A SIMULATION MODEL FOR DISTRIBUTION WAREHOUSES

by

Gülizar Hoyur

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ABSTRACT

A SIMULATION MODEL FOR DISTRIBUTION WAREHOUSES

The aim of this study is to aid logistics companies in their strategic and operational decision making processes in a fierce competition environment. With this point of view, an Arena-based simulation model has been developed. This model provides a fast, flexible and effective method to enable the company to understand its warehousing system and the relationship between system elements comprehensively, recognize the effects of the changes on the system in detail, and make immediate and appropriate changes within the system according to the outputs of the model.

Strategic decisions include determining the required number of slots and docks, and identifying the necessary amount of labor and equipment during system design of new, large warehouses. The simulation model is a useful tool in the operational decision making process for obtaining valuable knowledge about operational characteristics of the warehouse, planning the shifts, and evaluating needed changes in the amount of fork lifts and labor in case of decrease in the warehouse traffic. Moreover, the model can be utilized to investigate equipment and labor requirements for each hour of a day, if there are scheduled arrivals with definite number of incoming and outgoing trucks. Benefiting from the outputs of the simulation model, the third party logistics company can meet customer expectations of prices, qualities and varieties in warehousing operations more efficiently.

ÖZET

DAĞITIM DEPOLARI İÇİN BİR SİMÜLASYON MODELİ

Bu tezin amacı zorlu rekabet ortamında lojistik şirketlerine stratejik ve operasyonel karar verme süreçlerinde destek sağlamaktır. Bu bakış açısıyla Arena tabanlı bir simülasyon modeli geliştirilmiştir. Model şirketin depolama sistemini ve bu sistemin elemanları arasındaki ilişkiyi kapsamlı bir şekilde anlaması, değişikliklerin sistem üzerindeki etkilerini detaylı bir şekilde görmesi ve modelin çıktılarına göre sistem üzerinde anında ve uygun değişiklikler gerçekleştirebilmesi için hızlı, esnek ve etkin bir yöntem sunmaktadır.

Stratejik kararlar yeni, büyük depoların tasarımı sırasında gerekli slot ve kapı sayıları ile ihtiyaç duyulan iş gücü ve ekipman miktarlarının belirlenmesini içermektedir. Simülasyon modeli operasyonel karar verme sürecinde deponun operasyonel karakteristiklerinin anlaşılması, vardiyaların planlanması ve depo giriş-çıkış trafiğinde azalma olması halinde fork lift ve iş gücü miktarlarında ihtiyaç duyulacak değişikliklerin değerlendirilmesi için yararlı bir araçtır. Ayrıca modelden girecek ve çıkacak kamyon sayılarının belirli olduğu saat aralıkları için ekipman ve iş gücü ihtiyaçlarının araştırılmasında faydalanılır. Üçüncü parti lojistik şirketi, simülasyon modelinin çıktılarından yararlanarak müşterilerinin depolama işlemlerindeki fiyat, kalite ve çeşitlilik konularındaki beklentilerini daha verimli bir şekilde karşılayabilir.

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LIST OF SYMBOLS/ABBREVIATIONS

BOVs	Battery operated vehicles
IW	Integrated warehouse
LRC	Large remaining capacity
SKU	Stock-keeping unit
WIP	Work in process
DF	Degrees of freedom
MS	Mean squares
SS	Sum of squares

1. INTRODUCTION

Nowadays, many industrial manufacturing companies prefer not to hold inventory in their own factories in order to minimize their costs. They let their warehousing operations be managed by professionals called third-party logistics companies. Through the professional approach of these companies, conflicting objectives like providing faster and more efficient services with an increasing quality in order to maximize customer satisfaction, handling a large number of stock keeping units, and achieving the least possible cost are handled easily, accurately, and effectively. In addition to that, they establish an information system to update kinds and quantities of stored items on a real time basis.

When the significant demand for these extensive warehousing operations and promising profit possibilities in this range of business were noticed in Turkey, a lot of companies entered into this sector. According to this, fierce competition is experienced. In order to gain valuable customer satisfaction, which is a concept of increasing importance, in one hand the logistics companies have to raise quality and variety, and on the other hand they have to keep the price of their services lower than their competitors. As all the rivals have the same basic input, technology and labor power, they have to investigate the ways how they can achieve better price, quality and variety in order to create an advantage in the eye of the customers.

That advantage can be realized not only in the service itself, but in its implementation. Companies which don't provide customer oriented service, and don't meet customer expectations of prices, qualities and varieties in warehousing operations may not survive. The right way to solve all these problems lies in knowing the system comprehensively, understanding the relationship between its elements, and in the ability to make immediate and appropriate changes within the system. Especially in physically large, complex systems, simulation is a fast, flexible and effective method which may provide the companies with the feedback of how the changes may affect the system.

With this point of view, an Arena-based warehouse simulation model has been developed for one of Turkey's biggest logistics companies. This company has a non-automated warehousing system including receiving, put away, order picking, and dispatching processes.

The simulation model can be utilized both in strategic and operational decision making processes. In order to support this processes, with help of the simulation model the below issues are studied:

1. Determining required docks and required location capacity.
2. Identifying required amount of equipments and headcounts to be used in warehouse operations considering permissible dissatisfaction of customer. According to this permissible dissatisfaction level, the percentage of outgoing trucks which are leaving the warehouse after more than 45 minutes should not exceed 5%.

Furthermore, the simulation model can support the operational decision making process as follows:

1. Obtaining valuable knowledge about the operational characteristics of the warehouse such as percentages of effective usage of present resources, average waiting time of outgoing trucks in the shipment queues, average times for picking the orders of different docks' outgoing trucks, average time for loading time of a truck, and average time that outgoing trucks spent in the warehouse etc.
2. In case of the decrease in the warehouse traffic, evaluating needed changes in the amount of fork lifts and labor
3. Planning the shifts with breaks
4. Investigating equipment and labor requirements for each hour of a day, if there are scheduled arrivals with definite number of incoming and outgoing trucks

The thesis is organized as follows: In Section 2, various warehouse simulation models are reviewed. Section 3 contains real system description, model objectives, and input modeling. In Section 4, model implementation with Arena is discussed. First, a naive approach for detailed warehouse simulation, and then a simplified version of the model for flexible implementation with their advantages and disadvantages are given. Moreover, this section also involves policies and assumptions of the simulation model. Finally, at the end of Section 4, the model setting process is explained in detail. In Section 5, the simulation model is run for strategic decision making process, and in section 6, it is run for supporting operational decisions. Consequently, in the last section, conclusion and recommendations for further studies are considered.

2. LITERATURE REVIEW

Simulation is a fast, flexible and effective method which can support companies with physically large and complex systems both in strategic and operational decision making processes. In this section, researches about warehousing systems, and researches in which simulation is used in decision making processes of warehousing systems are briefly described.

Senko and Suskind (1990) have suggested that the risk in a warehouse designed without proper planning is poor customer service and high operating costs resulting from inefficiencies related to material handling, space utilization, inventory, throughput, equipment, and labor. Success or failure of a warehouse hinges on whether or not the design reflects the nature of the business. Many failures occur because the facility's planning team was unaware of the system's constraints and potential bottlenecks under the dynamic operating characteristics of the business. Thorough analysis coupled with simulation modeling can eliminate those problems in the planning stage, before it's too late (Senko and Suskind, 1990).

Muroff (1993) has indicated that every activity in a warehouse is based upon, and is affected by, its layout, and because of this warehouse managers are turning to computer simulation, a high-tech way of generating the most effective facility design. According to Young (2002), the ability to simulate a solution gives that solution a much greater chance of being implemented more successfully and quickly than if it were not simulated. Total warehouse simulations are believed to be rare. Simulation at the warehouse level can be used in the management of risk, the investigation of potential or proposed changes and the ongoing management and engineering of entire facilities. Banks (1998) has considered studying warehousing operations via computer simulation an effective and powerful approach to improve the performance or design more efficient warehouse.

Daniels et al. (1998) have discussed models of order picking systems in their articles. Cormier and Gunn have developed models for warehouse capacity expansion (1999). Macro and Salmi (2002) have dedicated their research to develop a simulation model to quantify rack utilization and capacity of different configurations of pallet racks and to determine the type, amount and layout of pallet storage in a warehouse.

The objective of the simulation model is to answer the following concerns:

- Determine the following effects on warehouse size:
  − Production run size
  − Age of warehouse stock
  − Incoming material transfer from other plants
  − Shipping lead-time
  − Outsourced items
  − Poor inventory control
  − Different rack/storage types
- Equipment/resource limitations
- Storage method efficiency
- Order picking method performance
- Layout efficiency.

