Restructuring of Logistics Processes: Case Study of Cross-Docking Operations at Warehouse AZ1 of Grupo Luís Simões

Maria Vacas de Carvalho Silva Pereira

Thesis to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisor: Prof. Rui Manuel Moura de Carvalho Oliveira

Examination Committee

Chairperson: Prof. Carlos António Bana e Costa
Supervisor: Prof. Rui Manuel Moura de Carvalho Oliveira
Member of the Committee: Prof. Amílcar José Martins Arantes

November 2016

Acknowledgements

First of all, my deepest thanks to my supervisor Prof. Rui Oliveira for his continuous and extremely generous support and guidance. Without his commitment this work would not have been accomplished.

I would also like to thank the Luís Simões Group for supporting my dissertation, in particular to António Fernandes for proposing this challenge, João do Vale for his availability and providing me with everything that I needed and the rest of the AZ1 workers who were ready to help whenever it was necessary.

Finally, I would like to thank to all my family and friends for all the support and encouragement, especially to my mother for her help and patience through all.

ABSTRACT

Organizations involved in supply chain management face increasing pressures to reduce inventories and lead-times and to improve global efficiency. Cross-docking operations are being increasingly adopted as part of a strategy to centralize inventories and to reduce the number of stock-keeping locations, a trend that requires flexible and well-coordinated flows of goods and information along the logistic chain.

The present Master Dissertation is intended to improve the efficiency of processes associated with cross-docking operations in a logistics center of a major logistic operator in Portugal. And, for that end, a simulation model of the operations that take place at the facility was developed with the purpose of testing and evaluating alternatives in managing cross-docking operations. These include, dock-door assignment, truck scheduling and temporary storage space allocation.

The present report comprises background information and a description of the case study, a literature review on cross-docking and other relevant subjects, a description of the model development and implementation, the experiments' results and the respective conclusions.

Results presented that the best scenario consisted in the combination of a temporary storage policy which minimizes the distance travelled within the facility, an exclusive service mode with alternated doors for loading and unloading with a preferential dock door assignment policy and a first-come-first-served truck scheduling method.

It is recommended, for the warehouse, taking into consideration the implementation of these three methods, as well as a truck scheduling policy that prioritizes trucks based on its content due to the advantages it may bring in specific situations. As for cross-docking operations in general, the same recommendations apply, with the exception of the methods for the dock door assignment that depend on the facility's characteristics and should be adapted accordingly.

KEYWORDS: Logistics, Cross-docking, Simulation model

RESUMO

As organizações envolvidas em gestão de cadeias de abastecimento têm sofrido uma crescente pressão para reduzir os inventários e os *lead-times* de modo a melhorar a eficiência global. Uma das estratégias que tem sido adotada com o objetivo de concentrar inventários e reduzir o número de locais de armazenamento é a adoção de operações de passagem de cais. No entanto esta tendência exige fluxos flexíveis e coordenados tanto de produtos como de informações ao longo de toda a cadeia logística.

A presente dissertação de mestrado tem como objetivo melhorar a eficiência dos processos associados com as operações de *cross-docking*, num centro de operações logísticas de um dos maiores operadores logísticos em Portugal. Para tal, foi desenvolvido um modelo de simulação das operações que ocorrem na instalação com a finalidade de testar e avaliar alternativas na gestão de operações de *cross-docking*. Estes incluem, alocação camião-porta, sequenciamento de camiões e políticas de armazenamento temporário.

O presente relatório inclui uma descrição do caso de estudo, uma revisão da literatura sobre *cross-docking* e outros temas relevantes, uma descrição do modelo desenvolvido e da respetiva implementação, os resultados das experiências e respetivas conclusões.

Os resultados revelaram que o melhor cenário consiste na combinação de uma política de armazenamento temporário que minimiza a distância percorrida dentro da instalação, um modo de serviço exclusivo com portas alternadas para carga e descarga com uma política de atribuição de portas preferencial e um método *first-come-first-served* de sequenciamento de camiões.

Recomenda-se, para o armazém, considerar a implementação destes três métodos, bem como uma política de sequenciamento de camiões que priorize os camiões com base no seu conteúdo devido as vantagens que pode trazer em situações específicas. Quanto às operações de cross-docking no geral, aplicam-se as mesmas recomendações, com a exceção dos métodos de alocação camião-porta que, por dependerem das características do armazém, devem ser adaptados em conformidade.

PALAVRAS-CHAVE: Logística, *Cross-docking*, Modelo de simulação

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List of Acronyms

AZ1 – Azambuja Warehouse

CLM - Council of Logistics Management

COL - Logistic Operation Centers

DES – Discrete Event Simulation

FCFS – First-Come-First-Served Policy

JIT – Just-In-Time

LS – Luís Simões

MIP – Mixed Integer Programming

PT – Primary Transport

QAP - Quadratic Assignment Problem

RFID – Radio Frequency Identification

VL – Visual Logic

WMS – Warehouse Management System

Chapter 1. Introduction

1.1. Problem Contextualization

In every supply chain, one goal is generally to shorten response times, which are a sum of production, handling and waiting times, and a major component to total costs reduction and customer service improvement. Companies nowadays are searching for distribution alternatives that enable reducing these times as well as minimizing costs and risks of warehousing. Cross-docking is one strategy drawing increasing attention in this matter.

Cross-docking consists in transferring goods directly from inbound to outbound trucks with minimum or no storage in between. The main objectives are to eliminate storage and corresponding handling costs and consolidate less-than-truckload into full-truckload shipments.

Implementing this kind of strategy requires a well synchronized working system, not only inside the cross-dock but also the information flow. If this is not the case, costs will be more than assumed, contrary to the objective of cross-docking.

It is in this context that the present work arises in collaboration with the logistic operator Luís Simões (LS). The challenge proposed by the company is to study cross-docking operations in the AZ1 warehouse and find alternative methodologies to optimize the general operation.

1.2. Objectives

The objective of the present work is to assess and restructure the logistics processes of a warehouse of the Luís Simões Group, AZ1. Based on the observation of the warehouse, discussions with the warehouse manager and the literature review, it was decided that this work would focus on the cross-docking operations, specifically the temporary storage policy, the dock door assignment and the truck scheduling problems. The aim is to enhance cross docking operations that occur in the evening and night shifts.

When adopting a cross-docking distribution strategy, the objective is that pallets enter and leave a facility at the same day. Which is not only a labor intensive operation but also requires an extremely coordinated warehouse. This fact, put together with the core business being logistics and transportation explains the importance that cross-docking operations and the respective costs represent to the company.

The work to be done consisted in developing a methodology that assesses the performance of various scenarios, varying the methods for the identified controllable variables, so that recommendations can be made to the company based on its results. With this objective, a simulation model, based on discrete event simulation (DES) was developed.

The final objective is to find alternative methods that enhance cross-docking operations at the AZ1 warehouse and in general.

1.3. Methodology and Structure of the Dissertation

To fulfill the objectives above mentioned, four stages were required:

- **Stage 1:** Characterization of the AZ1 warehouse
- **Stage 2:** Literature review and assessment of possible improvement alternatives
- **Stage 3:** Construction of the simulation model, collection and process of the data and validation of the model
- **Stage 4:** Analysis and discussion of the results, assessment of performance and final conclusions.

The present report is a result of executing these stages and is structured in the following way:

- **Chapter 1:** this chapter presents the problem being regarded and the context in which it arises, as well as master thesis dissertation objectives. Moreover, it presents the outline of this report and its structure.
- **Chapter 2:** in the second chapter the case sudy is presented, including a brief description of the company and a detailed description of the cross-dock, its caracteristics, processes and information systems. In the end, conclusions are made about the problem in hands and what direction should the study follow.
- **Chapter 3:** existing literature is reviewed, concluding with a summary of the findings on each of the relevant subjects.
- **Chapter 4:** in this chapter the development of the model is presented, including the conceptual model and the detailed description of the model.
- **Chapter 5:** application of the model to the case sudy, presentation of the results and respective conclusions.
- **Chapter 6:** in the last chapter conclusions are presented and futher sudy is proposed.

Chapter 2. CASE STUDY: LUÍS SIMÕES

The aim of this chapter is to provide some background information and to present the case study. Starting with a brief description of the company and followed by the description of the logistic center under study, its characteristics and processes. In the end, an analysis of the processes related to cross-docking is conducted and the respective conclusions are presented.

2.1. BRIEF DESCRIPTION OF THE COMPANY

Luís Simões is a major Portuguese logistics operator currently providing logistics services to companies primarily in Portugal and Spain. Their history began in 1948, when Fernando Luís Simões and his wife Delfina Rosa Soares, purchase their first truck in order to start their own business in transportation of horticultural products.

Between 1952 and 1960 they bought more trucks and diversified their services to the transportation of building materials and later, in the 60’s, to the transport of bulk grain and materials for the construction industry. In 1968, the company "Transportes Luís Simões, Lda." is legally established and five years later the couple hands over its management to their three sons Leonel, José Luís and Jorge.

In 1981 the "Transportes Luís Simões" opens its first branch in Porto and in the 2000s decade widens the logistics activity to Spain. (Grupo Luís Simões, 2010)

Currently, the Luís Simões Group consists in 10 legally independent companies, grouped into three areas of business: transportation, logistics and diversification, managing a fleet of about 2,000 vehicles, owned and subcontracted, equipped with Embedded Computers and GPS, 20 logistics operations’ centers (COL’s) and about 1 508 collaborators.

As it is shown in Figure 2.1, Luís Simões has six types of facilities, located all around the Iberian Peninsula, being the two head offices, represented in blue, located in Loures and Madrid. The remaining facilities are either cross-docking platforms, represented in yellow, Logistic Operations Centers, represented in light blue, Transport Operations Centers, represented in red, Technical Assistance Centers, represented in orange or Assurances, represented in green.

Figure 2.1. Luís Simões facilities (source: Grupo Luís Simões, 2016)

Luís Simões core business is transportation and integrated logistics, representing 90% of the turnover. The remaining 10% represent a variety of activities such as Technical and Rent-a-Cargo Services, Insurance brokers and Real Estate.

The Groups' total turnover in 2013 was over 208 million euros, increasing 1.1% compared to the previous year. In Figure 2.2 it is represented the evolution of the turnover since 2008 and the turnover by business area in Figure 2.3.

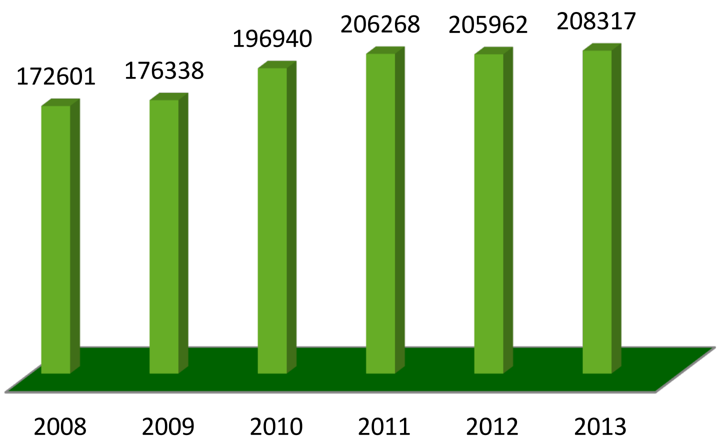

Figure 2.2. Evolution of Turnover (thousand euros) (source: Grupo Luís Simões, 2013)

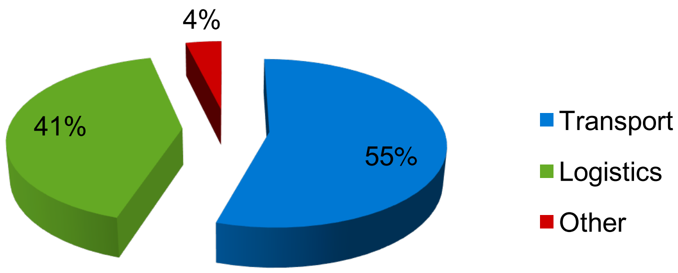

Figure 2.3. Turnover by Business Areas (million euros) (source: Grupo Luís Simões, 2013)

2.2. THE AZ1 WAREHOUSE

The AZ1 Warehouse is one of the two LS's warehouses located in Azambuja, Portugal. In addition to the traditional warehousing functions, it also operates as a cross-docking platform serving around 50 clients. Of the cross-dock products, 85% come from other Logistic Operation Centers (COL) of Luís Simões, while the other 15% are from different clients and are called Primary Transport (PT) as a way to internally differentiate them.

Other aspect to take into account about this warehouse is the strong presence of seasonality since during summer and Christmas it doubles or even triplicates its activity.

In this section, it is going to be described the warehouse, its characteristics and the processes related to cross-docking.

According to Ladier and Alpan (2015), the characteristics of a cross-dock are divided in three levels: strategic, tactical and operational, corresponding to the long, mid and short term decisions that have to be made about it.

2.2.1. Strategic Level

Strategic level characteristics are the ones which are fixed for operational planning purposes, which means the decisions were made before operations started. They are addressed by Van Belle et al. (2012) as "physical characteristics" and they correspond to shape, number of doors and internal transportation.

In the literature, shape is usually described as a letter according to where the doors are placed around the warehouse (I, L, U, T, H, E, X). The AZ1 case is a U-Shaped layout since all the doors are on a single side. The number of dock doors is 18 and one gate on the opposite side used to unload vehicles whose weight is less than 3.5 tons. Inside the warehouse, with total area of 20 000 m^2, material is carried by forklifts, pallet trucks and hydraulic claws for cartons.

2.2.2. Tactical Level

Tactical Level characteristics correspond to the mid-term decisions about how the cross-dock will work and are referred to as “operational characteristics” by Van Belle et al. (2012). These are the service mode, preemption, temporary storage and internal resource capacity.

Service mode can be exclusive, mixed or a combination of both. Exclusive is when the doors are pre-determined to be inbound or outbound and mixed when a truck can be docked at any door. Boysen & Fliedner (2010) and Ladier and Alpan (2015) consider another service mode in which each destination is allocated to each door called “given” or “destination exclusive” mode. In the case study the service mode is mixed, but, some doors have a destination associated due to its priority.

Preemption is the interruption of the loading or unloading of a truck and it is allowed at AZ1.

Cross-docking products are stored in areas between the doors and in front of the racks at ground level. Temporary storage capacity is not defined since it cannot be accurately measured but an estimative is presented in Table 2.1. and a general plant can be consulted at Appendix I to better understand the layout in question.

Table 2.1. Capacity (in pallets) of the ground space used to temporary store cross-docking products

Space Between Doors	Capacity (in pallets)
R8 and L9	12
1/2, 3/4, 5/6, 7/8, 9/10, 11/12, 12/13, 14/15, 15/16 and 17/18	2x12
R13, L14 and L17	3x12
R6, L7, R10 and R18	4x12
L11	7x12
4/5	9x12
Total	756
Space on Top of Structures	
ZA to ZC, ZE to ZG and ZP to QN	2x15
ZD	2x27
ZH to ZO	2x6
Total	738
Other Spaces	
Front of WC (3)	10
Structures (floor)	30x144
Front of Volume Area	10x15
Total	4500

R… - Space on the right of door

L… - Space on the left of door

…/… - Space between doors

AZ1 currently has twenty-four permanent workers and thirty-seven temporary that operate in nine different shifts covering twenty-four hours a day. There are seven to nine operators allocated exclusively to cross-docking operations, working in two different shifts, one from 4pm to 24pm and the other from 00am to 8am. As to equipment, there is an automatic pallet trucks available for each worker, from a total of 31 equipment in the warehouse (twenty-one automatic pallet trucks, six forklifts, three hydraulic claws and one frontal forklift).

2.2.3. Operational Level

As put by Belle et al. (2012), “flow characteristics” may not be controllable by the cross-dock manager since they might be imposed by stakeholders, namely clients or transportation providers (Ladier and Alpan, 2015). They concern truck arrival and departure times which are defined by time windows in the case study, and product interchangeability which is not a possibility since products cannot replace each other.

One of the aspects that the manager considers of major importance is the reduction of the intervals currently being used as time windows for arrival and departure of trucks. In this matter, it would be important to create some kind of discipline related to time windows, being one of the variables to be further developed in the dissertation.

2.2.4. Processes / Operational Mode

Cross-docking products usually require less handling than normal products that are meant to be stored since they should stay in the warehouse for short periods of time. These types of products, in the AZ1 warehouse, are handled mostly by pallet, which means that no picking is required, unless products in stock are included in the orders. Therefore, the main processes that cross-docking products undergo are reception, temporary storage and dispatch (with the respective preparation) and are represented in Figure 2.4. In the following paragraphs these operations will be described as they are conducted in the warehouse being studied.

The process starts with the arrival of trucks for unloading. Since they operate in a mixed service mode, as explained before, there are no dedicated doors so the team leader has to allocate each arriving truck to a dock door following typically a “first-in-first-served” criterion. In case of delay, he analyses the truck content and makes the decisions needed. For example, he can choose not to wait for a late delivery, send a truck without those products and later send a special delivery for those products. Despite the current efficiency of the method, other policies for dock door assignment could improve this operation, such as exclusive service mode or dedicated doors. Also, rules for truck sequencing should be implemented in order to reduce poor judgment and decisions. By approaching both dock door assignment and truck sequencing problems, poor decisions made by the team leader could be avoided, eliminating human error. Besides it would be time efficient if drivers knew before arriving where to park, and operators knew where to unload/load.

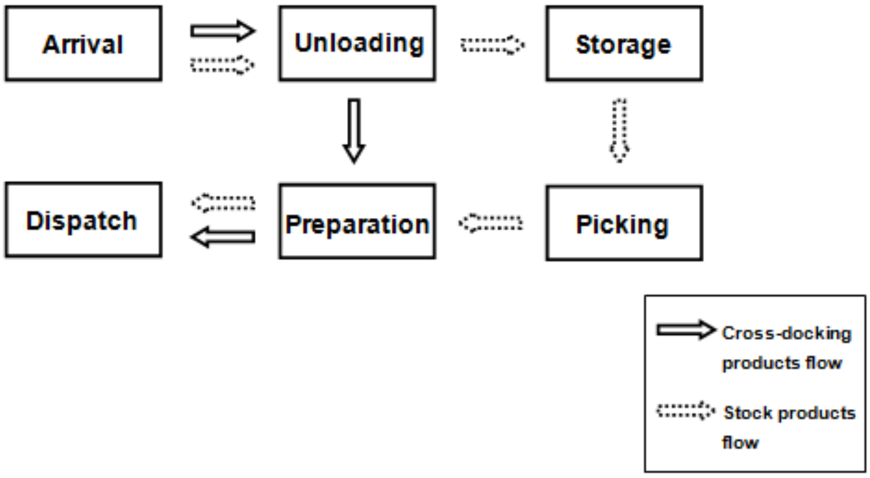

Figure 2.4. AZ1 Processes

After arrival, the team leader allocates the workers to unload the truck, indicating the corresponding dock door. The products are placed in the spaces between the doors and in front of the structures, as it was said before. If cross-docking products already have a designated truck to be loaded in, they are carried to the respective dispatch preparation area. One of the most influential factors in this operation is the layout design since the handling time depends on it. The current layout is not fixed for most products. Despite some clients have a designated area, most of the products unloaded are temporarily stored in the area most convenient to the worker which may not be the most efficient one. It becomes therefore important to study the impact that different types of layouts and space allocation rules would have, namely having areas allocated exclusively to destinations or clients.

In this operation, there is an important element, the tag. The tag is attached to each pallet or carton and contains the product's information, being crucial to the whole operation. When pallets are unloaded, the bar codes that are in the tags are scanned as well as the bar code of the space where it is going to be stored (there are also bar codes identifying each structure). This way, it is registered in the warehouse management system (WMS, described in the following section) where each truck was unloaded to. There are two types of cross-docking products: the ones arriving from other COL's and the ones arriving from clients (PT). In the first case, the tags of the pallets that arrive are according to the specifications so workers only need to read the bar codes with the manual reader to send the information to the WMS and confirm that everything was received. In the second case, an internal tag has to be printed and attached to each pallet. However, some clients are already using LS Net which is an application that allows clients to print their own tags according to LS specifications. Despite the problems currently occurring due to the tags, since these are mostly related to the information systems or the suppliers, they are not being included in the scope of the project.

Cross-docking products can be stored for more than one night. This temporary storage is made according to the information given to operators through the manual reader by the WMS at reception. Products that have to be stored for longer periods (more than one night) usually have a dedicated storage area. For the other goods, as it was said before, temporary storage is made in the space between dock doors and in front of the racks. Occasionally, when these areas are occupied, products are stored in the racks, at ground level.

The layout design has a major influence in this operation such as in the reception process, as it was mentioned before. It becomes essential for the global performance of the warehouse to find an integrating approach for the layout design. Which means to find a disciplined layout that takes into account all warehouse operations and the respective interrelationships.

The majority of cross-docking products do not require picking (there are only two cross-docking clients whose pallets have to be separated because each pallet contains more than one order). Picking is only necessary for products in storage that are sent together with cross-docking products.

The picking process is similar to the dispatch preparation process but based on volumes (cartons) instead of pallets.

As the dispatching operation is concerned, the team leader allocates one worker (normally one worker per truck except high-priority destinations or when there are free workers) to prepare the shipping load, handling to him the shipping list and indicating the respective dock door.

The operator then decides the sequence in which he is going to pick each product. When he reaches each location (indicated in the manual reader), he scans the bar code and a green light is shown indicating that it is the right product. Then the worker takes it to the area allocated to the shipping (normally the area next to the shipping door) and repeats the process until all products listed are picked. During this process, information may be received in the reader's monitor with more products to collect. This occurs because, although the shipping list is complete, pallets that are not prepared for shipping do not appear in the reader, only when they are ready.

When the list is complete and all the products are in the shipping area, a manual counting is conducted. It consists in checking each pallet or volume, one by one, and writing down in the shipping list. This is a labor intensive process.

The loading of the truck is done by the same workers or team that did the preparation, if the truck is priority (directed to other COL's). In the case of primary transport (not priority), drivers load the trucks themselves. Since each truck has floor space for 33 pallet, when they have to take more, workers have to group or stack up pallets, which requires a forklift and takes extra time to load. In the end, the truck is sealed and the WMS is updated.

Again, dock door allocation and truck sequencing methods could improve efficiency for the same reasons as the reception operation above mentioned. The manual counting is also a problem at dispatching but, since it involves information systems, it will not be further developed.

2.2.5. Software / Information System

Despite information systems are not in the scope of the dissertation, it is also important to understand their role in the warehouse management. In the AZ1 warehouse, the systems utilized are shown in Figure 2.5.

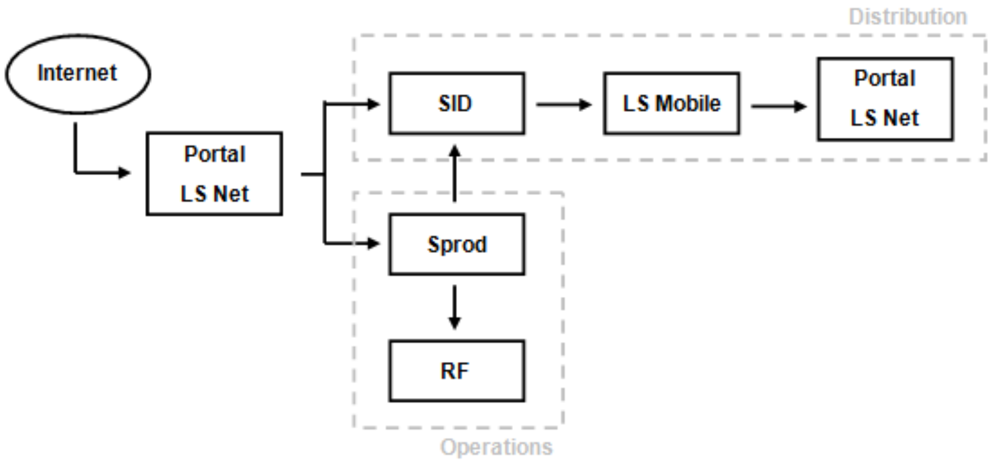

Figure 2.5. AZ1 Information Systems

Luís Simões uses the internet portal LS Net to communicate with clients. This platform allows each client to manage their relations with the company and provides real time reliable information. The flow of information within the company then follows two separate paths: SID and Sprod (WMS) softwares. Sprod is used in the operations, namely in the conference of goods that arrive to the warehouse. Then, the respective separation and dispatch are conducted using Radio Frequency Identification (RFID). During operations, workers can modify information if it is not correct in system. This alteration will change the information already available in SID software which is the system used in distribution. When all the information is available and correct on SID, it is sent to the LS Mobile platform so that drivers can access them and make the correspondent deliveries. When goods arrive to their destination, the respective information becomes available on LS Net and all documents are sent to the logistic operations center in Carregado so that they can be digitalized and filed.

2.3. Conclusions and Challenges

In this chapter the Cross-Docking Platform AZ1 was presented. Despite the typical warehouse services provided, the focus was on the operations related to cross-docking since they are the core object of study of the present work.

