such trucks exit the system without accounting for the pallets received.

Resources

The resources utilised are the unloading docks, the team member responsible for the unloading, and the reception area floor space. The latter was calculated with the maximum floor capacity of each zone, multiplied by a rate of 1.8 to represent the stackability factor that was assumed to be around 80% for all pallets that arrive. The team member was also considered to have time breaks, including lunch, into the daily working hours of 8am to 5pm.

Flow

After the vehicles are assigned a dock, the docking happens almost simultaneously between them. Whilst one is being unloaded, the already docked vehicles await. There is a usual tendency to first unload smaller vehicles in dock 8 or 12. Between the regular sized trucks, there was a tendency to begin with dock 9, followed by 10 and 11, as they were ordered to dock mostly in order of arrival, sometimes convenience. The flow represented in Figure 4.10 intends to visually depict a simplified system.

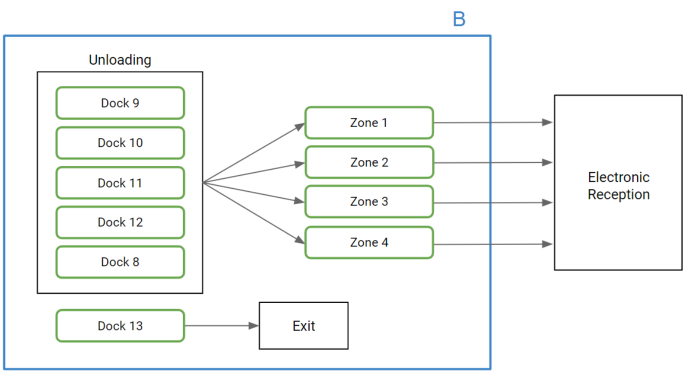

Figure 4.10: Area B Diagram

The zones, as previously explained, represent specific areas within the floor space available in the reception area. Smaller quantities have a tendency to be unloaded onto zone 4 and 2, and larger quantities have a tendency to be unloaded onto zone 1 and 3, due to the proximity to the different docks and the wider open space that allows for rows of pallets to be stacked and displayed side by side. On days with higher affluence of arrivals, it is occasionally necessary to temporarily store pallets in corridors. For this reason, and as to not create bottlenecks that do not represent the actual flow, an extra resource of ”Exceeding Zone” was created, alongside the others but with the least amount of priority. Finally, once the unloading is finished, the docks are released by the leaving vehicles, but maintain the reception area floor space occupied.

4.3.3 Electronic Reception

The data were retrieved from the distribution discussed in the subchapter dedicated to the statistical distribution of the electronic reception 4.2.3. The activity consists of entering all information into the system, with some occurrences of repalletizing and parametrization. These require special attention already considered in the time distribution inserted into the system.

Resources

The resources considered for this section were the team members that are responsible for the electronic reception. The zones in which the pallets are left after unloading are still attributed once the electronic reception starts, and remain that way at the end. Therefore these are not considered for alteration in this area, whilst not being released until later on.

Flow

The flow represented in Figure 4.11 is quite simple and represents what occurs in this step of the process.

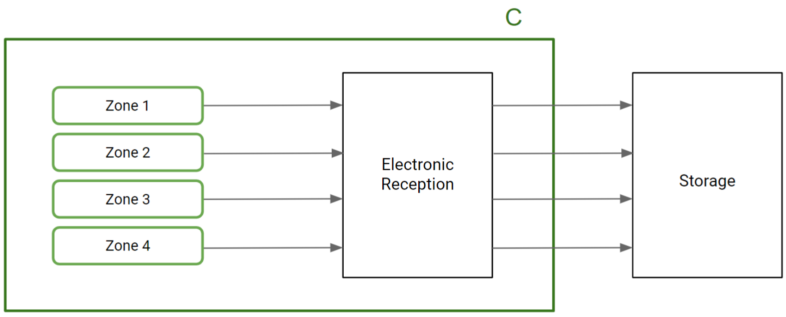

Figure 4.11: Area C Diagram

The actual work that goes into managing the reception area is quite complex and some aspects cannot be depicted in a simulation as their consistency and nature can differ greatly and be quite unpredictable. There is a standard to maintain the area clean and organised, whilst dealing with technical problems regarding the match between what the client said is going to arrive vs what actual arrived, as well as arrivals that account for different clients, arrivals that are missing items, have extra items, or even arrivals where the material is damaged. Despite not being depicted as extra activities, the availability of the resources towards actual electronic reception can be calculated simultaneously with the calculations to understand the time effort that goes into each one. This effort was calculated to be around 65%, in accordance with the scheduled shifts in place and the work by hour that was registered. That was inserted into the system as resource availability. There is also a detail added into the simulation that represents the average time the pallets spend waiting for the electronic reception. This allowed the system to be more accurately built. Nevertheless, this activity was then removed once the studied scenarios were to be compared. Given the study of the actual effort put into the electronic reception representing the data studied and not being estimated or arbitrarily attributed, the distinction between actual average waiting time and waiting time calculated by the simulation is a result important of attention in itself.

4.3.4 Storage

The activity consists of the transportation of the pallets to the location destined for storage and logging it into the system, as is depicted in Figure 4.12.

Resources

The resources considered as relevant to this activity were the team members assigned and the trilateral machine utilised to store pallets at heights in narrow corridors. There are currently 2 machines at the responsibility of the reception team, despite being used to retrieve and re-store pallets of products after the work of the co-packing and the re-labelling teams, which was accounted for in the availability of the resources. The trilateral machines have a mandatory charging period of 8h for every 8 hours worked, which was considered in the simulation.

Flow

The zones of the reception area floor space are released as the storage activity begins, as the transportation happens in a two step process that required the resources to work in pairs. One resource transports the pallets into the hallway where the pallets are to be stored, and the other does the actual storage process. After this, the WI leaves the system and is no longer relevant to the study at hand.

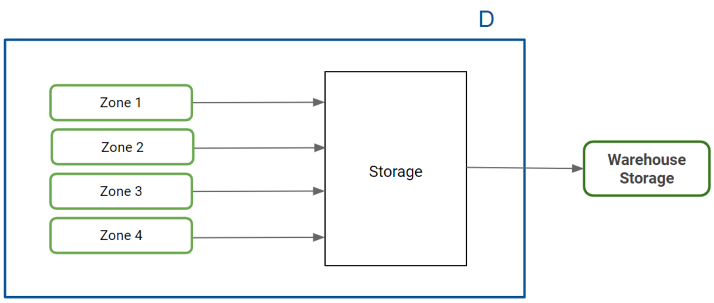

Figure 4.12: Area D Diagram

4.4 Model Validation and Set-up

The objective of the validation of the model is to ensure that the replication of reality can happen in the most detailed and accurate way possible. The process of validation required a separation of the simulation model built to be split into two parts. The first accounted for Area A and B, and the second to Area C and D. The first validation of the systems was conducted with use of the step-by-step simulation run available. It follows the system and advances the clock in intervals that allow the visualization of all the different events that alter the state of the system. The studied aspects in part one were: the behaviour of the arrivals and delegation of vehicles, the priorities through which the unloading resource allowed vehicle docking and performed the unloading, the distribution of trucks in dock 9, 10 and 11, and the priority through which the unloaded pallets are placed in zone 1, 2, 3 or 4 depending on where they were unloaded from.

To further detail the model validation, there were several important aspects studied within appropriate time frames to ensure that the behaviour is, in fact, accurate.

Arrival Verification

The arrival distribution for all days of the week is present in Table 4.1. In order to ensure that the daily differences are portrayed in the simulation, the period of one day was run five times. For the assessment to cover the specific day at hand, the warm-up period was designated so that each run only collected values from the desired day. In other words, in order to, for example, retrieve the number of arrivals for wednesday, the warm-up period was of two days and the collection period was of one. The results collected are present in Table 4.3.

Table 4.3: Verification of arrival distribution

	Monday	Tuesday	Wednesday	Thursday	Friday
Total Input	22.2	23.8	19.5	21.9	21.5
Trial 1	23	25	20	22	20
Trial 2	24	24	18	22	22
Trial 3	23	21	21	22	22
Trial 4	22	24	20	23	21
Trial 5	23	24	19	22	22
Average	23.0	23.6	19.6	22.2	21.4

There were some slight differences in the average of all trials as opposed to the original input. However, it is important to point out that the Total Input does not directly represent what was inserted in the system, as the averages were calculated by 3 hour intervals. The Total Tnput present in the table is the result of the sum of all inputs, and not the actual input itself.

Vehicle Type Verification

The arrival of trucks, large vans, small vans and cold trucks happens with a certain probability. The calculated estimate was of 70% for trucks, 21% for large vans, 7% for small vans and 2% for cold trucks. This verification does not require several runs with different focuses, but rather a long run that allowed for a relevant estimate of percentages. This run was of 2 weeks, corresponding to 209 vehicle arrivals. The number of arriving trucks was of 149, corresponding to 71.3%, the number of large vans was of 43, corresponding to 20.6%, the number of small vans was of 15, corresponding to 7.2%, and the number of cold trucks was of 2, corresponding to 1.0%. The numbers were not perfectly aligned, however it depicts a clear tendency towards the provided distribution.