These concerns affect the overall performance of a warehouse system according to Macro and Salmi (2002). Therefore, these items are considered as controllable factors of this system in their study. For each of these factors, there exists a set of different options that in some manner change the system (e.g., number of pallet racks). The simulation model of Macro and Salmi (2002) can be configured for each of these options. In order to compare and evaluate the options, they calculated a performance metric (e.g., rack utilization) that best quantifies the system performance for analysis and that have the most potential to change due to difference in options within the factor. Examples for performance metrics of controllable factors are as follows:

1. Storage Methods/Warehouse Management: Storage equipment utilization (%), average warehouse inventory, maximum warehouse inventory
2. Warehouse Crew Size: Operator utilization (%), hours to satisfy demand
3. Case Picking Methods: Picking duration, picking crew utilization (%), picking throughput (pallets/hr)

4. Customer Order Staging Capacity: Picking duration, staging utilization (%), picking throughput (pallets/hr)
5. Production Cycles: Production line utilization (%)

Applications of the model have been executed with success to analyze the storage capacity and rack efficiency of a medium volume, low stock-keeping unit (SKU) warehouse and a medium volume, large SKU warehouse. Each warehouse was experiencing an overcapacity situation and the owners were looking for solutions to their storage needs without having to resort to brick and mortar. Therefore, the different conceptual warehouse designs that included different rack type configurations were represented by the model. For each warehouse three significant output metrics; the rack utilization by rack type, the average and maximum number of pallets in storage were calculated. During the applications, existent historical data of production orders and customer orders has been converted into a format which the model had been able to read efficiently. According to the application results, Macro and Salmi (2002) have stated that the model is scaleable and can be modified to simulate any warehouse configuration, including selective racks, bulk floor storage, push-back, flow-through, drive-in and drive-through racks.

Kosfeld (1998) has constructed a simulation model to aid in the design of a new warehouse for Intel's new processors which were dramatically increased in speed and size over their ancestors in mid-1997. The increased size caused box volume to increase beyond the capacity of the existing warehouses. New warehouses were scheduled to be constructed and simulation modeling was used to validate each warehouse design. Kosfeld's simulation model (1998) identifies the labor and equipment required to support warehouse operations.

In Kosfeld's paper, an insight into the simulation model for one of the warehouses built recently, the Integrated Warehouse (IW), is provided. The objective of this simulation model is to recommend both headcount and equipment required to support warehouse operations. There are three items that make the IW simulation effort unique. First, the analysis is performed on a strategic level before the warehouse is built. Second, a new warehouse management system will be installed creating new operator jobs and eliminating some as Intel's warehouses move from batch processing to parallel processing of orders. Third, new battery operated vehicles (BOVs) and conveyor lines are purchased to support operations.

According to Kosfeld (1998), the target throughput out of the warehouse is composed of two pieces: the product plan and the surge rate. The product plan is the forecasted volume of each product type stored in the IW. Whereas the product plan looks forward, the surge rate is calculated by looking backward at historical shipping volumes and is defined as:

$$\frac{\text{End of quarter ship outs per day}}{\text{Average ship outs per day}}$$

Since ship outs increase dramatically at the end of a quarter, the new warehouse must be designed to handle this end-of-quarter surge in customer shipments.

As a starting point for the simulation model, static calculations were performed in a spreadsheet model to identify the number of operators and equipment by type with which to begin the simulation analysis. More operators and pieces of equipment were then built into the simulation model to allow analysis on varying combinations of operators and equipment. Warehouse start-up is not modeled, and time study data are not increased in an attempt to model an operator's first day in the warehouse.

Kosfeld (1998) has utilized two different methods in conjunction to determine if a given combination of headcount and equipment is able to meet a simulated volume of orders, or throughput. Firstly, WIP is tracked in the system over time at various order volumes. If the system is unstable below the target order volume, utilization of each operator and equipment type versus order volume is plotted. The operator or equipment type that crosses the utilization cutoff point first is identified. Resources are added to this bottleneck, and the model is rerun. These steps are repeated until the system is stable at or beyond the target order volume.

In Kosfeld's paper, the number of each operator and equipment type required at the end of the quarter is identified through the simulation analysis. The critical and non-critical areas in the new IW are highlighted for management, and solutions for handling the critical areas are explored. Recommendations to combine the job functions of some underutilized operators are also made to the IW management team (Kosfeld, 1998).

In addition to analyzing the WIP and utilizations for each operator and equipment type, two side analyses impacting the layout and design are also performed. The first analysis is performed on the queues located immediately after Picking and the second analysis is performed on the Consolidation Area located immediately after the Processing Workstations.

Kosfeld (1998) has observed that when the numbers of queue locations at the end of each aisle were reduced, there was a significant increase in the waiting time of the Picking BOVs. Therefore, to keep the BOVs picking instead of waiting, various queue sizes are analyzed, and the average BOV waiting time (due to a full queue) is recorded. Five queue locations at the end of each aisle are recommended through simulation to minimize BOV wait time.

The second queue analysis is performed on the consolidation area located immediately after the Processing Workstations. It is aimed that this area should be large enough to handle the volume in the consolidation area 90% of the time, assuming operations would use work-arounds to accommodate the other 10% of the time. Using the model, it is found how many boxes this area should accommodate.

The simulation analysis of Kosfeld (1998) proved very beneficial for both management and the Logistics industrial engineers. Management’s uncertainty about the new warehouse and warehouse management system was reduced after the model results showed the warehouse would be able to meet the target throughput. Furthermore, the new warehousing equipment could be purchased with confidence that the quantities would support the end-of-quarter surge.

Nowadays, the warehouse management has been asked to increase customer service, reduce inventories, handle a large number of stock keeping units, and improve space utilization. Warehouse management has realized that these conflicting objectives require a much more professional approach (Smith 1992). Galé et al. (2002) carry out a simulation study to identify potential improvements in the management of a non-automated distribution warehouse which is located between manufacturers and small retailers. The simulation model has been used to obtain valuable knowledge of the operational characteristics of the warehouse. It is aimed to understand the effect of an automatic storage upon the occupied space of the warehouse. Different scenarios are taken into account by using an experimental design technique. The analysis of the simulation results lead up to find out the value of the parameters causing the strongest effect on the performance measures, allow to assess the value of introducing changes provided the current storage procedure, and give important insights about the behavior of the whole system.

Gale et al. (2002) have built a simulation model using WITNESS. The factors to generate different scenarios are position size, number of days using the same location, location of products, and initial space. A 2^4 factorial design is used for providing the alternative system configurations. The maximum of necessary shelves over the time horizon is considered as response. It is investigated that how each factor affects the response, whether the factors interact with each other, and what are the combinations of factor levels that minimize the response. The proposed model provides a new and useful tool for the analysis of alternative management systems, at the lowest cost and with the least disruption to the storing operations (Galé et al., 2002).

Takakuwa et al. (2000) have presented a practical modeling method for performing simulation of complicated and non-automated distribution warehouses. The method consists of two phases: the program for generating parameters of materials handling and the simulation program. The simulation is performed by SIMAN/Arena. A series of the approaches for performing simulation are developed to evaluate the performance of the distribution warehouse. An overall procedure of the system for generating parameters is developed to perform simulation. All necessary input data are generated automatically on all operations at the distribution warehouse using this procedure. There are three major groups of input data: receiving/put away, order picking/truck loading, and replenishment operations. Regarding the number of reach-lift forklift trucks, two alternatives; one truck and two trucks; are examined by performing simulation experiment. The numbers of other types of forklift trucks are the same for both alternatives. By increasing the number of reach-lift forklift trucks, the replenishment operations were drastically shortened. The proposed modeling method is presented using an actual case to demonstrate the applicability to the actual large-scale and non-automated distribution warehouses (Takakuwa et al., 2000).

Zhou et al. (2005) have proposed a pattern-based modeling approach. This approach identifies and represents the key operational processes of warehousing as robust and reusable patterns. These patterns are used to build conceptual simulation models more efficiently and effectively. Issues in pattern-based modeling, such as structural and behavioral representations, model element definitions, classification and abstraction, are addressed in the research. A small example is presented to illustrate the proposed concept.

Burnet and LeBaron (2001) have created a flexible simulation model to be used as an engineering tool to validate automated warehouse designs, to predict resource requirements, and to determine operational throughput capacities for E-channel operations. The model's flexible demand generation and operating parameters allow potential clients to quickly witness "what-if scenarios" of their specific operations. The model has gained acceptance within the logistics filed as an analytical tool. In addition, it is being used as a business development tool for sales and pre-sales opportunities.

António et al. (1998) have developed an object oriented simulator where one could look at the warehouse from a hierarchic decision level point of view, which has permitted a more realistic separation of the responsibilities on the system. The present group of results achieved by the usage of such a simulator had the intention of characterizing the behavior of the layout in study, mainly its maximum rates of inputting and outputting material and the delay times expected for the most relevant processes. In this study, the chosen programming language is Microsoft Visual C++.

As stated in the above paragraphs, in the literature there are mostly papers about analyzing actual systems and developing simulation models in order to evaluate performance of the warehouses, predict resource requirements, and validate new warehouse designs. Since most of the warehousing systems are different from each others, their simulation models are also different from each others. It is common for all simulation studies that alternative models are developed and performance measures are used for comparing and evaluating these alternative models. In the warehousing system for which this study is accomplished, there aren't any rack systems, shelves, and replenishment operations etc. Therefore the simulation model for this warehousing system was developed independently from the models in the literature. But, the perspective used in the papers encountered during the literature review is maintained in this study.