From the analysis of these processes, there are some evident controllable (or decision) variables that need further study. The first, is “time windows” since it would be important to impose smaller intervals for truck arrivals and departures. The second is the assignment of trucks to doors, namely analyzing the effect of different types of service modes (exclusive and destination exclusive). Relatively to the arrival of trucks, it would also be important to establish rules for truck sequencing so that it would not depend on the team leader and therefore avoid human misjudgment.

In order to reduce handling time and travel time inside the warehouse, new layouts should also be analyzed, for example, having areas allocated exclusively to destinations or clients.

The last variable identified in this preliminary analysis is the allocation of workers, being extremely important to find the optimal number of worker for each shift and the optimal repartition of shifts through the day.

Warehouse management systems could also be further studied due to the major influence they have in warehouse performance, but it will not be the focus of the dissertation.

Chapter 3. LITERATURE REVIEW

The objective of the present chapter is to analyze the existing literature in order to understand the problems identified in the case study previously described and try to find the respective proposed approaches. Therefore, the relevant subjects that were considered in the research were logistics, supply chain, cross-docking and warehouse simulation.

3.1. LOGISTICS AND SUPPLY CHAIN

3.1.1. Definition

In 1986, the Council of Logistics Management (CLM) defined logistics management as “the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods, and related information flow from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements.”

The term “supply chain management” only appeared later, and came into widespread use in the 1990s as a substitute for “logistics” and “operations management” with a more comprehensive meaning involving different sectors and entities. The main difference is that supply chain concerns the network of infrastructures including warehouses, factories, ports, transport and information systems that link suppliers and customers while logistics is the activity that develops within the supply chain. (Gaspar, 2014)

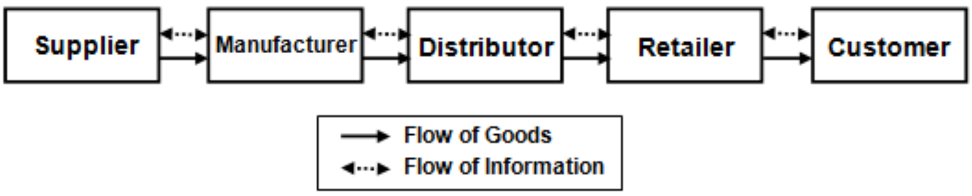

Figure 3.1. Basic Supply Chain (adapted from: Habib, 2011)

The Council of Supply Chain Management Professionals (former CLM) defines supply chain management as follows: "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, and finance and information technology."

In the XX century, companies focused on an efficient production and increasing profits but with globalization the competition increased and companies now focus on improving the costumer experience. This means that companies are increasingly pressured to have efficient and effective supply chain management since it can provide a competitive advantage, for example by reducing overall costs or reducing lead times making the products readily available.

3.1.2. Costs

"Logistics costs have been a major focus for all manufacturing and distribution firms for the past decade" (Bartholdi & Gue, 2000). Companies are facing increasing pressures to reduce inventories and lead-times and to improve global efficiency.

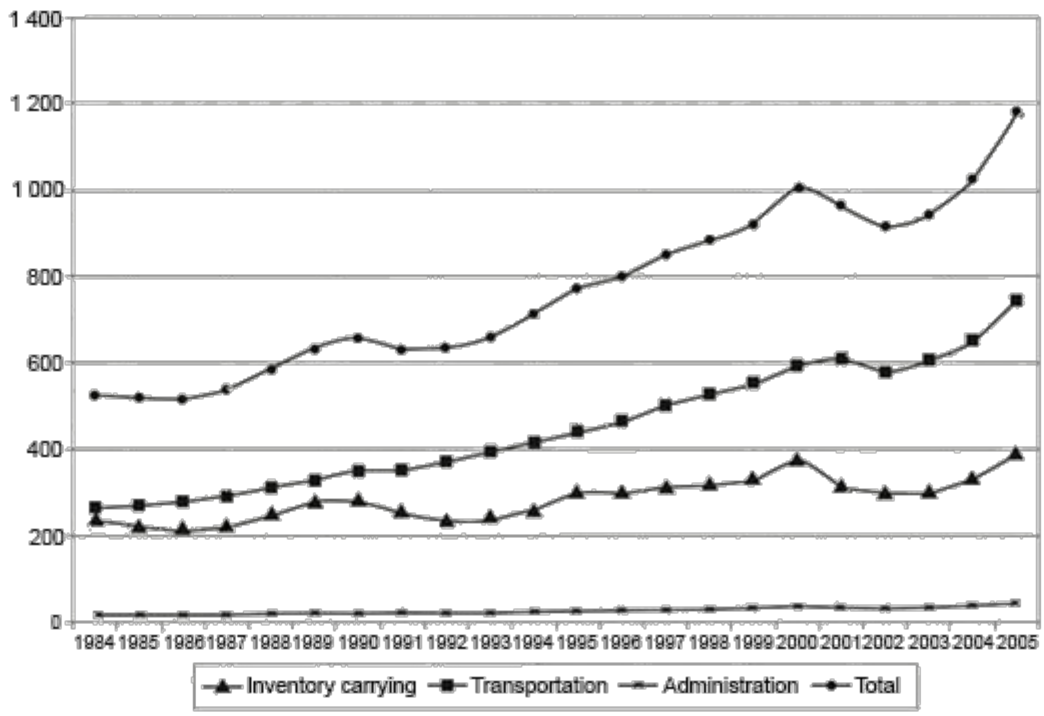

Figure 3.2. Total U.S. Logistics Costs Between 1984 and 2005 (adapted from: Simchi-Levi, et al., 2008)

As Figure 3.2 shows, logistics costs can be divided in three categories: inventory (including warehousing), transportations and administration costs, being transportation costs the more influent part.

"Cross-docking however is an approach that eliminates the two most expensive handling operations: storage and order picking" (Belle, et al., 2012).

3.2. CROSS-DOCKING

"Cross-docking is a relatively new technique in supply chain operations that consists in transfer shipments directly from incoming to outgoing trucks without storage in between" (Shuib & Fatthi, 2012). The main objectives when implementing this kind of strategy are to reduce inventory and the respective handling costs, consolidate less-than-truckload shipments into full truckload and increase the service level and customer satisfaction namely by reducing lead times.

"Cross-docks are essentially transshipment facilities to which trucks arrive with goods that must be sorted, consolidated with other goods, and loaded onto outbound trucks. The end product of a cross-dock operation is a loaded container bound to its intermediary or terminal destination" (Luo & Noble, 2012).

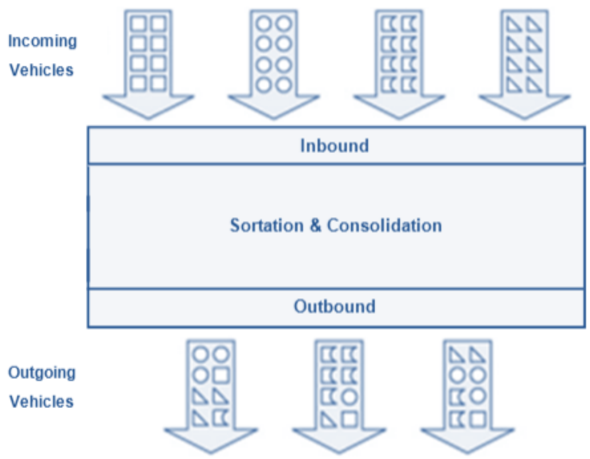

Figure 3.3. Cross-Docking Distribution Center

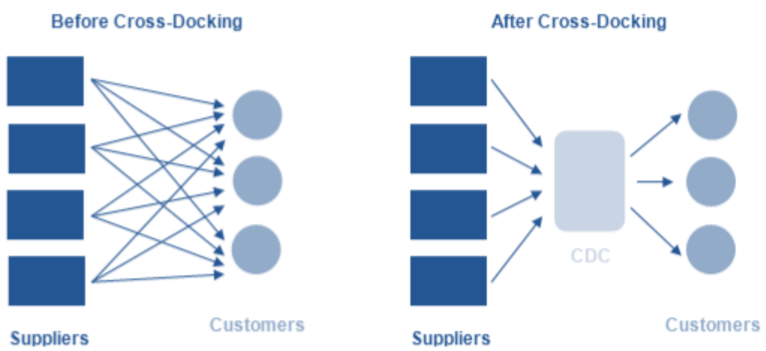

Figure 3.4. Implementation of Cross-Docking

"Success stories on cross docking, which resulted in considerable competitive advantages are reported for several industries with high proportions of distribution cost, such as retail chains (Wal

Mart), mailing companies (UPS), automobile manufacturers (Toyota) and less-than-truckload logistics providers.” (Stephan & Boysen, 2011)

According to the 2011 Cross-Docking Trends Report published by Saddle Creek Logistics Services, this practice has been growing among companies. From the 219 survey respondents, which were all professionals with backgrounds in logistics related areas, 68.5% currently use cross docking while only 52% gave the same answer in the 2008 report.

In the same report it is showed which are the benefits of implementing a cross-docking strategy, according to the respondents that currently cross-dock, as we can see in Table 1.

Table 3.1. Benefits of Cross-Docking (adapted from: Cross-Docking Trends Report 2011)

Greatest Benefits of Cross-Docking	
Improved Service Level	19.4%
Reduced Transportation Costs	14.3%
Consolidated Shipments to Destination	13.1%
Get Products to Market More Quickly	10.2%
Reduced Need for Warehouse Space	8.5%
Improved Inventory Management	8%
Savings from Reduced Inventory Carrying Costs	5.7%
Increased Demand for JIT Service	4.5%
Shipments/ Consignee Customization	4%
Reduced Labor Costs	4%
Other	8.3%

Results confirm that, as it was mentioned before, the main benefits of a cross-docking distribution strategy are to improve service level, to reduce transportation costs and to consolidate shipments.

Cross-docking can also be defined as “just-in-time (JIT) for distribution systems” as put by Napolitano (2000) and Gue (2001). JIT is a strategy used mainly to decrease waste by receiving goods only as they are needed. In fact, the increasing popularity of just-in-time methods is causing a continuous growth in cross-docking usage (Kulwiec, 2004). This is due to the fact that cross-docking can complement a JIT strategy in its objectives of reducing reducing inventory costs and increasing efficiency.

Augustina Lee and Piplani (2010) present a literature review about cross docking planning models. After classifying each cross docking problem as operational, tactical, or strategic according to the decision level associated, the authors collect and review about fifty papers related to mathematical models for cross docking planning. A further state of the art analysis is provided by Belle et al (2012). The authors classify each problem according to seven different categories identified in the literature and present several articles related to each one. Walha et al (2014) conduct a literature review based on a problem classification according to the type of uncertainty (external and internal uncertainty) associated with each problem. The authors consider three external uncertainties: truck arrival times; number of inbound trailers; freight flow/content of truck; and four internal: truck departure times; processing time; available resources and number of available trucks. Conclusions are that cross docking under uncertainty should be further studied, namely taking into account different types of uncertainty simultaneously.

Buijs et al. (2014) classify the existing cross-docking research based on a proposed framework that includes interdependencies between different cross-docking problems. They conclude that the majority of papers address isolated cross-docking problems and present a framework to support future research in cross-docking synchronization between local and network-wide cross-docking operations.

The most recent paper analyzed about cross docking current practices was developed by Ladier and Alpan (2015) and compares the literature with real world observations. The main objective is that the analysis of the differences between the state-of-the-art literature and current practices gives directions to future research. The authors state that the major gaps are:

- Service mode: lack of academic paper with mixed service mode;
- Preemption: is not used in real world systems and therefore, its benefits should be further studied;
- Storage and resource capacity: only 3% of the cross-docking literature take into account both constrains;
- Arrival and departure times: cross-docking models should include deadlines for the truck departure times;
- Performance measures: it is probably the major difference between literature and real life. It is going to be further analyzed in the section “Performance Measures”.

Despite the several cross-docking problems identified in these articles, there were four relevant to the present project that are going to be presented in the following sections: layout design, dock door assignment, truck scheduling and temporary storage. The remaining problems present in the literature that are not going to be further studied were relative to areas which are not in the scope of the project such as network planning and design and vehicle routing.

3.2.1. Layout Design

“The layout is interpreted as the dimension and shape of the cross-dock, as well as the dimension and shape of the internal cross-dock areas and their arrangement” (Belle, et al., 2012).

“Changing the layout of a terminal is a simple way to reduce labor costs without investing in new systems or worker training. Benefits accrue immediately, as workers spend less time traveling the moment they step onto the dock. And because it is expensive to handle freight, even a small percentage reduction in labor cost at the terminals can have a significant effect on profits.” ((Bartholdi & Gue, 2000).

Bartholdi and Gue (2004) conduct computational experiments with heuristics about how the shape of the cross-dock affects the labor cost of the warehouse. The results suggest that the best shape depends on the number of doors, being I-shape preferable for less than 150 doors, T for intermediate and X for more than 200. Heragu et al (2005) focus on the internal layout and develop a mathematical model and a heuristic algorithm to find the optimal product allocation to the functional areas in the warehouse and size of each area. The objective is to minimize annual handling and storage costs. Hauser and Chung (2006) use genetic algorithms to plan the arrangement of lanes in order to reduce the workload of the team members in the cross docking area.

Vis and Roodbergen (2008) use the minimum cost flow problem, solved through linear programming, to determine temporary storage locations for incoming freight. The algorithm’s objective is to minimize the total travel distance and can also be used during the design phase to determine the optimal number of parallel storage rows and their lengths. The same authors, in 2011 developed a dynamic methodology to select control policies and determine layout rules for cross-docking facilities. They present the advantages and disadvantages of three different layouts: fixed, category-based and flexible. The first, and most traditional, consists in fixing the layout of the storage area for a considerable time period. The second consists in distinguishing a limited number of different situations, based on the activity level within the facility and defining a layout for each one. Then the layout for the day is determined based on the type of situation expected. The third and last layout proposed consists in simply adapting the layout to the activity level expected for the day. The authors then present a case study in which they change the routing policy, the assignment policy and implement category-based layouts obtaining a total saving of 16% of the total travel distances (which translates in 75,000 Euro per year).

Gue and Kang (2001) introduce the concept of staging queues: queues where entities are incapable of moving forward autonomously. The authors compare two situations: one with only receiving (single-stage) and sorting activities and another including sorting (two-stage, see Figure 3.5). Through simulation, the results suggest that two-stage cross-docking systems suffer significantly lower throughput than an equivalent single-stage system.

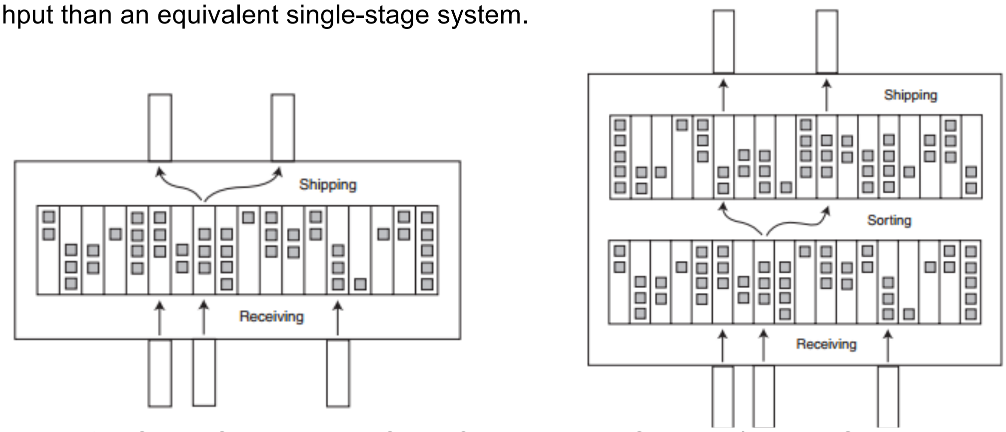

Figure 3.5. Single-Stage vs. Two-Stage Cross-Docking Systems (source: Gue and Kang, 2001)

3.2.2. Dock Door Assignment

The dock door assignment problem is one of the most studied cross-docking problems. It consists in finding the optimal allocation of inbound and outbound trucks to dock doors. A good assignment can increase the productivity of the cross-dock and can decrease the (handling) costs (Belle, et al., 2012).

The first study of this problem was presented by Tsui & Chang (1990) which developed a model to determine the assignment of receiving doors to the origins and shipping doors to the destinations. The authors' intent is to minimize the total travel distance of the forklifts and use a microcomputer tool based on bilinear programming. Later, Tsui and Chang (1992) extend their work by solving the same model using a branch-and-bound algorithm. In both works, it is assumed that all shipments go directly from inbound to outbound trucks and the designation of doors as inbound or outbound (designated strip or stack in the paper) doors is fixed.

Bermúdez and Cole (2001) adopt the model of Tsui and Chang (1990) to take into account that all doors can have assigned either an origin or a destination. They propose a genetic algorithm with the objective of minimizing the total travel distance. Cohen and Keren (2008) also extend the work of Tsui and Chang (1990), adapting it to take into account the capacity of outbound trucks and proposing a heuristic algorithm to solve it. The authors then compare the proposed heuristic with Tsui and Chang assignment heuristic. The results show average savings of about 5% in the total distance traveled.

In the paper written by Oh et al. (2006), doors (and respective destinations) are clustered into groups. The aim is to find an assignment of destinations to stack doors and a clustering of destinations in groups that minimizes the total travel distance. The authors present a non-linear programming model of the problem and propose a decomposition heuristic and a genetic algorithm to solve it. The results show a reduction of 13% and 9%, respectively, of the travel distance.

Bartholdi and Gue (2000) develop a heuristic algorithm with the objective of finding the optimal layout. They define layout as the specification of doors as strip or stack and the assignment of destinations to stack doors and assume that incoming trucks are unloaded according to a first-come-first-served (FCFS) policy. The authors also define travel time as a function of the type of freight, the used material handling system and congestion, besides the usual travel distance. Therefore, the model developed can take different types of material handling systems into account and uses models of different types of congestion. The objective is to minimize total labor costs which include both travel costs (based on travel time) and congestion costs (based on waiting times due to congestion). To conclude, the author provides guidelines for efficient layouts

Gue (1999) proposes a look-ahead algorithm. The author states that it enables the ability of cross-dock operators to allocate inbound trailers to strip doors based on the information about the destinations of their shipments (Gue, 1999).The author tests the solutions using simulation which indicate that it is possible to save 15–20% in labor costs compared to a FCFS policy.

Bozer and Carlo (2008) extend the work of Bartholdi and Gue (2000) and Gue (1999) by taking into account the performance effects of daily variations in freight flows. The authors consider a semi-permanent (static stack door assignment model) and a dynamic layout (model that uses detailed freight flow information to daily assign strip and stack doors). For the first, a linear assignment problem is solved to determine optimal inbound trailer-to-door assignment to each outbound door assignment. The procedure is repeated several times and the travel distances of each solution are summed, which allows to find the optimal outbound assignment. Then the linear assignment problem is solved again to determine the short-term assignment of inbound trucks. For the dynamic layout, the authors model the problem as a quadratic assignment problem (QAP) with rectilinear distances and present a MIP formulation but propose using simulated annealing to solve larger problems since it provides better results. The results also suggest that a dynamic layout provides better solutions than a semi-permanent.

Yu, Sharma, and Murty (2008) deal with a problem similar to Bozer and Carlo (2008). The authors first assume a semi-permanent layout and develop a scheduling policy for inbound trailers. Then they optimize the stack door assignment based on that policy. The inbound assignment is also conducted by operators in real time. The objective function of this problem is the expected value of the travel time with respect to several representative scenarios. A local search and a genetic algorithm are provided to solve the destination-door allocation problem (DDAP) and the results show that both can reduce the total travel time by about 20% compared with current practice.

Lim et al. (2006) and Miao, et al. (2009) construct a model taking into account the capacity of the cross dock and time window constraint. While in the first paper the aim is to minimize he travel distance, in the second the objective is to minimize the total cost (operation cost and penalty cost of unfulfilled demand). The problem is modeled as Integer Programming model and a Genetic Algorithm and a Tabu Search Algorithm are used to solve the model.

Stephan and Boysen (2011b) compare two dock door assignment policies: exclusive (pre-determined) and mixed (free). After modeling the destination assignment problem (DAP) and systematically varying different layout characteristics and thus generating thousands of different test instances, these DAP-instances are solved by a heuristic simulated annealing procedure for both layout-policies. The results show that an exclusive mode with doors on opposite sides of the cross dock is less efficient in most cases, except when information about inbound loads is lacking.

The works of Chmielewski, Naujoks, Janas, and Clausen (2009) and Luo and Noble (2012) combine the dock door assignment problem with cross-dock scheduling. In the first paper, the objective is to assign stack door to destinations and determine a schedule for the inbound trucks. The authors take into account internal capacity limits while trying to minimize the total travel distance and the waiting time for inbound trailers. The problem is modeled as a time-discrete, multicommodity flow problem with side constraints and solved using two algorithms: decomposition-and-column-generation approach and an evolutionary algorithm. Luo and Noble (2012), apart from assigning strip doors to origins and stack doors to destinations, determine the departure times for outbound trailers. The objective is to develop a model that optimizes the trade-off between outgoing truck cube utilization and load dwell time in the cross-dock. The authors assume that the arrival time distribution for inbound trailers is known and inbound trailers are served directly at the strip door pre-determined to their origin. The chosen solving methodologies were the LINGO solver and a genetic algorithm (for larger problems). Based on the results, the authors recall the importance of considering the overall logistics system as a whole and not only the cross-dock distribution center since it is concluded that cargo consolidation operations are affected by many factors such as flow profile, arrival time, and available time (that may not depend solely on the cross-dock).

3.2.3. Truck Scheduling

The dock door assignment problem previously studied does not take into account temporal constrains or the possibility of assigning multiple trucks to the same door sequentially. To include these factors it is now presented a review on the truck scheduling problem which deals with the decision on the succession of trucks processing at the dock doors of a cross-dock.

Since all of the articles described in this section have the same objective (to find the optimal truck sequence for loading and/or unloading) a table was constructed to better understand the existing literature about this subject. Table 3.2 represents the characteristics of each model synthesized, containing the following information:

- Inbound (In.): Y if the objective is to determine the inbound schedule, N if it isn´t.
- Outbound (Out.): Y if the objective is to determine the outbound schedule, N if it isn´t.
- Number of Dock Doors (NDD): Not defined (nd) if it is a decision variable
- Staging Capacity (SC): Infinite (Inf) when there are no capacity constraints, limited (Lim) when there is limited storage space or none when there is no storage.
- Service Mode (SM): exclusive (Exc), mixed (Mix) or a combination of both (Comb). Exclusive when the doors are pre-determined to be inbound or outbound and mixed when a truck can be docked at any door.

From the analysis of Table 3.2, it can be concluded that there is a wide variety of models developed to solve the truck scheduling problem, being probably the most studied of all cross-docking problems. However, most models are over simplified. For example, there are only two studies on scheduling inbound and outbound trucks with multiple dock doors under a mixed service mode (Miao et al. (2009) and Shakeri et al. (2012)) which is a common problem in real world. It can also be observed that most of the studies use heuristics and meta-heuristics approaches to minimize the length of the planning horizon (makespan).

Table 3.2. Truck Scheduling Problem

	In.	Out.	NDD	SC	SM	Performance Measures	Solving Methodology
(Arabani, et al., 2010)	Y	Y	2	Inf	Exc	Earliness and tardiness	Meta-heuristics
(Arabani, et al., 2012)	Y	Y	2	Inf	Exc	Makespan and total lateness of outbound trucks	Meta-heuristics (Genetic Algorithm)
(Arabani, et al., 2011a)	Y	Y	2	Inf	Exc	Makespan	Meta-heuristics (Genetic Algorithm, Tabu Search, Particle Swarm Optimization, Ant Colony Optimization and Differential Equations)
(Arabani, et al., 2011b)	Y	Y	2	Inf	Exc	Makespan and lateness	Meta-heuristics (Genetic Algorithm and Evolutionary Algorithm)
(Boysen, et al., 2010)	Y	Y	2	Inf	Exc	Makespan	Dynamic Programming
(Forouharfard & Zandieh, 2010)	Y	Y	2	Inf	Exc	Temporary storage	Imperialistic Competitive Algorithm
(Larbi, et al., 2011)	Y	Y	2	Inf	Exc	handling and truck replacement costs	Polynomial Time Algorithm Heuristics
(Liao, et al., 2012)	Y	Y	2	Inf	Exc	Makespan	Meta-heuristics (Evolutionary Algorithm)
(Liao, et al., 2013)	Y	N	nd	Inf	Exc	Tardiness	Meta-heuristics
(Vahdani & Zandieh, 2010)	Y	Y	2	Inf	Exc	Makespan	Meta-heuristics (Genetic Algorithm, Tabu Search, Simulated Annealing, Expectation–Maximization Algorithm and Variable neighborhood search)
(Yu & Egbelu, 2008)	Y	Y	2	Inf	Exc	Makespan	Heuristic
(Vahdani, et al., 2010)	Y	Y	2	None	Exc	Makespan	Meta-heuristics (Genetic Algorithm and Expectation–Maximization Algorithm)
(Chen & Lee, 2009)	Y	Y	2	Inf	Exc	Makespan	Polynomial Approximation and Branch-and-Bound Algorithms
(Briskorn, et al., 2010)	Y	Y	1	Inf	Mix	Makespan and tardiness	Model formulation only (not solved)*

Table 3.3. Truck Scheduling Problem (Cont.)