It is important to note that both the arrival verification and the vehicle type verification were made with a deconstructed version of the final simulation model, which can be observed in Figure 4.13. Only the arrival of vehicles, the delegation of whether the vehicle is truck, large van, small van or cold truck, the dock attribution and the unloading activity are taken into account, with the WIs exiting the system right afterwards.

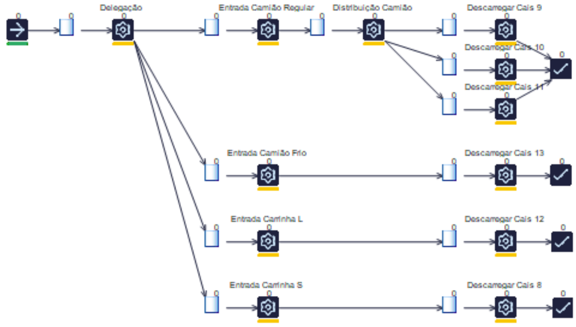

Figure 4.13: Arrival and Vehicle Type Verification

Batching-Out Verification

After the implementation of the batching-out feature, the verification was conducted with the same section of the simulation model present in Figure 4.13, except with a different dimension of WIs exiting. Given that the different distribution of batching-out depending on the vehicle type is represented by an exponential and geometrical function, the verification was carried out with a comparison of averages. With a run period of 2 weeks, there can be an assumption of around 72.3% arrivals being of trucks (regular and cold coupled) and 27.7% of vans (large or small). From the 151 trucks, and the 58 vans, there was an arrival of 4049 and 188 pallets respectively. This represents an average of about 26.81 pallets per each truck, which can be compared to the average of an exponential distribution with $\lambda = 0.037$ of 27.03 pallets. As for vans, the total number represents an average of 3.24 per van, almost similar to the average of the geometric distribution with $p = 0.310$ of 3.23.

Reception Area Utilization Verification

As previously stated, there is a preference of unloading in certain areas, by the different types of vehicles. Whilst trucks are preferentially unloaded in zone 3, followed right after by zone 1, vans tend to be unloaded mostly onto zone 4 and zone 2. Given the difference in amount of pallets carried by trucks versus vans, there is a clear distinction in average number of resource space utilised. The utilization is not a linear calculation, given that the different zones have different capacities. Furthermore, the final simulation model accounts for, not only the tendency for pallets to be placed in certain zones depending on coming from trucks or vans, but also the tendency to first electronically receive and store from certain zones as well. For this reason, it was needed to again study a section of the model, with a small addition from the previous verifications. This small addition is present in Figure 4.14.

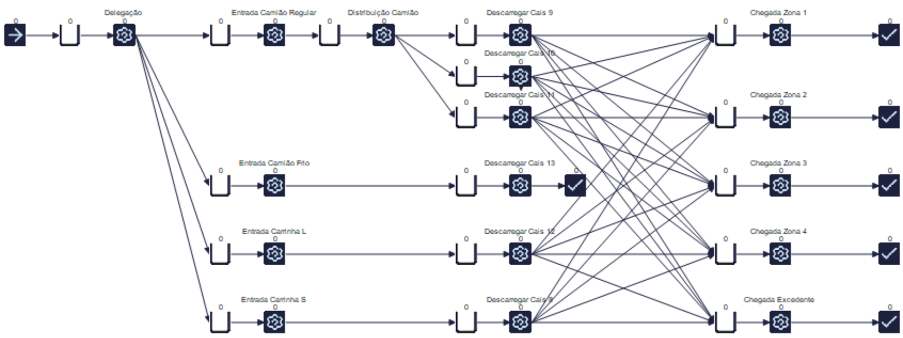

Figure 4.14: Reception Area Verification

A run was conducted with the same period of 2 weeks in order to understand the distribution of pallets between zones. Zone 3 had a total of 3128 pallets, whilst zone 1 had 827 pallets, zone 4 had 188 pallets and zone 2 had 0. The same happened with the exceeding area. Given the activity being merely auxiliary with 5 minutes average time, there was no congestion and no apparent necessity for both resources.

Overall Verification

The second step in terms of verification was made with the analysis of the actual flow of the WI throughout the simulation. The verifications made were relative to amounts entering and exiting the system, if the waiting times were accurate once compared to actual data, if the shifts and schedules behaved in an accurate way as to not create bottlenecks, and if the utilization and release of resources was appropriate.

To increase the significance of the study, it was then analysed the recommended number of runs and the warm-up period. An important aspect of these calculations are the KPIs that were considered relevant to the study, for the recommended number of runs to reflect a confidence interval within 5%. The queue awaiting dock delegation after entrance in the system, for all different docks, was considered relevant in order to reflect the interactions with entities outside the company and analyse the scenario in which these can be affected. The utilization of docks is examined alongside. All zones that pallets occupy once unloaded and throughout the process of reception was also considered, including the ”Exceeding Zone”. The queues pertaining to the activities of ”Electronic Reception” and ”Storage” reflect an also important KPI, as well as the human resources that handle the activities were considered in the analysis. Lastly, but most importantly, the time the WI spends in the system.

4.4.1 Results Collection and Warm-up Period

The warm-up period was established with the objective of starting the analysis on an already stable system. Given the nature of the cycle happening in the system, where there are different arrivals depending on the day of the week, which in turn affects the activities of the unloading, electronic reception and storage, it was considered that a relevant result collection period would be the analysis of 8 weeks. This allows for an analysis of the weekly behaviour and tendencies of the system, given that under normal circumstances there are no shifts on the weekend. In a normal state, two weeks would be sufficient in terms of establishing the amount of WI in the system once the first shift arrives on Monday. However, given the size of some resources such as the number of pallets fitting in the area, and the circumstances that some possible bottlenecks are the slow result of a slightly higher arrival of WI in the system vs the capacity the system has to process and treat all, it will be used a time interval of exactly 8 weeks. This ensures that, once studying sensitivities or long term effects of any decision, the collection period falls after the aggravation of some slight growing problems.

Some important KPIs mentioned are the queue for the electronic reception and the queue for storage. With a simple run of 4 versus 16 weeks it is possible to understand this effect for the first activity. Figure 4.15 is the amount of WI in queue awaiting reception for a period of 4 weeks, without warm-up. Figure 4.16, in contrast, is the amount of WI in queue awaiting reception for a period of 16 weeks. The first two weeks are noticeably lighter as the WI are able to be received mostly on the same day, not allowing the queue to surpass a certain level. However, once analysing the levels after the 8 week mark, represented in green in Figure 4.16, it is possible to identify that there are recurring peaks of over 300 pallets in waiting.

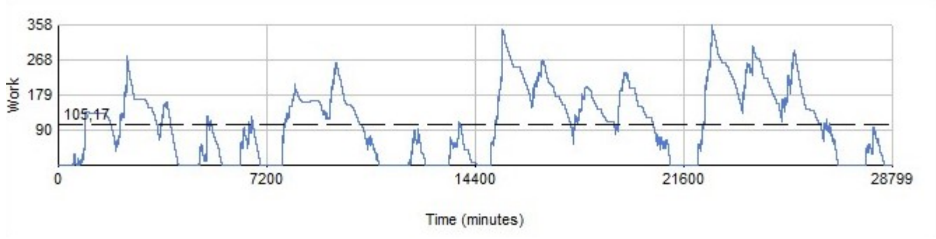

Figure 4.15: Reception Queue 4 weeks

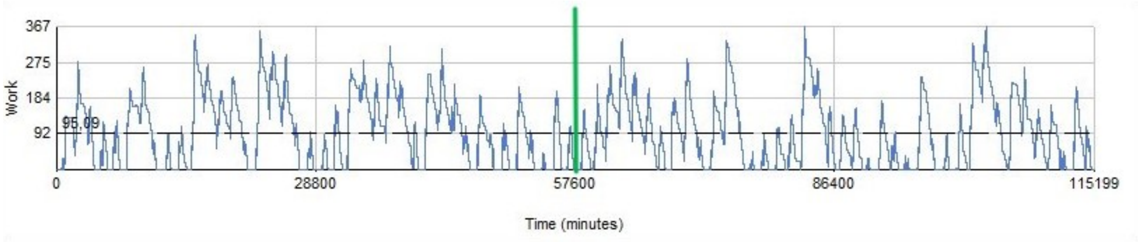

Figure 4.16: Reception Queue 16 weeks

This situation is more aggravated in the queue for electronic reception than in the queue for storage, as it is possible to analyse in Figure 4.17 and Figure 4.18. Nevertheless, there is still a clear need to consider a warm-up period greater than 4 weeks.