3. MODELLING THE REAL SYSTEM

3.1. Real System Description

In this study, the logistics center of one of Turkey's biggest third party logistics company is considered. This logistics center is able to store many types of products and raw materials of several customers. At the beginning of the study, only one of the customers of this logistics company is chosen. Services given to this customer with a contract are receiving, put away, order picking, and shipment.

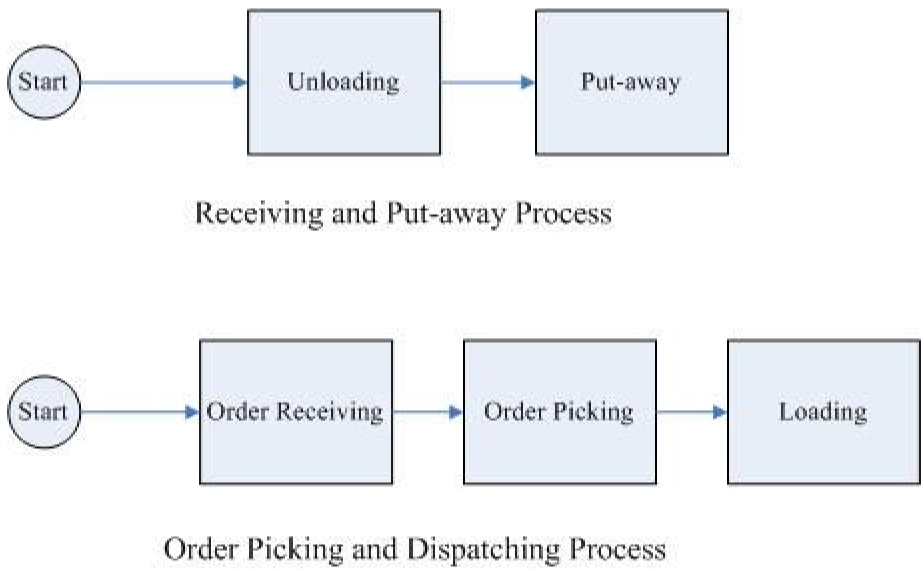

Figure 3.1. Warehouse processes

In the receiving process, materials in the arriving loaded trucks are unloaded at the receiving ramp through physical controls. These materials at the receiving ramps are carried to the storage locations and put away there. This process is called put away process.

When orders arrive, relevant materials are picked up from storage locations and brought to the shipment ramps according to the order picking process. In the dispatching process, materials at the shipment ramps are loaded to the empty trucks.

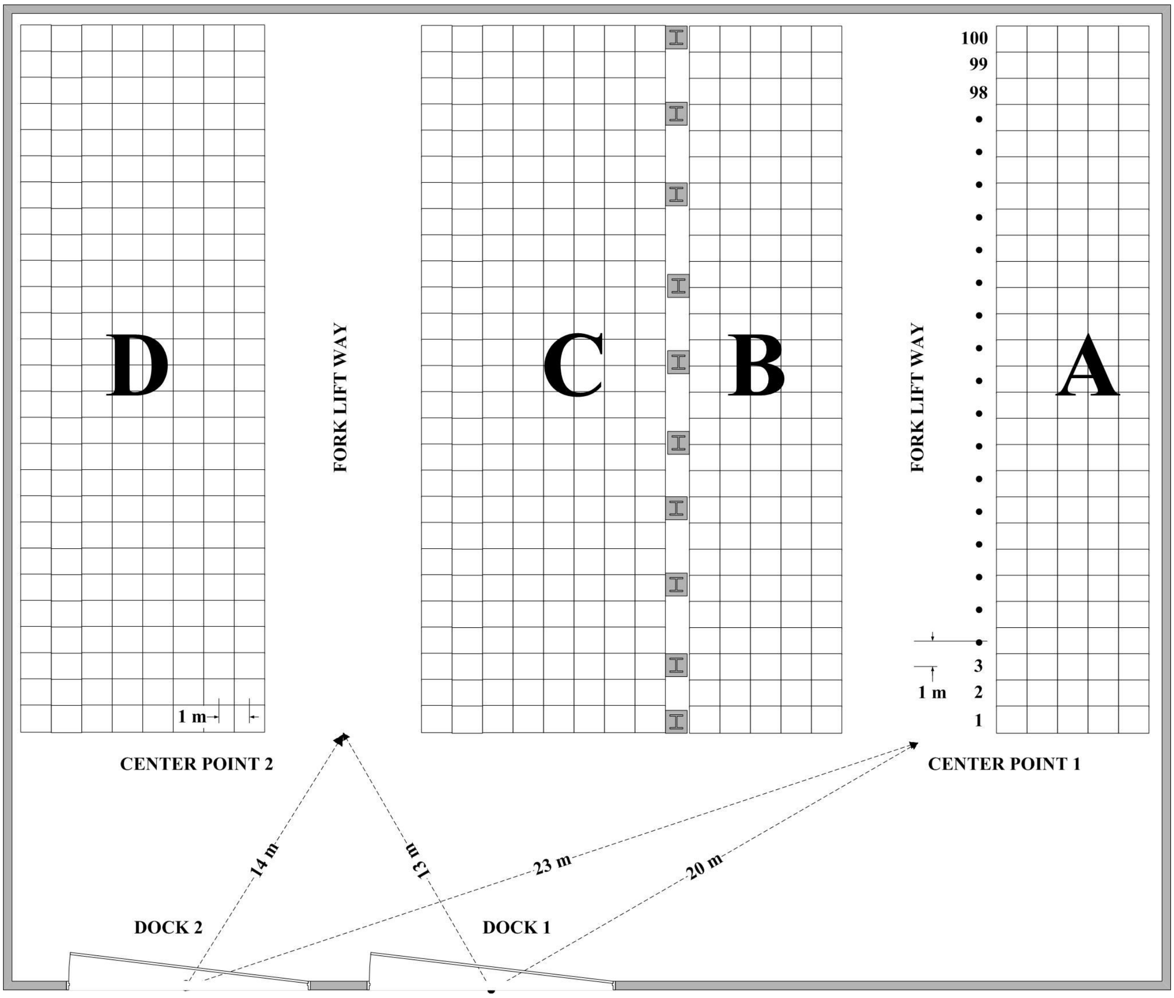

Figure 3.2. Warehouse layout

The warehouse area allocated to the customer is 5500 m^2 with two docks, both of which can be used for receiving and dispatching. The layout of this warehouse area can be seen in Figure 3.2. Stocking areas are divided into 4 disjoint areas which are called sector A, sector B, sector C, and sector D. Each of these sectors is also divided into 100 locations called slots. While the capacity of the slots in sectors A and B is 5 pallets, the capacity of the slots in sectors C and D is 8 pallets. So, the total stocking capacity is 2600 pallets. When the stock size exceeds 2600 pallets, the incoming goods can be stored on the fork lift paths and areas allotted for preparation of goods until some space becomes available in stock locations.

The fork lift path between sections A and B starts from center point 1. The distance from the center point 1 to door 1 is 20 meters, and to door 2 is 23 meters. The fork lift path between sections C and D starts from center point 2. The distance from the center point 2 to door 1 is 13 meters, and to door 2 is 14 meters. In one sector, the distance between successive slots is one meter. Additionally, the total length of a slot at section A and section B is 5 meters, and the total length of the slots at section C and section D is 8 meters.

Figure 3.3. A picture of Sector A and Sector B

In a week, there are six workdays. Sundays are holidays. The warehouse operates on two shifts basis. The first shift starts at 8:30 a.m. and finishes at 06:30 p.m. The second shift starts at 06:30 p.m. and finishes at 08:30 a.m. While four fork lifts are used during the first shift, the number of the fork lifts used during the second shift is two for the whole warehouse. There is a lunch break of one hour between 12:30 p.m. and 13:30 p.m. during the first shift. And there are two fifteen-minute tea-breaks during the first shift, which are provided in the morning and in the afternoon. The times allocated for meal breaks and tea breaks during the second shift are not predetermined. The workers decide about their break times based on their work loads.

The customer has three types of raw materials stacked in the warehouse. They are Soda, Sodium Phosphate, and Sodium Sulphate. The warehouse uses the drive-in one way warehousing system in which the pallets are stacked one after another. Only one type of product can be stacked in one slot. All trucks used for receiving orders and shipment orders contain eight big bag pallets. The materials are received and dispatched on pallets. No other type of packaging is used.

During the first shift, sometimes both docks can be used at the same time. In such cases, two fork lifts operate at each dock. At a dock; in case of a receiving activity, one of the fork lifts unloads the truck, while the other one carries the materials to the storage locations. In case of dispatching; one of the fork lifts carries the materials to the shipment ramp, while the other one loads the truck. When there is only one occupied dock during the receiving activity, one fork lift unloads the truck, while the other three fork lifts carry the materials to the storage locations. And similarly, in case of a dispatching activity and only one occupied dock, one fork lift loads the truck, while the other three fork lifts carry the materials to the shipment ramp.