	In.	Out.	NDD	SC	SM	Performance Measures	Solving Methodology
(Alpan, et al., 2011)	N	Y	nd	Inf/ Lim	Exc	Handling costs Truck replacement cost	Heuristics
(Boysen & Fliedner, 2010)	Y	N	nd	Inf	Exc	Delayed shipments	Model formulation only (not solved)
(Boysen, et al., 2013)	Y	N	nd	None	Exc	Profit	Heuristics (decomposition and Simulated Annealing)
(Rosales, et al., 2009)	Y	N	nd		Exc	Total cost	CPLEX
(McWilliams, 2009b)	Y	N	nd	None	Exc	Makespan	Dynamic Load-Balancing Algorithm
(McWilliams, 2010)	Y	N	nd	None	Exc	Makespan	Local search and Simulated annealing
(McWilliams, et al., 2008)	Y	N	nd	Inf	Exc	Makespan	Simulation with Genetic Algorithm
(McWilliams & McBride, 2012)	Y	N	nd	None	Exc	Makespan	Beam search scheduling heuristic
(McWilliams, 2009a)	Y	N	nd	None	Exc	Workload	Genetic Algorithm
(Wang & Regan, 2008)	Y	N	8/12/16	Inf	Exc	Makespan Travel Time Throughput	Simulation
(Miao, et al., 2009)	Y	Y	nd	Lim	Mix	Operational cost Unfulfilled shipments	CPLEX Meta-heuristics (Tabu Search and Genetic Algorithm)
(Chen & Song, 2009)	Y	Y	nd	none	Exc	Makespan	CPLEX and Heuristics
(Boysen, 2010)	Y	Y	nd	None	Exc	Makespan Tardiness	Exact (Dynamic Programming) Heuristic (Simulated Annealing)
(Belle, et al., 2013)	Y	Y	nd	Inf	Exc	Tardiness	Tabu Search
(Shakeri a, et al., 2012)	Y	Y	nd	Inf	Mix	Makespan	Two-phase Heuristic Algorithm
(Ley & Elfayoumy, 2007)	Y	Y	nd	Inf	Exc	Unloading and loading times	Genetic Algorithm

*the objective is to find the complexity of each model.

Based on the articles above mentioned, there are four policies that can be adopted to schedule incoming trucks:

- First-come-first-served (FCFS): consists in the traditional method of allocating truck by order of arrival.
- Look-ahead: an algorithm developed by Gue (1999) that consists in assigning each arriving trailer to the door that minimizes the workers travel distance. This implies that the content (and respective destination) of each truck is previously known, as well as the dock door assigned to the outgoing truck correspondent to that each destination. The study shows that this method can reduce labor costs due to travel by 15–20% compared to a first-come–first-served.
- Minimum processing total time: proposed by Wang & Regan (2008), this policy consists in minimizing the sum of pallets travel time between receiving doors and shipping doors, wait time at receiving doors, and wait time at shipping doors, wich the authors call “total processing time”. It also requires full information about the incoming trailers content.
- Minimum total transfer time: it is similar to the previous but also considers the wait time in the waiting trailer line.

In their paper, Wang and Regan (2008) compare these four policies and results show no differences when the trailer arrivals are sparse. However, a look-ahead schedule has advantage in most cases.

Note that these policies only solve the problem of assigning arriving trucks to receiving doors, revealing the lack of literature on assigning outgoing trucks to shipping doors or using a mixed service mode.

3.2.4. Temporary Storage

In a previous section, it was discussed the layout of a cross-dock. Despite some authors mention the internal layout, the focus was on the facility design. In this section it will be discussed the operational decision about where to temporary store cross-docking products.

“Although the idea of cross-docking is to unload products from trucks and directly load the products into departing trucks, temporary storage is usually inevitable. Freight has to be staged because of the imperfect synchronization of inbound and outbound trucks and because the goods do not arrive in the sequence in which they must be loaded.” (Belle, et al., 2012)

Sandal (2005), in his Master’s Thesis, uses Discrete Event Simulation to compare two different staging approaches: Random Staging in a Single Queue (RS) and Zoned Staging (ZS). To do so, the author models three different cross-dock scenarios: “all staged”, “direct loading” and “simultaneous”. The first represents a situation in which all goods received are staged, the second, a situation where goods are directly transferred from inbound to outbound trucks and “simultaneous” a combination of both. To evaluate the performance of each scenario in each staging approach, the following metrics are collected: waiting time. sorting time, maximum area utilization and total operation time per outbound trailer. The results show that a zone staging strategy is more efficient to deal with loads that cannot be directly transferred. Despite “Direct Loading” shows better results in most performance indicators, it might not be feasible due to the inevitable need for staging at some point of the process.

Another study is performed by Vis and Roodbergen (2008). The objective is to determine temporary storage locations door incoming unit loads minimizing forklifts' total travel distance. The authors use Linear Programming to solve the problem, modeling it as a minimum cost problem. The proposed algorithm can be used multiple times in order to use each storage location more than once a day. The authors then compare their approach with ''the nearest location first heuristic'' which consists in the situation where employees select storage locations themselves. After the model was applied to different layouts and for situations where loading incurs a higher time pressure than unloading. Experiments show that effectiveness can improve up to 40%.

Werners and Wulfing (2010) later developed a MILP model with the objective of trying to minimize the travel distances between the endpoints and dock doors by layout modifications. The model determines where the freight has to be temporary stored (in which endpoint) and at which dock door the outbound trucks have to be assigned. The problem is solved with a hierarchical decomposition approach and adaptations are made to deal with data uncertainties and find a robust solution. The results show a reduction of 37 (deterministic solution) to 39% (robust solution) in the total travel distance compared with the current situation.

3.2.5. Performance Measures

"The effectiveness of cross-docking can be measured in a variety of ways— freight turn time, cube or weight efficiency, order date to delivery date, etc.," says Saddle Creek's Patterson, in Saddle Creek Logistics Services (2011). "In identifying possible metrics, however, you first must have a solid understanding of why your company is cross-docking. Is it speed to market? Transportation savings? Customer service? Once you've determined your objectives, it's easier to find meaningful forms of measurement." (Saddle Creek Logistics Services 2011).

Ladier & Alpan (2015) , as mentioned before, compared current cross-docking practices with the literature. One of the aspects studied in their paper was performance measures. Results show that the most used metrics in the literature were makespan and distance traveled while respondents consider that the most important measure is the number of hours worked by emplooyes. The authors state that travel distance is a managerial concern but data is not always accessible and does not reflet the number of workers needed. Makespan is not considered as relevant because the end of the day depends on departuture times which may not be flexible. Table 3.3 shows the study outcome.

A brief analysis of the performance measures identified in the literature reviewed in the present chapter (shown in Table 3.4) shows similar results to Ladier & Alpan (2015). The complete table showing all performance measures can be consulted in Appendix III, but the results confirm the findings of the previously mentioned work: the metrics most used are, by decreasing order, makespan, total travel distance and total tardiness of outgoing shipments.

Table 3.4. Performance Measures

Performance Measures	Literature (%)	Industry (%)
Inventory Level	12	13
Working Hours	2	75
Distance Traveled	26	0
Congestion	3	38
Total Product Stay Time	5	0
Number of Touches	2	25
Truck Process Time Deviation	17	13
Loading Time	6	0
Unloading Time	7	13
Door Utilization	4	25
Products Not Loaded	5	13
Makespan	45	25
Preemption Costs	6	0
Balance Workload	2	0

Table 3.5. Performance Measures II

Performance Measure	Makespan	Travel Time	Travel Distance	Handling & Storage Costs	Throughput	Congestion	Workload	Total Operational Costs	Operational Performance	Truck Utilization	Staging Time	Tardiness	Profit	Staging Space Utilization	Transportation effort
%	38	8	21	6	4	2	6	6	2	2	4	17	2	2	2

It was also noticed that different performance measures are more used to solve different cross docking problems. For example, most of the articles that use "makespan" were relative to truck scheduling while "travel distance" was found mostly on articles about the dock door assignment problem.

3.3. Simulation

"Simulation is a general technique most widely used for warehouse performance evaluation in the academic literature as well as in practice" (Gu, et al., 2010). "The main reason is the fact that other modeling approaches are very expensive to perform or infeasible due to other real environment" (Sandal, 2005).

Some of the papers above mentioned use simulation (e.g. Gue & Kang (2001), Sandal (2005) and Wang & Regan (2008)) to deal with the respective problems. In this section, a brief literature review is conducted with focus on cross-docking simulation in order to better understand this technique, its advantages and how to use it.

“Simulation allows to compare alternative cross-dock layouts or can be used to test various dock door assignment strategies, and this for one or more selected performance metrics.” (Belle, et al., 2012).

Roher (1995) emphasizes the importance of simulation in cross-docking. The author determines optimal hardware configuration and software control, stating that “simulation is required to determine whether all the proposed equipment will function together properly” and that it “is the next best method of giving confidence that the proposed system will meet a company’s requirements”. In this work there are also important guidelines on how to model a cross-docking facility.

Magableh & Rossetti (2005) developed a simulation model of a generic cross-docking facility. The objective is to access the operational risks associated with individual cross-docking facilities within a company’s distribution network under a dynamic environment. The authors sate that the model can be adapted to model other cross-docking facilities and used, for instance, to analyze the effect of an increased demand or to compare the performance of different dispatching rules.

Liu & Takakuwa (2009) apply a procedure that includes simulation and integer programming to a cross-docking facility in order to optimize personnel planning. In this paper, each step of developing a cross-docking simulation model is explained in detail. The authors conclude that the proposed procedures are efficient and effective in finding the optimal man-hour requirement for operating activities.

Since cross-docking simulation is an area not much studied, the search was extended to warehouse simulation, more specifically warehouse operations simulation.

Petersen & Aase (2004), Gagliardi, et al. (2007) and Faria (2015) use discrete event simulation to improve the efficiency of picking operation. Despite this kind of operations is not included in the scope of the present project (since one of the objectives of cross-docking is to eliminate storage and picking), all works provide useful guidelines in how to develop a simulation model of a warehouse.

Petersen & Aase (2004) compare the effect of picking, storage and routing policies on total fulfillment time and conclude that batch picking has the largest impact of all policies. Regarding storage policies, results show that a class-based policy can significantly reduce total fulfillment time nearly as much as a more information intensive volume-based storage policy. Lastly, switching from traversal to optimal routing affects picker travel, but not as much as changing picking or storage policies.

In (Gagliardi, et al., 2007) the objective is to reduce the picker’s idle time caused by stock-outs at the shelves. The authors propose four storage space sharing rules simulated for eight working weeks. Results do not show dominance between the space allocation strategies tested.

In his master's thesis, Faria (2015) evaluates the performance of multiple scenarios varying storage assignment policies and routing methods in order to access and restructure the storage assignmet in the picking area and the order picking process. The author suggests, based on the simulation results, that a class-based storage assignment and a s-shape routing method would significantly improve warehouse performance and states that "methodical practices should always prevail over cunning actions", emphasizing the importance of implementing proven methods instead of in-the-moment decisions.

3.4. Summary

In this section, some conclusions are made based on the literature review and a synthesis of the solutions proposed for each one of the cross-docking problems found is presented. The objective is to have a clearer idea of the existing options relates with the problems that are the focus of this dissertation.

After a brief introduction about logistics and supply chain, a detailed study about cross-docking is conducted. Although the various benefits of a cross-docking distribution strategy already mentioned, its implementation has to be carefully planned and executed. The greatest challenges include the unpredictability in customer demand, the IT support systems and the changes in business dynamics (Saddle Creek Logistics Services, 2011).

Various problems were found in the existing literature about cross-docking. Since the majority is related to network design and facilities layout, and the focus is on operational issues, the problems identified were reduced to four which were relevant to the project: layout design, dock door assignment, truck scheduling and temporary storage.

Despite layout design may not be relevant since the warehouse is already built and the doors constructed, some of the articles mention internal layout which is important to this project. Three different layouts were identified:

- Fixed: fixing the layout of the storage area for a considerable time period
- Category-based: distinguish a limited number of different situations, based on the activity level within the facility and define a layout for each one. Then the layout for the day is determined based on the type of situation expected
- Flexible: adapt the layout to the activity level expected for the day.

The second cross-docking problem reviewed was the dock door assignment problem. In the existing literature, three methods are proposed:

- Exclusive service mode: having designated doors to inbound and outbound.
- Dedicated doors: each truck has its assigned door fixed
- Mixed: all doors serve all trucks

To complement the dock door assignment problem, there was a need to introduce not only time constrains but also the possibility of allocating more than one truck to each door. With this in mind, a review on the truck scheduling problem was conducted. The strategies found were:

- First-Come-First-Served (FCFS): consist in the traditional method of allocating truck by order of arrival.
- Look-ahead: an algorithm developed by Gue (1999) that consists in assigning each arriving trailer to the door that minimizes the workers travel distance. This implies that the content (and respective destination) of each truck is previously known, as well as the dock door assigned to the outgoing truck correspondent to that each destination. The study shows that this method can reduce labor costs due to travel by 15–20% compared to a first-come–first-served.
- Minimum processing total time: proposed by Wang & Regan (2008), this policy consists in minimizing the sum of pallets travel time between receiving doors and shipping doors, wait time at receiving doors, and wait time at shipping doors, wich the authors call "total processing time". It also requires full information about the incoming trailers content.
- Minimum total transfer time: similar to the previous, but also considers the wait time in the waiting trailer line.

The last problem approached was where to temporarily store cross-docking products. From the three articles found on this subject, authors suggest that goods can be:

- Stored on the areas near inbound doors, when unloaded,
- Stored on the areas near the respective outbound doors; or
- Directly transferred from inbound trucks to outbound trucks.

In addition, a study was performed about staging strategies by Sandal (2005), comparing Random Staging in a Single Queue and Zoned Staging. Results show that zone staging is more efficient.

3.5. Conclusions

With all the relevant cross-docking problems reviewed, it becomes important to access the performance measures used. Ladier & Alpan (2015), studied this issue and concluded that literature was different for real world: the most used metrics in the literature were makespan and distance traveled, while managers consider that the most important measure is the number of hours worked by emplooyes and congestion. Results from the articles analysed through this chapter confirm the authors' conclusions.

Despite heuristics and meta-heuristics are by far the most used methodologies, various papers demonstrated that simulation is a powerful and pragmatic tool for analyzing warehouse operations. Therefore, a section about warehouse simulation was included in the literature review. Six studies were analyzed and it is concluded that this method is both practical and powerful to access cross-docking operations allowing to test different methods and strategies without the risk of the possible costs of altering the real life system. It was also found to be efficient when there are a large number of controllable variables and no objective function.

Overall there is a need for an integrated approach that addresses the various aspects of cross-docking operations mentioned above as well as their interactions which determine the global system performance. The insufficient structuring of the problem regarding the objective function to be adopted, the diversity of performance measures and the lack of definition of trade-offs between conflicting measures/objectives, lead to a situation in which a predictive approach is more appropriate than normative models.

Chapter 4. Model Development

Simulation has proven to be a very useful technique for warehouse design and operational policies performance evaluation both in literature and in practice. Therefore, it was the methodology considered more adequate to this dissertation purposes.

In this chapter it is described the justification, development and specifics of the model developed.

4.1. Justification of the Adopted Methodology: Why Simulation?

When developing an academic work to optimize a real world system, authors create theories that have to be tested to be considered correct and valid (Faria, 2015). To test these theories it is almost never of the interest of stakeholders to change the real world system. It might even be impossible or have too much costs associated. Which means there is a necessity to "test alterations" without really making them. And one way of doing so is through simulation.

"It is understood by simulation the "imitation" of the functioning of a real system using a suitable representation of the system. With these representations, commonly known as models, the intent is to conduct trials (which is not possible or desirable to perform in the real system) in order to draw conclusions that can be applied in the real system." (Tavares, et al., 1996)

The main advantage of simulation is that it allows to test theories without incur in unnecessary costs or labor, and for this reason it has become a powerful tool in warehouse optimization.

Cross-docking operations in AZ1 are one case where real world experimentations are not acceptable. Not only due to the losses it may bring to the company, but also because, being a logistics operator, any changes in the current practice would have to be previously approved by all clients. So a decision was made of developing a simulation model since it allows a level of detail that analytic models do not. It is also a better tool to deal with random factors and facilitates decision making since it does not require a formal definition of constraints and objective function, which often serve as an obstacle to a good formulation of the problem.

4.1.1. Discrete Event Simulation

Recalling the objective of the dissertation, to assess and restructure cross-docking operations in AZ1, there is a need for a methodology that allows testing different scenarios, evaluating the chosen performance indicators of each one. To this end, the approach considered more appropriate was Discrete Event Simulation (DES).

Discrete event simulation consists in the modeling of continuous real-world processes with discrete events, dividing each activity and/or process into discrete parts to simplify the analysis. In a simplified perspective, the simulator can be considered as composed by three main components: a database, a list of events, and a simulation clock. “The database contains the list of orders to be processed and stores the system parameters. (…)The events list is a chronologically ordered list containing the time when each type of event will occur. Events list is sequentially examined and, each time an event is processed, future – either conditional or bounded – events are created and added to the event list. After executed an event, it is deleted from the list and the clock is advanced to the following event.” (Gagliardi, et al., 2007)

This sequence of events is performed on entities that can be of different types, such as costumers, documents, parts, phone calls or trucks. Entities can have associated attributes that will define the way they are handled in the system and can be altered through the process. Some events may require resources such as workers or equipment.

A basic DES model consists in a source which represents the arrival of temporary entities into the system, an operation with the respective queue which will simulate the real world operation, and a sink that represents entities leaving the system after being processed. Resources are required when the operation starts and released at the end, being represented as shown in Figure 4.1.

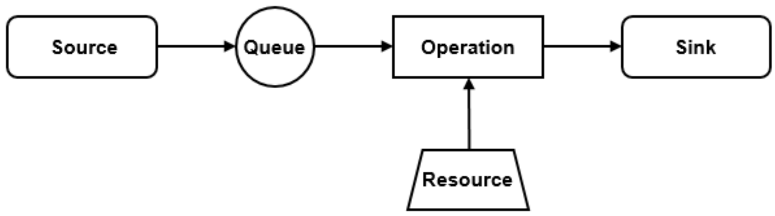

Figure 4.1. Basic Discrete Event Model with resources (adapted from: Faria, 2015)

One of the main objectives is to simplify the real world system, which leads to the disposal of unnecessary details such as exact geometry of entities or the geography of the modelled problem. This means, for example, that the model’s operations will be only defined by its duration and the alterations made to the entities’ attributes. Also, the model geography is not correlated to the real world.

After establishing the need for simulation in this research and explaining DES, there are presented the reasons for the choice of DES. Faria (2015) indicates three major factors in choosing the right method:

- The purposes of the research project – assess and restructure cross-docking operations.
- The specific properties of the real world phenomenon – a wide range of variables (controllable and uncontrollable), some of which with random behavior and multiple and complex interactions.
- The fitness of the method of modeling to achieve the desired outcomes (first factor) while keeping in line with the necessary properties (second factor).

Since cross-docking operations at AZ1 are easily described as a sequence of discrete processes, DES allows to assess its performance, in different scenarios, through the evaluation of the chosen performance indicators, being the best and natural choice for this research work.

4.1.2. SIMUL8

After considering different simulation software like AnyLogic and Arena, SIMUL8 was chosen. This program, developed by the SIMUL8 Corporation, uses dynamic discrete simulation to plan, design and optimize real-world system by modeling discrete entities at discrete times. The main reasons for the choice of SIMUL8 were its simplicity while fulfilling the requirements to the dissertation work development and also the familiarity of the author with the software.

Furthermore, SIMUL8 allows modeling real life constraints, capacities, failure rates, shift patterns, and other factors that may affect performance and efficiency. With these features, the computer model developed can be used to test real scenarios in a virtual environment.

The outputs consist in values and statistics of performance indicators chosen by the user, which provide concrete results and proofs on how the designed system will actually function. This allows, not only to compare different scenarios, but also to understand the direction that the experiments design should follow in order to optimize the real world system.

Figure 4.2. Basic SIMUL8 model

The basic components of a SIMUL8 model are:

- **Work Item** (Temporary Entity): objects that move through the system. They enter through **work entry points**, are processed in **work centers** (that may require **resources**), temporarily stay in **storage areas** if necessary, and leave through **work exit point**. These entities can have associated attributes that may change through the system, called "**labels**". Work items may be costumers, products, documents, ect…
- **Work Center** (Activity): represent the activities that the work items undergo. Can be "dummy" activities if necessary to model the real life system. Usually have a duration associated and make use of resources.
- **Work Entry Point:** objects that represent the entry of work items.
- **Queue**: objects where work items "wait". Normally queues are placed before activities since it may be necessary to wait for other objects (for example resources or other work items from other queues) to perform the activity.
- **Work Exit Point:** object that represents work items leaving the system.
- **Resource:** objects used to model workers and equipment when they are limited.

- **Route:** set of arrows that represent the sequence of activities.

After drawing the organization scheme on the screen using these elements, some parameters are set for each element. For example: arrival pattern, duration of activities, queues' maximum capacity, number of resources, production rates, and statistics of production equipment failures.

When there is need for detailed logic that is not possible to implement using only the above mentioned features of the software, SIMUL8 provides its own simulation language based on Visual Basic called Visual Logic (VL). VL allows the user to describe exactly how the simulation should behave using specific commands.

SIMUL8 also allows communication with other software such as Microsoft Access, Excel and Visio, and databases using SQL. For example, the support of XML permits working with external sources of data and exporting internal data.

4.2. Model Description

This chapter describes the simulation model developed. The complete model can be consulted in Appendix V.

4.2.1. Objectives

The purpose of the presented model is to assess the performance of different scenarios regarding the cross-docking operations in AZ1. The model will provide evidence in favor or against said premises in conducted tests, presented in the next chapter, validating theories and ultimately, supporting the conclusions of this dissertation.

4.2.2. Conceptual Model

"A system can be generally understood as a set of entities (...) that interact with a particular end (purpose)" (Tavares, et al., 1996)

Entities may be classified as permanent or temporary: permanent if they always stay in the system or temporary if they enter and leave the system through the simulation. In the proposed case, and given that the aim was to create a model that has as focus the interactions in the AZ1 warehouse, there were defined the following entities:

- **Pallets**: are temporary entities since their stay in the system is not constant. Pallets are the main objects of the model as they undergo all the main activities: <u>Unloading</u>, <u>Manual Conference</u>, <u>RFID Conference</u>, <u>Travel to</u>, <u>Travel from</u>, <u>RFID Conference II</u>, <u>Manual Conference II</u> and <u>Loading</u>. Arrivals are defined by an external XLS file containing real data provided by the company.

- **Trucks to load**: temporary entities involved in the Loading activity. Arrivals are defined by an external XLS file containing real data provided by the company..
- **Trucks to unload**: temporary entities involved in the Unloading activity. Arrivals are defined by an external XLS file containing real data provided by the company.
- **Operators**: are permanent entities, as they are always present in the system, and are defined as a resource to be used in Unloading, Manual Conference, RFID Conference, Travel to, Travel from, RFID Conference II, Manual Conference II and Loading.
- **Doors**: are permanent entities and resources used only in the Loading and Unloading activities.

The durations of the activities above mention (underlined) were defined based on data collected by the author. After the appropriate tests, all durations proved to follow normal distributions. A statistic description of the data is presented in Table 4.1.

Table 4.1. Normal Distributions' Tests for Each Activity

Activity		No Obs.	Min. (min)	Max. (min)	Parameters		Kolmogorov-Smirnov Test	P-value
					μ	σ		
Unloading		90	16	139	53.6	23.9	0.134	0.071
Manual Conference		18	8	296	102.7	69.3	0.126	0.920
RFID Conference		49	5	99	27.2	20.7	0.159	0.155
Loading	Operator	19	12	71	35.3	15.4	0.112	0.962
	Driver	17	53	335	139.3	74.4	0.267	0.150

*Loading can be performed by an operator from LS or the driver himself as explained before.

Since activities "Travel to" and "Travel from" represent the travel time within the facility, their duration will depend on the origin and destination of each displacement. A linear regression (Table 4.2, Table 4.3 and Figure 4.3) was performed with the available data and, based on the results, a table (Appendix VIII) was constructed containing the estimated travel time between each pair of door/storage space as a function the distance between the origin and destination locations.