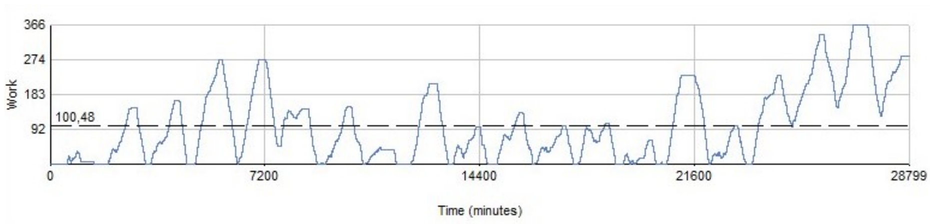

Figure 4.17: Reception Queue 4 weeks

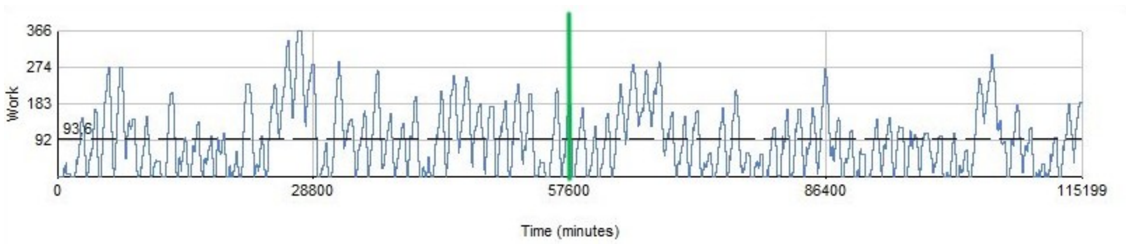

Figure 4.18: Reception Queue 16 weeks

It is important to note that not all queues require this warm-up time, as some function on a daily basis and are reset to 0. The utilization of the reception area floor zones presents this same tendency to require some warm-up weeks, as it is a direct result of the queue for reception and queue for storage.

4.4.2 Recommended Number of Runs

The recommended number of runs was calculated with the tool ”Trial Calculator”, which returned a recommendation of 171 runs for the considered KPIs and precision interval. The number of runs considered for this study was then 180, to ensure no additional doubt.

Chapter 5

Results and Discussion

This section presents all results and analysis performed to the system that assists in the final objective of improving the flow with which the WI goes through the reception process. It is organised in three sections that depict scenarios built in order to study possible implementations or alterations to the existing flow. A sensitivity analysis was also performed in order to control possible limits that need to be taken into account. Scenario 0 aims to study the already existing system in terms of all KPIs considered. The following scenarios will be compared with scenario 0, in all aspects that are relevant and fitting, for the analysis to be thorough. Scenario 1 aims to analyse how a possible change in resources' shifts can impact the natural daily flow and possibly lower the average time in the system and congestion in the reception area floor space. Scenario 2 aims to analyse a different perspective of how an external change in behaviours can impact the daily flow, by arranging an organised arrival of vehicles, all with scheduled and mandatory intervals throughout the day, and merging the resources of unloading and electronic reception given the identical skill level and higher range of working hours.

5.1 Scenario 0 - Regular Flow

Scenario 0 represents the current flow and state of the system. There are several average queuing time, resource utilization and maximum utilization values that can be analysed to understand what aspects can present potential problems. In order to study the sensitivity of the system, the daily amount of arrivals was increased. It is important to note that all time entries are in minutes, arrivals are in vehicle units and exceeding zone amount is in pallets. Table 5.1 represents the values of a regular amount of arrivals, an additional arrival of +1 per day, +2 and +3. A lot of information can be retrieved from this analysis. Initially, and as expected, the average waiting time of the queue that results from the distribution of trucks increase slightly given a higher number of vehicles. The most dramatic increases were in the average waiting time of the queues that result from the electronic reception and storage. The first increase by around 200, 300 and 700 minutes with each increase in arrivals, and the latter increased around 60, 80 and 180 minutes with each increase. Clearly the electronic reception is the activity less prepared to withstand changes, however this increase cannot be analysed in a straightforward way. The resources that are responsible for the electronic reception are at 65% availability, which was calculated in accordance to scheduled shifts and hours that showed registered work. In actuality, these are the most flexible resources, that not only perform some work not accounted for in the simulation, as well as work as reinforcement when other activities are falling behind or require assistance. When there is more work present to be done, this availability can actually increase given the necessity and is not a predetermined number. For this reason, and despite the impact this has on the system, an increase of flow does not necessarily mean that the queuing for electronic reception will increase by this amount as it is not observed data. The queuing for storage, on the other hand, is more accurate given the requirements that make the responsible resource have qualification to operate a trilateral machine. In the event of a higher inflow of pallets, a trilateral machine can be borrowed from other departments, however this happens on a more sporadic basis rather than regularly.

Table 5.1: Sensitivity analysis of increasing arrivals

KPIs		Regular	+1 daily	+2 daily	+3 daily
Arrivals	Total	904	944	984	1024
Queue for Truck Distribution		17.02	18.87	21.90	22.07
Queue for Electronic Reception	Average time (min)	577.55	768.41	1061.56	1788.16
Queue for Storage		473.39	522.74	640.06	829.83
Reception area space	Percentage utilization (%)	34.25	42.95	53.93	70.08
Exceeding Zone	Maximum amount	311.84	392.08	486.26	729.22
End	Time in System (min)	1088.39	1351.70	1754.75	2685.58

The reception area space utilization, which accounts for zones 1 through 4, also increased and impacts a more relevant KPI in analysis, the exceeding zone. As mentioned, this zone was created as a representation of when the amount of pallet inflow cannot be met with the actual floor space in the reception area, and some pallets are unloaded onto extra space like corridors or space attributed to other departments. This does not happen too often, but the KPI in evaluation is the maximum amount that the exceeding zone had at a given point. The number is already substantially high in the regular amount of arrivals, proving some inadequacy to respond to shifts in such predicted quantities. Lastly, the total time in system also increased. This can be observed also in Figure 5.1.

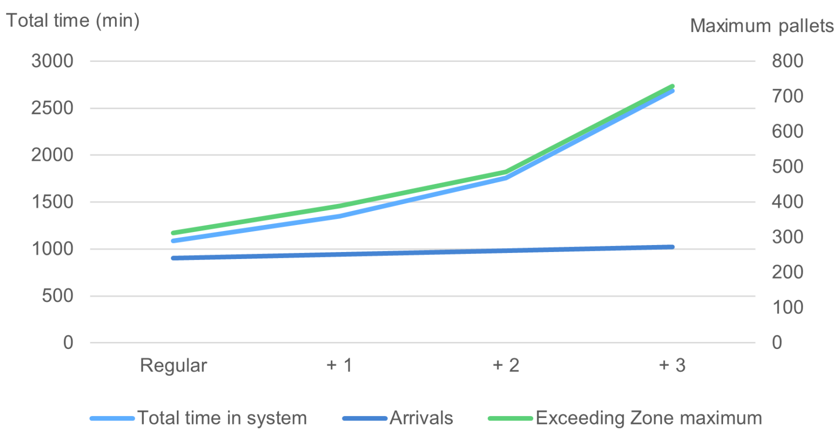

Figure 5.1: Sensitivity analysis of increasing arrivals

This time should always remain under 24 hours, or 1440 minutes. The current regular time in system is, on average, 1088 minutes or 18 hours. This does not depict the actual time previously discussed in the problem description of 26 hours, as the simulation account for the capacity rate with which the system can work. Delays in work or any sort of non-priority stance towards electronic reception and storage are not predicted or modelled. All that can be studied is the system's capacity.

Further analysis of sensitivities within the system will most likely not represent actual sensitivities in the flow of the reception area. Reducing the number of docks, in terms of warehouse adjustment, would have no significant impact as dock 11 has an utilization of 1.2%, and vans can use docks shared with the distribution department. Reducing the reception area space, which happens when other departments such as re-labelling, co-packing and distribution require so, would directly impact the exceeding zone that does not have a limit set. For that reason, the impact cannot be quantified and, as mentioned, the exceeding area maximum utilization already presents a possible problem. Lastly, the unavailability of resources responsible for unloading, electronic reception and storage. These resources can be numerically altered in the system, however this does not represent how the system would react to such alteration. This is due again to the availability attribution to the electronic reception resources, and the possible interchangeability of the resources between activities.

5.2 Scenario 1 - Shift Improvement

Scenario 1 represents a study into the alteration of daily task distribution in order to understand if a better management in terms of when items arrive, are received and are stored can impact the use of physical resources and improve the overall average time in the system. The alterations performed are firstly related to the electronic reception, which has 8 team members distributed in 4 different shift arrangements. Secondly shifts related to storage, with 3 team members in 2 shifts.

These changes affect different parts of the process, therefore relevant KPIs were selected to evaluate the results of each situation. The two main KPIs of the study are common to any situation and the overall goal. These are the average time spent in the system, and the necessity for exceeding area utilization. The average time spent in the system can be considered a collective result of all other queues throughout the system. Nevertheless, both the queue in question and the average time in the system are considered for all comparisons. An important note to add to the KPIs evaluated is that the actual number of resources and the amount of activities that require them does not change, what changes is their availability. For this reason, the utilization of the resources will still be studied for all the different scenarios, but does not infer a relevant impact in the analysis process. In other words, the activity will always require the resource to be performed and that amount of work results in a utilization that should, in theory, be identical in all scenarios, as the attempt is to simply better distribute the work so that the queue is reduced.

