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

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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 concentrate 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 work 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.

Results revealed 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.

Keywords: Logistics, Cross-docking, Simulation model

1. Introduction

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.

2. Case Study

2.1 The Company

Luís Simões is a major Portuguese logistics operator currently providing logistics services to companies primarily in Portugal and Spain. Nowadays it consists in 10 legally independent companies, grouped into three areas of business: transportation, logistics and diversification.

2.2 The 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. The warehouse has a U-Shaped layout since all the eighteen doors are on a single side. Inside the warehouse, with total area of 20 000 m2, material is carried by forklifts, pallet trucks and hydraulic claws for cartons.
For normal storage purposes there are 30 structures along the facility, while cross-docking products are stored in the areas between doors and in front of those structures at ground level.
The main processes that cross-docking products undergo are reception, temporary storage and dispatch (with the respective preparation) and are represented in Figure 1.

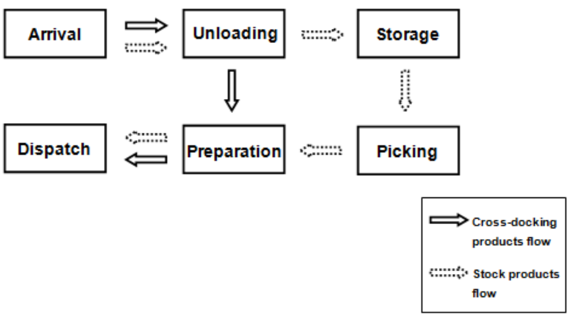

Figure 1 - AZ1 Processes

3. 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).
Despite the several cross-docking problems found in the literature, only three were considered relevant to the present work and are going to be presented in the following sections.

3.1 Temporary storage

The first 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.

3.2 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).
Fourteen papers were reviewed dating from 1990 to 2012 and three possible methods were found:
• 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

3.3 Truck Scheduling

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.

3.4 Performance measures

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.

3.5 Conclusions

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.

4. Model Development

4.1 Justification of the Methodology Choices: Why Simulation?

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 work purposes.

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.

The main advantage of simulation is that it allows to test theories without incur in unnecessary costs or labor, and for this reason is 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

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 of three main components: a database, a list of events, and a simulation clock.

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 2.

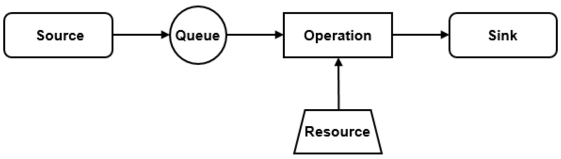

Figure 2 - Basic Discrete Event Model with resources (adapted from: Faria, 2015)

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.

4.2 Model description

4.2.1. Objectives

The purpose of the developed 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 view (s) 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 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: Unloading, Manual Conference, RFID Conference, Travel to, Travel from, RFID Conference II, Manual Conference II and Loading. 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 a external XLS file containing real data provided by the company.
- **Trucks to unload**: temporary entities involved in the Unloading activity. Arrivals are defined by a 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 1.

Table 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 2 and Figure 3) was performed with the available data and, based on the results, a table 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 2 - Descriptive statistics of the Linear Regression Variables

Variable	Obs.	Min.	Max,	Mean	Std. Dev.
Y1 (min)	58	6,368	138,246	48,203	33,856
X1 (m)	58	20,000	221,000	68,603	47,681

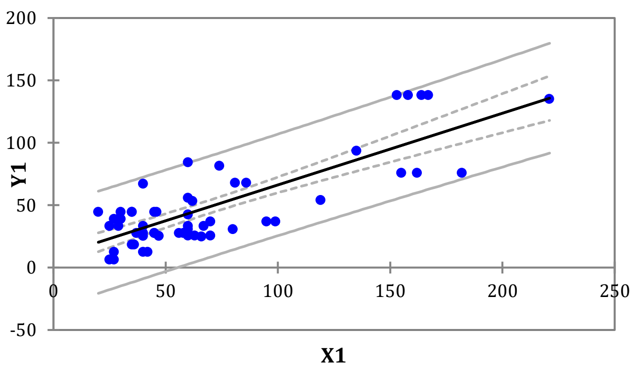

Figure 3 - Y1 Variable Regression

The equation of the estimated model is:
Model Equation: Y1 = 8,794+0,574*X1
Adjusted R^2 = 0.648