Table 4.2. Descriptive statistics of the Linear Regression Variables

Variable	Observations	Minimum	Maximum	Mean	Standard Deviation
Y1 (m)	58	6.368	138.246	48.203	33.856
X1 (s)	58	20.000	221.000	68.603	47.681

Table 4.3. Correlation Matrix

Variables	X1	Y1
X1	1.000	0.809
Y1	0.809	1.000

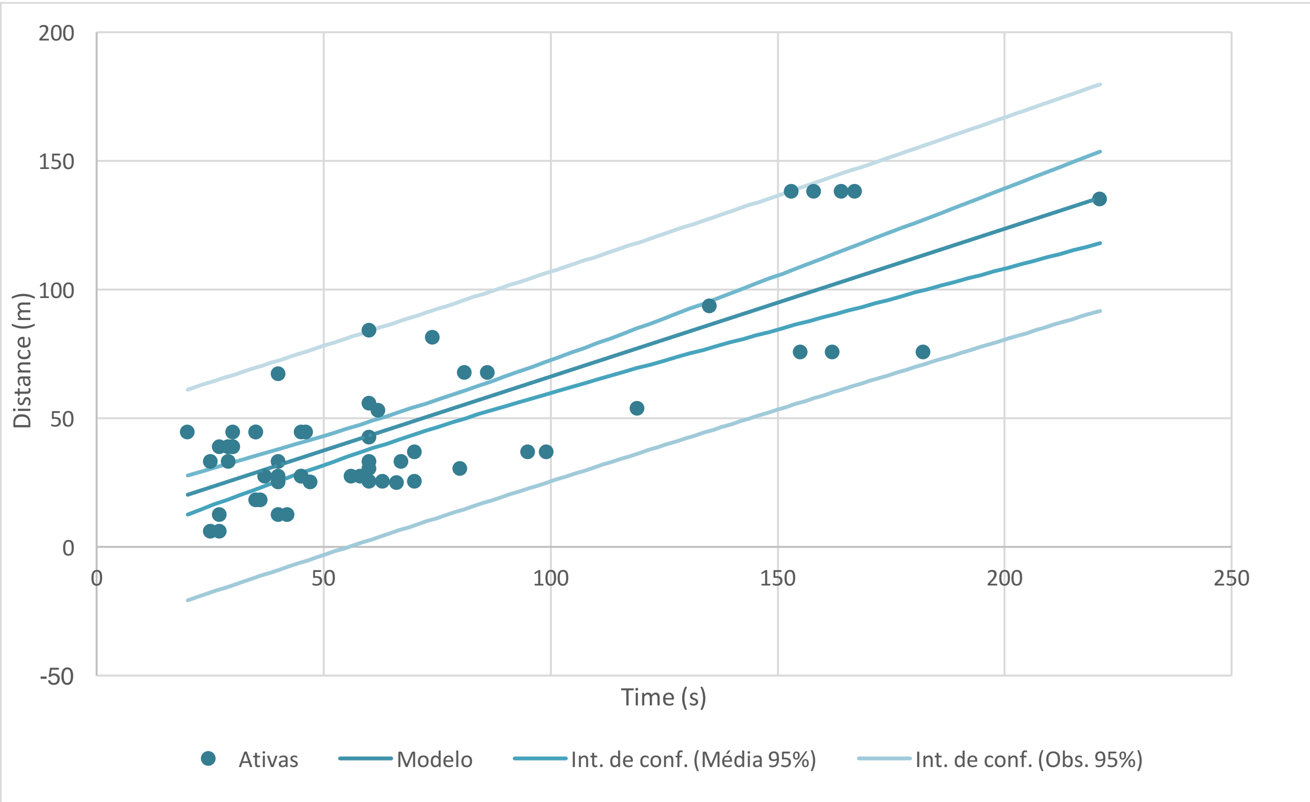

Figure 4.3. Y1 Variable Regression

Table 4.4. Model's Parameters

Source	Value	Standard Error	t	Pr > |t|	Lower Limit (95%)	Upper Limit (95%)
Intercept	8.94	4.647	1.893	0.064	-0.514	18.103
X1	0.574	0.056	10.299	< 0.0001	0.463	0.686

Although the intercept was not statistically significant (p = 0.064) for a 5% significance level (but significant for a 10% significance level), it was decided to include in the model due to better adjustment obtained by a higher value of adjusted R^2.

The equation of the estimated model is:

Model Equation: Y1 = 8.794+0.574*X1

Adjusted R^2 = 0.648

After the description of the relevant entities and shared activities, Life Cycle Diagrams were defined for each entity (Figures 4.4 to 4.8) as well as the Activity Cycle Diagram. The DCA uses three concepts presented above: entity, queue and activity. According to this perspective, it is possible to describe the path of an entity in the system (or its life cycle) through a series of active states (when an entity is involved in the development of activity) and passive states (when the entity waits for the materialization of conditions to start a new activity). To have this alternation between active and passive states sometimes you have to add fictitious queues. The Activity-Cycle Diagram is attached in Appendix IV.

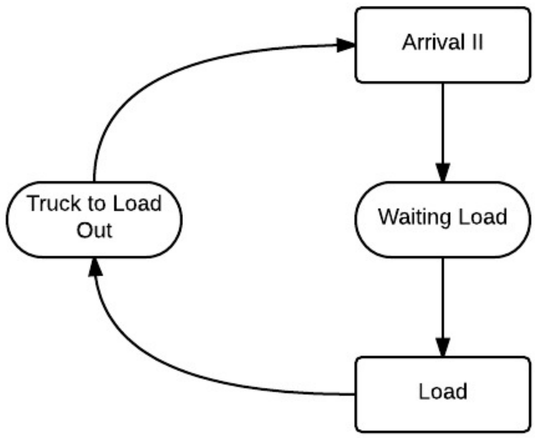

Figure 4.4. Trucks to Load Life-Cycle Diagram

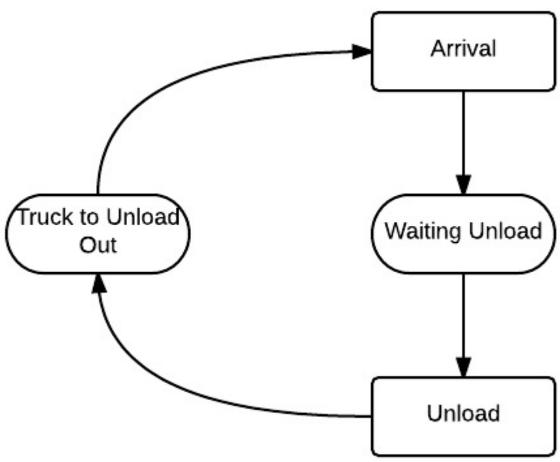

Figure 4.5. Trucks to Unload Life-Cycle Diagram

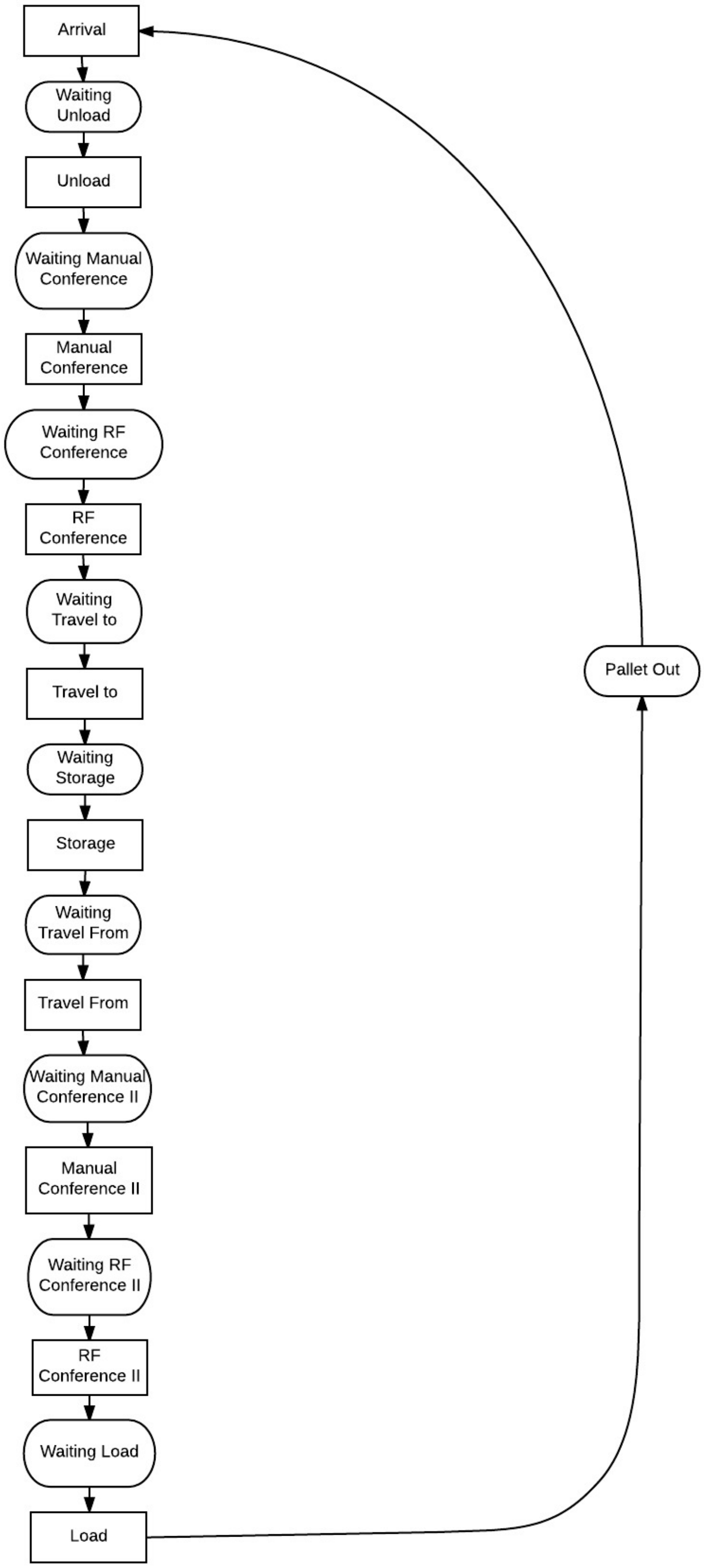

Figure 4.6. Pallets Life-Cycle Diagram

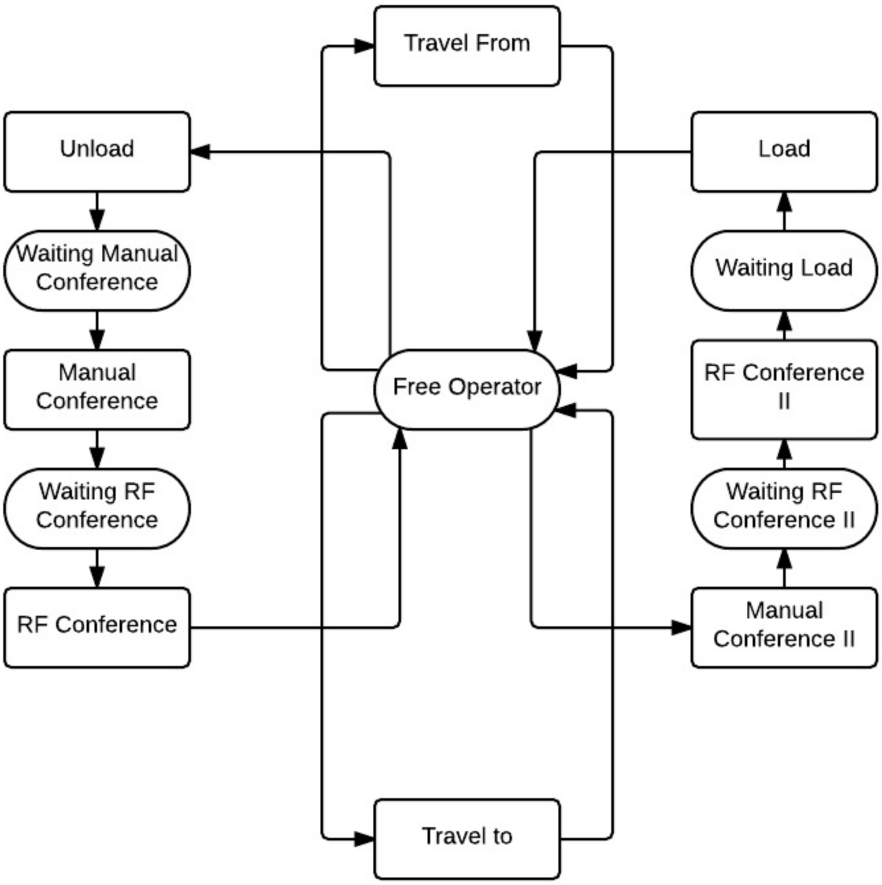

Figure 4.7. Workers Life-Cycle Diagram

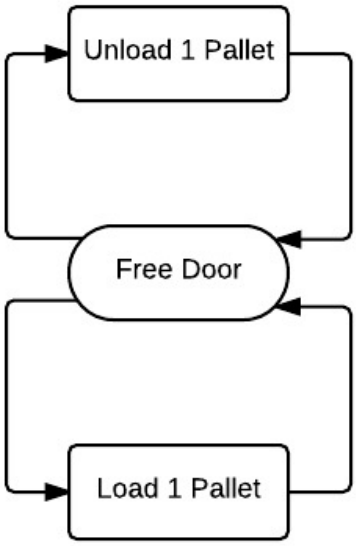

Figure 4.8. Doors Life-Cycle Diagram

4.2.3. Model Implementation

To model the problem in SIMUL8, the first step was to draw the Activity Cycle Diagram in the graphical interface using the available objects previously described. In the next sub-chapters, each part of the implemented model will be explained in detail, including the graphics, the inputs, the logic commands and Visual Logic used.

a. Arrival

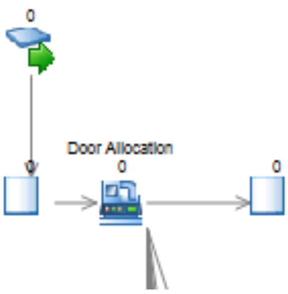

Figure 4.9. Pallet's Arrival in SIMLU8 Software

The arrival of pallets is represented by a "Start Point" which will receive information from a spread sheet (ssArrivals_1) imported from Excel. This spread sheet, which can be consulted in Appendix VII, contains eight columns (correspondent to the pallets' attributes):

- **Time:** time of arrival, in minutes.
- **Batch size:** it is required by the program to indicate the number of objects arriving, in this case it is set to one.
- **Pallet_Number:** number of the pallet in the truck.
- **Total_Pal:** total number of pallets in the truck.
- **Tournee_E_:** unique identifier of the truck in which the pallet arrives (origin).
- **Tournee_S_:** unique identifier of the truck in which the pallet will leave the facility (destination).
- **Entity_Type_:** since each line of the imported spread sheet represents a pallet, there is an extra line at the end of each set (load) that represents the temporary entity "truck to unload". "Entity_Type_" is set to "1" if the object is a pallet and "2" if it is the truck. This attribute will be necessary to count the time of each truck in the system.
- **Unload_:** attribute that will define the duration of the activity "Unloading". "U1" means it is a pallet and will have the normal duration of unloading a pallet, "U2" means that it is a truck and the duration will be null.
- **Door_1_:** attribute that indicates the door in which the pallet will be unloaded.
- **Door_2_:** attribute that indicates the door in which the pallet will be loaded.
- **Operator__:** attribute that defines if it is necessary an operator to load the pallet or not (as explained before in the case study chapter, only trucks form the company are loaded by

operators). The attribute is set to "O1" if it is and "O2" if it is not and will be used in the loading activity to define its duration and resources.

After the arrival, work items are sent to a "dummy" activity named "Door Allocation", with null duration that will determine to which door the object should go. The "Routing Out" feature of this activity will depend on the scenario, allowing to test different methods of the Dock Door Assignment Problem.

b. Unloading

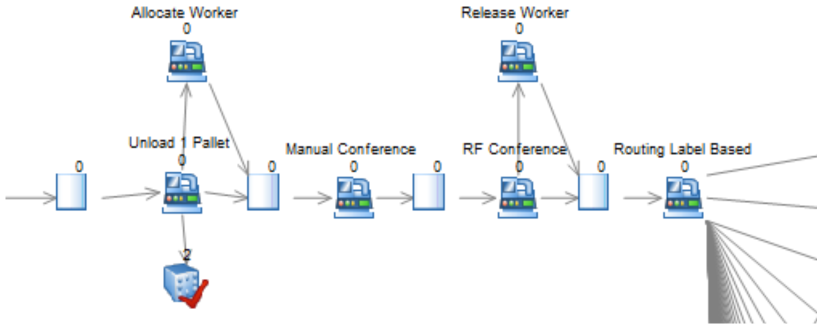

Figure 4.10. Unloading (One Door) in SIMLU8 Software

In Figure 4.5 there is represented the set of the activities that are linked with each door. In Appendix V, where the complete model is represented, there can be seen eighteen sets similar to this, representing the eighteen available dock doors.

To model the real life loading activity, to complement the activities already mentioned: "Unloading", "Manual Conference" and "RFID Conference", there was a need to introduce some "dummy" activities: "Allocate Worker", "Release Worker" and "Routing Label Based". Note that, as explained before, each activity as a preceding waiting queue in case it cannot be readily performed due to lack of resources. This way, delays can be accounted from the analysis of the queues' results. In this case, all queues have the standard definitions (infinite capacity, no minimum time waiting…) and the activities are defined as follows:

- **Unload 1 Pallet:** Simulates the real world activity of unloading one pallet. A distribution called "Unload_" was created that defined the duration of the activity according to the respective attribute of each work item: U1 means it has the above mentioned of "Unloading" duration while U2 means a null duration. In order to model workers allocation correctly, that is having one and only one worker unloading and conferencing all the pallets in the same truck, this activity will move the first pallet of each truck to a "dummy" activity called "Allocate Worker" that will be explained ahead. Visual Logic was used to this end, as can be consulted in Appendix VI. This activity will also move work items with the "Entity_Type_" attribute equal to 2 to the "End Unloading Truck" which represents the exit of the temporary entities "Trucks to Unload" from the system.
- **Allocate Worker:** "dummy" activity that will require a "Free Worker" and release it as "Occupied Worker" guaranteeing that this resource is not available for any other activity. The

work item processed (representing the first pallet of each truck) will continue the normal sequence of activities. When a work item enters this activity, the “U1” queue’s capacity is set to zero guaranteeing that no trucks are allocated to that door.

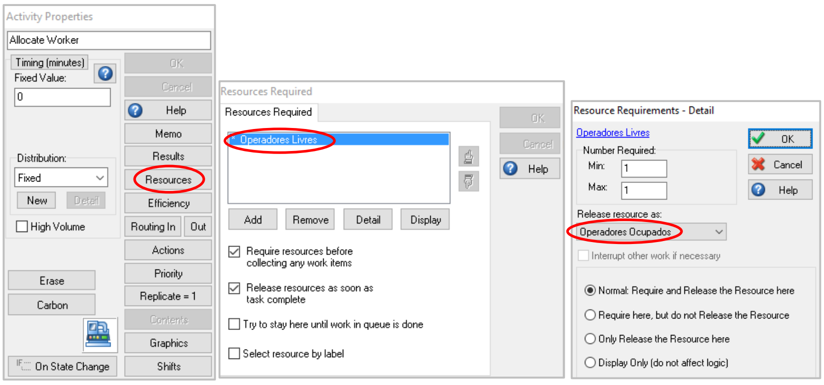

Figure 4.11. “Allocate Worker” Features in SIMLU8 Software

- **Manual Conference:** represents the real world activity of manual conferencing each pallet and has the respective duration, already explained.
- **RF Conference:** Besides simulating the activity of Radio Frequency conferencing (having the respective duration), it also moves the last pallet of each truck to the “Release Worker” activity so that the allocated worker can be released.
- **Release Worker:** similarly to “Allocate Worker” it is a “dummy” activity that will require an “Occupied Worker” and release it as a “Free Worker” guaranteeing that this resource is available for other activities. The work item processed (representing the last pallet of each truck) will continue the normal sequence of activities. This activity resets “U1” queue’s capacity allowing another truck to be allocated to the dock door.
- **Routing Label Based:** “dummy” activity used to model the temporary storage policy. Routing out priorities are set based on an excel file that will depend on the chosen methodology.

c. *Temporary Storage*

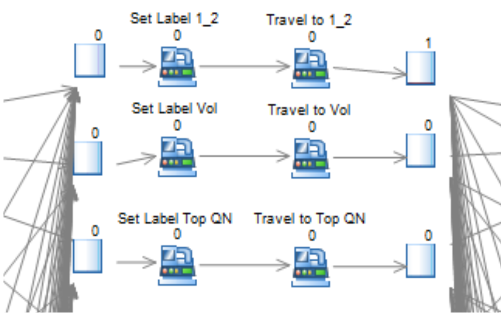

Figure 4.12. Temporary Storage (representation of three storage spaces of eighty-five: 1_2, Vol and Top QN) in SIMLU8 Software

The storage area is divided into eighty-five storage spaces, each one represented by a sequence of four simulation objects (two queues and two work centers), as represented in Figure 4.7. The purpose of each object is the following:

- **Queue 1:** used to define the capacity of the storage space.
- **Set Label (…):** Sets the label “TRAVEL TIME TO” that will define the travel time based on the label “Door_1_” and the current storage space calling upon a spread sheet that contains that information. Both the VL used and the imported spread sheet can be consulted in Appendixes VI and VIII. This activity also assigns a new label named “Storage_Space” that defines the current position of the pallet and will be used in a following activity.
- **Travel to (…):** represents the activity of travelling from the unloading door to the respective space. As Figure 4.8 shows, its duration is based on the label “TRAVEL TIME TO”, previously defined.

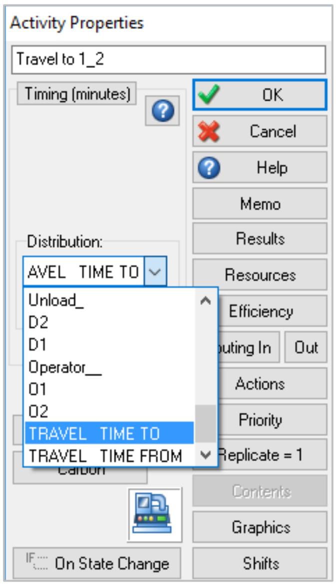

Figure 4.13. “Travel to” Activity’s Features

- **Queue 2:** where pallets wait for trucks to arrive. These have limited capacity (according to the real life corresponding space) and set the capacity of “Queue 1” trough VL. As can be seen in Appendix VI, each time a work item (pallet) enters or leaves this queue, the capacity of the first queue is set to the difference between the maximum capacity of the storage space and the number of work items currently in it. This way it is guaranteed that the number of pallets in the modeled storage space does not exceed its real capacity.

d. Loading

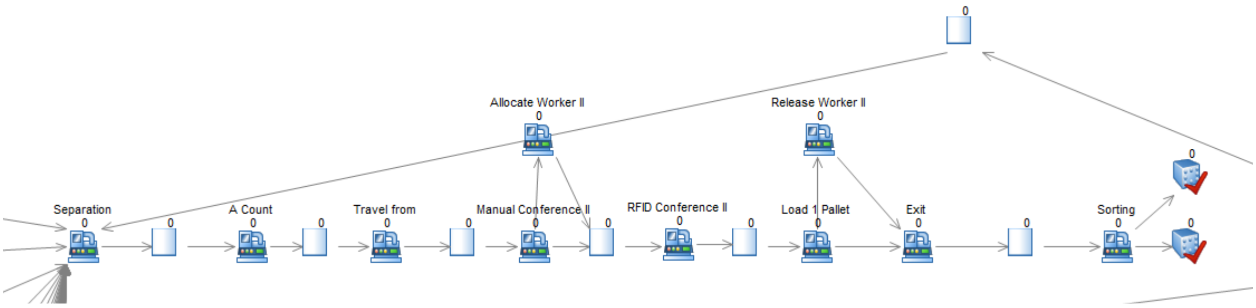

Figure 4.14. Loading (One Door) in SIMLU8 Software

As Figure 4.9 shows, the loading process is very similar to unloading. The activities that it comprises are defined as follows:

- **Separation:** "dummy" activity that will collect all the pallets (in the storage spaces) that have the same attribute "Tournee_S_" as the arriving truck. While the global variable "C1" is different than zero, meaning that there is a truck being currently loaded, the work items cannot move forward. This situation will be better explained in the next sections.

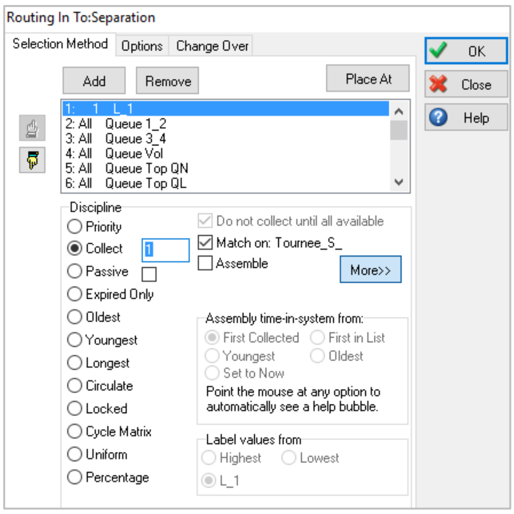

Figure 4.15. "Separation" Activity's Routing In and VL in SIMLU8 Software

- **A Count:** "dummy" activity created to accurately model the allocation of workers. Similarly to the unloading process, the allocation of workers is done through two "dummy" activities: "Allocate Worker II" and "Release Worker II". In order to track the number of pallets in each load, a global variable was created, called "C1". This variable will count the number of pallet and assign the respective number (within the load) to each one in an attribute called "NoPal_1". Both "C1" and "NoPal_1" will be needed in the following activities. This activity also sets the label "TRAVEL TIME FROM", based on the current door and the "Storage_Space" label. VL can be consulted in Appendix VI.
- **Travel from:** activity that represents the transfer of each pallet from the storage space to the respective loading dock door. It makes use of the already assigned attribute "TRAVEL TIME FROM" to define the duration.