5.2.1 Electronic Reception Shifts

The current distribution of efforts in the electronic reception shifts divides 8 team members into 4 different shifts. Not all situations are of interest to be studied and therefore only situations that have been deemed relevant or interesting will be analysed. This refers to, for example, the complete cutting of one shift or an extreme concentration in one specific shift. The warehouse works in a 24 hour system and, as mentioned, resources can sometimes tend to other responsibilities not accounted for, or be required by other departments to help, demanding a constant presence of qualified workers.

The KPIs all subscenarios will be compared in are the average queuing time for electronic reception, average time spent in the system, reception area space percent utilization and exceeding zone maximum amount. The different subscenarios' resource distribution will be as follows:

- Subscenario A - 1 night shift, 2 morning shift, 2 afternoon shift, 3 normal shift.
- Subscenario B - 2 night shift, 2 morning shift, 2 afternoon shift, 2 normal shift.

- Subscenario C - 1 night shift, 3 morning shift, 2 afternoon shift, 2 normal shift.
- Subscenario D - 1 night shift, 2 morning shift, 3 afternoon shift, 2 normal shift.
- Subscenario E - 2 night shift, 3 morning shift, 2 afternoon shift, 1 normal shift.
- Subscenario F - 2 night shift, 2 morning shift, 3 afternoon shift, 1 normal shift.
- Subscenario G - 2 night shift, 1 morning shift, 2 afternoon shift, 3 normal shift.
- Subscenario H - 2 night shift, 2 morning shift, 1 afternoon shift, 3 normal shift.
- Subscenario I - 2 night shift, 3 morning shift, 1 afternoon shift, 2 normal shift.

Subscenario A

This situation represents the current system and will serve as the staple of comparison for all further situations studied. The results obtained are represented in Table 5.2

Table 5.2: Simulation results for subscenario A

	Average Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84

Subscenario B

This situation results in a modification of 3 normal shift resources to 2, where the other is placed at night. The results are present in Table 5.3.

Table 5.3: Simulation results for subscenario B

	Average Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario B	1394.39	1738.40	48.38	440.91

The shift clearly worsened the situation by doubling the average reception queuing time, resulting in a higher need for floor area utilization given the longer waiting period, and impacted in that amount the total time spent in the system. This subscenario does not bring any foreseeable benefits to the system.

Subscenario C

This situation results in a modification of 3 normal shift resources to 2, where the other is placed in the morning. The results are present in Table 5.4.

Table 5.4: Simulation results for subscenario C

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario C	668.87	1145.77	37.29	330.19

The shift delayed the average queuing time for the electronic reception by around 90 minutes, which is not the ideal solution being searched. Nevertheless, the general idea of reinforcement of the morning shift cannot be discarded, as the total time in system showed a smaller change in time. It is still not an interesting change.

Subscenario D

This situation results in a modification of 3 normal shift resources to 2, where the other is placed in the afternoon. The results are present in Table 5.5.

Table 5.5: Simulation results for subscenario D

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario D	643.48	1123.88	35.72	319.92

The shift, as mostly expected, did not show a very significant difference in values given the proximity of shifts between normal and afternoon. Nevertheless, given that all other shifts remained unaltered, it is possible to conclude that a simple alteration of normal to afternoon shift did not improve the flow of the system.

Subscenario E

This situation results in a modification of adding to the night and morning shifts, subtracting both from the normal shift. The results are present in Table 5.6.

Table 5.6: Simulation results for subscenario E

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario E	494.32	968.07	31.18	292.31

The shift significantly improved the average queuing time for the electronic reception, with a final impact in the total time spent in the system of less 120 minutes. The reinforcement of night and afternoon shifts resulted also in a slight decrease in exceeding area maximum.

Subscenario F

This situation results in a modification of reinforcement of the night and afternoon shifts, subtracting both from the normal shift. The results are present in Table 5.7.

Table 5.7: Simulation results for subscenario F

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario F	471.91	979.61	30.39	292.97

The shift improved mostly the reception queuing time, when compared not only to subscenario A but also to subscenario E. This decrease in reception queuing did not, however, positively impact the total time in the system when compared to the latter. This might be due to the concentration of afternoon and night shifts, where despite having two working resources in storage, if it is not finished by the end of the nights shift, the remainder of received pallets will have to await for the next normal shift to be stored.

Subscenario G

This situation stems from maintaining the normal shift incidence of 3, but switching one morning resource to the night shift. The results are present in Table 5.8.

Table 5.8: Simulation results for subscenario G

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario G	423.65	942.16	29.20	286.74

The shift significantly improved the average queuing time for the electronic reception, with a final impact in the total time spent in the system of less 146 minutes, almost 2h30 minutes. Given the simplicity of the switch, where only one resource is to be altered from morning to night shift, the subscenario is interesting and worth further study. Thus far, it is also the scenario that required less exceeding area utilization at its maximum.

Subscenario H

This situation also stems from maintining the normal shift incidence of 3, but switching one afternoon resource to the night shift. The results are present in Table 5.9.

Table 5.9: Simulation results for subscenario H

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario H	684.07	1120.09	35.05	318.43

The shift delayed the average queuing time for the electronic reception and the total time in system, despite not in the same amount, with the total time in system increasing only a third of the reception queue. It is also relevant to point out that the reception area utilization showed only a 0.5% increase even with an almost 105 minutes increase in reception queue.

Subscenario I

This situation results in a modification of all shifts at hand. Both the night and the morning shifts saw an increase of one resource, whilst the night and normal shifts were decreased by one as well. The objective of this last subscenario is to contrast subscenario A whilst following the guidelines of no shifts consuming most resources and depleting others. The results are present in Table 5.10.

Table 5.10: Simulation results for subscenario I

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario I	884.40	1272.89	40.20	348.13

The shift saw a very aggravated worsening of all aspects, and can be removed from consideration for improvement of the system.

Analysis of Subscenarios

There were clear improvements seen in some scenarios, whilst others worsened the situation by 50% (subscenario I) or even over 140% (subscenario B). Initially it is possible to conclude that it is, in fact, quite a relevant decision for the entire flow of the reception area. The comparison of all results is present in Table 5.11.

Table 5.11: Simulation results and comparison for all subscenarios

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
Subscenario B	1394.39	1738.40	48.38	440.91
	+ 141%	+ 60%	+ 41%	+ 41%
Subscenario C	668.87	1145.77	37.29	330.19
	+ 16%	+ 5%	+ 9%	+ 6%
Subscenario D	643.48	1123.88	35.72	319.92
	+ 11%	+ 3%	+ 4%	+ 3%
Subscenario E	494.32	968.07	31.18	292.31
	- 14%	- 11%	- 9%	- 6%
Subscenario F	471.91	979.61	30.40	292.97
	- 18%	- 10%	- 11%	- 6%
Subscenario G	423.65	942.16	29.20	286.74
	- 27%	- 13%	- 15%	- 8%
Subscenario H	684.07	1120.09	35.05	318.43
	+ 18%	+ 3%	+ 2%	+ 2%
Subscenario I	884.40	1272.89	40.20	348.13
	+ 53%	+ 17%	+ 17%	+ 12%

At first glance, it is clear to see that worsened situations are a lot greater than possible improvements, with only one situation theoretically capable of improving the total time in the system by 13%. What all three situations have in common that subscenario A does not is the presence of two night shift resources instead of one. In fact, the total reception queuing time lowered less in subscenario E, compared with a higher difference in subscenario F and even greater in subscenario G. Subscenario E has 3 morning resources, F has 2 and G has 1. It is possible to speculate that a higher number of resources in the morning, when crossed with the data referring to arrival distributions in Figure 4.1, will most likely still be handling pallets from the previous day, or awaiting for more to arrive at peak time.

It is relevant to also point out that the data were collected with a 5% interval confidence. This does not necessarily mean that positive results under 5% will not have a positive impact, but it is important to understand that there is a margin where the difference between scenarios is not, in fact, that great. Nevertheless, scenario G has a clear improvement margin in the reception queuing time, that might require some fitting to the storage queuing time. This is due to the alteration of the reception flow directly impacting the arrival of WI to the storage queue. For this reason, in the subsequent evaluation of storage shifts, both the current electronic reception shifting scenario and scenario G will be taken into account.

The alteration performed is, once again, related to the capacity of work on the system, not the actual waiting times in place. This means that, since there is no way of actually calculating the waiting times of pallets for every step of the process, but only the waiting periods created because of amount of work being processed, the total time in system might prove to be different that what was simulated in case of behavioural deviations from what is estimated.

5.2.2 Storage Shifts

The storage team members work within the same shifting system, with two team members on the night shift and one on the normal. Once again, not all situations are of interest to be studied, and therefore only situations that still offer diverse shifts and do not compile all resources will be evaluated. It is also important to note that there are two important resources in this section of the simulation. For unloading and electronic reception, the bikes and stackers considered are never limiting so as to represent the daily flow. However, trilateral machines still require a specific time dedicated to charging and utilization. They can, nevertheless, last over an entire shift. Given the previous establishment of a possible improved shifting system for the electronic reception, all the situations pertaining to subscenarios within the storage shifting problem will be analysed comparing to the current situation of electronic reception and the suggested improvement. This is mostly due to how impactful the shifting of queuing resources is to the distribution of WI arrivals to the queue awaiting storage.

