Simulation and Improvement of Inbound Operations in a Pharmaceutical Warehouse
An Alloga-Logifarma Case Study

Ana Sara Guedes da Costa Marques
ana.guedes.da.costa.marques@ist.utl.pt

Instituto Superior Técnico, Lisboa, Portugal

June 2024

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

1. Introduction

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 [1]. 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.

The objective of this thesis is to study the possibility of improving the everyday flow of one of the main activities within the warehouse, inbound operations, by attempting to take better advantage of current resources available whilst proposing a different organization of activities and schedules. Inbound operations, as a crucial part of any warehouse, with the responsibility of accurately logging information of the product and ensuring all entities involved in the supply chain can receive updated and accurate data.

Simulation was the selected methodology to study both the flow of activities currently happening in the system, and the possibility of implementing specific changes. 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 [3].
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. 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. The two opportunities identified as hypothesis worth studying were, for 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, and for 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. These scenarios were studied in an attempt to prove that an improved daily flow of work throughout the warehouse can decrease the average time between arrival and storage to under 24 hours.

2. Literature Review

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 [4]. In order 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 [5]. This results in a cost-controlled alternative to real-life experimentation with methods that produce results comparable to the experimental design settings [6]. As Pidd described, there are five pillars to consider as advantages to simulation [3]: cost, time, replication capacity, safety and legality. It is nevertheless noteworthy to mention that it is not always the most reasonable solution, given that computational simulations can take hundreds of hours to retrieve relevant data [7].

2.1. Warehouse Management

Warehouse management includes numerous activities, mostly focused in control of available internal resources and supplying resources to the needed activity so as to constantly ensure order management. The management process within warehouses can be categorised in six distinct areas: reception and inventory management of inbound products into the warehouse, replenishment of dynamic picking zones, inventory allocation - assigning stock to orders, order assignment - assign orders to resources and/or work stations, load balancing and control of picking posts or order picking resources, and consolidation of orders and dispatch labelling [8].

2.2. Warehouse Activities and Simulation

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 [9]. 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. 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 activity 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 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 and can entail different areas to assemble different order quantities and batches. 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 [10].

2.3. Inbound Operations and Simulation

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.

Nevertheless, this option is not feasible for all warehouses, as most are utilised for storage, rather than order redistribution alone.

There are several studies that focus on activities that are strongly correlated with inbound activities. The optimal scheduling of inbound and outbound trucks in cross-docking systems can reduce total operation time and improve system performance [11]. Despite the cross-docking component of the study, this can clearly be linked to regular warehousing systems. The assignment of available docking stations also stems from cross-docking, so as to find an optimal solution that minimises operational costs of unloading and trucks awaiting processing [12]. Another aspect can be borrowed from studies mostly focused on outbound movements, is staff shifting utilising queuing theory. The comparable aspects are mostly focused on time distribution of order arrival and fulfillment necessities, so that all activities related to picking, packing and sorting can be executed in appropriate time. This takes into account the capacity and requirements between each resource available. Overall, optimal staff management shows adequate approximations in the optimal number of skilled resources and a consequential improvement in processing efficiency and service quality [13].

3. Case Study

Alloga-Logifarma, present in Sintra, Portugal, is a warehouse comprised of over 24 thousand squared meters, with a capacity of 27 thousand units of storage. 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 changing demand. 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.

3.1. Warehouse Flow

Alloga-Logifarma works in different inbound situations, as 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. 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 Euro-pallet has a standard size of 800×1200×144mm, and the storage display is strategically designed in accordance to these measures, as well as the load's height, requiring some deliveries to be 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. Lastly, the distribution is mainly organised by regions where the different orders were placed. The orders can have different amounts of specific products, requiring diverse logistics going into order assembly. Orders that require small amounts of different products are processed with Kardex machines. These need to be stocked, 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. Warehouse 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 Figure 1.

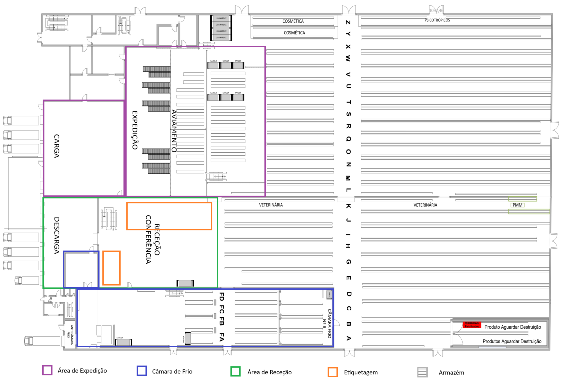

Figure 1: Alloga-Logifarma Warehouse

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. 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, with the 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 via a specific vehicle unloading dock, or through a door from the reception area for vehicles with mixed temperature chambers. Vehicles arriving can be categorised into different types, that require different unloading methodologies and spaces. Average trucks can dock at Dock 9, 10 and 11 if the temperature corresponds to 15ºC-25ºC, and Dock 13 for 2ºC-8ºC or negative cold, leading directly to the Cold Chamber. Larger vans, or smaller trucks, fit specifically in Dock 12. Lastly, small vans dock at Dock 8 and can either be unloaded by hand or require pallet stackers. The docks and areas are represented in Figure 2.