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. In the next sections, each part of the implemented model will be explained.

a. *Arrival*

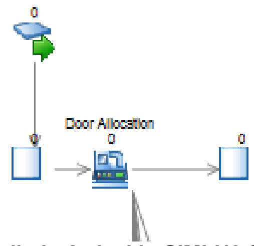

Figure 4 - Pallet's Arrival in SIMLU8 Software

The arrival of pallets is represented by a "Start Point" which will receive information from a spread sheet imported from Excel. This spread sheet contains eight columns (correspondent to the pallets' attributes).
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*

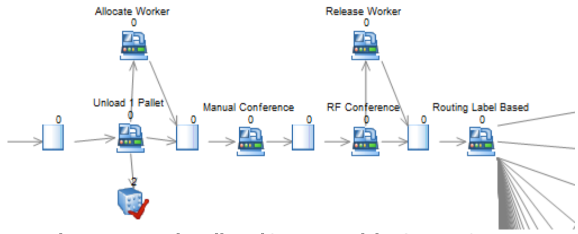

Figure 5 - Unloading (One Door) in SIMLU8 Software

In Figure 5 there is represented the set of the activities that are linked with each door. In the complete model 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 analyses of the queues’ results. In this case, all queues have the standard definitions (infinite capacity, no minimum time waiting…) and the activities are defined according to the conceptual model being the dummy activities used to accurately model the allocation of workers (that is having one and only one worker unloading and conferencing all the pallets in the same truck) and the temporary storage policy (that depends on the scenario).

c. Temporary Storage

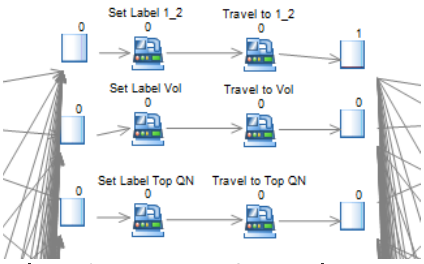

Figure 6 - Temporary Storage (representation of three storage spaces of eighty-five: 1_2, Vol and Top QN) in SIMLU8 Software

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 6. The two activities represented were introduced to model the travel times within the warehouse. Pallets will wait in the second queue until the correspondent truck to load arrives.

d. Loading

As Figure 7 shows, the loading process is very similar to unloading, the main differences being:

• “Separation”, which is a “dummy” activity that will collect all the pallets when a truck arrives to load;

• “A Count”, which is a “dummy” activity created to accurately model the allocation of workers.

• “Travel from”: activity that represents the transfer of each pallet from the storage space to the respective loading dock door.

• “Sorting”: “dummy” activity that forwards work items based their type so that truck and pallets are sorted and the respective times in the system can be computed.

e. Arrival of Trucks (to be loaded)

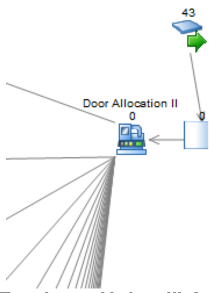

Figure 8 - “Trucks to Unload” Arrival in SIMLU8 Software

The process is equal to the arrival of pallets and trucks to load. The arrivals’ information is imported from excel and the “Door Allocation” activity’s routing out policy is based on the dock door assignment chosen.

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

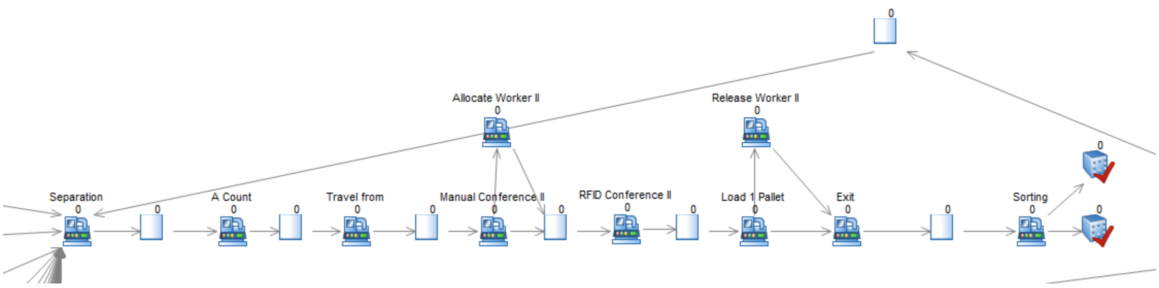

Figure 7 - Loading (One Door) in SIMLU8 Software

number of hours worked by employees. With this in mind, the chosen KPI's and the respective collection method are described below.