The KPIs all subscenarios will be compared in are the average queuing time for storage, average time spent in the system, reception area space percent utilization and exceeding zone maximum amount. The different subscenarios' resource distribution will be as follows:

- Subscenario A - 2 night shift, 1 normal shift.
- Subscenario B - 1 night shift, 1 afternoon shift, 1 normal shift.
- Subscenario C - 1 night shift, 1 morning shift, 1 normal shift.
- Subscenario D - 2 night shift, 1 afternoon shift.
- Subscenario E - 1 night shift, 1 morning shift, 1 afternoon shift.
- Subscenario F - 1 night shift, 2 normal shift.
- Subscenario G - 1 night shift, 2 afternoon shift.

Subscenario A

In this situation, subscenario A represents the current system and will serve as the staple of comparison for all further situations studied. New subscenario A is the current distribution of storage shifts, with the recommended new shifting system for the electronic reception. It is also to serve as a staple of comparison. The results obtained are represented in Table 5.2

Table 5.12: Simulation results for subscenario A and new subscenario A

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	279.20	1088.39	34.25	311.84
New Subscenario A	464.36	942.16	29.20	286.74

Subscenario B

This scenario results from a simple alteration where the normal shift resource is placed in the afternoon shift. The results are present in Table 5.13.

Table 5.13: Simulation results for subscenario B and new subscenario B

	Storage Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	479.20	1088.39	34.25	311.84
Subscenario B	750.63	1329.49	38.18	365.44
New Subscenario A	464.36	942.16	29.20	286.74
New Subscenario B	843.36	1271.04	35.84	351.13

In both comparisons of current system and new improved system, the alteration worsened significantly the results. It is worth mentioning that the new alteration made to the electronic reception flow still lessened the effect scenario B has on the system. This is seen since the storage queuing time was worse in new subscenario B, but the overall total time in the system was worse in subscenario B. The same can be said about the exceeding area maximum and the reception area utilization.

Subscenario C

This scenario stems from placing one of the resources from the night shift, in the morning shift. The normal shift resource was, once again, left intact. The results are present in Table 5.14.

Table 5.14: Simulation results for subscenario C and new subscenario C

	Storage Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	479.20	1088.39	34.25	311.84
Subscenario C	928.26	1555.19	44.19	418.09
New Subscenario A	464.36	942.16	29.20	286.74
New Subscenario C	893.50	1471.62	40.26	334.51

Once again, in both new scenarios there was a significant worsening of average time flow. This time, however, new scenario C had a slight advantage when compared to scenario C, indicating that the new previously proposed resolution is somewhat compatible with this alteration. Nevertheless, this situation still showed no improvement.

Subscenario D

This study results from maintaining the 2 night shift resources but switching the normal shift one to the afternoon shift. The results are present in Table 5.15.

Table 5.15: Simulation results for subscenario D and new subscenario D

	Storage Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	479.20	1088.39	34.25	311.84
Subscenario D	551.73	1173.73	38.57	395.32
New Subscenario A	464.36	942.16	29.20	286.74
New Subscenario D	543.53	1023.61	33.64	326.09

This situation, in both the new and old comparison of subscenarios, showed a small delay to the total time in system, warranting a further look into what could be done with said changes. The shift in total time and storage queuing had an increase of around 80 minutes in all situations, the slightest increase seen thus far. It is quite relevant to note that, despite the increase not being too large, the exceeding area maximum increased the most significantly, implying perhaps that this slight delay had a big impact on the flow of the area occupied by pallets and when the start of storing begins on a daily basis, thus not allowing for a better preparation for when the unloading of pallets peaks. This suggest perhaps that a normal shift should always be considered so that the maximum arrival time can cover for most, if not all, pallets.

Subscenario E

This situation results in an almost contrasting situation to the original subscenario, with 1 night shift, 1 morning shift and 1 afternoon shifts, allowing for a comparison into a somewhat more extreme level of how the original decision stands. The results are present in Table 5.16.

Table 5.16: Simulation results for subscenario E and new subscenario E

	Storage Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	479.20	1088.39	34.25	311.84
Subscenario E	928.47	1555.38	44.20	418.09
New Subscenario A	464.36	942.16	29.20	286.74
New Subscenario E	988.51	1467.40	41.46	400.77

The situation was once again worsened by the studied scenario, as the shifts were dispersed throughout the day, not allowing the system to readily tackle the high affluence of pallets coming at specific times of the day. The exceeding area maximum is also quite concerning, proving that a delayed storage approach highly influences the capacity that the reception area of the warehouse requires.

Subscenario F

This scenario is the result of simply switching one of the two resources in the night shift to the normal shift. It leaves 1 night shift resource and 2 normal shift resources. The results are present in Table 5.17.

Table 5.17: Simulation results for subscenario F and new subscenario F

	Storage Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	479.20	1088.39	34.25	311.84
Subscenario F	205.87	815.33	24.47	270.02
New Subscenario A	464.36	942.16	29.20	286.74
New Subscenario F	250.95	683.53	19.73	247.96

The improvement in cutting the queue in more than half stems from fitting the storage and electronic reception to the actual flow of unloading happening in the system. Despite subscenario F having a shorter queuing time for storage, it is the new subscenario that appears to better fit, since the decrease in total time in the system is a lot more significant. It results also in a reception area utilization under 20% and the exceeding area maximum of around 250 pallets. It is, thus far, the only solution that proved to have a positive impact and show that an alteration has the possibility to, indeed, improve the system's flow. It is also noteworthy to point out that, for the new subscenario, despite reducing the queuing time by around 210 minutes, it reduced the total time in system by around 260 minutes. Given that this is the last step of the simulation, to have reduced more that only on the last queue and together with the reception area utilization, it can be presumed that the fitting of two resources on the normal shift can better fit the actual flow happening by responding in due time to the peak arrivals happening at specific times of the day.

Subscenario G

This situation results in a modification to the approach in subscenario F, where instead of having two resources in the normal shift, there are two resources in the afternoon shift. The results are present in Table 5.18.

Table 5.18: Simulation results for subscenario G and new subscenario G

	Storage Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	479.20	1088.39	34.25	311.84
Subscenario G	380.12	998.13	33.29	348.18
New Subscenario A	464.36	942.16	29.20	286.74
New Subscenario G	365.30	842.79	28.49	333.70

The situation was once again improved, despite not at the same rate as subscenario F. In this instance, both the subscenario and the new subscenario G lowered the storage queuing time and the time in system by around 100 minutes. The situation seems ideal, with the total time in system average rounding the 14 hour daily cycle. However, it is important to note that the shift this alteration had on the system significantly worsened the exceeding area maximum, showing that despite an improved queuing time inside the system, there is an incompatibility with the peak arrival of pallets.

Analysis of Subscenarios

There were, once again, clear improvements shown in some subscenarios. The results are present in Table 5.19. The subscenarios that showed the worse results were C and E, both of which had dispersed shifts throughout the day, instead of shifts focusing on specific time intervals. In fact, the two best scenarios had either two shifts in the normal working hours or the afternoon. It is interesting to point out that the normal shift and the afternoon shift share around 2h30 of the same time, but scenario B which split this tactic into one in the normal shift and one in the afternoon was worse even in comparison to subscenario A. This might happen since the shifts where the resources are coupled tend to establish a daily cycle where most WI are treated within a confined interval, whilst the more divided shifts might not in fact correctly handle the distribution of WI that get to the storage part of the process at specific times. However, scenario B should not be discarded if the arrival distribution were ever to be stabilised and there were no distinct and accentuated peaks at any time of the day.

In this analysis, in contrast with the previous, the discrepancy between system capacity and the rate at which the resources actually perform the work does not present such discrepancies. The resource availability was calculated at 80% and the queuing time of the simulation did not represent a significant difference when compared to the estimated actual waiting time. This results in more accurate and relevant results and an easier understanding of how impactful these scenarios are.

Table 5.19: Simulation results and comparison for all subscenarios and new subscenarios

	Reception Queuing Time (min)	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Subscenario A	577.55	1088.39	34.25	311.84
New Subscenario A	464.36	942.16	29.20	286.74
Subscenario B	750.63	1329.49	38.18	365.44
	+ 57%	+ 22%	+ 11%	+ 17%
New Subscenario B	843.36	1271.04	35.84	351.13
	+ 82%	+ 35%	+ 23%	+ 22%
Subscenario C	928.26	1555.19	44.19	418.09
	+ 94%	+ 43%	+ 29%	+ 34%
New Subscenario C	893.50	1471.62	40.26	334.51
	+ 92%	+ 56%	+ 38%	+ 17%
Subscenario D	551.76	1173.73	38.57	395.32
	+ 15%	+ 8%	+ 13%	+ 27%
New Subscenario D	543.53	1023.61	33.64	326.09
	+ 17%	+ 9%	+ 15%	+ 14%
Subscenario E	928.47	1555.38	44.20	418.09
	+ 94%	+ 43%	+ 29%	+ 34%
New Subscenario E	988.51	1467.4	41.46	400.77
	+ 113%	+ 56%	+ 42%	+ 40%
Subscenario F	205.87	815.33	24.47	270.02
	- 57%	- 25%	- 29%	- 13%
New Subscenario F	250.95	683.53	19.74	247.96
	- 46%	- 27%	- 32%	- 14%
Subscenario G	380.12	998.13	33.29	348.18
	- 21%	- 8%	- 3%	+ 12%
New Subscenario G	365.30	842.79	28.49	333.70
	- 21%	- 11%	- 2%	+ 16%

Nevertheless, the arrival distribution at the queue for storage resulting from the processing of WI in the electronic reception greatly impacts these subsequent results, implying that a more thorough analysis of the behavious of the electronic reception might influence these scenarios' behaviour and time intervals.