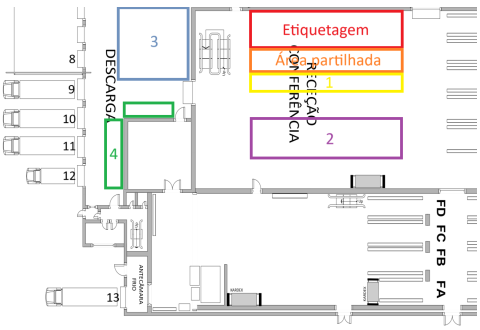

Figure 2: Warehouse Inbound Zoom-in

3.3. Problem Formulation

An area that is often overlook as it does not directly impact the daily order shipment is the reception area. Currently it 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 storage all products. A mistake in the electronic reception of products can also 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.

The important entities identified within the system can be categorised as four types of resources: unloading docks, reception areas, human resources and warehouse machinery. The only resources that require additional specification on how they operate are personnel and warehouse machinery. The team can also be divided into three different functions and skill set: Reception, Storage and Unloading. These activities are distributed in shifts described as night, morning, normal and afternoon.

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. The response time to the peak between 10am and 12pm does not, however, necessarily translate into the highest processing time, but rather that the most concerning times are those between 5am and 7am, as the resource specifically working in unloading works the normal shift between 8am and 5pm. The task of unloading before 8am falls to the resources in Reception. Furthermore, this arrival concentration impacts not only its own processing time, but that of all subsequent arrivals as resources can be stretched thin.

The situation presented is tackled with a study into how possible changes in the reception system can have a positive impact in the selected KPIs of total time spent in the system by inbound pallets and the maximum amount of exceeding area necessary throughout the simulation time.

4. Data Collection and Model Construction

The data were initially studied with Excel, as it was the original format retrieved from the company's different systems 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.

4.1. Data Analysis

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. The tests performed as goodness-of-fit statistics were the Kolmogorov-Smirnov, Cramér-von Mises, Anderson-Darling and the chi-squared test, and the tests performed as goodness-of-fit criteria were Akaike's Information Criteria and the

Bayesian Information Criteria.
It is important to note that, for arrivals, a weekly distribution table was constructed with averages of arrivals within 3 hour intervals, given specificities of the software and a more accurate depiction of trends in different weekdays. The distribution is present in Table 1.

Table 1: Weekly average distribution of arrivals

Interval	Mon	Tue	Wed	Thu	Fri
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

The remaining activities followed distributions best fitted to them, with a division made between trucks and vans, as the time and resource efforts are entirely different. The distributions are as follows: time effort going into unloading trucks and vans, the quantity of pallets resulting from unloading of both vehicles (given their different capacities), the time effort going into electronic reception for each pallet and time effort going into storage for each pallet. All statistical distributions are found below.

- Unloading Time
  - Lognormal Unloading Truck Distribution $\mu = 2.706$, $\sigma = 0.925$
  - Exponential Unloading Van Distribution $\lambda = 0.172$
- Unloading Quantity
  - Exponential Truck Quantity Distribution $\lambda = 0.037$
  - Geometrical Van Quantity Distribution $p = 0.310$
- Electronic Reception Time
  - Exponential Reception Time Distribution $\alpha = k = 5.983$ $\beta = \frac{1}{k} = 1.341$
- Storage Time
  - Lognormal Storage Time Distribution $\mu = 1.161$ $\sigma = 0.925$

4.2. Model Construction
In Figure 3 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 in the warehouse. Area C refers to the electronic reception and area D refers to storage.

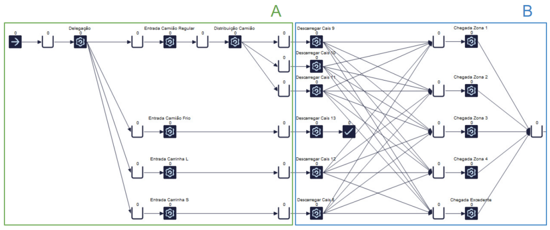

Figure 3: Diagram of area A and B in Simul8

In area A, 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. The 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.
In area B, the resources utilised are the unloading docks, the team member responsible, 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.