- **Manual Conference II:** it simulates the real world activity of manually conferencing one pallet and also the allocation of workers. As in the unloading process, this activity will move the first pallet of each truck (in this case when NoPal_1=1) to “Allocate Worker”. As can be seen in Figure 4.11 there is another constraint that serves to model the fact that only the company-owned trucks are loaded by workers. The remaining trucks are loaded by the drivers themselves and so they do not require allocating a worker. The attribute “Operator_” allows to distinguish this situations since it its defined that company-owned trucks have “O1” while others have “O2” in this attribute.

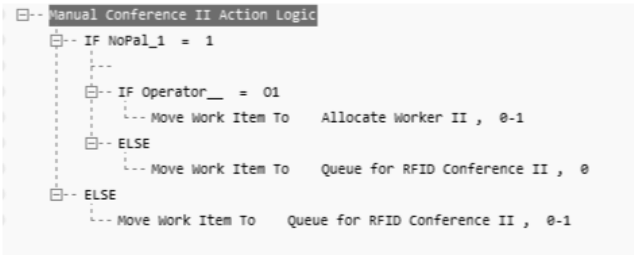

Figure 4.16. “Manual Conference II” Activity’s VL in SIMUL8 Software

- **Allocate Worker II:** same as in the unloading process.
- **RFID conference II:** activity with two functions: simulate radio frequency conference of each pallet and defining the new “NoPal_1” attribute value (by decreasing the global variable).
- **Load 1 Pallet:** besides simulating the loading of one pallet (with the respective duration), releases the previously allocated worker once the complete load has been loaded, by moving the last pallet to “Release Worker II” (In this case when the new “NoPal_1” attribute is equal to 0). In this situation, “C1” is null which means that the loading process is completed and the activity “Separation” is no longer blocked, allowing to start the process of loading a new truck.

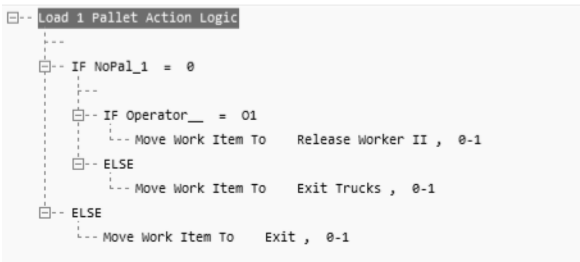

Figure 4.17. “RFID Conference II” Activity’s VL in SIMLU8 Software

- **Release Worker:** same as in the unloading process.
- **Exit:** “dummy” activity with null duration needed in the modeling process in VL.
- **Sorting:** “dummy” activity that forwards work items based on the label “Entity_type_” so that truck and pallets are sorted and the respective times in the system can be computed. This activity is blocked if the global variable C1 is not null so that the truck with the respective load leave the system at the same time.

e. Arrival of Trucks (to be loaded)

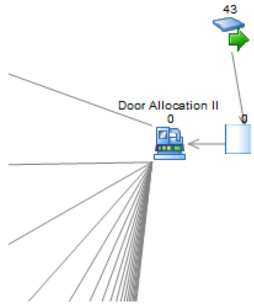

Figure 4.18. "Trucks to Unload" Arrival in SIMLU8 Software

The process is equal to the arrival of pallets and trucks to load. The arrivals' information is imported from excel (Appendix VII) and the door allocation routing out policy is based on the dock door assignment chosen, which will be explained in detail in the next chapter.

f. Resources

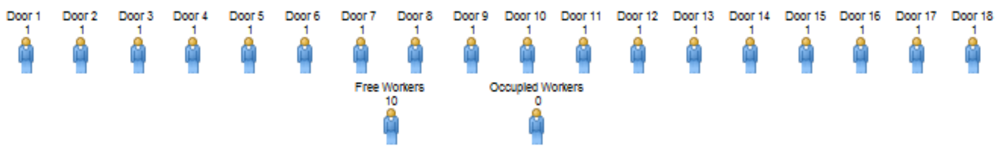

Figure 4.19. Resources in SIMLU8 Software

As explained in the "Conceptual Model" chapter, the resources used to model the real world system were doors ad workers. This way, one resource was created to each door that is required in the "Unload 1 Pallet" and "Load 1 Pallet" activities. For the workers, there was a need to create two different resources: "Free Workers" and "Occupied Workers", for reasons already explained. Besides the activities above mentioned, "Free Workers" are also required by the travelling activities.

4.3. KEY PERFORMANCE INDICATORS (KPIS)

As found in the literature review, makespan and distance traveled are the two most used performance indicators in the literature, while real life managers consider that the most important measure is the number of hours worked by emplooyes. With this in mind, the chosen KPI's and the respective collection method are described bellow.

4.3.1. Time in System

As Ladier and Alpan (2015) mentioned, makespan may not be relevant for the assessment of performance since trucks may have pre-determined departures times, and in this case, it is not of interest to minimize the length of a day. However, it is still important to study the time spent in the warehouse of each entity since it can show delays, problems with resource allocation, or other details that otherwise would have gone unnoticed.

Making use of the outputs of SIMLU8 and guaranteeing that each entity leaves the system through a different end, it is possible to collect the average time in the system (in minutes) of the three temporary entities: trucks to unload, trucks to load and pallets.

4.3.2. Travel Time

Travel time is one of the most used indicators and a very important one since it has a great influence not only in the total operations' time, but also in its cost since travelling requires resources like workers and pallet trucks. Any lack of efficiency in the internal transportation of pallets will translate in loss of profit and possible delays. For these reasons, it is of extreme importance to analyze the behavior of each scenario in what this performance indicator is concerned.

In this model, it is possible to collect the percentage of time spent travelling by summing the percentage of working time of all the activities "travel to" and "travel from". These indicators will show how much time is spent travelling from the inbound door to the allocated storage space, from the storage space to the outbound door and the total travel time. Note that, in the case of a pallet being allocated to a space adjacent to the inbound or outbound door, its travel time from or travel time to, respectively, will be null. The travel times can be consulted in Appendix VIII.

4.3.3. Storage Space Utilization

Since one of the variables being assessed is the temporary storage policy, the third KPI considered relevant was the utilization of the storages spaces. As there are eighty-five different spaces, a division was made so that different areas can be compared, these areas are: between doors, the tops of the structures, the structures, the volume area and the areas in front of WCs. The descriptions of each area, and respective capacities, can be consulted in the case study chapter of the dissertation. The occupation results were collected by dividing the output of the software "Average queue size" by the capacity of each storage area and calculating the mean within each type of area.

4.3.4. Doors Utilization

Despite not being very utilized in the literature (used by 4% of the analyzed articles), door utilization is considered important by the respondents in Ladier & Alpan (2015) (25% of the respondents considered important) and is an important indicator when assessing dock door assignment policicies since it can lead to relevant conclusions or give indication about what directions to follow. With this in mind, each door occupation will be analysed in each scenario, as well as the average utilization. These nineteen KPIs are provided directly as an output of SIMUL8.

4.3.5. Number of workers

The allocation of workers will not be treated as a controllable variable but as output of the model. This means that scenarios varying the number of workers are not going to be constructed, but its utilization is going to be analyzed for each scenario.

Due to the model's construction mode, the outputs relative to the resource "Free Workers" will only give information about the time this resource spends in the activities "Travel to" and "Travel from", not taking into account the time a worker is "Occupied". To overcome this issue, a global variable was created called "W1" which will serve as a counter for workers. To this end, W1 will increase every time a worker is allocated and decrease every time it is released. Another global variable called "MaxWorkers" will then save the maximum value of W1 through the run, giving information about the maximum number of workers being simultaneously used.

4.4. Verification and Validation of the Model

Sargent (2003), in his work, uses the following definitions of verification and validation of simulation models, respectively:

- "ensuring that the computer program of the computerized model and its implementation are correct"
- "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model"

After the implementation of the model, it is necessary to resort to its verification and validation, that is, check if the model accurately represents the real world system. Despite being commonly done simultaneous, verification and validation have different meanings. While the first refers to the inner part of the model (make sure if it is running well), validation regards the suitability of the model to the real world as well as its outputs.

In the model presented, verification consisted in:

- Stage-by-stage construction of the model, with each stage being tested separately and extensively.
- Debugging the model through SIMUL8, by solving the necessary problems each time the software alerted to any model issue.
- Review, whenever necessary, by a more senior modeler (or the author's supervisor or someone from the software's support team)
- Documenting the model development continuously, resulting in the present report, making the model transparent to others.

The validation technique adopted was based on the work of Reis (2010 cit by Faria 2015) and is divided in four areas:

- Requirements validation: the model should answer to clear requirements and questions about the real world.

- The model should simulate cross-docking operations in AZ1 so that it serves as a tool to assess different scenarios.
  - Data validation: the data in the model should be valid.
- As explained before, the data was either given by the company or collected by the author.
  - Face Validation: the assumptions of the model should be valid.
- The assumptions were also based on field observations or discussed with people from the company.
  - Process Validation: the steps in the model have to be clear, meaningful and correspond to the real world process.
- As described in the present chapter, the model describes the real world operations and, therefore, the properties of every object also reproduce the reality.

Chapter 5. Case Study Application

This chapter presents the experimental scenarios and the respective results, resorting to the model described in the previous chapter for the assessment of their validity.

5.1. Scenarios

As it was explained in chapter 1.2., the objective of the present work is to assess and restructure the logistics processes of a warehouse, specifically the temporary storage policy, the dock door assignment, truck scheduling and the workers allocations problems of the cross-docking operations at AZ1. The choice of these control variables was grounded in chapters 2.3 and 3.2 with the study of the warehouse and the relevant existing literature on cross-docking.

In this chapter, the methods chosen for each control variable are described (and the alterations made in order to model each one of them) as well as the strategy used to find the experimental scenarios to be assessed and those scenarios.

5.1.1. Layout/Temporary Storage

In chapter 3.2.4, three articles on temporary storage were analyzed. The proposed methods found in those articles were:

- Store on the areas near inbound doors, when unloaded,
- Store on the areas near the respective outbound doors; or
- Directly transfer from inbound trucks to outbound trucks.

Based on the available data provided by LS that shows that unloading trucks arrive at different schedules than loading trucks, direct transfer the pallets was not a valid option. Instead, a third option was created that consist in a combination of the existing two: minimizing the two travelling distances that compose the total one. This means that, each time a pallet arrives, it will be temporary stored in the storage space that minimizes the distances inbound door-storage space and storage space-outbound door. The three temporary storage policies that are going to be tested are then:

- Prioritize the areas that minimize the distance between doors,
- Prioritize the areas near the inbound door,
- Prioritize the areas near the outbound door.

In order to model these policies, there was a need to add VL in the activity “Routing Label based” that would allocate storage spaces according to each policy.

For the first method evaluated (Minimum Distance), the first step was to create a spread sheet with the preferences for each door. These sheets can be consulted in Appendix IX and were constructed as follows:

1. A table with the distances from each door to each storage place was created.
2. For each door, a new table was constructed summing the distance between that door and each storage space with the distance between that space and each door (representing the total travel distance: travelling to the storage space and from), resulting in eighteen spread sheets that cover all the possible door-space-door combinations.
3. Those distances were converted into priorities being the null distance correspondent to priority one and the longest distance correspondent to a priority value of 85. This way, knowing the inbound and the outbound doors, it is known the priorities of space allocation.

Having the priorities defined, the VL code was implemented, as in Figure 5.1. This command will set the space allocation priorities to the ones in sheet “ssPrioritiesDoorX”, line “Door_2_” (where X is the inbound door and “Door_2_” is the label that indicates the outbound door).

```
⊟-- Routing Label Based Route In After Logic
    ⊟-- LOOP 1 >>> loopvar >>> 85
        --- Set Route Out Priority    Routing Label Based ,  ssPrioritiesDoor1[loopvar+1,1] ,  ssPrioritiesDoor1[loopvar+1,Door_2_+1]
        ---
```

Figure 5.1. VL code for Minimum Distance Policy

For the other two policies (Near outbound and Near Inbound), the same strategy was used but only one spread sheet was needed for all doors, with the priorities based on the distance between each pair door-space. In these cases, priorities were set based on one label, “Door_2_” for “Near Outbound” policy and “Door_1_” for “Near Inbound”. VL commands are shown in Figures 5.2. and 5.3.

```
⊟-- Routing Label Based Route In After Logic
    ⊟-- LOOP 1 >>> loopvar >>> 85
        --- Set Route Out Priority    Routing Label Based ,  ssPriorities[loopvar+1,1] ,  ssPriorities[loopvar+1,Door_2_+1]
        ---
```

Figure 5.2. VL code for Near Outbound Policy

```
⊟-- Routing Label Based Route In After Logic
    ⊟-- LOOP 1 >>> loopvar >>> 85
        --- Set Route Out Priority    Routing Label Based ,  ssPriorities[loopvar+1,1] ,  ssPriorities[loopvar+1,Door_1_+1]
        ---
```

Figure 5.3. VL code for Near Inbound Policy

5.1.2. Dock Door Assignment Problem

The second cross-docking problem reviewed in chapter 3.2.2, was the dock door assignment problem. In the existing literature, three methods are proposed:

- Exclusive service mode: having designated doors to inbound and outbound.

- Dedicated doors: each truck has its assigned door fixed
- Mixed: all doors serve all trucks

Despite being all valid for experimentation, details had to be defined since each method had several possible variations. The chosen policies for the dock door assignment problem were:

- Exclusive 9/9: policy with exclusive service mode where the first nine doors are only used for unloading and the last nine for loading.
- Exclusive 9/9 Alternated: policy with exclusive service mode where the odd doors are only used for unloading and the even ones for loading.
- Shift exclusive: policy with exclusive service mode that depends on the shift. Doors one to ten are exclusively for unloading in the first shift (16:00 – 24:00) and for loading in the second (00:00 – 08:00).
- Preferential (mixed): each truck has a list of door preferences (similarly to the space allocation). The list can be consulted in Appendix X and it was constructed based on the arrival times of each truck.
- Dedicated: policy where each truck has a specific door to be served at.
- Exclusive 9/9 Preferential: similar to “Exclusive 9/9” but with preferences, i.e. if the expected door is being used, then the truck can be served in another one according to a preference list.
- Exclusive 9/9 Alternated Preferential: similar to “Exclusive 9/9 Alternated” but with preferences.

Since in the cases where allocation is not preferential the doors are set in the arrivals’ spread sheets, by pre-defining the labels “Door_1_” and “Door_2_”, alterations in the model are only needed in the preferential policies. In these cases, a VL command is set in the “Door Allocation” and “Door Allocation II” activities, as it was done in the temporary storage policies. VL commands can be consulted in Appendix VI.

5.1.3. Truck Scheduling

The last variable used to construct scenarios was truck scheduling which was studied in chapter 3.2.3. In this chapter, the strategies found were:

- First-Come-First-Served (FCFS): consist in the traditional method of allocating truck by order of arrival.
- Look-ahead: an algorithm developed by Gue (1999) that consists in assigning each arriving trailer to the door that minimizes the workers travel distance. This implies that the content (and respective destination) of each truck is previously known, as well as the dock door assigned to the outgoing truck correspondent to that each destination. The study shows that this method can reduce labor costs due to travel by 15–20% compared to a first-come–first-served.
- Minimum processing total time: proposed by Wang & Regan (2008), this policy consists in minimizing the sum of pallets travel time between receiving doors and shipping doors, waiting

time at receiving doors, and waiting time at shipping doors, which the authors call "total processing time". It also requires full information about the incoming trailers content.

- Minimum total transfer time: similar to the previous, but also considers the waiting time in the waiting trailer line.

Due to the lack of available data and the way the model was constructed, only two methods for truck scheduling were assessed: First-Come-First-Served and Prioritize. The first consists in the common method of serving each truck by order of arrival, which did not need any changes in the model. The second consists in prioritizing the trucks which contain pallets that will leave the facility earlier. To model this policy, a new label was created and set in the arrivals' file called "Priority". This label's values were set in decreasing order based on the content of each truck, guaranteeing that trucks that contain pallets leaving earlier have the highest values. Then, the queues feature "prioritize" was turned on, which assures that work items with higher values of priority are served first.

5.1.4. Solutions Search Strategy

In simulation, it is common that one has to be decided which combinations of controllable variables to test / simulate knowing that each could lead to better solutions. This is one of the biggest problems of the simulation technique: the cost (in terms of time) of testing scenarios that, with careful consideration of some performance indicators, would make them unviable.

In the present work, having three different variables and three, seven and two values, respectively, for each one of them, it is infeasible to test all combinations (it would give a total of forty-two scenarios). Testing all of these scenarios, in addition to being time consuming, it is not necessarily effective. Thus, and in order to avoid that pitfall, an "intelligent" search strategy was conducted to complement the "traditional" strategy of testing all the combinations. This means that, for each variable, a traditional search strategy was used, and within variables an "intelligent" search.

An "intelligent" search strategy consists in a search strategy of the solutions space aiming at improving the current "best" solution in which the outputs of each simulation experiment give information about what direction to follow in the subsequent experiments. And so, each scenario is defined based on the results of previous ones.

Therefore, the results will be presented sequentially, as follows:

1. First, the methods for temporary storage are tested, maintaining the remaining variables' value constant (choosing the less restrictive method for each one of them).
2. Based on the results, the best solution for this variable will be chosen and maintained in the rest of the experiments.
3. Having the first variable fixed, the dock door assignment policies will be assessed. Since there are seven different methods, two groups were formed: preferential and non-preferential. The first group (four different scenarios) will be tested and the results compared within the group.

4. The second group (three different scenarios) will be tested and the results compared with each other and with the respective non-preferential methods in order to evaluate not only each one of the dock door assignment policies, but also the difference between preferential and non-preferential.
5. The two methods for the truck scheduling problems will be tested along with the two best scenarios of the dock door assignment problem (one of each group).
6. After having the results for all the scenarios (eleven in total), and due to the limitations of the model regarding this subject, the workers' utilization and "MaxWorkers" are presented for all scenarios owing to the influence this indicator may have in the final conclusions.
7. In the end, conclusions are made around the results.

5.1.5. Results Space

After defining the general strategy for the search of solutions, begins the process of determining a results space with solutions that are viable. The feasibility of solutions is determined simply by the fact that they meet the minimum services - pallets entering and leaving the facility with no abnormally long waiting lists.

The result of the chosen search strategy was the eleven scenarios shown in Table 5.1.

Table 5.1. Results Space

<table>
<tr><th>Scenario</th><th>Temporary Storage</th><th>Dock Door Assignment</th><th>Truck Scheduling</th></tr>
<tr><td>C1</td><td>Minimum Distance</td><td rowspan="3">Preferential</td><td rowspan="9">FCFS</td></tr>
<tr><td>C2</td><td>Near Outbound</td></tr>
<tr><td>C3</td><td>Near Inbound</td></tr>
<tr><td>C4</td><td rowspan="8">Best</td><td>Exclusive 9/9</td></tr>
<tr><td>C5</td><td>Exclusive 9/9 Alter.</td></tr>
<tr><td>C6</td><td>Shift Exclusive</td></tr>
<tr><td>C7</td><td>Dedicated</td></tr>
<tr><td>C8</td><td>Exclusive 9/9 Pref.</td></tr>
<tr><td>C9</td><td>Exclusive 9/9 Alter. Pref.</td></tr>
<tr><td>C10</td><td>Best Preferential</td><td rowspan="2">Prioritize</td></tr>
<tr><td>C11</td><td>Best Non-Preferential</td></tr>
</table>

5.2. OTHER CONSIDERATIONS ON SIMULATION EXPERIMENTS

This section intends to clarify some considerations that the reader should have about the simulation.

In the first place, and as for the scope of the simulation, it was decided with consultation from LS, that the model would simulate a week of operations, from clients that are either cross-docking or served in the same schedule.

Secondly, as the inputs are concerned, LS only provided information about the trucks that arrived the facility for loading (number of pallets and times) so the arrival of trucks to unload was generated using the random number tool in Excel matching the available data.

The last consideration concerns the number of runs recommended by the “Trial Calculator” of SIMUL8: to surpass the effects of randomness, every scenario has run 50 times, guaranteeing an error lower than 5% in 90% of KPI’s.

5.3. RESULTS

In this chapter, the results of all the experiments are presented, as well as their assessment. The complete results and outputs of the software can be consulted in Appendix XI.

5.3.1 Temporary Storage

Table 5.2. Temporary Storage Scenarios

Scenario	Temporary Storage	Dock Door Assignment	Truck Scheduling
C1	Minimum Distance		
C2	Near Outbound	Preferential	FCFS
C3	Near Inbound		

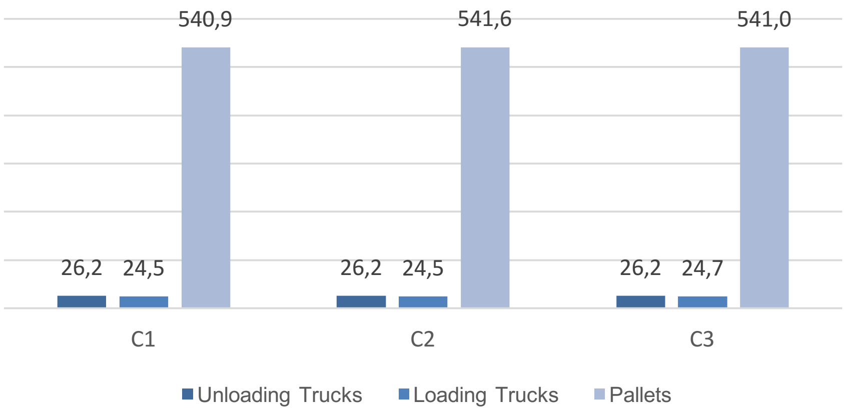

Figure 5.4. Average Time in System for C1, C2 and C3

According to the graph observation (Figure 5.4) it appears that the three scenarios have the same average time in system. Since loading and unloading times depend only on the door allocation method, on the input data and on the time of loading and unloading, which follow normal distributions already explained, the equality of the values is justified by the fact that these three factors are the same for all scenarios. So the scenarios have 26.2 average time for unloading trucks and 24.5 and 24.7 for loading truck.

Pallets time average is between 540.9 (9 h 01m) and 541.6 (9 h 02m) showing that pallets arrive and leave in the same day, since one day has two eight hours shifts. Differences found are due to times' distributions.

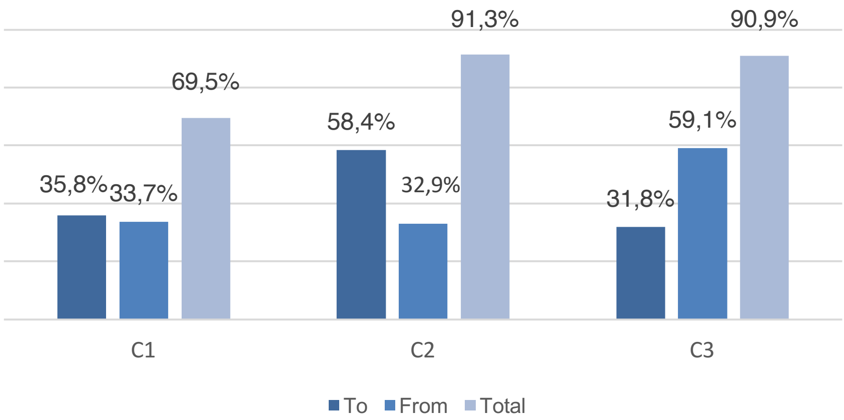

Figure 5.5. Average Percentage of Time Travelling for C1, C2 and C3

In Figure 5.5 the three methods of temporary storage are compared in terms of travelling time. As explained in chapter 4.3.2, this indicator is divided in three KPIs: travel time to ("To"), travel time from ("From") and total travel time ("Total")..

C1 (Minimum Distance) scenario showed a lower value in total percentage of time travelling comparing with near outbound (C2) and near inbound (C3) storage policies.

The graphic shows that, while in C1, travel time to and travel time from are similar (near 35%), C2 and C3 increase in 65% travel times to and from, respectively. This is due to the fact that the first scenario minimizes both distances while the second only minimizes travelling between storage spaces and outbound doors and the third minimizes travelling between inbound doors and storage spaces.