There are two different queues in the warehouse, one of which is allotted to the incoming trucks and the other of which is allotted to outgoing trucks. Incoming trucks are trucks that have materials on them and come to the warehouse for being unloaded. Outgoing trucks are trucks that are empty and come to the warehouse for taking materials. Since the materials stocked in the warehouse are solely the raw materials, and such raw materials are used in production, any delay in delivery of such raw materials may cause an interruption in the line of the customer. For this reason, the priority of the trucks in the outgoing trucks queue is higher than that of the trucks in the incoming trucks queue. In case that any truck arrives for a dispatching activity, and if there are some other trucks in the incoming trucks queue, then the truck arrived for loading is first drawn up alongside the dock. If an outgoing truck arrives while another truck is being unloaded and the other dock is also unavailable, the unloading activity will not be stopped. The loading process for the newly arriving truck will be started after the unloading activity has been finished.

If break time starts while a truck is being loaded or unloaded, then fork lifts cannot stop working for the break until they finish their job. If this is an unloading task, trucks get unloaded. If the task is loading them, then they get loaded. Fork lifts start their breaks after the completion of this task. Although there is a delay for these fork lifts to begin the break, they end it always at 13:30 which is the end time of the lunch break.

3.2. Model Objectives

The primary objective of the simulation model is to facilitate system designs of large warehouses. The model aids strategic and operational decision making processes. Strategic decisions include determining the required number of slots and docks, and identifying the necessary amount of labor and equipment to execute warehouse operations. Operational decisions cover planning the shifts and evaluating needed changes in the amount of fork lifts and labor in case of decrease in the warehouse traffic. Moreover, the model can be utilized to investigate equipment and labor requirements for each hour of a day, if there are scheduled arrivals with definite number of incoming and outgoing trucks. The model supports operational decisions by obtaining knowledge about operational characteristics of the warehouse such as percentages of effective usage of present sources, average waiting time of outgoing trucks in the system, percentage of outgoing trucks that are in system more than 45 minutes etc. Benefiting from the outputs of the simulation model, the third party logistics company can determine the prices of its services more efficiently.

3.3. Input Modeling

3.3.1. Input and Output Distributions

The products of the chosen customer are raw materials transported from abroad by sea. As these raw materials don't belong to third party logistics company, there is inadequate information about whether all raw materials are transported by the same ship or not. In addition to this, current data is not sufficient for determining a correlation between inputs and outputs of different materials. Therefore, it is assumed that inputs and outputs are independent of each other. The collected data for three types of material cover only the last six months of 2005. The input and output information required for the study was collected for two shifts separately and given in the CD accompanied with the Thesis. The number of incoming and outgoing trucks per shift per day is modeled by the discrete empirical distribution. The discrete empirical distributions of three materials are given in Appendix A. By the help of these distributions day by day the number of incoming and outgoing trucks in each shift is determined. As the total working hour of a shift and the total amount of incoming and outgoing trucks are known, the rate is calculated by dividing number of trucks by hours of the shift. Consequently, an exponential distribution with mean $1/\lambda$ is used for the distribution of inter arrival times for incoming and outgoing trucks.

3.3.2. Determining Total Time of Fork lift

During the calculation of the total time of fork lift, not only transporting the pallets, but also taking and replacing them carefully are considered. During two different days, the time of the process mentioned above was recorded for 60 observations. These records can be seen in Appendix A and data plot for total time of fork lift versus distance can be seen in Figure 3.4. It's assumed that no other factor can affect total time of fork lift except distance. Distances are taken as explanatory variable of the regression. According to the data, the regression equation is:

Total time of fork lift = 34.521 + 0.915 * Distance

Table 3.1. Regression analysis results of total time of fork lift

Predictor	Coefficient	SE Coefficient	T	P
Constant	34.521	2.623	13.15	0.000
Distance	0.915	0.031	29.09	0.000

R-Sq = 93.5%   R-Sq (adj.) = 93.4%

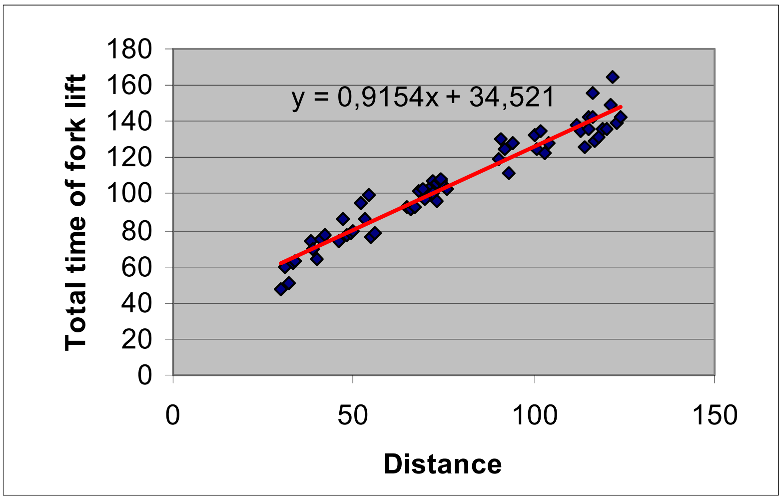

Figure 3.4. Data plot for total time of fork lift versus distance

According to regression results, 34.521 is the fixed time needed for taking up, transporting, and putting down the pallets. 0.915 is the average speed of the fork lift.

Table 3.2. Analysis of variance table for total time of fork lifts

Source	DF	SS	MS	F	P
Regression	1	45068.339	45068.34	846.383	0.000
Residual Error	58	3088.393	53.248		
Total	59	48156.733			

The p-value in the Analysis of Variance table (0.000) indicates that the relationship between "Total time of fork lifts" and "Distance" is statistically significant at an α-level of 0.05. This is also shown by the p-value for the estimated coefficient of Distance, which is 0.000. The R^2 value shows that Distance explains 93.5 % of the variance in total time of fork lift, indicating that the model fits the data well. When normality probability plot which is indicated in Figure 3.5. is analyzed, it can be seen that residuals are approximately normally distributed. As the estimate for the standard deviation of residuals is 7.3, we add a normal variate N(0,7.3) to the total times of the fork lift to make these times behave like the data. As a result, the equation for calculating the total time of fork lift is:

Total time of fork lift = 34.521 + 0.915 * Distance+ Normal (0, 7.3)

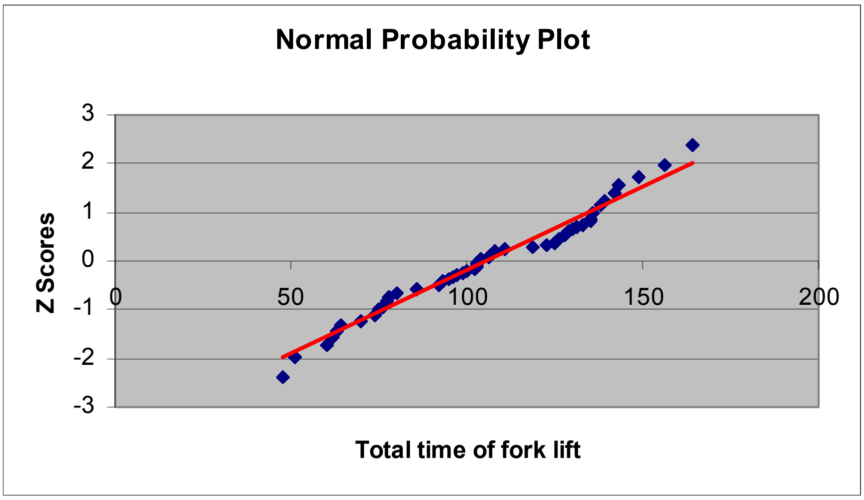

Figure 3.5. Normal probability plot for total time of fork lift

3.3.3. Identifying Loading and Unloading Time Distributions

25 observations have been made for unloading operations, and 25 observations for loading operations. These observations can be seen in Appendix A. It is seen that loading and unloading operations take up approximately the same times. The reason for that may lie in performing the loading and unloading operations for materials on standard pallets. In order to be sure about the identity of loading and unloading time observation values, two sample t-test is implemented to these values. According to the outputs of two sample t-test, given in Appendix A, it can be concluded that there is no difference between loading and unloading times. Because of that, 50 time observation values are brought together to find a distribution. The histogram of these values is drawn as it can be seen in Figure 3.6.