5.3 Scenario 2 - Scheduling of Vehicle Arrival

Scenario 2 represents a study into an alternative approach to improvement of pallet flow within the reception area - a controlled and timed entry of WI in the system. The current system, as mentioned, allows deliveries to be scheduled to specific days and times, with a limit for daily pallets. This is not too efficient for a variety of reasons. Firstly the estimation of pallets provided by clients tends to not correspond to the actual delivery, not allowing the daily reception capacity to be met, or forcing a surpass. Secondly because, as discussed in subchapter 3.2.3, more specifically pertaining to Figure 3.8, the non-compliance to scheduled times results in a peak in arrivals between the hours of 10 am and 12 pm. The scheduling of shifts must then revolve around the behaviour of outside factors that can have a certain unpredictability. The objective of this scenario is to analyse how an implementation of scheduled arrivals that are only allowed to unload within a strict interval can impact the resource utilization and time in the system. This scenario is, at its base, a speculation of how the system could react to dispersed and predictable arrivals.

The main alteration within the system to more accurately depict this scenario has to do with the utilization of the unloading and electronic reception resources. Since the different scheduling technique directly impacts the range of hours between which unloading takes place, the resources designated to both activities were pooled and can effectively perform both tasks. The skill level does not interfere. This also allows a better utilization of the already 24 hour working shifts.

The KPIs utilised to understand if there was an effective improvement reflect both the impact the alteration has in the beginning of the process and at the end. The beginning is reflected by a study into the KPIs reflecting the unloading resource utilization, the electronic reception utilization, the waiting time in the truck distribution queue and the utilization of all unloading docks. To reflect the rest of the process, very similarly to the previously studied scenario, are the KPIs reflecting the reception area utilization, exceeding area maximum and total time in the system. It is important to note that the pooling of resources and the definitions of the selected pooling allow both the unloading resource and the electronic reception resources to perform both the unloading and electronic reception tasks, with a priority given to the unloading of vehicles. This priority works for both resources. This alteration allows for a KPI referring to the individual resources and the pooled version. For this analysis, and to best compare with the current scenario, both the individual resources KPIs were selected. There are no subscenarios studied, therefore the study was divided into the new KPIs referring to the impact on unloading, followed by the analysis of the time spent in the system as a whole.

5.3.1 Unloading Impact

The first relevant impact this alteration has in the system has to do with how differently the arrivals are timed and planned. For this, the same numbers of arrivals was planned for each day of the week, but with a set distribution of 3 to 4 vehicles arriving between 12am and 9pm, in increments of 3 hours. In other words, there is the same amount of daily arrivals, with 3 or 4 vehicles arriving every 3 hour window.

The resources studied had then a different utilization behaviour. The previous results showed a utilization percentage of the unloading resource of 68.42% and of the electronic reception resource of 91.57%. It is important to note that this utilization is already the result of an availability of 65% of the resource, making it only comparable in terms of alteration between scenarios, but not an actual reflection of overwork in the system or that the resource requires additions. The new scenario presented a utilization percentage of the unloading resource of 88.08% and of the electronic reception of 80.86%, with a pooled result of 82.04%. This shows a more dispersed workload where the tasks can be met in more suitable time and distribution. A different impact can be seen on the utilization of unloading docks. The different results are present in Table 5.20.

Table 5.20: Simulation results for scenario 2 related to dock utilization

		Dock 8	Dock 9	Dock 10	Dock 11	Dock 12	Dock 13
Current	Total Utilization	63.16	548.49	72.63	11.82	189.56	18.35
	Queuing Time (min)	9.56	3.40	18.90	36.73	14.78	9.48
Scenario 2	Total Utilization	64.32	619.16	22.12	2.82	193.02	18.59
		+ 1.84%	+ 12.88%	-69.54%	-76.14%	+ 1.83%	+ 1.31%
	Queuing Time (min)	14.29	8.45	24.19	34.83	13.64	15.62
		+ 49.48%	+ 148.53%	+ 27.99%	- 5.17%	- 7.71%	+ 64.77%

There are clear shifts that are important to note, and some details that help understand the results. Firstly, and given the imposed change, the utilization of both dock 10 and 11 significantly decreased, with dock 11 almost not being used at all. Given the usual priority given to dock 9 for its strategic placement closer to the zone where the pallets are unloaded to, it is only natural that a decrease in queues formed by vehicles results in a near non-utilization of the dock placed in third priority. Docks 8, 12 and 13 do not present any difference given that their utilization is crucial to the unloading of vehicles of specific characteristics and cannot easily be replaced. This focus on dock 9 resulted in an increase utilization and, for that reason, an increase on the average queuing time. The queuing time of almost all other docks also increased, however not in a significant manner. All numbers present for dock 8, 9, 12 and 13 are under 15 minutes, with only dock 10 and 11 presenting values over 15. The significant decrease in the utilization of such docks also represents a decrease in significance of the average queuing time, as less vehicles are subjected to it. This increase in queuing time might also be the result of the elimination of the singular resource directed only at the unloading, given that even with the priority falling on the task of unloading vehicles, resources would still be required to perform the electronic reception simultaneously. The overall decrease in truck distribution time is also worth mentioning, with an average of 17.02 minutes in the current scenario, and 14.45 minutes in scenario 2. The most radical change observed, however, lies in the maximum queuing time. For the current scenario, the maximum queuing time is at 230.56 minutes, whilst scenario 2 presents a maximum of 90.02 minutes, a decrease of -60.87%. The distribution of vehicles, as expected, results in a dispersion of arrivals and, therefore, an elimination of longer vehicle queues. This, however, is only a more extreme scenario, which should not dictate the validity of the decision on its own.

5.3.2 Overall Impact

As per the KPIs selected to represent the overall best interest of the system, the comparison is once again made between the current scenario and the scenario with an implementation of scheduled vehicle arrival. These results are impacted but are not the direct result of the proposed change, as time in system, reception area utilization and maximum area are still dependent on the resources and natural flow inside the warehouse. This scenario only tests how the system's arrival distribution can contribute, maintaining fixed the resources' behaviour. The results are present in table 5.21

Table 5.21: Simulation results for scenario 2 related to overall impact

	Total Time in System (min)	Reception Area Utilization (%)	Exceeding Area Maximum
Current Scenario	1088.39	34.25	311.84
Scenario 2	687.72	21.81	98.53

The main observation that can be made is that, in fact, all values significantly decreased. This comes to prove that, in theory, an arrival that is scheduled, predictable and evenly defined can impact the system almost without change from within. It is again important to note that the implementation mentioned in this scenario does not require any alteration made to the team's shifts or skill levels. It would only take advantage of the hours that members are already present in the warehouse, and resources that are available all day. This implementation, however, could present some impact, perhaps negative, to the relationship with the courier and the client, given the current flexibility in planning on the other end, that results in how randomly the arrivals are witnessed in this system.

The results allow an analysis of how the exceeding area maximum utilization is at the lowest seen in this report. This is perhaps the most significant change observed in the system as the exceeding area utilization is the direct result of how accumulated the arrivals can get and the response time not being sufficient because of shifts, restrictions and already existing work. This evenly spread of WI arriving in the system can significantly reduce how overwhelmed the electronic reception team can get. As expected, this also impacted the reception area utilization, albeit not as significantly, and the total time in system, proving once again the existence of a daily bottleneck given high arrivals at specific times.

5.4 Scenario Discussion

From all the results, there are some takeaways worth mentioning. Firstly, pertaining to the electronic reception shifts. It is a team comprised of 8 elements, that can present a greater amount of subscenarios than the ones studied. Nevertheless, following common sense ruling, the subscenarios studied represent a broad study into how the situation can be improved. Most subscenarios did not show any improvement, rather on the contrary, with some time KPIs increases of over 100%, ensuring that the current scenario is, in fact, logical. The improved scenarios focused on the night and afternoon shift are improvements that make sense, given the current behaviour of peak arrival in pallets. This improvement on the overall system functioning, of less 13% in the total time in the system and less 8% in exceeding area maximum, is not too great but significant enough to warrant some action towards a different focus when scheduling shifts. These values are not too comfortable, given the predefined 5% interval confidence provided by the system, where the margin for improvement might not be significant enough.