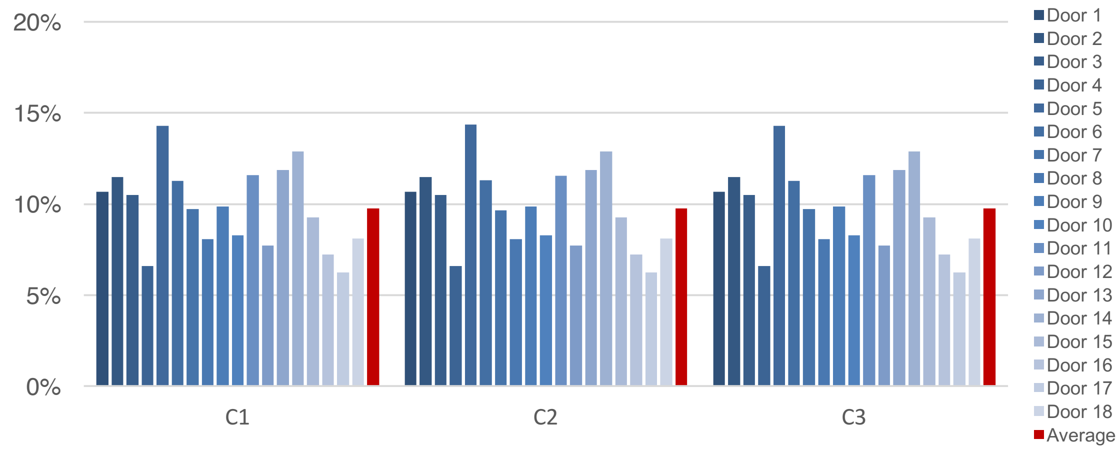

Figure 5.6. Average Percentage of Door Utilization for C1, C2 and C3

Door utilization, represented in Figure 5.6., was similar in the three scenarios. As expected for the same reasons as the average times in system.

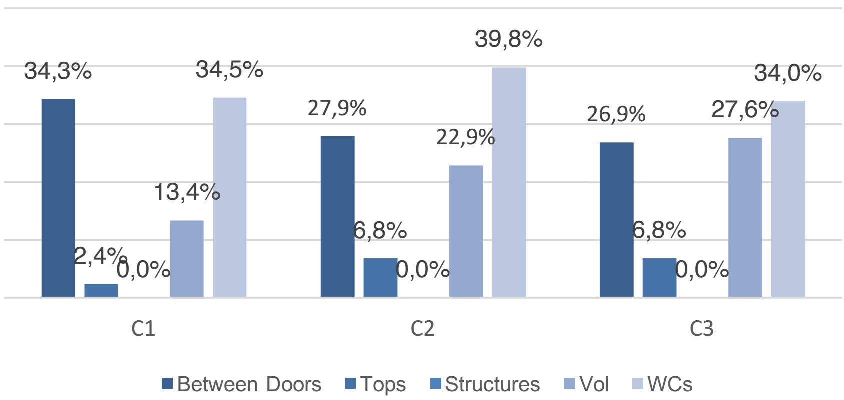

Figure 5.7. Average Percentage of Storage Space Occupation for C1, C2 and C3

The highest value for "Between Doors" in C1 scenario is due to the fact that this policy prioritize the spaces near the doors where each pallet arrives or leaves the facility, while C2 and C3 prioritize only one of the doors (outbound or inbound). This way the probability of a pallet being allocated to a space between doors is higher in C1. For the same reason, "Tops" have a higher occupation rate in C2 and C3 since it has priority over spaces near inbound (in C2) and outbound (in C3) doors.

The occupation of "Structures" is null since it was modelled in a way that priorities would be the highest (last to be chosen). The main reason is that, in the real life system, structures are rarely used.

The volume area ("Vol") utilization in C2 and C3 is higher than in C1 since it compensates the area between doors not being used. The area in front of WC's has the highest utilization rates since it has low capacity (10 pallets) and it has zero distance to the central hallway, which increases its priority.

From the three scenarios assessed, C1 was selected due to having the best results as travel times are concerned, and the other KPI's similar in the three scenarios. The total travel time, as said before, is one of the most important factors in this type of facility since it influences both operational time and cost. For these reasons, C1 results, by showing a reduction of 22% in time travelling, emphasize the importance of minimizing the distance travelled between doors. In real world, these time savings could translate in a decrease in costs, due to its influence in the total operational time and in the use of resources.

5.3.2. Dock Door Assignment Non-Preferential

With the temporary storage policy chosen (minimum travelling distance), different scenarios for the dock door assignment problem were tested, starting with the four that have defined inbound and outbound doors (non-preferential). The methods used in each scenario are described in Table 5.3.

Table 5.3. Dock Door Assignment Preferential Scenarios

Scenario	Temporary Storage	Dock Door Assignment	Truck Scheduling
C4	Minimum Distance	Exclusive 9/9	FCFS
C5		Exclusive 9/9 Inter	
C6		Shift Exclusive	
C7		Dedicated	

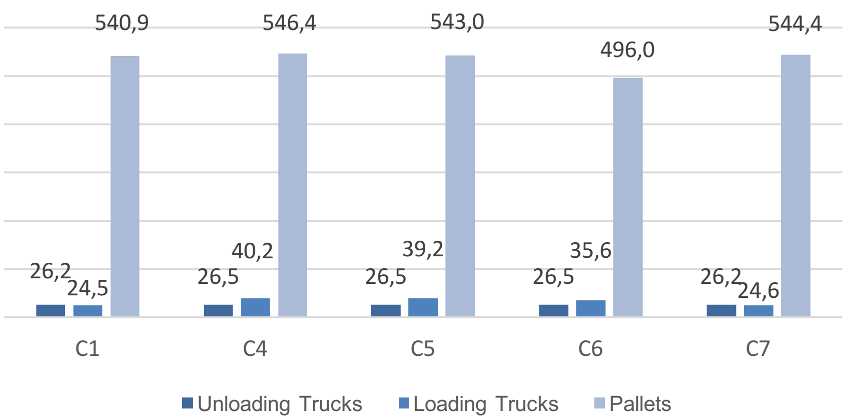

Figure 5.8. Average Time in system for C1, C4, C5, C6 and C7

As Figure 5.8 shows, average time in the system of "trucks to unload" is similar in all the scenarios, with a difference of eighteen seconds on C4, C5 and C6 which is neglegible. However the same indicator for "trucks to load" has substantially increased in the same scenarios (64%, 60% and 45%

respectively). Since the variable being assessed is the dock door assignment, these results show that an exclusive service mode with non-preferential door allocation increases the loading time. Furthermore, C7 shows nearly no alteration in this indicator. Since this scenario has a non-preferential policy but dedicated doors, it indicates that the increased loading time is due to the exclusive service mode and not to the non-preferential policy.

In what pallets are concerned, the average time spent in the system decreases in 8.3% in scenario C6, having almost no alterations in the other scenarios. This is justified by the fact that this is the “shift exclusive” door allocation method and therefore, pallets have a higher probability of being assigned inbound and outbound doors that are close to each other. This way, when “trucks to load” arrive at the facility, pallets have a higher probability of being stored near the outbound doors, avoiding situations where they have to stay until the next day in the warehouse.

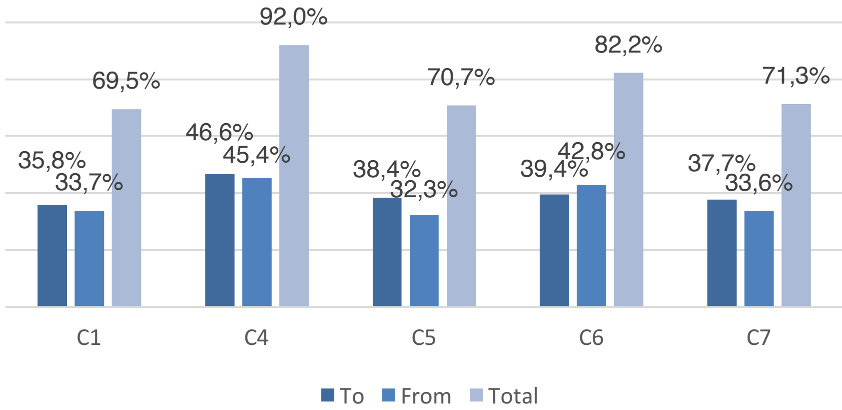

Figure 5.9. Average Percentage of Time Travelling for C1, C4, C5, C6 and C7

In what travel times are concerned, Figure 5.9 shows some differences between the scenarios, being the more obvious the higher values for C4 and C6 totals. C4 higher percentage (more 22.5%) in all three KPI’s is justified by the fact that, being the scenario with exclusive service mode where the first nine doors are only used for unloading and the last nine for loading, it is the scenario where pallets will have to travel the biggest distances and consequently, will have the biggest travel times.

In the “shift exclusive” scenario, what happens is that, all of the pallets arrive between 16:00h and 00:00h and the majority only leaves after 00:00h, at the same doors (1 to 10). This implies that the preferential areas for temporary storage are the same (due to “Minimum Distance” policy, see chapter 5.1.1). Consequently, the storage spaces that reduce travel distance will be rapidly full and pallets will be allocated to spaces away from the doors, increasing the travel times (both “To” and “From”), resulting in more 12.7% of total travel time.

C5 and C7 show very similar results to C1.

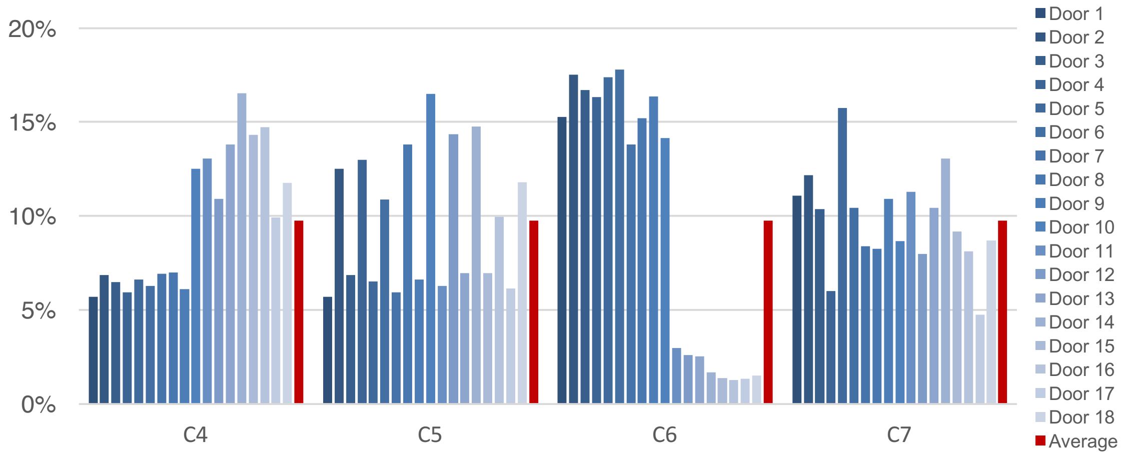

Figure 5.10. Average Percentage of Door Utilization for C4, C5, C6 and C7

In Figure 5.10, it can clearly be seen the dock door allocation policy utilized: 9/9, 9/9 Alternated, Shift exclusive and dedicated. From the graph observation, it can be concluded that doors used exclusively for unloading are less used (nearly 50%) than the ones used for loading. This conclusion was expected based on the average time in the system of trucks. Also, the average utilization of doors is equal for all the scenarios, which is justified by the fact that the same number of trucks and pallets are served in every scenario.

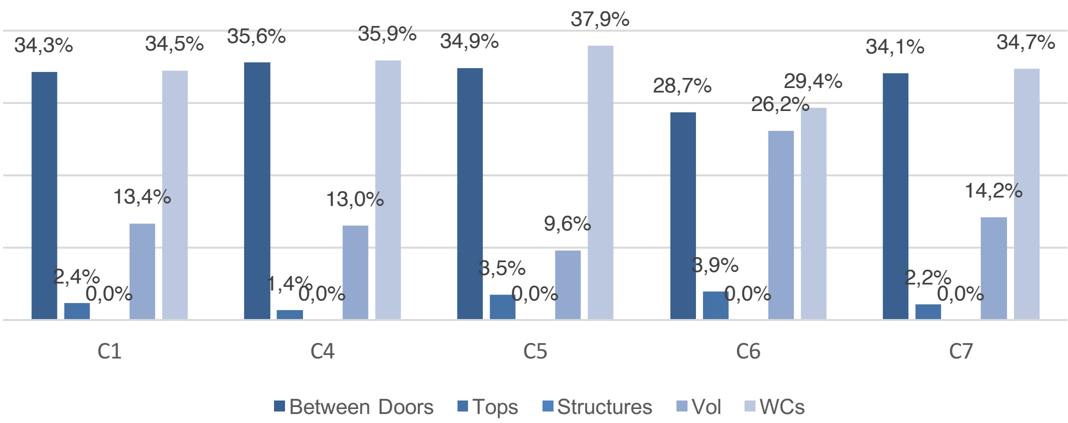

Figure 5.11. Average Percentage of Storage Space Occupation for C1, C4, C5, C6 and C7

As Figure 5.11 shows, “Between Doors” continues to be the most used area. This indicator’s value decreases in C6 but is compensated by an increased usage of the “Vol” area justified by the fact that the most used doors are near that area.

“Structures” continue with zero utilization and “WC”’s with higher percentages, as it was explained in chapter 5.3.1.

The conclusions made on the Non-Preferential Dock Door Assignment experiments are that no scenario is better that C1, however, C6 has the advantage of pallets spending less time in the system and C7 is almost equal to C1 in every aspect so it should be further studied.

5.3.3 Dock Door Assignment Preferential

In this section, each "Preferential" scenario is compared with its respective "Non-Preferential": C7 e C1; C4 e C8; C5 e C9. This means that each pair of scenarios has the same dock door allocation policy except in one the inbound and outbound doors are defined and, in the other, if that door is being used, the truck will be served in another, according to a list of preferences. The methods used for each variable are showed in Table 5.4.

Table 5.4. Dock Door Assignment Preferential Scenarios

Scenario	Temporary Storage	Dock Door Assignment	Truck Scheduling
C7	Minimum Distance	Dedicated	FCFS
C1		Preferential (=Dedicated Preferential)	
C4		Exclusive 9/9	
C8		Exclusive 9/9 Pref.	
C5		Exclusive 9/9 Inter	
C9		Exclusive 9/9 Inter Pref.	

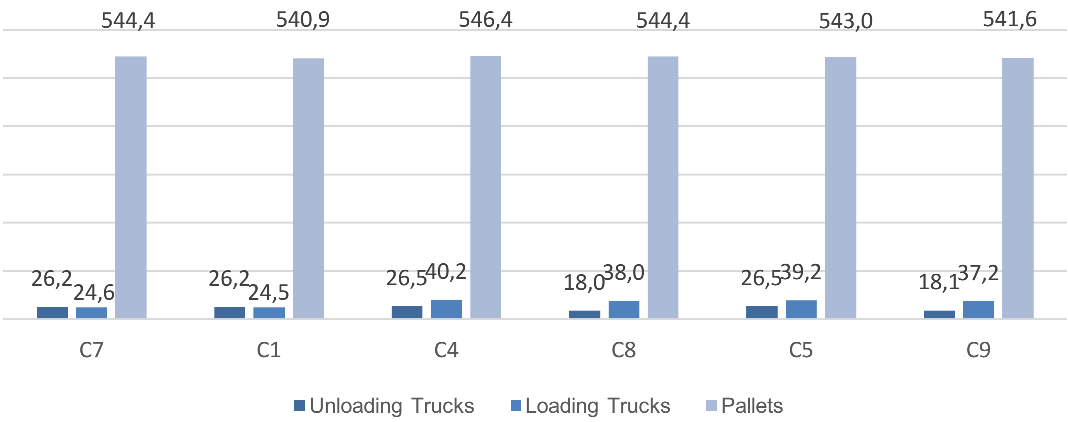

Figure 5.12. Average Time in System for C7, C1, C4, C8, C5 and C9

From the observation of Figure 5.12, it can be seen that C8 and C9 have decreased values of "unloading Trucks" average time in system (31%). Consulting the detailed results, available in Appendix XI, this occurs because in C4's and C5's only the results of the doors that were used are considered (the rest is null), in C8 and C9 were considered all the doors for the "Unloading Trucks" because there were no zeros but there were small values (on the doors less used), that incite these lower results. Therefore, these should not have implications in the final conclusions.

Both “Loading Trucks” and pallets’ time in the system show variations of less than two minutes from C8 to C4 and C5 to C9. Despite not being a substantial value, provides some evidence in favor of “preferential” policy. Either way, C1 and C7 continue to show better results.

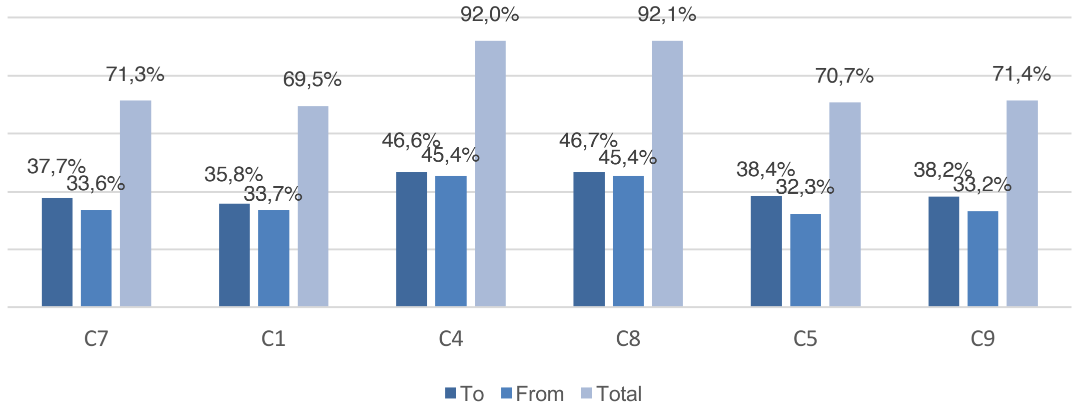

Figure 5.13. Average Percentage of Time Travelling for C7, C1, C4, C8, C5 and C9

Figure 5.13 shows that there are no alterations in travel times for “Preferential” methods. C1, C7, C5 e C9 are the best with very similar results.

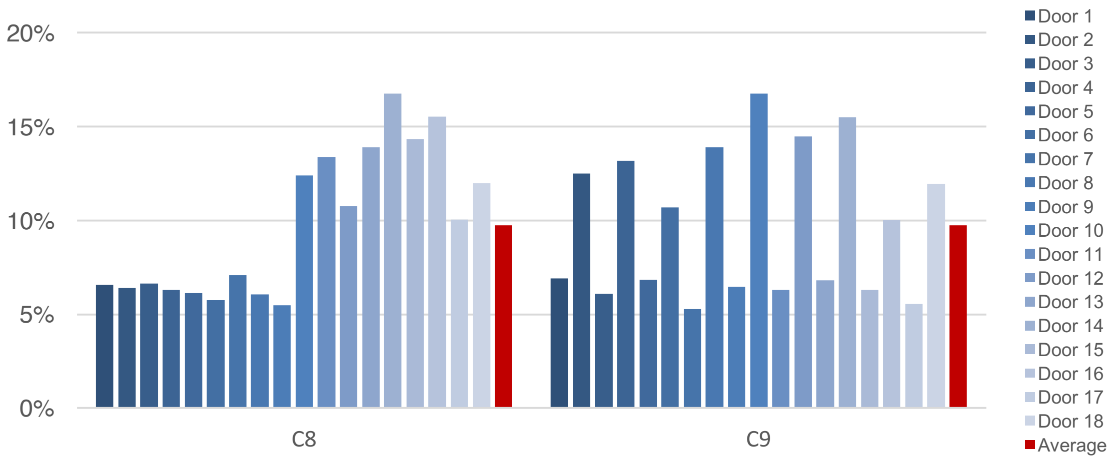

Figure 5.14. Average Percentage of Door Utilization for C8 and C9

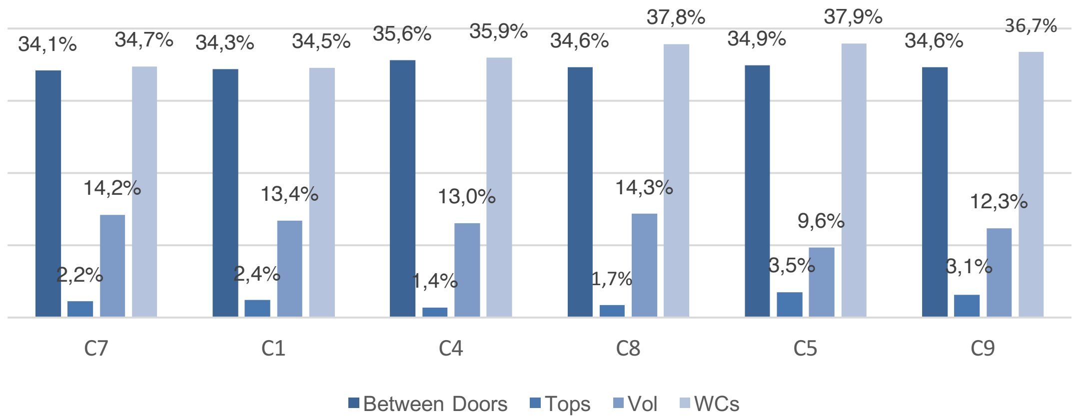

Figure 5.15. Average Percentage of Storage Space Occupation for C7, C1, C4, C8, C5 and C9

Door utilization's (Figure 5.14) and Storage Space occupation's (Figure 5.15) results are equal to C4 and C5, giving no evidence in favor or against this policy.

The equality in all the results regarding "Preferential"/"Non-Preferential" comparisons are due to the high number of doors when compared to the number of trucks. This way, the cases where doors are occupied are rare and a "preferential" policy will have no advantages.

Due to the likeness of C1 and C7 results, the distribution of doors' utilization was compared.

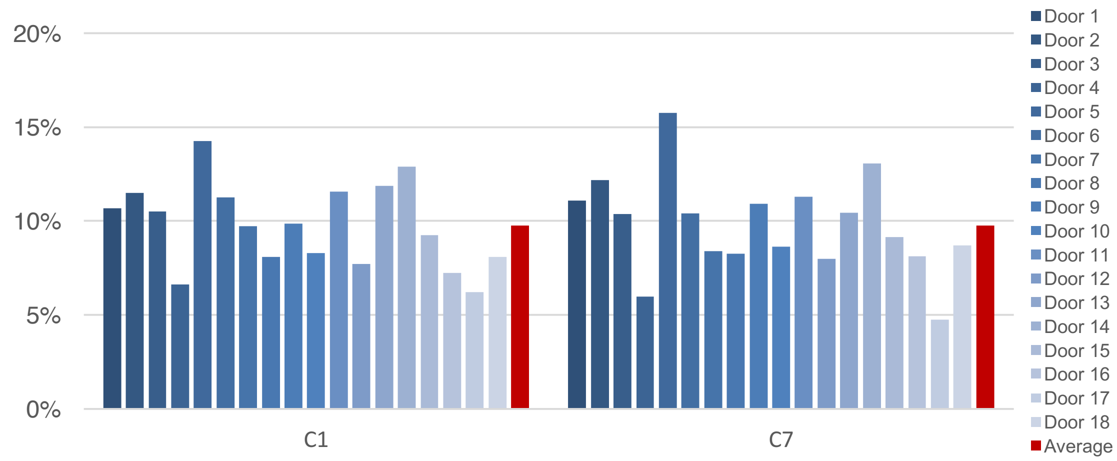

Figure 5.16. Average Percentage of Door Utilization for C1 and C7

Despite Figure 5.16 shows very similar distributions, a closer look reveals a more homogeneous door utilization in Scenario C1 (specially in doors 3, 4, 5 and 17). Being this the only difference between C1 and C7, it follows that C1 continues to be the best solution.

5.3.4 Truck Scheduling

In this section, the scenarios tested were constructed varying the truck scheduling method. Scenarios are showed in Table 5.5.

Table 5.5. Truck Scheduling Scenarios

<table>
<tr><th>Scenario</th><th>Temporary Storage</th><th>Dock Door Assignment</th><th>Truck Scheduling</th></tr>
<tr><td>C1</td><td rowspan="4">Minimum Distance</td><td rowspan="2">Preferential</td><td>FCFS</td></tr>
<tr><td>C10</td><td>Prioritize</td></tr>
<tr><td>C7</td><td rowspan="2">Dedicated</td><td>FCFS</td></tr>
<tr><td>C11</td><td>Prioritize</td></tr>
</table>

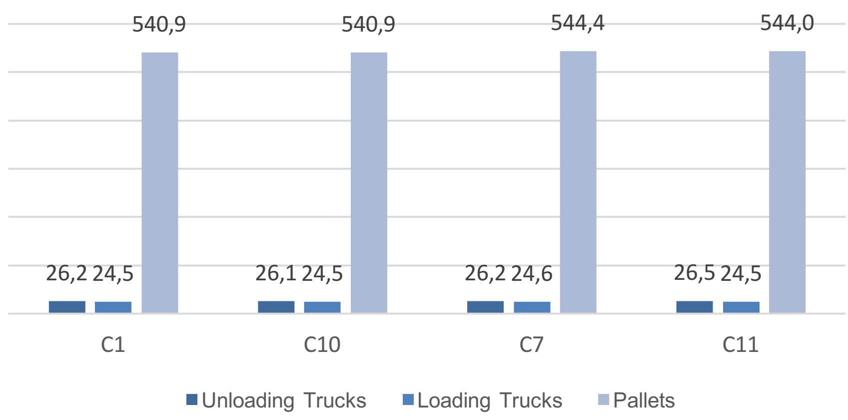

Figure 5.17. Average time in System for C1, C10, C7 and C11

As Figure 5.17 shows, there are no significant alterations between “FCFS” and “Prioritize” methods.