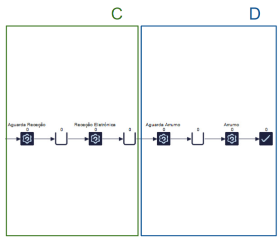

Figure 4: Diagram of area C and D in Simul8

In area C, 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. The actual work that goes into managing the reception area is quite complex and some aspects cannot be depicted as their consistency and nature can be unpredictable. For this reason, the resource availability was calculated to be around 65%.
Finally, in area D there are currently 2 trilateral machines shared with the co-packing and the relabelling teams, which was accounted for in the availability of the resources, as well as the charging period of 8 hous for every 8 hours of work.

4.3. Results Collection, Warm-up Period and Recommended Number of Runs

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.

As for the warm-up period, given the relevant KPIs of queue for electronic reception and storage, the decision was made with a comparison of a simple run of 4 weeks versus 16 weeks, which showed that the system is made quite stable at around the 2 week mark, with the maximum amount staying equal between the 4 and 16 week mark. For this reason, the 4 week mark was selected to ensure the system is stable enough in terms of accumulated WI.

Lastly, according to the "Trial Calculator", in order to ensure that the important KPIs are within the recommended precision interval, the minimum number of runs is 171. To remove any additional doubt, the considered number was 180 runs.

5. Results and Discussion

Scenario 0 aims to study the already existing system in terms of all KPIs considered. The following scenarios will be compared with scenario 0. 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.

Table 2 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, the average waiting time of the queue for the distribution of trucks increases slightly given a higher number of vehicles.

Table 2: Sensitivity analysis of increasing arrivals

KPIs	Regular	+1 daily	+2 daily	+3 daily
WI	904	944	984	1024
1	17.02	18.87	21.90	22.07
2	577.55	768.41	1061.56	1788.16
3	473.39	522.74	640.06	829.83
4	34.25	42.95	53.93	70.08
5	311.84	392.08	486.26	729.22
6	1088.39	1351.70	1754.75	2685.58

The mentioned KPIs are, from 1 to 3, the average queuing time for truck distribution, electronic reception and storage, all in minutes. The next KPIs are the reception area space utilization in percentage, the exceeding zone maximum utilization in number of WI and the total time spent in the system in minutes again.

The most dramatic increases were in the average waiting time of the queues that result from the electronic reception and storage. 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. 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.

The total time in system and reception area space utilization also increased and impacts a more relevant KPI in analysis, the exceeding zone. The number is already substantially high in the regular amount of arrivals, proving some inadequacy to respond to shifts in such predicted quantities.

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 flow management can impact the use of physical resources and improve the overall average time in the system. The alterations performed are firstly to the electronic reception, which has 8 team members distributed in 4 different shift arrangements, and secondly to storage, with 3 team members in 2 shifts. The relevant KPIs selected to evaluate the results of each situation were the average time spent in the system, and the necessity for exceeding area utilization.

5.2.1 Electronic Reception Shifts

A large number of situations can be simulated when combining all 8 resources in the 4 shifts available, however not all situations are of interest to be studied and therefore only situations that have been deemed relevant or interesting will be analysed. The different subscenarios' resource distribution will be as depicted in Table 3.

Table 3: Reception Resource Shifting Subscenarios

Sub scenario	Shifts			
	Night	Morning	Afternoon	Normal
A	1	2	2	3
B	2	2	2	2
C	1	3	2	2
D	1	2	3	2
E	2	3	2	1
F	2	2	3	1
G	2	1	2	3
H	2	2	1	3
I	2	3	1	2

All results are present in table 4.

Table 4: Simulation Results for all Subscenarios

	Reception Queuing	Total Time in System	Reception Area Util.	Exceeding Area Max.
A	577.55	1088.39	34.25	311.84
B	1394.39	1738.40	48.38	440.91
	+ 141%	+ 60%	+ 41%	+ 41%
C	668.87	1145.77	37.29	330.19
	+ 16%	+ 5%	+ 9%	+ 6%
D	643.48	1123.88	35.72	319.92
	+ 11%	+ 3%	+ 4%	+ 3%
E	494.32	968.07	31.18	292.31
	- 14%	- 11%	- 9%	- 6%
F	471.91	979.61	30.40	292.97
	- 18%	- 10%	- 11%	- 6%
G	423.65	942.16	29.20	27.79
	- 27%	- 13%	- 15%	- 8%
H	684.07	1120.09	35.05	318.43
	+ 18%	+ 3%	+ 2%	+ 2%
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, which can imply that a higher number of resources in the morning 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 F has a clear improvement margin in the reception queuing time, which directly impacts 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 F will be taken into account.

5.2.2 Storage Shifts

The storage team members work within the same shifting system and, once again, not all situations are of interest to be studied. Therefore only situations that still offer diverse shifts and do not compile all resources will be evaluated. The different subscenarios' resource distribution will be as depicted in Table 5.