Storage shifts, despite having only 3 resources to test the distribution, also present a number of possibilities in terms of how shifting can be made. The studied shifts maintain always a night shift schedule. These were compared with the current scenario and with the subscenario selected in the previous shifting study that proved to have the most potential for improvement. Once again, most subscenarios did not show a positive impact on the system, with only two showing improvements. These two improvements, however, were significantly greater than those previously seen. The subscenario with 1 night shift and 2 normal shifts showed a decrease in the total time in system KPI by 27% and exceeding area maximum utilization of less 14%. The subscenario that proved to be the most likely to improve the system resulted from the previously selected improved subscenario and this night/normal shift alteration. This subscenario showed a similar decrease once compared to the already current state of electronic reception shifting, with improvements of only less 1 or 2%. This comparison, however, is made in regards to the current values. In other words, the shifting of one night shift member to the normal shift had an improvement of 25% or 27% in both the current situation and the previously improved electronic reception scenario. The previously improved scenario had already improved the current situation by 13%, showing that the most impactful change is the combination between the two best subscenarios in each study, with a total decrease in total time in the system of about 37%.

Most importantly, the scenario that showed the largest impact in the main KPIs was focused on the external arrivals in the system. This solution impacts the normal flow of the system a lot more significantly than the previously studied hypothesis, showing the best reduction in total time in system and exceeding area maximum utilization result combined thus far. In the first KPI, the time was previously lowered by 37.20%, which was replicated with a decrease in this scenario of 36.82%, virtually the same. This shows that both studies are relevant and can improve the system independently. The more significant reduction that the previous study could not replicate is the exceeding area maximum. The current decrease sits at 68.40%, whilst the previously achieved decrease sat at 20.49%. The behaviour of arrivals where there is a daily peak goes against an unproblematic flow of pallets and requires a daily cycle of responding to one peak before the next. With scheduled arrivals, the peak is significantly reduced, as the system has the capacity of dealing with the arriving amount in a more phased and structured cycle and avoid an overflow of pallets.

It is important to note that the comparison of both systems cannot be taken linearly, as despite both having an impact on both KPIs, they do not impact directly the same parts of the system. For this reason, it would be possible to study the impact of both scenarios combined in the system. In fact, it would be interesting to conduct the shifting subscenarios study in case of implementation of scheduled arrivals in the system, as such arrivals completely alter the behaviour of the system in terms of pallet flow distribution. This discrepancy in the distribution will most likely result in a completely different shifting optimization scenario for both electronic reception and storage. The other way around, however, might not prove to be as relevant. This is mostly given that an alteration to the final parts of the system, in activities such as the electronic reception and storage, has no impact on the arrival distribution. The relationship is mostly one sided, with the arrival distribution greatly impacting the final stages and the shifting methodology behind them. For this reason, only the study of scenario 1 after scenario 2 would be relevant. This study was not conducted, as the behaviour of the system was only studied under the current working situation, and all statistical values and analysis was conducted under such pretenses.

To conclude, there were relevant results and situations mentioned that can improve the current state of the system. Electronic reception and storage respond to arrivals in large periods of the day, and with a significant team. An improvement of the team shifting, on both activities, could produce a decrease in total time spent in the system by pallets of around 37% and exceeding area utilization of around 14%. These shifting alterations showed a reinforcement of the afternoon shift for the electronic reception, and a reinforcement of the normal shift for the storage. As for the arrival of vehicles, the same improvement of around 37% was obtained independently for the total time spent in the system, with the most significant impact seen on the exceeding area utilization that decreased by around 68%. This can lead to the conclusion that the most important scenario to analyse and study the possibility of implementation would be scenario 2, with a more relevant decrease in exceeding area. Both scenarios are, however, not mutually exclusive, and further study into subscenarios pertaining to electronic shifting and storage could be conducted after the implementation of scenario 2 as a way to better fit the new distribution of arrivals to how resources should fit. Nevertheless, scenario 2 independently presents the same decrease in total time in the system which, despite not exactly tackling the exceeding area issue equally well, is still relevant and a solution in case scenario 2 is not to be implemented.

Chapter 6

Conclusion

The objective of this study was to improve the inbound operations at Alloga-Logifarma's warehouse, by addressing the current situation as a simulation design and testing improvement possibilities to attempt to decrease the average time it takes for any given pallet to be processed. In order to understand possible solutions and provide an accurate depiction of the system, firstly there was a study conducted into how the flow effectively happens on a daily basis and the time and effort distributions that could be retrieved from the data. Secondly, the information was applied into the simulation that follows all the logistic and sequential steps according to the previous observations, with an increased focus on resources that are crucial and limited, such as human resources, unloading docks, and reception floor space. After the construction of the model, different hypothesis construed as scenarios were tested, following the same logic of comparison with the current state and the previously found suggested solution.

The elaboration of this study had stronger and weaker aspects. One strong aspect was the easily observed and described logistics of pallet flow within the inbound operations responsibility, allowing for a quite simple and straightforward understanding and, therefore, facilitating the construction of the simulation model. This also allowed for the results to be easily understood, as the KPIs that were taken into account could be easily retrieved and dealt with. The maximum exceeding floor space utilization and the total time spent in the system by the pallets allow an analysis into how the worst situation within the simulation time frame translated into overuse of space, and how the average time a pallet spends being received and processed affects the workings of a warehouse that strives for a 24 hour or under service. Another strong aspect were the distributions obtained from the data collection and analysis. The fit tests proved that the distributions considered in the simulations were accurately representing the behaviour of the actual system, which is both due to the flexibility of the software Simul8 in the realm of available distributions to consider, and due to the systematic behaviour of the reception operations funneling into a specific routine and time frame for most activities. Lastly, the simulation itself, when coupled with an understanding of the system, proved to be reasonable in all retrieved data, with identifiable justification behind shifts happening in the time distributions and maximum exceeding floor space. These two are quite strongly correlated, however some scenarios analysed impacted one more strongly than the other, and the other way around. The same can be said about dock utilization, truck waiting time before unloading and other relevant yet not principal KPIs.

Acknowledged weaknesses in the conducted study are also quite evident. Firstly, the utilization by the company of two different systems to store specific data could potentially cause an inconsistency in analysed connections, as the scheduling of arrivals happens in one system, the arrival and departure of trucks is registered only by the security office, and the unloading, electronic reception and storage and present in another system. To add to the situation, unloading time stamps were not accurately depicted, as the distribution of truck unloading registered in the system, by hand, by reception resources did not match the time frame and the distribution collected from the security office and the first was, therefore, discarded. A second instance was already within the same system, as data from the electronic reception of any pallet were not retrieved simultaneously with its storing, which required cross-referencing of pallet information. These acknowledged weaknesses serve not only as flaws within the study, but also as suggestions of improvement in terms of the current state of information management and logistics within the company. Lastly, another weakness relating to the simulation itself has to do with the utilization of resources, as some are shared with other departments within the warehouse and the resource allocation cannot be accurately determined in cases of more workload and stress responses. The same can be said about either human resources or floor area.

As recommendations for future work to be possible and of higher accuracy in terms of depiction and applicability, there are some topics relevant to mention:

1. Data collection from one source could provide a more accurate depiction of the system, with better tracking of service in terms of truck unloading, pallet processing and space utilization, preventing lost or inaccurate information.

2. With the implementation of scenario 2, relating to the scheduling of arrivals within a wider but stricter time frame, scenario 1 should be studied again with new data, as both scenarios proved interesting to explore but the data used in scenario 1 would be completely influenced by the implementation of scenario 2, rendering most shifting conclusions outdated.

3. Another interesting topic would be to study all physical flows that are secondary to the unloading-reception-storage flow, given that some pallets were moved in-between and that there is some traffic in the warehouse with both bikes and collaborators from the same and other departments that influence time productivity and resource utilization. The flow of the entire warehouse and how it affects and is affected by inbound operations would ultimately be the best scenario for testing any possible change.

Overall the study was quite interesting so as to depict how possible changes can positively or negatively impact a system, without physical changes being required to formulate hypothesis ans scenarios. The study was also quite specific to a single aspect of the warehouse, inbound operations, allowing a highly detailed study of a fragment of larger operations. It is also a lesser addressed topic within supply chain, or even warehouse management, with most studies focusing on cross-docking facilities for dock attribution purposes, often overlooking the relevance of information management and the crucial data inputs from the electronic reception of any material for organization within the company and for potential suppliers and clients.

The perspective of Alloga-Logifarma, as a business, towards the results also warrants some importance. Scenario 1 can be easily implemented and the veracity of the simulation can be attested for in a short amount of time. The switching of resources within the warehouse is already done with ease, given the skill level required to perform several activities being relatively equal. In the event of a department requiring help from another, resources are easily shared and flexible. This is true for both the unloading and electronic reception resources, and storage. However, scenario 1 will only be considered if the plans for scenario 2 do not go forward.