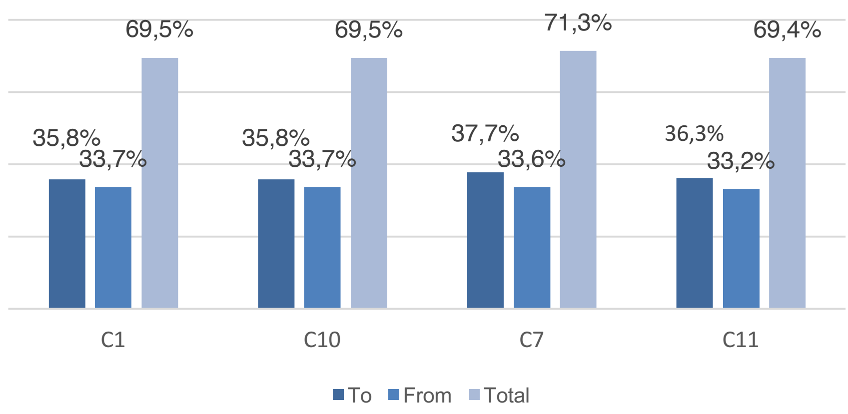

Figure 5.18. Average Percentage of Time Travelling for C1, C10, C7 and C11

Regarding travel times, there is a reduction of 2% in the total when using “Prioritize” with a dedicated dock door assignment policy. The fact that there is no alteration between C1 and C10 and there is a slight difference between C7 and C11 that is due to the fact that C1 is Preferential and C7 is not. These results reflect the fact that, while in C1 if a door is being used the arriving truck will be allocated to another door, in C7 if two trucks arrive at the same time and are supposed to be served at the same door, one will have to wait for the other. With this “Prioritize” method, there is a valid criterion to choose which one will be served first and that is what triggering this alterations in the results.

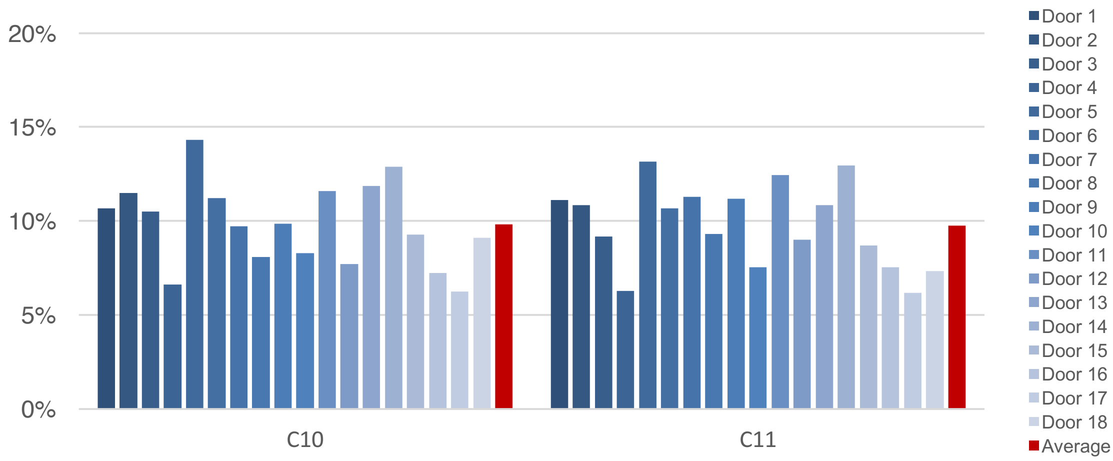

Figure 5.19. Average Percentage of Door Utilization for C10 and C11

The door utilization distribution (Figure 5.19) gives no information about this variable.

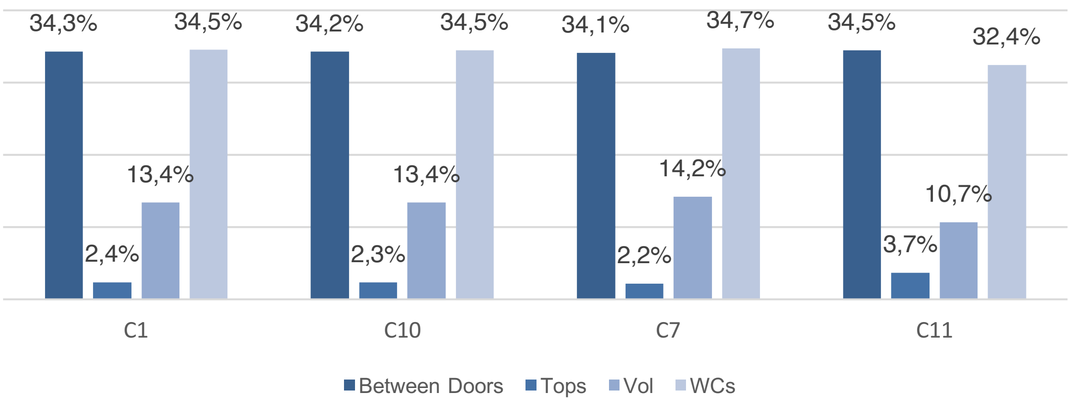

Figure 5.20. Average Percentage of Storage Space Occupation for C1, C10, C7 and C11

Despite showing some differences between C7 and C11, namely on “Tops” and “Vol”, one variation compensates the other. This only proves that space allocation is different for both scenarios and therefore, that pallets are being served in a different order. Regardless of implying that the trucks are being prioritized, it does not give any argument in favor or against the method.

The lack of differences when applying a prioritization method for the truck scheduling problem to the previous tested scenarios is justified by the fact already mentioned of having an high number of doors when compared to the number of trucks.

5.3.5 Number of Workers

In this section the results regarding the operators for all the scenarios are presented.

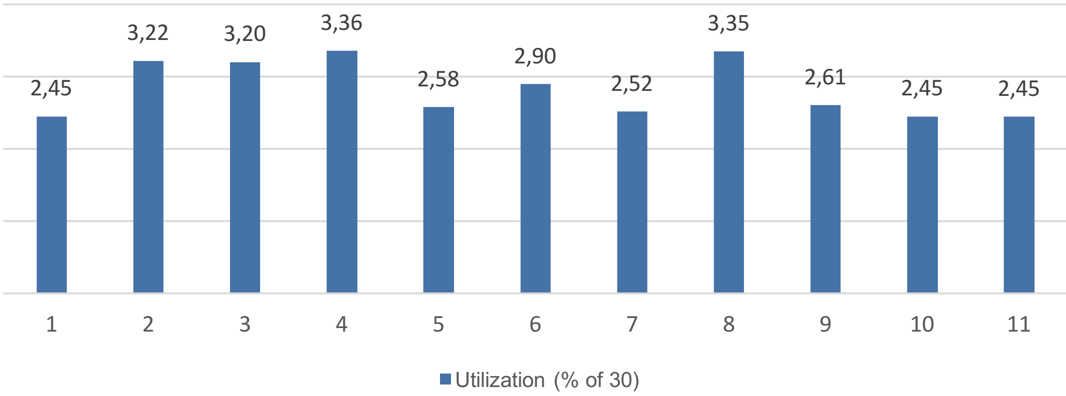

Figure 5.21. Average Percentage of Workers Utilization

Figure 5.21 shows the average percentage of workers utilization for travelling. The best scenarios are C1, C10 and C11 with an average of 0.74 (2.45% of 30 workers) workers followed by C7 with 0.76 and C5 with 0.77. The scenarios that use more workers are C4 and C8 (average of 1 worker).

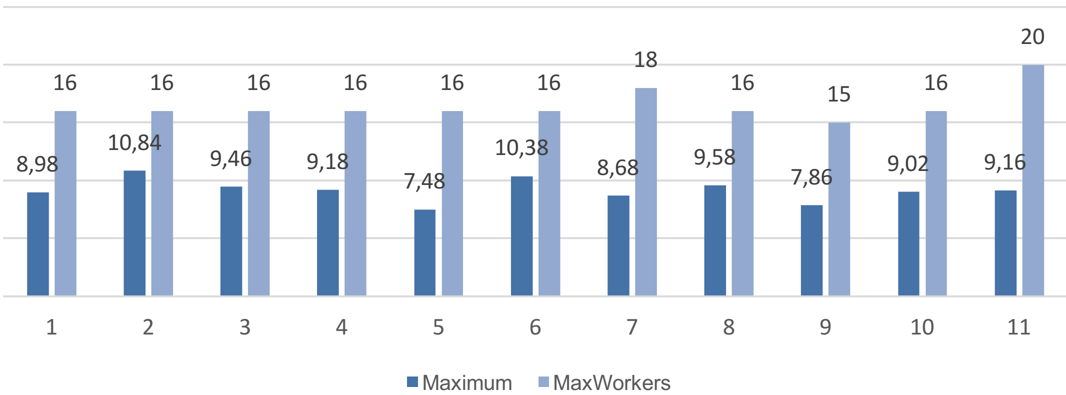

Figure 5.22. Maximum Number of Workers

From the observation of the maximum workers graph (Figure 5.22), the best scenarios in terms of maximum utilization of worker are C9 (8 for travelling and 15 for loading and unloading) followed by C5 (8 and 16) and C1 (9 and 16). Due to the importance of workers in every institution, especially in one that depends so much on their performance like this one, this will influence the final conclusions and recommendations, namely when considering C7 and C11, since they have the worst workers' utilization.

5.4. Results Conclusions

In this section, conclusions are made on the previously presented results.

First, the three scenarios representing the temporary storage policies were compared. Results showed similarities in almost every KPI for the three except travel times, in which the "Minimum Distance" policy presented a reduction 22% in time travelling.

The second variable evaluated was the non-preferential dock door assignment where it was concluded that no scenario is better than the first (Minimum Distance). However, C6 has the advantage of pallets spending less time in the system (but 12.7% more travelling time) and C5 and C7 are almost equal to C1 in every aspect.

Results regarding the third experiments set: “Preferential” dock door assignment policies presented to be very similar to their “Non-Preferential” respective. Nevertheless, a slightly decrease in travel times showed the potential of “preferential” policies.

A fourth set of scenarios were experimented where “FCFS” truck scheduling policy was replaced with “Prioritize” with almost no alterations in the results. It was concluded that the equality in all the results regarding “Preferential”/ ”Non-Preferential” and “FCFS”/ ”Prioritize” comparisons are due to the high number of doors when compared to the number of trucks. This way, the cases where doors are occupied are rare and a “preferential” or “prioritize” policy will have no advantages.

In the last section, the allocation of workers was assessed in all scenarios simultaneously. Despite the Maximum utilization of workers presented to be homogeneous for almost every scenario, C9 revealed to be the best followed by C5 and C1, while the worst were C7 and C11.

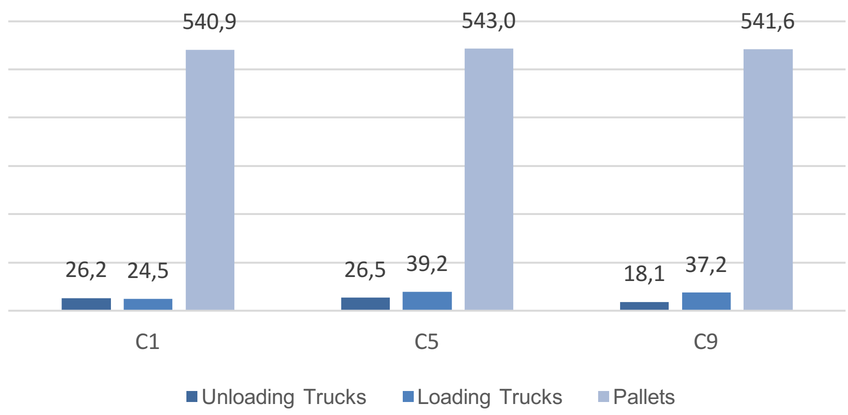

Figure 5.23. Average Time in System for C1, C5 and C9

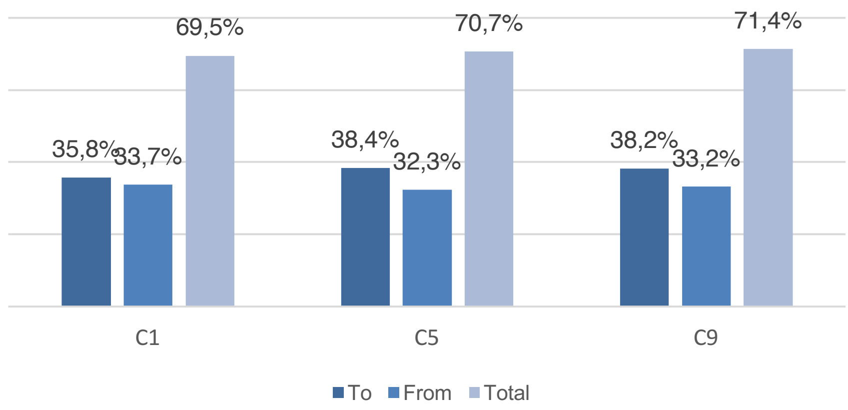

Figure 5.24. Average Percentage of Time Travelling for C1, C5 and C9

In Figures 5.23 and 5.24 the three scenarios with the best results in term of workers allocation are compared. Despite C1 shows lower values in the “Loading Trucks” time in the system (what should not be disregarded), the results are similar and owing to the importance of the workers, the author considers that, from the eleven scenarios tested C9 was the best, followed by C5 and C1. Table 5.6 shows the methods used in each scenario.

Table 5.6. Best Scenarios

Scenario	Temporary Storage	Dock Door Assignment	Truck Scheduling
C1	Minimum Distance	Preferential	FCFS
C5		Exclusive 9/9 Alter.	
C9		Exclusive 9/9 Alter. Pref.	

Results show that the dock door assignment policy of having an exclusive service mode with alternated doors for loading and unloading requires a lower maximum number of workers than any other policy.

Despite C5 showed worse results than C9, due to being non-preferential, it may have an easier implementation and advantages that cannot be seen in the results. For example:

- Operators know in advance the doors where inbound and outbound trucks will be for each pallet so they can make better decisions about space allocation;
- Drivers already know where to unload/load so they can leave the trucks in the right place before handling with the necessary bureaucracy;
- Managers have more information and less uncertainty which allows to try new policies, for example, having storage areas dedicated to origins or destinations.

Nevertheless, the author strongly believes that both “Preferential and “Prioritize” methods would have better results in a situation where there were less doors or more trucks to serve, considering the best solution to be C9.

Chapter 6. Conclusions and Future Work

6.1. Summary

The present dissertation is intended to assess and make recommendations for the problem proposed by the Luís Simões Group which consists in optimizing the cross-coking operations being held at the AZ1 warehouse, located in Azambuja.

With this objective in mind, a description of the company and the warehouse were presented, with emphasis on the cross-docking operations. After a better understanding of the case in hands, the relevant literature was reviewed and the approach was chosen. Having chosen simulation as the most suitable methodology for the problem, a model was constructed with the objective of imitating the real life operations at AZ1 as accurately as possible. The next step was to decide the solutions search strategy and, consequently, the results space. This led to eleven different scenarios constructed varying the methods of three of the identified cross-docking problems: temporary storage, dock door assignment and truck scheduling. Despite not having constructed scenarios relatively to the allocation of workers and team management, these have been considered in the results and conclusions. Then, those scenarios were assessed and the results of all the performance indicators were compared, aiming at finding the best solution within the proposed ones. In the end, conclusions are made and recommendations are given.

In the case study, it became evident which problems should be addressed in future work. These were the dock door assignment problem, truck sequencing, layout design, reducing time windows, reducing conference times and team management.

After this preliminary analysis, a literature review revealed that most of these problems are common in a cross-docking system and have been studied throughout the last decades. Therefore, it was not difficult to find many different approaches to the problems. A synthesis of these approaches is then presented in the summary of the chapter allowing a better understanding of the options, in terms of formulations, frameworks and methods to be used. It is concluded that there is a need for an integrated approach that addresses the various aspects of cross-docking operations mentioned above as well as their interactions which determine the global system performance and, for this reason simulation was chosen to approach the problem.

The following stages were to choose, within simulation, the most adequate technique and subsequently the software to be used. Since cross-docking operations at AZ1 are easily described as a sequence of discrete processes, discrete event simulation was chosen and SIMUL8 software was used to create a simulation model. After designing the conceptual model, its implementation followed. Note that, the data presented in this chapter was collected *in loco* by the author. Due to the dimensions and complexity of the real world system, many difficulties were felt in this stage. First, in the collection of data, needed to define the duration of every activity as well as possible interactions between activities and resources, more than one person at the scene would lead to better results. As we are dealing with as U-shaped facility, with more than twenty-thousand square meters, doors are all located in the same side of the warehouse what makes it impossible for only one person to observe every operation happening at the same time.

In what SIMUL8 is concerned, the major difficulties were in the allocation of workers, the allocation of storage spaces and the separation process. The first because, using the standard features of resources allocation of the software, the real world would not be accurately represented. So, with consultation from the author's supervisor, a solution was found. The other difficulties were due to the complexity of the conceptual model compared to the author's experience in SIMUL8 and were solved resorting to the software's support system.

Despite having some limitations, the final result of the model was consistent with the conceptual model designed and described the real world accurately. The major limitations being:

- Depends on external data treatment since inputs have to be in Excel format with specific requirements;
- Due to the previous limitation, it does not depend on random factors (only the durations' distributions) restricting the result analysis;
- The number of workers is not limitative which is why the allocation of workers was not considered to the scenario construction;
- Gate was not considered due to lack of data;
- If a pallet is not in the storage area when the respective truck arrives, the pallet stays in the warehouse until the next truck with the same destination arrives. This inhibits the evaluation of truck delays in these type of situations.

The next step was defining the scenarios to be tested, keeping in mind the above mentioned limitations and the data available. To this end, an "intelligent" search strategy was conducted to complement the "traditional" strategy of testing all the combinations. This means that, for each variable, a traditional search strategy was used, and within variables an "intelligent" search. The results space found consisted in eleven sequentially constructed scenarios.

6.2. Results

The last two sections of the present report intend to present, assess and make conclusions about the experiments results. The outputs of the model for each scenario were then treated and analyzed. The main conclusions to be drawn from this dissertation, grounded on the attained results, as the temporary storage methods is concerned are:

- A policy that minimizes the distance travelled within the warehouse shows better results than storing near inbound or near outbound.

As for the dock door assignment methods:

- An exclusive service mode with alternated doors for loading and unloading is better that the other exclusive and dedicated policies tested.
- Preferential policies do not enhance non-preferential policies results.
- However, in what workers' allocation is concerned, the preferential exclusive alternated method is better than the non-preferential respective.

As for the truck scheduling methods:

- No difference between the two methods except in terms of workers allocation, in which FCFS had better results.

As a result:

- The scenario with the best results consists in the combination of "minimum Distance" temporary storage policy, "Exclusive 9/9 Alternated Preferential" dock door assignment policy and "FCFS" truck scheduling method.

6.3. Recommendations

With the case study analysis, literature review and conclusions provided by the model and its results, this dissertation can sum its main contributions, specifically for AZ1 and in general for cross docking operations.

For AZ1, the author suggests taking into consideration the storage space allocation that minimizes the travel distance and, consequently, time. Despite the necessary information not being always available, results showed the importance of considering both doors when choosing where to temporary store pallets. Furthermore, an exclusive alternated dock door assignment policy should be tested in real life since its implementation should be easygoing and with no expected costs associated. This way, if results' conclusions were confirmed, a decrease in time and possibly in cost would materialize. As for the two proposed methods "Preferential" and "Prioritize", the author believes that their implementation should be considered due to the advantages it may bring in situations where the number of trucks to be served is larger than the number of available doors.

For cross-docking operations in general, the same recommendations apply, with emphasis on "Minimum Distance" temporary storage and "Prioritize" truck scheduling policies since the methods for the dock door assignment depend on the facility's dimensions, number of doors and layout shape and should be adapted accordingly.

6.4. Future Work

Future work to be developed regarding the presented model should focus on the above presented limitations, namely:

- Collect and statistically treat more data in a way that the arrival of trucks and pallets can be approximated to distributions and inserted in the software. This way, different situations can be tested and for longer periods of time.
- Improve the model in what workers allocation is concerned so that scenarios can be constructed varying the number of available operators and assessing its impact.
- Include the loading operations at the gate.
- Model situations where trucks wait for pallets that have not arrived to the warehouse at the time of their loading.

In addition to the improvement of the model, there are other situations that could be considered in future work, for example:

- Situations where cross-docking products require picking, since it is a labor-intensive and time consuming operation.
- Situations where more than one worker loads or unloads a truck, since it may lead to a more efficient allocation of workers and reduced times in the system for trucks.
- Other methods of the variables used should be experimented, for example, a storage area allocation policy by origins and destinations.
- Other decision variables can be assess by adding complexity to the model, namely time windows and conference times.

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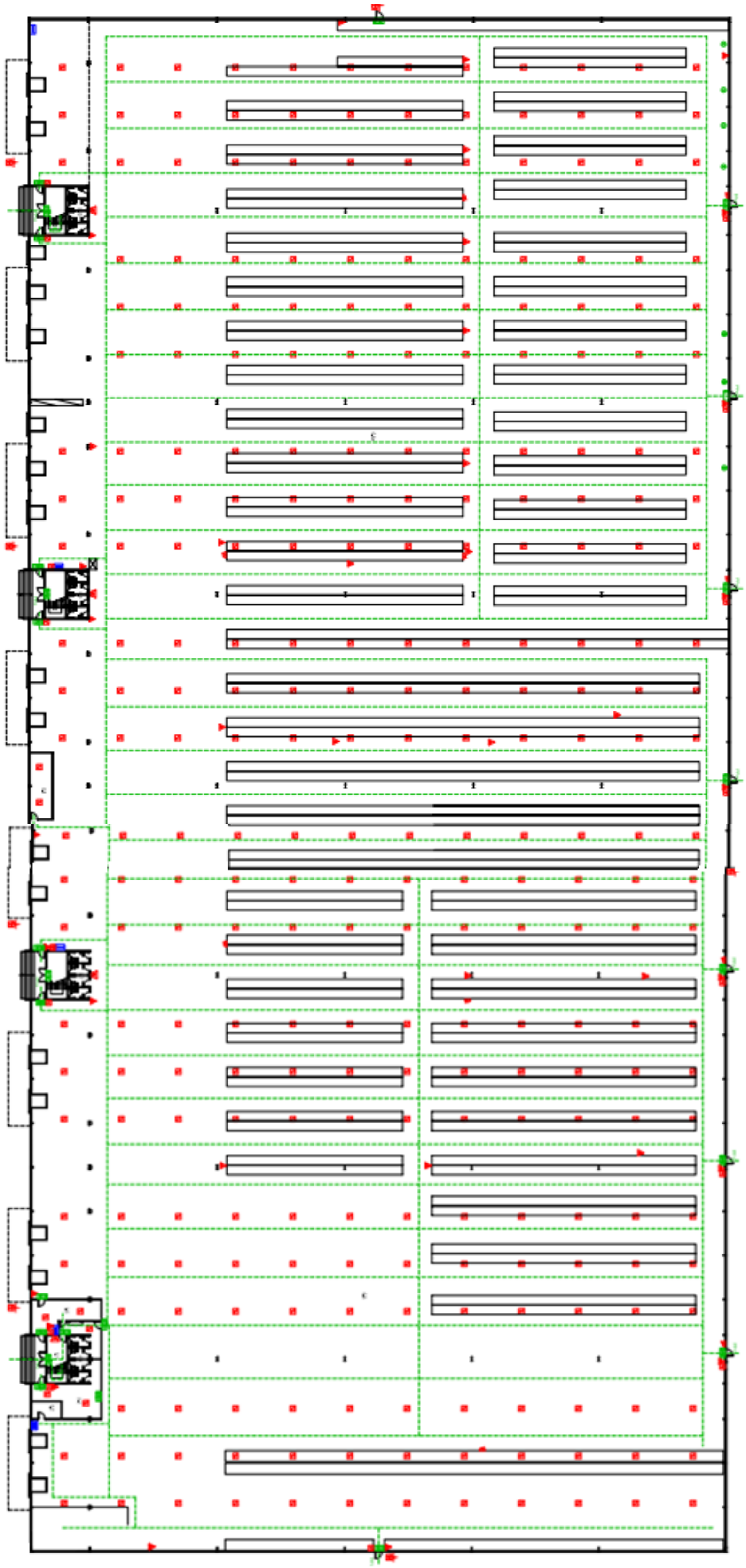
APPENDIXES