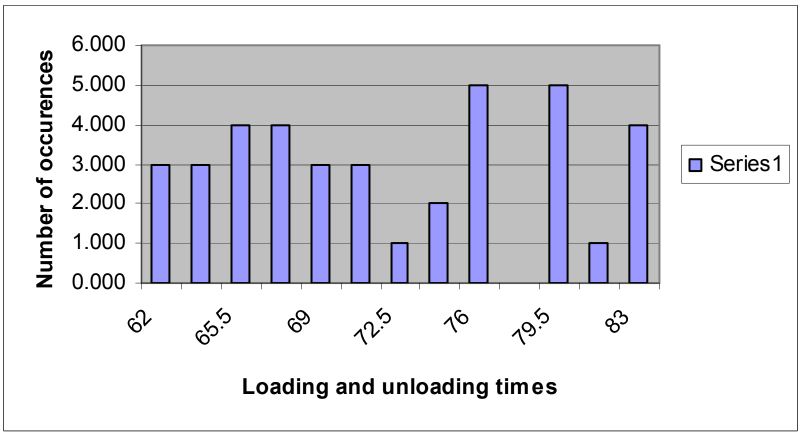

Figure 3.6. Histogram of loading and unloading times

When the histogram is inspected, it is figured out that the distribution resembles a uniform distribution. To examine it, a chi-square test is implemented. The result of chi-square test is presented in the form of *p*-value. The *p*-value is the largest value of the type-I error probability that allows the distribution to fit the data. In general, the higher the p value the better the distribution fit to the data.

Table 3.3. Chi-square table for unloading and loading time observations

	#Smaller	# in Interval	Expected	Chi2
62	3			
65	10	7	7.143	0.003
68	18	8	7.143	0.103
71	24	6	7.143	0.183
74	28	4	7.143	1.383
77	34	6	7.143	0.183
80	43	9	7.143	0.483
83	50	7	7.143	0.003

Table 3.4. Results of chi-square test for loading and unloading time distribution

Chi Square Test Results	Values
Number of Intervals	7
Degrees of freedom	4
Corresponding P-Value	0.673

The threshold value of p is 0.05 and the null hypothesis under threshold value is rejected. For our model p-value is 0.673. This can be seen from Table 3.4. It shows that data fits the uniform distribution below:

Probability Distribution Function: UNIF (62, 83)

4. MODEL IMPLEMENTATION USING ARENA

4.1. Implementing a Warehouse Simulation

4.1.1. Naive Approach

The simulation model is developed using the Arena software tool. While the model is first being set up, locations and docks are selected as resources, fork lifts as transporters. In order to use transporters, stations have to be defined because transporters can travel between stations. With a distance matrix composed of distances between the stations, travel lengths of transporters are computed.

When a truck arrives at the warehouse it seizes an available dock, if there isn't any, it waits in the queue. After the truck has seized the dock, the unloading operation is executed by the fork lifts, transporters at this model. In the put away process a transporter is carrying an entity (product) which is seizing a location, here a resource. Until an order is stated for this product this resource remains busy, and when this order is satisfied the resource becomes released.

This model has the following advantages:

1. Selecting fork lifts as transporters enables and facilitates the animation of the model.
2. In this model, fork lifts are used more efficiently. During the incoming process at a dock, when a fork lift finishes its put away task at a station, it can respond to a request from another station, and pick up product for the outbound process at another dock. After it has carried the product to this dock, it can return to the first dock, and continue its put away task in the inbound process.
3. In defining average speeds for the fork lifts, a very detailed simulation can be executed. As speeds and distances are known by the model, it can automatically calculate transporting times.

The model has also the disadvantages stated below:

1- As there are a lot of locations, the size of the distance matrix becomes very large. For the first model there are two docks and 2600 locations. Distance matrix of this model includes 3.383.901 different values for distances between docks and locations and locations within themselves. Accordingly, it is difficult and time consuming to add a new location into the warehousing system. The reason of that is the need for adding the distances between this new location and the other existent locations into the distance matrix.
2- The products wait at the locations, until an order arrives. As the average amount of products in the stock is large, there are a lot of entities in the system which slows down the model.

4.1.2. Flexible Implementation for Large Warehouses

For flexible implementation in large warehouses, the naive approach model is converted into a simpler and faster one. In this new model fork lifts and docks are defined as resources. In addition to that, a variable is used for locations of each sector instead of defining them as resources. Each row of the variable belongs to a single slot. The first column holds the current number of pallets in the slot, and the second column the product type. The model is designed according to the rule that only one product type can be stocked at one slot. When there is a product entry into a slot, at the row of this slot in the first column the amount of product will be set to 1 if the slot was empty before. In the second column, the type of the product is recorded. Afterwards, only this type of product can enter this slot until the slot becomes full. If there were already entries of the same type of product to the slot, the amount of product is increased by 1. When there is an exit out of the slot, the amount of product in the first column is reduced by 1. If by an exit the amount of the product gets “0” and the slot becomes empty, the product type in the second column will be deleted. In this way the system holds only the record of the products entering the warehouse instead of the products themselves. Consequently, the amount of entities existent simultaneously in the system is decreased significantly.

The simplified model has the following advantages:

1- Keeping the locations in a variable provides convenience and flexibility in changing the number of locations. In order to add a slot to the warehouse system, this model only requires changing the number of rows of the location variable.
2- Defining fork lifts as resources eliminated the necessity of building up a large dimensional distance matrix which is a first condition to use fork lifts as transporters.
3- As the model holds only the record of the products, there are fewer entities in the system at the same time. Hereby, the running time is shortened.

The disadvantages of the model are indicated below:

1- Because of selecting the fork lifts as resources, the animation of the fork lifts' movements is not possible.
2- As fork lifts are resources in this model and they are not used as transporters, transporting times could not be automatically calculated. The transporting time is implemented by a delay block. So, a detailed simulation can't be performed.

4.2. Assumptions and Policies of the Simulation Model

In addition to system definition, following simplifying assumptions have been made for developing the model:

1. As it's mentioned before, in real system Sundays are holidays so there is no activity in Sundays. Since there is no activity, Sundays are not included in the model.
2. In the real system fork lifts are not allowed to stop for breaks when their unloading or loading tasks are not completed. However, in the model, fork lifts can't have breaks until they finish both unloading operation and putting away operation or both picking up operation and loading operation.
3. In this model, it is assumed that the putting away tasks or the picking tasks of the fork lifts always start from docks. Therefore, after finishing its put away task at a location the fork lift has to return empty to the dock. It can't go to another location

and pick up a product for the outgoing process at the second dock unless it returns to the dock after it completed its put away task.

4. The length of transport for put-away and pick-up operations are composed of three parts: The first part is the distance from a dock to a center point. The second part consists of the length between the line where the slot stands on the fork lift path and the center point. The third part is the distance from where the pallet is placed in the slot to the fork lift path.
5. In an incoming truck, there is only one type of product. The order of an outgoing truck contains only one type of product. Therefore, the pallets in an incoming and outgoing process are the same.
6. During the put away process, fork lift operators put the same types of products to each slot.
7. Cyclical resource selection method is used for selecting a fork lift among available resources in fork lift sets. The cycle continues through available members as in the example “1-2-3-1-2-3”.
8. Large remaining capacity resource selection rule is used for selecting a dock among available dock sets. Largest Remaining Capacity method selects the resource that has the largest remaining resource capacity. Break has been tied using the Preferred Order Rule. According to this rule, the first seize block for which the required resource units are available is selected.

The policies for the simulation model are as follows:

1. All incoming goods are put away to one of the closest empty storage locations.
2. Orders are also picked up from one of the closest storage locations.

4.2.1. Infinite Capacity Locations

In real system, it is possible not to have any empty storage location in the warehouse. In such cases, products can be placed on the fork lift paths, receiving and shipment ramps, and outside of the warehouse.

In the simulation model, to be able to continue the simulation when all locations are full, additional locations that have infinite capacity have been defined to hold the exceeding stock levels. For each of the three different types of products, an infinite capacity location has been defined. When the stock size exceeds the location capacity, exceeding stocks are put away at these infinite capacity locations. The distances of the infinite capacity locations from docks are calculated as average distance between docks and middle of the sector.

4.2.2. Warm-up Period

The inventory level is out of the scope of this thesis since the inventory level is under control of third party Logistics Company's customer and third party Logistics Company is not able to intervene in the incoming and outgoing truck traffic. In this study, we are interested in operation in the warehouse. At the beginning, there is no initial stock level for the model. To be close to the real operational characteristics of a warehouse system, the warehouse has to be filled up first. Therefore, a warm-up period is added to the run replication length. This warm-up period lasts until a semi-full system is acquired. During the warm-up period, there will be some unsatisfied orders. These orders are cancelled as if they have never been realized. No analysis is performed for the warm-up period. After the warm-up period, the model is run for 365 days. All of the analysis for determining restrictions of warehouse and measuring operational performance are done for 365 days period.

4.3. Arena Model

The simulation model considers two processes:

1. The inbound process which consists of arrival of incoming trucks to the warehouse, unloading the trucks, and putting away the products
2. The outbound process which consists of arrival of orders and outgoing trucks, order picking, and loading the trucks.

For every process, a separate flow is formed in the Arena model. The flow diagram for the inbound process is indicated in Figure 4.1., and the flow diagram for the outbound process is indicated in Figure 4.2. ARENA models for each scenario and their outputs are given in the accompanied CD.