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 type 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 time". 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.

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 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 an 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 time", 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.

5. Case Study Application

5.1. Scenarios

5.1.1. Layout/Temporary Storage

Based on the literature review and on the available data provided by LS, the three temporary storage policies that were chosen for testing are:

• 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 Visual Logic in the activity "Routing Label based" that would allocate storage spaces according to each policy.

5.1.2. Dock Door Assignment Problem

The chosen policies for the dock door assignment problem were the three found in the literature (exclusive, dedicated and mixed), however, details had to be defined for each one, resulting in the following methods:

• 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).
• 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.

5.1.3. Truck Scheduling

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 consist in the common method of serving each truck by order of arrival and the second consists in prioritizing the trucks which contain pallets that will leave the facility earlier.

5.1.4. Solutions Search Strategy

In the present work, having three different variables and three, seven and two methods, 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 not to make those mistakes, 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.

5.1.5. Results Space

The result of the chosen search strategy was the eleven scenarios shown in Table 3.

Table 3 - Results Space

Scenario	Temporary Storage	Dock Door Assignment	Truck Scheduling
C1	Minimum Distance	Preferential	FCFS
C2	Near Outbound		
C3	Near Inbound		
C4	Best	Exclusive 9/9	
C5		Exclusive 9/9 Alter.	
C6		Shift Exclusive	
C7		Dedicated	
C8		Exclusive 9/9 Pref.	
C9		Exclusive 9/9 Alter. Pref.	
C10		Best Preferential	Prioritize
C11		Best Non-Preferential	

5.3. Results

5.3.1 Temporary Storage

Results showed similarities in almost every KPI for the three except travel times, in which the "Minimum Distance" policy presented a difference of less 22% time travelling.

5.3.2 Dock Door Assignment Non-Preferential

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 (but 12.7% more travelling time) and C7 is almost equal to C1 in every aspect so it should be further studied.

5.3.3 Dock Door Assignment Preferential

The "Preferential" scenarios C1, C8 and C9 showed similar results to their respective "Non-Preferential" scenarios C7, C4 and C5. Nevertheless, a slightly decrease in travel times showed the potential of "preferential" policies.

5.3.4 Truck Scheduling

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 elevated 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.

5.3.5 Number of Workers

Lastly, 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 with a maximum of eight workers for travelling and fifteen for loading and unloading) followed by C5 (8 and 16) and C1 (9 and 16), while the worst were C7 (9 and 18) and C11 (10 and 20).

5.4. Results Conclusions

For a better assessment of the results, the three best scenarios were compared with each other.

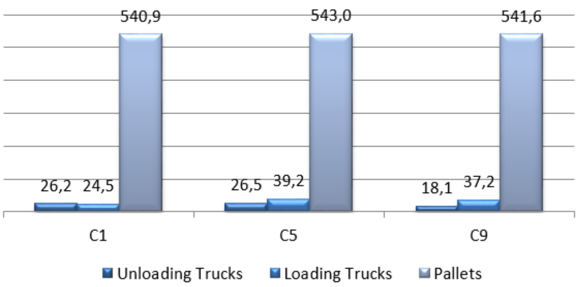

Figure 9 - Average Time in System for C1, C5 and C9

In Figures 9 and 10 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.

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.

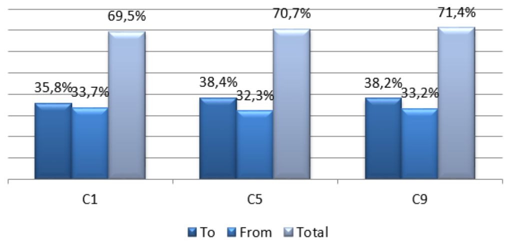

Figure 10 - Average Percentage of Time Travelling for C1, C5 and C9

Table 4 - 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.	

6. Conclusions and Future Work

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.

With the case study analysis, literature review and conclusions provided by the model and its results, this work 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.

Future work to be developed regarding the presented model should focus majorly on the model's 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.

• 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.

7. References

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