Table 5: Storage Resource Shifting Subscenarios

Sub scenario	Shifts			
	Night	Morning	Afternoon	Normal
A	2	0	0	1
B	1	0	1	1
C	1	1	0	1
D	2	0	1	0
E	1	1	1	0
F	1	0	0	2
G	1	0	2	0

As previously mentioned, 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. There were, once again, clear improvements shown in some subscenarios. The results are present in Table 6. 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. Interestingly, the normal and 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 ate specific times.

Table 6: Simulation Results all Subscenarios

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

In further comment to subscenario F, 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 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.

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.

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. As discussed previously, 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. 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.

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%. 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. In results analysed by dock, there were substantial differences identified, with special importance given to an increase of queuing time in dock 8 of 49.48%, dock 9 of 148.53% and in dock 13 of 64.77%. Other docks also suffered alterations, however in a smaller order of greatness. Despite seeming quite significant, these increases represent an increase of minutes, given that the previous average was around 5 minutes, with the new rounding 15 minutes. This is due to the fact that, in the current scenario, all waiting is done prior to being assigned a specific dock. The relevant results were, however, a decrease in total utilization of dock 10 and 11 by 69.54% and 76.14%, respectively. This is to be expected, given that a spreading of arrivals that significantly lowers the overlapping of trucks, coupled with a clear preference for unloading trucks in dock 9, results in a near obsolescence of both dock 10 and 11. This also results in a greater insignificance for the average queuing times obtained for dock 10 and 11, as there were very few instances of use. 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%.

5.3.2 Overall Impact

The results obtained 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 7.

Table 7: Simulation Results for Scenario 2

	Total Time in System	Reception Area Util.	Exceeding Area Max.
Current	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. 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.

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.

5.4. Discussion

From all the results, there are some takeaways worth mentioning. Firstly, pertaining to the electronic reception shifts. Despite most subscenarios showing no advantage, the 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.

As for the storage shifts, which always maintain a night shift schedule, there was once again a large number of subscenarios that 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.

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.

6. Conclusions

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 and 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.

There are some acknowledged weaknesses important to mention. 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, the arrival and departure of trucks, and the unloading, electronic reception and storage are all present in different systems. To add to the situation, unloading time stamps with input by hand were not accurately depicted and were, 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 study flaws, but also as improvement suggestions in terms of information management.

Lastly, in the perspective of Alloga-Logifarma, scenario 1 can be easily implemented and the veracity of the simulation can be attested for in a short amount of time. 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 in terms of strategic approaches, as well as financial, to understand the actual advantages this implementation can have.

References

[1] R. Uthayakumar and S. Priyan, "Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital," *Operations research for health care*, vol. 2, pp. 52–64, 2013.

[2] S. Priyan and R. Uthayakumar, "Optimal inventory management strategies for pharmaceutical company and hospital supply chain in a fuzzy–stochastic environment," *Operations research for health care*, vol. 3, pp. 177–190, 2014.

[3] M. Pidd, *Computer Simulation in Management Science*. John Wiley & Sons, Ltd, 5th ed., 2004.

[4] A. M. Law, *Simulation Modeling and Analysis*. 5th ed., 2015.

[5] E. Winsberg, "Simulated experiments: Methodology for a virtual world," *Philosophy of Science*, vol. 70, no. 1, pp. 105–125, 2003.

[6] K. Crombecq, E. Laermans, and T. Dhaene, "Efficient space-filling and non-collapsing sequential design strategies for simulation-based modeling," *European Journal of Operational Research*, vol. 214, pp. 683–696, 2011.

[7] D. Gorissen, K. Crombecq, W. Hendrickx, and T. Dhaene, "Lncs 4395 - adaptive distributed metamodeling," 2006.

[8] N. Ruiz, A. Giret, V. Botti, and V. Feria, "Agent-supported simulation environment for intelligent manufacturing and warehouse management systems," *International Journal of Production Research*, vol. 49, pp. 1469–1482, 3 2011.

[9] H. Nee and A. Yong, "Warehouse management system and business performance: Case study of a regional distribution centre," 2009.

[10] R. L. Daniels, J. L. Rummel, and R. Schantz, "A model for warehouse order picking," *Eur. J. Oper. Res.*, vol. 105, pp. 1–17, 1998.

[11] W. Yu and P. Egbelu, "Scheduling of inbound and outbound trucks in cross docking systems with temporary storage," *Eur. J. Oper. Res.*, vol. 184, pp. 377–396, 2008.

[12] Z. Miao, A. Lim, and H. Ma, "Truck dock assignment problem with operational time constraint within crossdocks," *Eur. J. Oper. Res.*, vol. 192, pp. 105–115, 2006.

[13] W. Han-klup and T. Samanchuen, "Design and simulation of outbound functions in warehouse operations with queueing theory," pp. 451–455, IEEE, 2021.