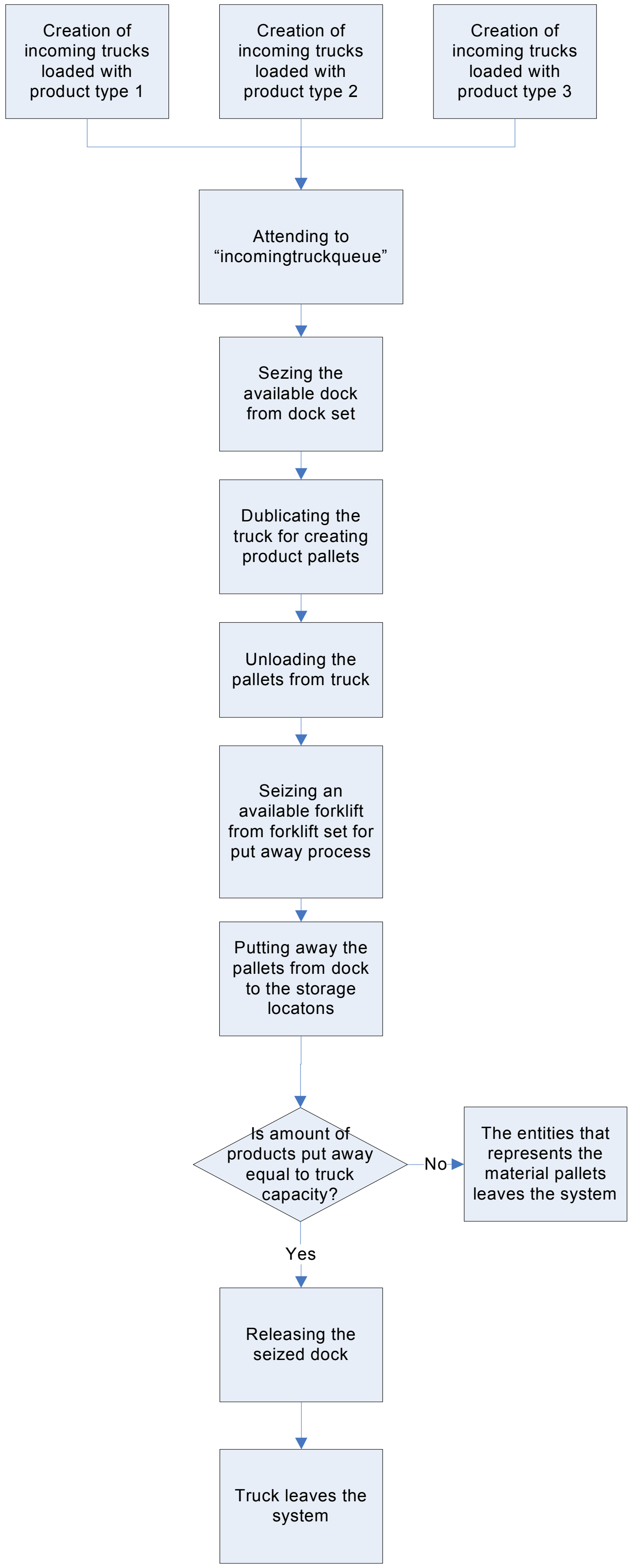

Figure 4.1. Inbound process in the Arena model

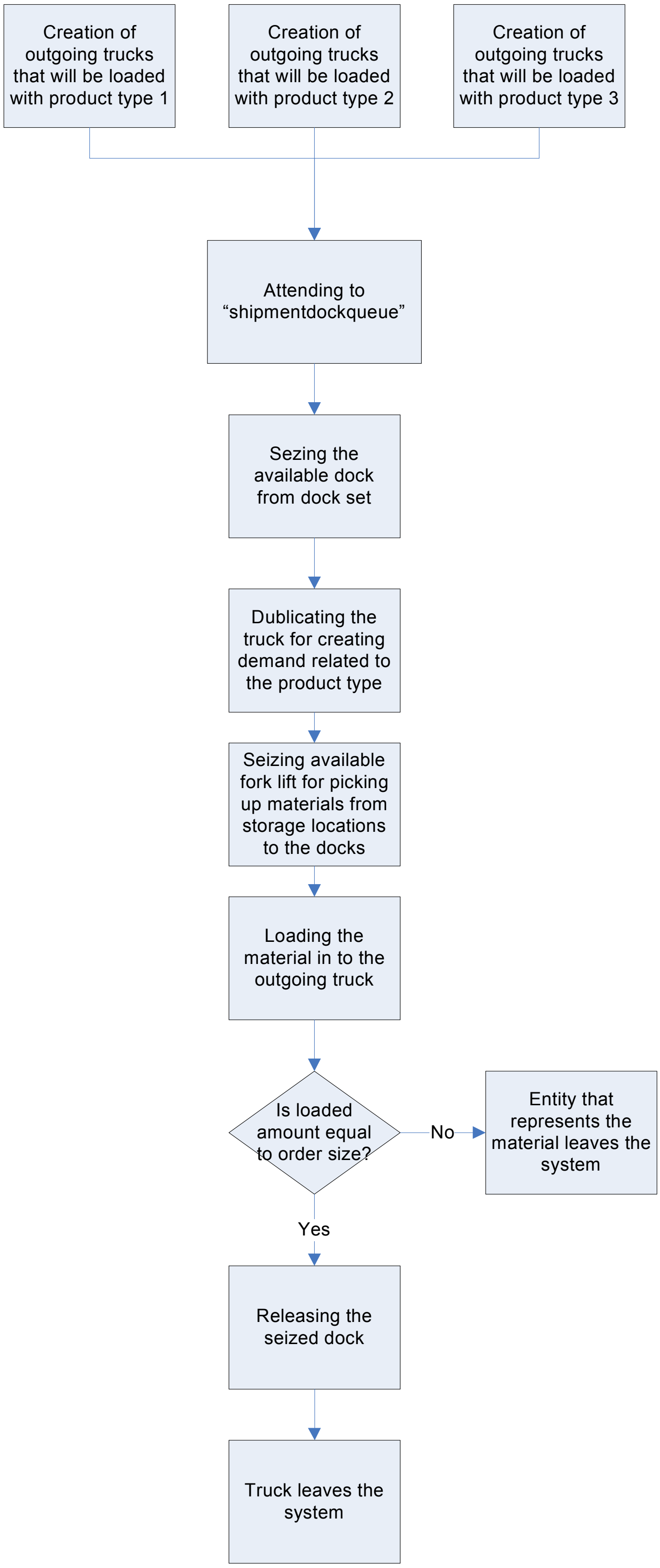

Figure 4.2. Outbound process in the Arena model

4.3.1. Inbound Process

<u>4.3.1.1. Creation of Incoming Trucks and Seizing Available Docks.</u> At the beginning of each day, an entity is created for each shift of each product type by a create module. This entity is used to determine how many incoming trucks will arrive for a product type in a shift. There are 3 product types and 2 shifts. The create module for shift 1 of product type 1 is indicated in Figure 4.3. as an example.

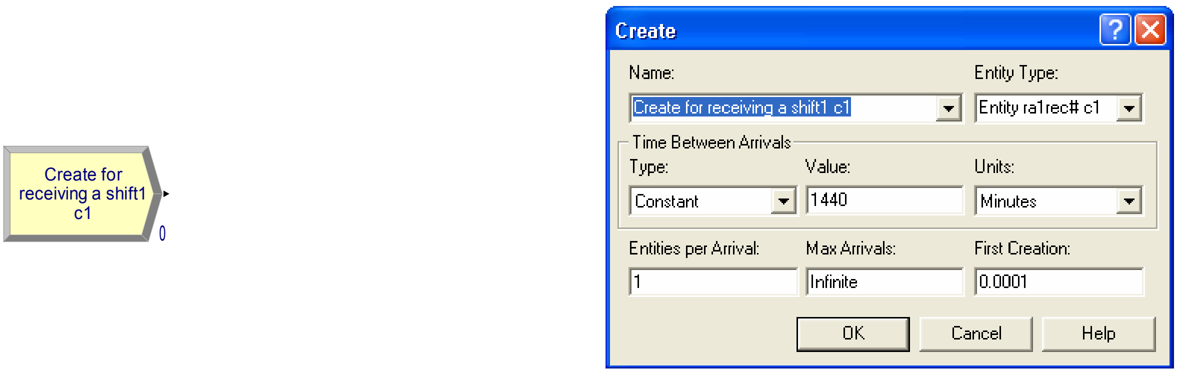

Figure 4.3. Create module for the entity to determine the number of incoming trucks carrying product type 1 which arrive at the warehouse at shift 1

Entities come to a decide module. In this decide module, the entities for each shift are separated according to shift period. The decide module is shown in Figure 4.4.