APPENDIX I - AZ1 PLAN



APPENDIX II - SYNTHESIS OF THE PAPERS REVIEWED

Table II. 1. Synthesis of the papers reviewed

AUTHOR(S)	Objective	Controllable variables	Performance Measures	Methodology
Layout Design				
(Bartholdi & Gue, 2004)	Best shape	- Number of doors - Number of inbound doors - Assign destinations to doors - Pattern of Freight flow	Travel time	Computational experiments
(Heragu, et al., 2005)	Product allocation and area sizing	- Number of products - Annual demands - Order costs - Prices per unit load - Average time in storage for each product - Areas available - Cost of handling - Costs of storing - Space requirements	Handling and storage costs	Branch-and-bound Heuristic
(Hauser & Chung, 2006)	Lane arrangement	- Different areas within the facility - Distances between areas - Flow between areas	Travel distance	Genetic Algorithm
(Vis & Roodbergen, 2008)	Temporary storage locations	- Number and position of loading and unloading doors - Travel distances - Number of strorage rows - Length and width of each storage row - Storage capacity of each row	Travel distance	Linear Programming (minimum cost flow problem)

(Vis & Roodbergen, 2011)	Select routing and storage policies and set layout rules	- Maximum number of aisles - Maximum aisle length - Minimum sub aisle length - Maximum number of cross aisles - Minimum width of a cross aisle	Travel distance	Dynamic methodology
(Yanchang & Min, 2009)	Best shape	- Number of doors - Number of trucks - Time Windows - Distances between doors - Freight volume between trucks	Travel distance	Genetic Algorithm
(Gue & Kang, 2001)	Analysis of staging queues configurations	-	Throughput	Simulation

Dock Door Assignment Problem

(Tsui & Chang, 1990)	- Number of receiving and sipping doors - Distances between doors - Origins and destinations	Travel distance	Microcomputer based tool
(Tsui & Chang, 1992)	- Number of receiving and sipping doors - Distances between doors - Origins and destinations	Travel distance	Branch-and-Bound
(Bermúdez & Cole, 2001)	- Number of doors - Number of origins - Number of destinations - Distance between doors - Weight of loads from each origin to each destination	Travel distance	Genetic Algorithm
(Cohen & Keren, 2008)	- Number of doors - Number of origins - Number of destinations	Travel distance	Heuristic

	- Distance between doors - Weight of loads from each origin to each destination - Capacity of inbound truck - Minimum number of trucks that must contain freight for any destination.		
(Oh, et al., 2006)	- Number of doors - Number of origins - Number of destinations - Distance between doors - Weight of loads from each origin to each destination	Travel Distance	Three-phase heuristic Genetic Algorithm
(Bartholdi & Gue, 2000)	- Number of doors - Number of origins - Number of destinations - Distance between doors - Weight of loads from each origin to each destination - Number of forklifts - Storage space in front of each door	Travel time Congestion	Simulated Annealing
(Gue, 1999)	- Set of strip truck - Set of destination truck - Weigth of freight from each inbound truck for each destination - Distance between doors - Total weight of freight for each destination - Capacity of each inbound truck	Travel time	Simulation
(Bozer & Carlo, 2008)	- Number of doors - X and Y coordenates of each door - Weight of loads from each inbound truck to each outbound truck	Workload	Simulated Annealing
(Yu, et al., 2008)	- Number of pallets inside each trailer - Destination of each door - Travel time between doors - Average pallet loading and unloading time	Workload	Local Search Genetic Algorithm
(Lim, et al., 2006)	- Number of doors - Number of trucks arriving and/or departing	Total shipping distance	Tabu Search Genetic Algorithm

	- Arrival and departure time of each truck - Travel time between doors - Number of pallets from each inbound truck to each outbound truck - Operational and penalty costs - Capacity		
(Miao, et al., 2009)	- Number of doors - Number of trucks arriving and/or departing - Arrival and departure time of each truck - Travel time between doors - Number of pallets from each inbound truck to each outbound truck - Operational and penalty costs - Capacity	Operational cost	Tabu Search Genetic Algorithm
(Stephan & Boysen, 2011)	- Number of doors - Width of terminal - Distance from door to horizontal aisle - Number of outbound destination served per inbound	Operational performance	Simulated Annealing
(Chmielewski, et al., 2009)	- Number of inbound and outbound doors - Earliest arrival times - Latest departure times - Set of destinations - Distances within facility	Travel distance Waiting time	Decomposition-and-column generation Evolutionary Algorithm
(Luo & Noble, 2012)	- Number of doors - Distances between doors - Quantity of freight from each inbound truck to eacha outbound truck - Capacity of each strorage lane -	Truck utilization Staging time	LINGO solver Genetic Algorithm
Temporary Storage			
(Vis & Roodbergen, 2008)	- Number and position of loading and unloading dock door - Travel distances - Number of storage rows	Travel distances	Linear Programming (minimum cost flow problem)

	- Length and width of each storage row - Storage capacity of each row		
(Sandal, 2005)	- Dimensions of boxes and containers - Weight limits	Truck utilization Staging space utilization Makespan	Simulation
(Werners & Wülfing, 2010)	- Number of inbound and outbound doors - Quantity of parcels - Delivery groups - Endpoints (staging spaces) - Distances	Transportation effort	Mixed-Integer Linear Programming software

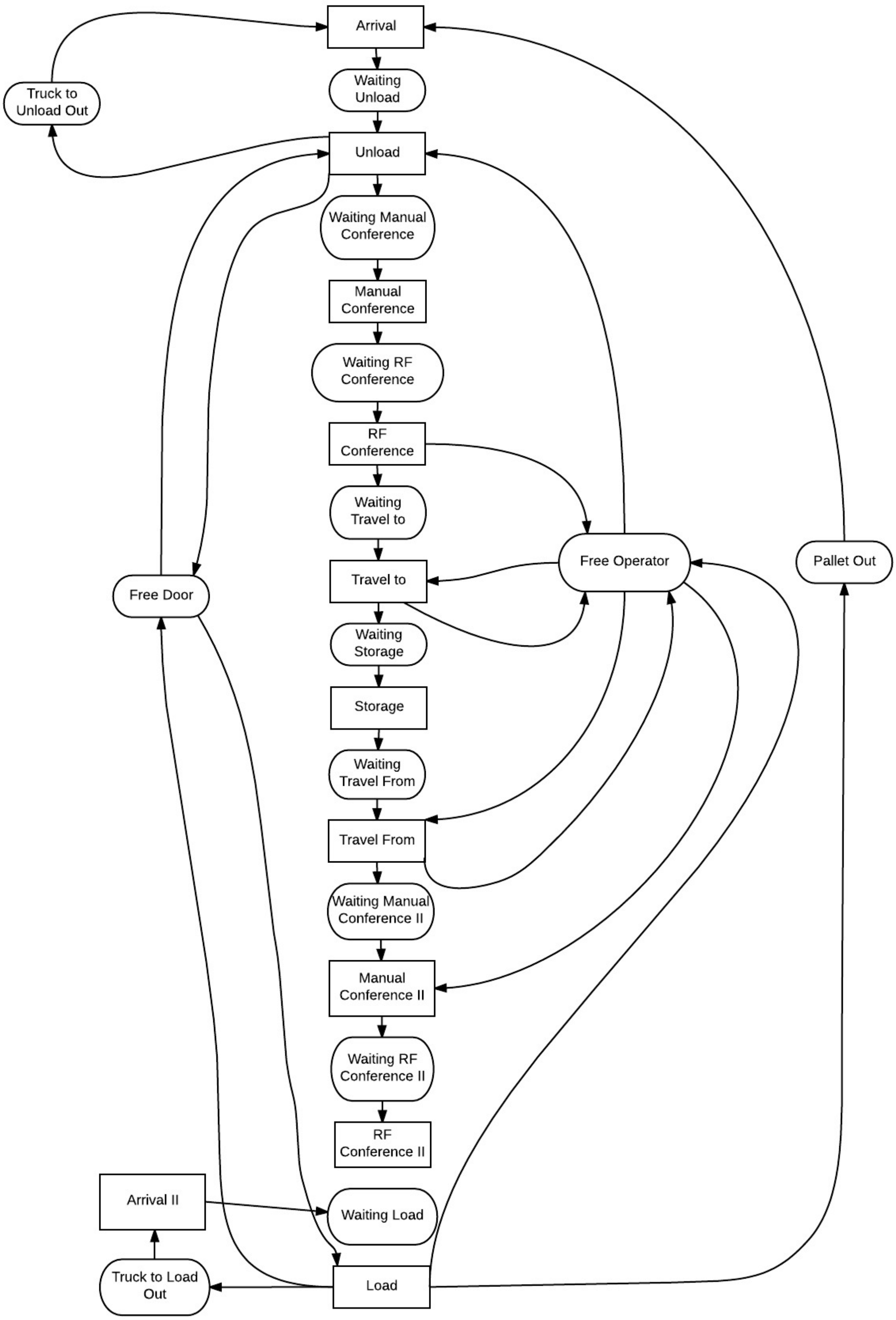
APPENDIX III - PERFORMANCE MEASURES

Table III. 1. Performance Measures III

AUTHOR(S)	Makespan	Travel Time	Travel Distance	Handling & StorageTCosts	Throughput	Congestion	Workload	Total Operational Costs	Operational Performance	Truck Utilization	Staging Time	Tardiness	Profit	Staging Space Utilization	Transportation effort
(Bartholdi & Gue, 2004)		X													
(Heragu, et al., 2005)				X											
(Hauser & Chung, 2006)			X												
(Vis & Roodbergen, 2008)			X												
(Vis & Roodbergen, 2011)			X												
(Yanchang & Min, 2009)			X												
(Gue & Kang, 2001)					X										
(Tsui & Chang, 1990)			X												
(Tsui & Chang, 1992)			X												
(Bermúdez & Cole, 2001)			X												
(Cohen & Keren, 2008)			X												
(Oh, et al., 2006)			X												
(Bartholdi & Gue, 2000)		X				X									
(Gue, 1999)		X													
(Bozer & Carlo, 2008)							X								
(Yu, et al., 2008)							X								
(Lim, et al., 2006)			X												
(Miao, et al., 2009)								X							
(Stephan & Boysen, 2011)									X						
(Chmielewski, et al., 2009)			X												
(Luo & Noble, 2012)										X	X				
(Arabani, et al., 2010)												X			
(Arabani, et al., 2012)	X											X			
(Arabani, et al., 2011a)	X														
(Arabani, et al., 2011b)	X											X			
(Boysen, et al., 2010)	X														
(Forouharfard & Zandieh, 2010)											X				

(Larbi, et al., 2011)				X											
(Liao, et al., 2012)	X														
(Liao, et al., 2013)												X			
(Vahdani & Zandieh, 2010)	X														
(Yu & Egbelu, 2008)	X														
(Vahdani, et al., 2010)	X														
(Chen & Lee, 2009)	X														
(Briskorn, et al., 2010)	X											X			
(Alpan, et al., 2011)				X											
(Boysen & Fliedner, 2010)												X			
(Boysen, et al., 2013)													X		
(Rosales, et al., 2009)								X							
(McWilliams, 2009b)	X														
(McWilliams, 2010)	X														
(McWilliams, et al., 2008)	X														
(McWilliams & McBride, 2012)	X														
(McWilliams, 2009a)							X								
(Wang & Regan, 2008)	X	X			X										
(Miao, et al., 2009)								X				X			
(Chen & Song, 2009)	X														
(Boysen, 2010)	X											X			
(Belle, et al., 2013)												X			
(Shakeri a, et al., 2012)	X														
(Ley & Elfayoumy, 2007)	X														
(Sandal, 2005)	X									X				X	
(Werners & Wülfing, 2010)															X
Total (53)	20	4	11	3	2	1	3	3	1	2	2	9	1	1	1
%	38	8	21	6	4	2	6	6	2	2	4	17	2	2	2

APPENDIX IV - LIFE-CYCLE AND ACTIVITY-CYCLE DIAGRAMS



APPENDIX V - SIMUL8 MODEL

The model developed in SIMLU8 is available in the accompanying CD, inside the folder “Digital Appendices”, under the name “A.V – Model”.

Note that, to run and analyze the model, SIMUL8 must be installed.

APPENDIX VI - VISUAL LOGIC

```
⊟-- A Count Action Logic
  |-- SET C1 = C1+1
  |-- SET NoPal_1 = C1
  ⊟-- IF Entity_Type_ = 1
  |    └-- SET TRAVEL  TIME FROM = ssTravelTimes[2,Storage_Space]
```

Figure VI. 1. “A Count” Activity’s VL in SIMUL8 Software

```
⊟-- Allocate Worker Route In After Logic
  |-- SET U1.Max size = 0
  |--
  |--
  |-- SET W1 = W1+1
  ⊟-- IF W1 > MaxWorkers
       └-- SET MaxWorkers = W1
```

Figure VI. 2. “Allocate Worker” Activity’s VL in SIMUL8 Software

```
⊟-- Allocate Worker II Route In After Logic
  |--
  |--
  |--
  |-- SET W1 = W1+1
  ⊟-- IF W1 > MaxWorkers
       └-- SET MaxWorkers = W1
```

Figure VI. 3. “Allocate Worker II” Activity’s VL in SIMUL8 Software

```
⊟-- Load 1 Pallet Action Logic
  |--
  ⊟-- IF NoPal_1 = 0
  |    |--
  |    ⊟-- IF Operator__ = O1
  |    |    └-- Move Work Item To   Release Worker II , 0-1
  |    ⊟-- ELSE
  |         └-- Move Work Item To   Exit , 0-1
  ⊟-- ELSE
       └-- Move Work Item To   Exit , 0-1
```

Figure VI. 4. "Load 1 Pallet” Activity’s VL in SIMUL8 Software

```
⊟-- Load 1 Pallet Before Exit Logic
    |--
    ⊟-- IF NoPal_1  =  1
        ⊟-- IF Operator__  =  01
            ⊟-- IF Free Workers.Current Available  =  0
                └-- Block Current Routing
```

Figure VI. 5. "Load 1 Pallet" Activity's VL in SIMUL8 Software II

```
⊟-- Manual Conference II Action Logic
    ⊟-- IF NoPal_1  =  1
    |   |--
    |   ⊟-- IF Operator__  =  01
    |   |   └-- Move Work Item To    Allocate Worker II ,  0-1
    |   ⊟-- ELSE
    |       └-- Move Work Item To    Queue for RFID Conference II ,  0
    ⊟-- ELSE
        └-- Move Work Item To    Queue for RFID Conference II ,  0-1
```

Figure VI. 6. "Manual Conference" Activity's VL in SIMUL8 Software

```
⊟-- Manual Conference II Before Exit Logic
    |--
    ⊟-- IF NoPal_1  =  1
        ⊟-- IF Operator__  =  01
            ⊟-- IF Free Workers.Current Available  =  0
                └-- Block Current Routing
```

Figure VI. 7. "Manual Conference II" Activity's VL in SIMUL8 Software

```
⊟-- Queue 3_4 On Entry Logic
    |-- Obeyed just after a work item enters the Queue
    └-- SET 3_4.Max size  =  Queue 3_4.Max size-Queue 3_4.Count Contents
```

Figure VI. 8. "Queue 3_4"'s VL in SIMUL8 Software

```
⊟-- Queue 3_4 On Exit Logic
    |-- Obeyed just after a work item exits the Queue but before it begins travelling to the next object
    └-- SET 3_4.Max size  =  Queue 3_4.Max size-Queue 3_4.Count Contents
```

Figure VI. 9. "Queue 3_4"'s VL in SIMUL8 Software II

```
⊟-- Release Worker II Route In After Logic
    └-- SET W1 = W1-1
```

Figure VI. 10. “Release Worker II” Activity’s VL in SIMUL8 Software

```
⊟-- Release Worker Route In After Logic
    ├-- SET U1.Max size = 100
    └-- SET W1 = W1-1
```

Figure VI. 11. "Release Worker” Activity’s VL in SIMUL8 Software

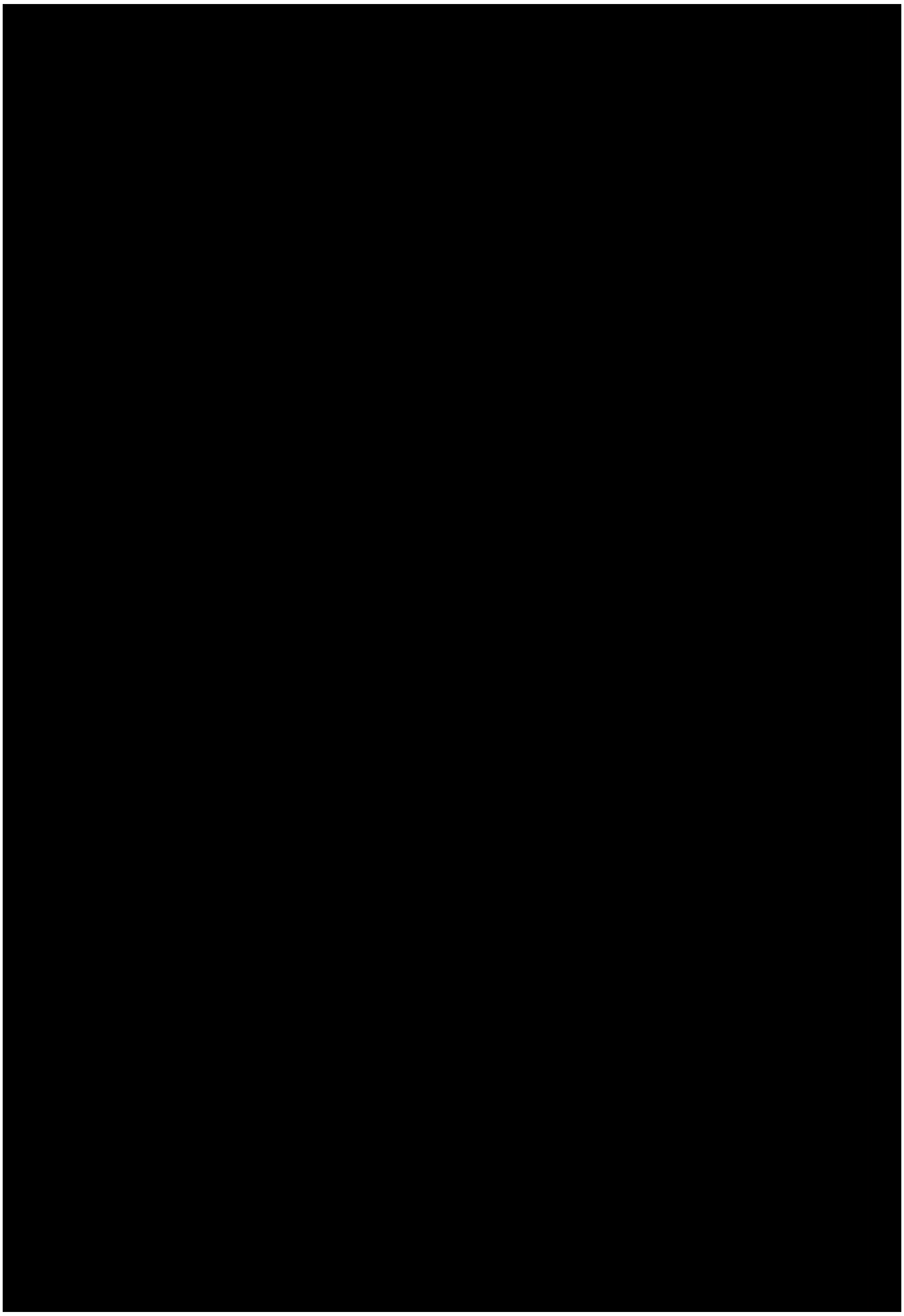


Figure VI. 12. On Reset VL in SIMUL8 Software

[redacted]

Figure VI. 13. On Reset VL in SIMUL8 Software II

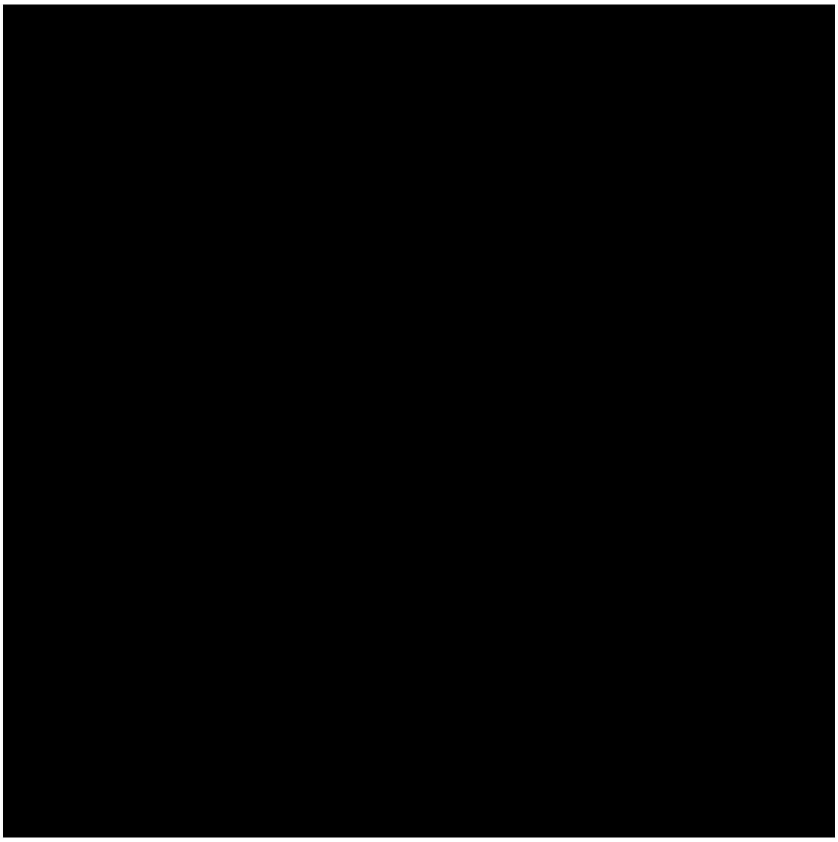


Figure VI. 14. On Reset VL in SIMUL8 Software III

Figure VI. 15. “RF Conference” Activity’s VL in SIMUL8 Software

Figure VI. 16. “RF Conference” Activity’s VL in SIMUL8 Software II

Figure VI. 17. “RFID Conference” Activity’s VL in SIMUL8 Software

Figure VI. 18. “Separation” Activity’s VL in SIMUL8 Software

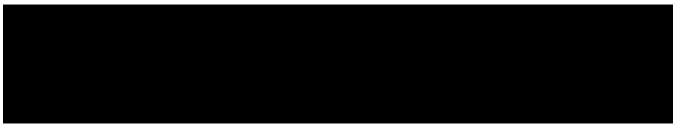


Figure VI. 19. “Set Label 3_4” Activity’s VL in SIMUL8 Software

Figure VI. 20. “Sorting” Activity’s VL in SIMUL8 Software

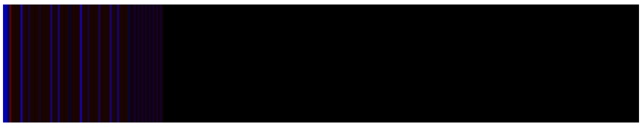


Figure VI. 21. “Unload 1 Pallet” Activity’s VL in SIMUL8 Software

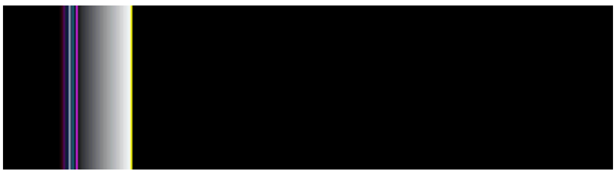


Figure VI. 22. “Unload 1 Pallet” Activity’s VL in SIMUL8 Software II

APPENDIX VII - ARRIVALS

Due to the extensive size of the data, the arrivals' information that served as input for the simulation model is available in the Excel file "A.VII – Arrivals", inside the "Digital Appendices" folder of the accompanying CD. The file contains two sheets: "Arrivals_1" for pallets and trucks to unload and "Arrival_2" for trucks to load.

Note that the content of this file was explained in detail in chapter 4.2.3.

APPENDIX VIII - TRAVEL TIMES

Due to its extensive size, the table containing travel times used in the simulation model is available in the Excel file “A.VIII – Travel Times”, inside the “Digital Appendices” folder of the accompanying CD.

Note that the content of this file was explained in detail in chapter 4.2.2.

APPENDIX IX - TEMPORARY STORAGE PRIORITIES

Due to its extensive size, the tables containing temporary storage priorities used in the simulation model is available in the Excel file "A.IX – Temporary Storage Priorities", inside the "Digital Appendices" folder of the accompanying CD. The file contains nineteen sheets being the first ("Priority") the input for "Near Inbound" and "Near Outbound" policies while the remaining ("Door 1" to "Door 18") represent the priorities for each door in the "Minimum Distance" policy.

Note that the construction of the tables in this file was explained in detail in chapter 5.1.1.

Appendix X - Door Allocation Priorities

Due to its extensive size, the tables containing door allocation priorities used in the simulation model is available in the Excel file "A.X – Door Allocation Priorities", inside the "Digital Appendices" folder of the accompanying CD. The file contains six sheets representing the preferences for loading and unloading trucks in the three preferential scenarios.

Note that the use of this file was explained in detail in chapter 5.1.2.

APPENDIX XI - RESULTS

Due to its extensive size, the tables containing the outputs of the simulation model is available in the Excel file “A.XI – Results”, inside the “Digital Appendices” folder of the accompanying CD. The file contains the results for each KPI (row) in each scenario (column). The results presented in Chapter 5 are the outcome of the data here presented after being properly organized and treated.