Scenario 2 proved the most impactful in terms of flow in the system, with the time spent in the system lowered by around 37% and the utilization of exceeding area by 68%. This implementation would then require additional study into how to improve shifting given that the whole system would be functioning differently in terms of daily behaviour trends. There is, nevertheless, a slight problem with the implementation of scenario 2. There is no possibility for a trial period to understand if the alteration can actually prove to be a competitive advantage for the warehouse. With the flexibility provided to client companies where the arrival window is not considered and even delays of several days can be overlooked or slightly fined, the response to this change might deter future deal negotiations with new or already existing partners. Given that around half the pallets arriving are international, the predictability of transportation time significantly decreases and the possible fines and problems proposed to the clients by restricting their flexibility in terms of arrival date and time can cause them to consider other options for storing and sales. The other half, nonetheless, might also be taken aback given that most national delivery systems that have routes and require different points of delivery, have their plans made a lot closer to the delivery date than when the booking is made. In other words, 3PL companies are used by many clients that they, themselves, do the arrival booking at Alloga-Logifarma. These companies, however, plan their routes a lot closer to the actual delivery date when the cargo does not justify a trip solely dedicated to them. This is mostly due to the variety of transported goods and all incoming requests from other companies. To book 3PL companies with a specific time and place entails a more expensive transportation bill that might not be ideal for clients. This lack of flexibility and higher costs might, similarly to international arrivals, have implications in terms of competitiveness with other pharmaceutical warehouse solutions.

Given the aforementioned implications of applying a strict scheduling of arrivals, the scenario entails further study in terms of strategic approaches, as well as financial, to understand the actual advantages this implementation can have. The logistical improvement of evenly timing arrivals might not outweigh the financial impact this solution might cause.

Lastly, simulation as a tool for studying improvements before implementation of testing in the real system can certainly have its limitations, as mentioned above, but can also contribute to the formulation of improvement opportunities given both the visual aspect and the simplicity that comes with testing theories without committing to change. There are other opportunities within Alloga-Logifarma to test simulation, both in other departments and in the warehouse as a whole, so as to test the complete flow of pallets, from entry until delivery. Given the insight provided by the analysis to inbound operations, a more complete study and understanding of all departments could stem from a simulation entailing aspects and resources of the real system, allowing all interactions to be depicted, should also be considered.

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Appendix A

Appendix

Histogram and theoretical densities and QQ plots of studied distributions.

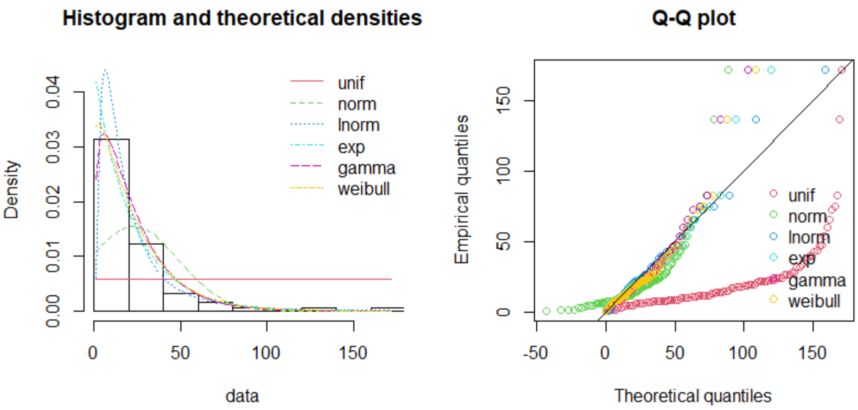

Figure A.1: Unloading Truck Distribution

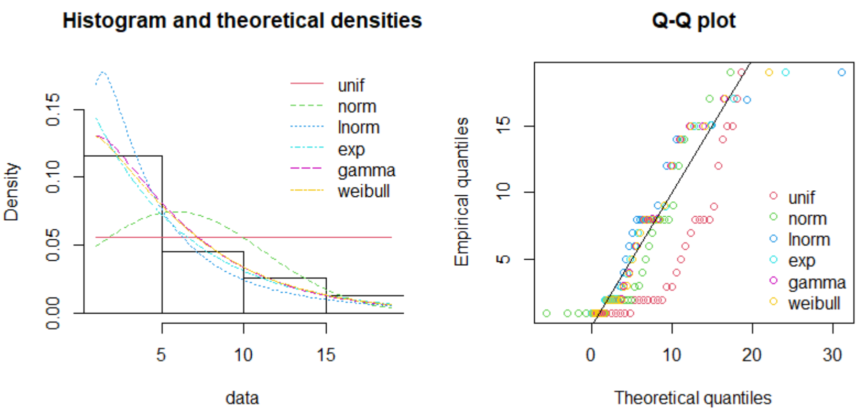

Figure A.2: Unloading Van Distribution

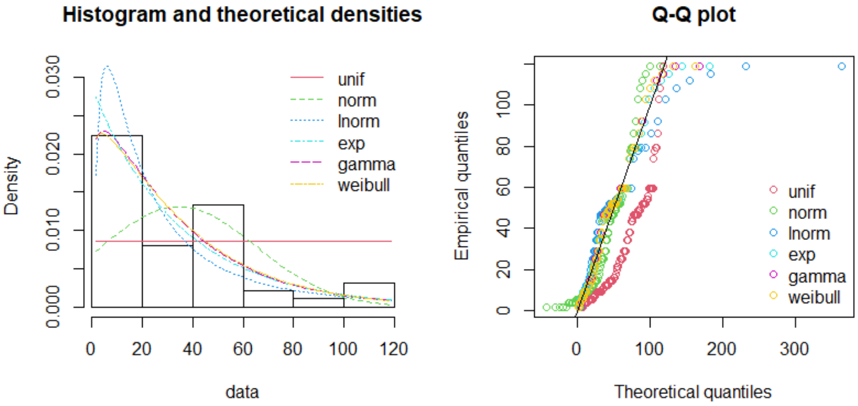

Figure A.3: Truck Quantity Distribution

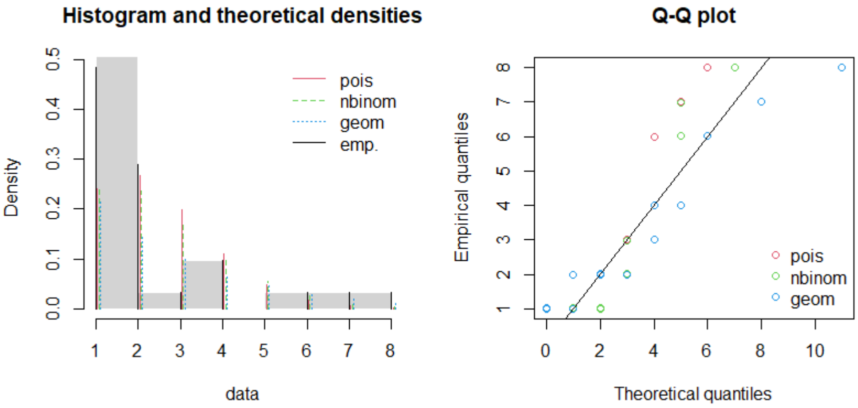

Figure A.4: Van Quantity Distribution

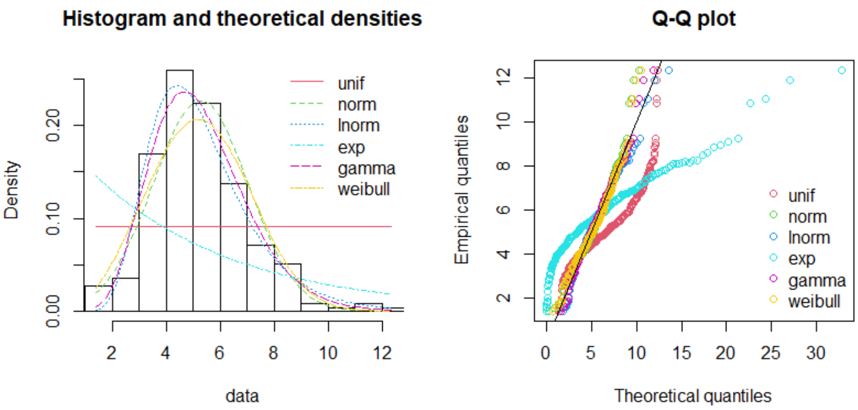

Figure A.5: Reception Time Distribution

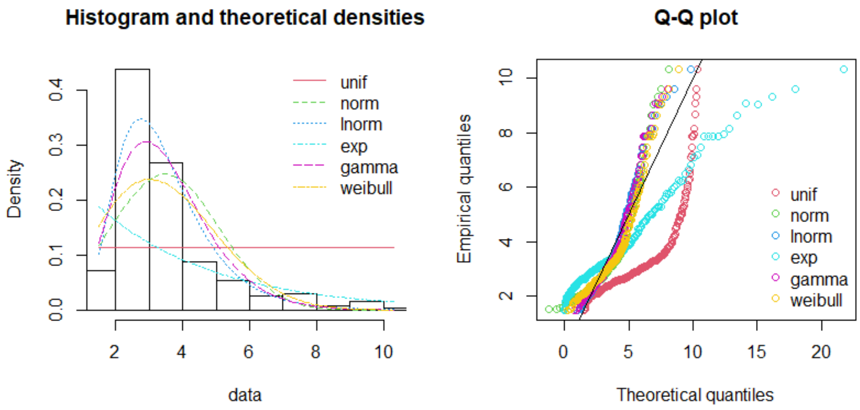

Figure A.6: Storage Time Distribution