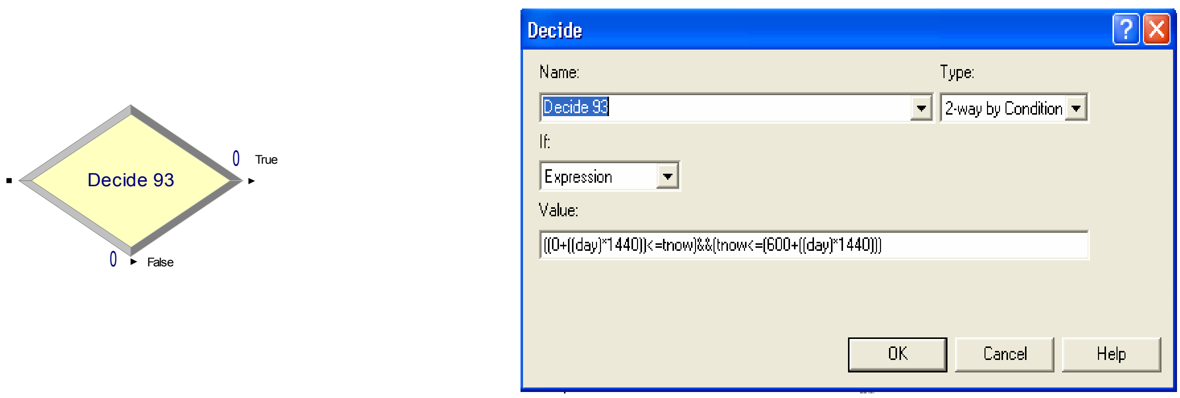

Figure 4.4. Decide module for separating the entities for each shift

The entities separated for each shift get the information of how many incoming trucks will arrive at a day in an assign module. Discrete empirical distributions which have been computed in input modeling are entered to the value area of the assign module.

Through these distributions, number of the incoming trucks is determined randomly. The assign module to determine the number of incoming trucks carrying product type 1 which arrive at the warehouse at shift 1 is given in Figure 4.5.

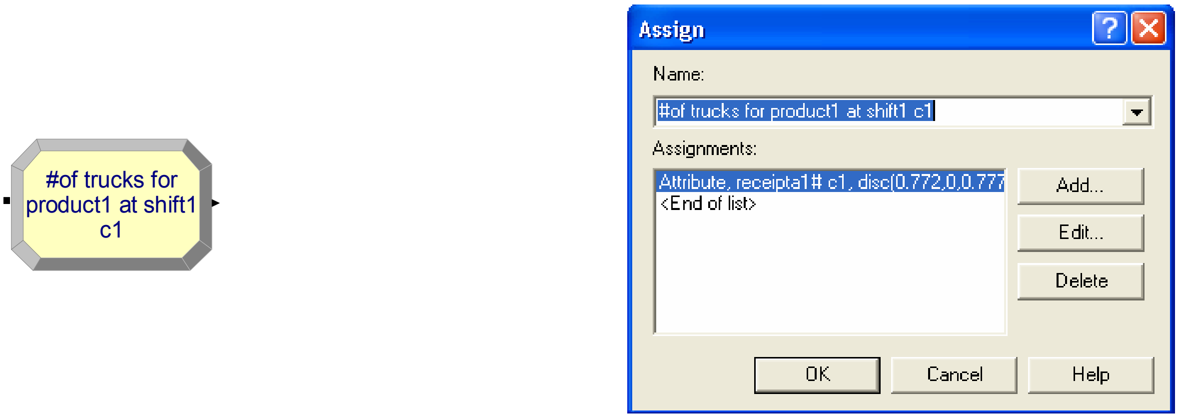

Figure 4.5. Assign module to determine the number of incoming trucks carrying product type 1 which arrive at the warehouse at shift 1

According to the number of the incoming trucks in a day, the entities follow different paths in the model. There are three possibilities for the number:

1. Number = 0: No truck arrives
2. Number = 1: One truck arrives
3. Number > 1: More than one truck arrive

The entities which represent the trucks from now on are sent to their paths by the decide modules. Decide module for incoming trucks carrying product type 1 which arrive at the warehouse at shift 1 is indicated in Figure 4.6.

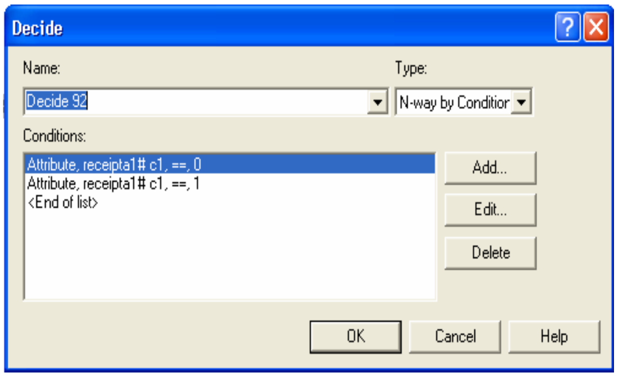

Figure 4.6. Decide module for incoming trucks carrying product type 1 which arrive at the warehouse at shift 1

If the number of incoming trucks is zero which means no truck will arrive, the entity is made to leave the system by the dispose module shown in Figure 4.7.

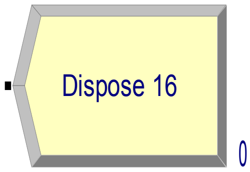

Figure 4.7. Dispose module

If the number of incoming trucks is one, then the entity, here the truck is directed to the process module.

If the number of incoming trucks is more than one, then the entity is duplicated as many times as 1 less than the determined number by the separate module given in Figure 4.8. All entities, here the trucks are directed to the same process module mentioned in the preceding paragraph. Process module for incoming trucks carrying product type 1 which arrive at the warehouse at shift 1 is indicated in Figure 4.9.

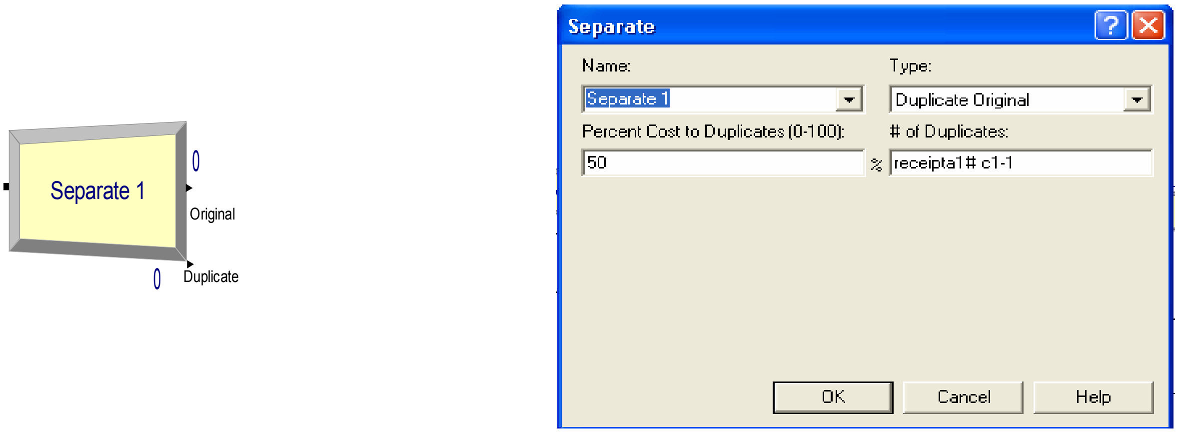

Figure 4.8. Separate module for duplicating incoming trucks carrying product type 1 which arrive at the warehouse at shift 1

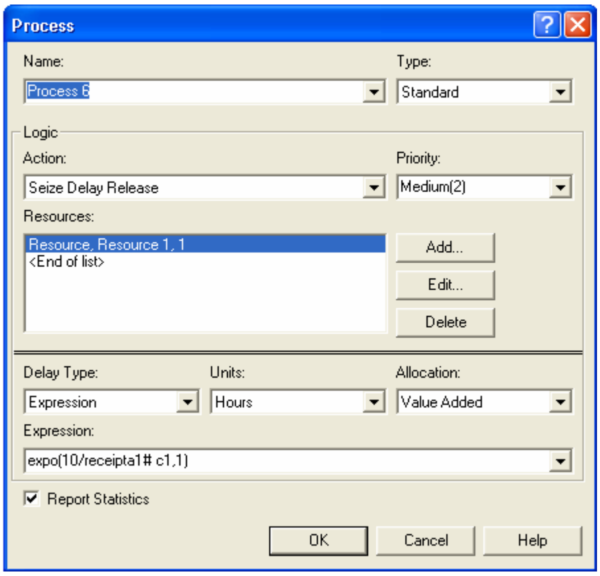

Figure 4.9. Process module for incoming trucks carrying product type 1 which arrive at the warehouse at shift 1

In the process module the delay type is chosen as “Expression”, and time unit is chosen as “Hour”. An exponential distribution with the average of 1/λ is used for the expression. Herein λ represents the number of incoming trucks for a specific product type in each shift span, as explained in the input modeling. Through this module, the incoming trucks are provided to arrive at the warehouse in intervals. Separate and process modules for shift 2 also exist in the model.

Finally, an attribute is defined for the incoming trucks to make them demonstrate the product type which they are carrying by the assign module shown in Figure 4.10.

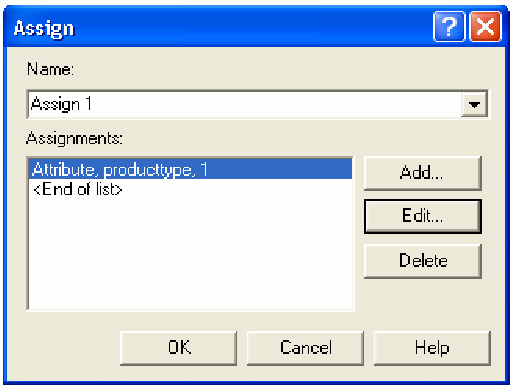

Figure 4.10. Assign module for incoming trucks of product type 1

The process of creating the incoming trucks through the modules explained until now is repeated for each of the 3 product types. Consequently, it is provided that incoming trucks carrying different product types arrive at the warehouse. The incoming trucks enter the “incoming truck queue” that is named “receiptdockqueue” in the model. The block for “receiptdockqueue” is selected among the siman blocks in the siman-level panel as indicated in Figure 4.11. In order to use this block, “receiptdockqueue” has been defined in queues element which is given in Figure 4.12.

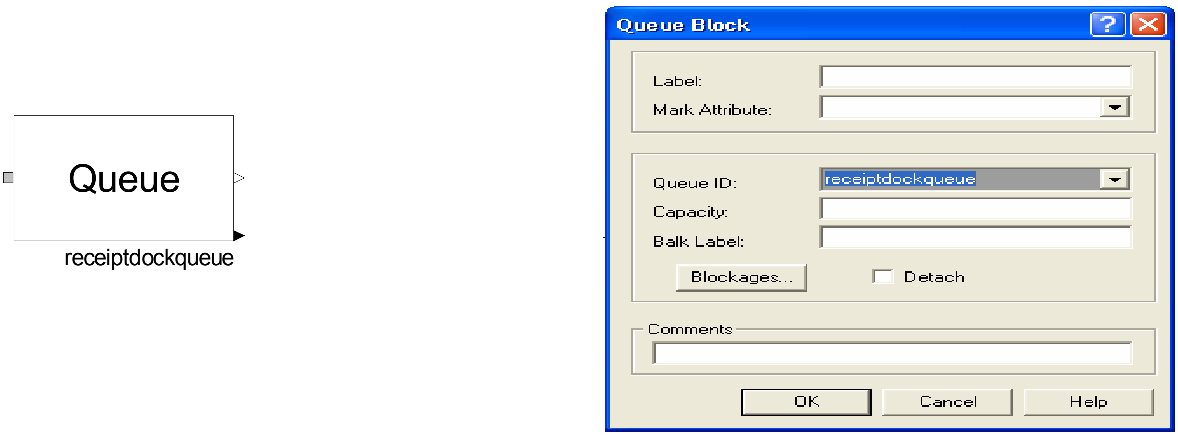

Figure 4.11. Queue block for incoming trucks

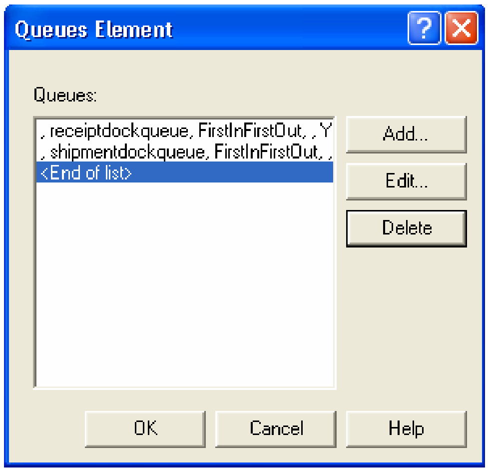

Figure 4.12. Queues element for defining the queues

There are two docks in the model. These docks are defined as resources, and they form the resource set called "Docks". LRC is used as resource selection rule in this set. This rule is explained in Assumption 8 in detail. According to this rule, the incoming trucks seize one of the two docks in the seize block shown in Figure 4.13. The dock remains seized until the products in the trucks are unloaded and put away to the storage locations. As the same docks are used in the outbound process, and the outbound operations have the higher priority than the inbound operations, the seize block for the incoming trucks is given the lower priority which is equal to 2.

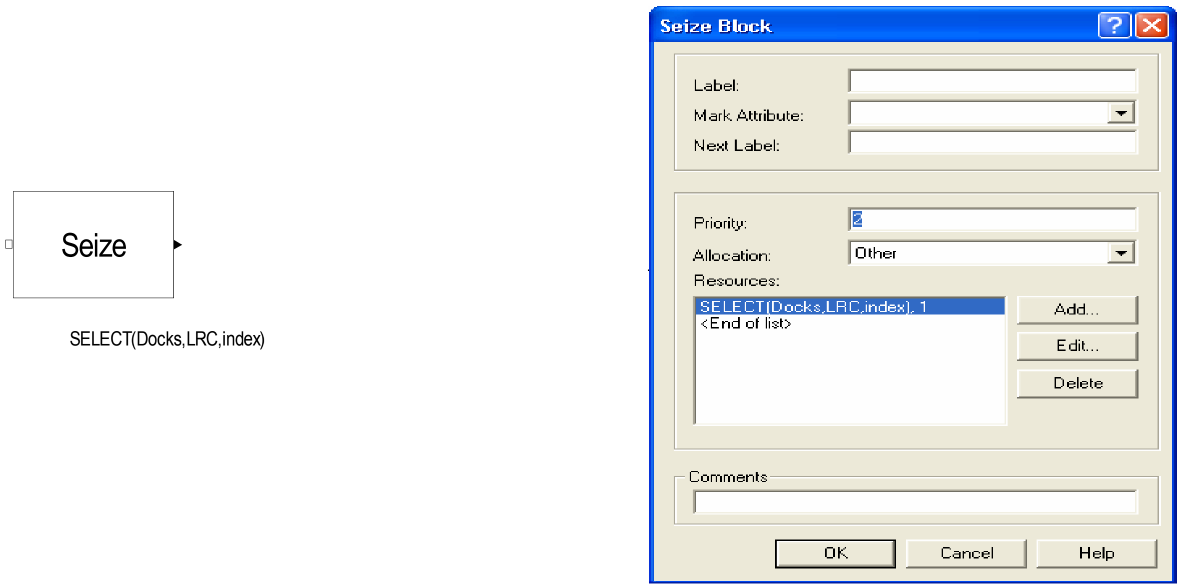

Figure 4.13. Seize block for incoming trucks to seize an available dock during receiving process

The incoming trucks are separated according to their seized dock through the decide module indicated in Figure 4.14.

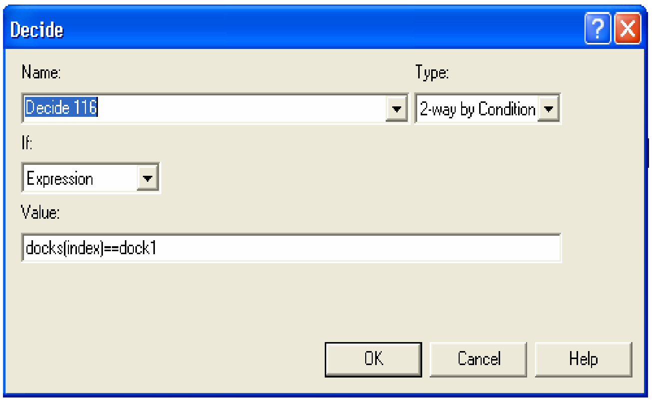

Figure 4.14. Decide module to send the incoming trucks to dock 1

With an assign module, shown in Figure 4.15., two attributes are defined for the incoming trucks. These attributes are as follows:

1. The capacity of the incoming trucks
2. The number of the dock which the incoming trucks have seized

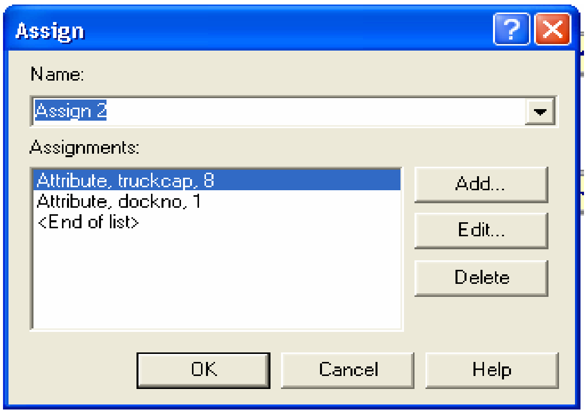

Figure 4.15. Assign module for defining the capacity and dock number attributes of the incoming trucks

The entity which was known as truck until now is transformed into one pallet of products. As there are 8 pallets in a truck, the entity is duplicated seven times, and these 8 entities are considered to be the pallets of the products which will be unloaded from the incoming trucks. The duplicate module is indicated in Figure 4.16.

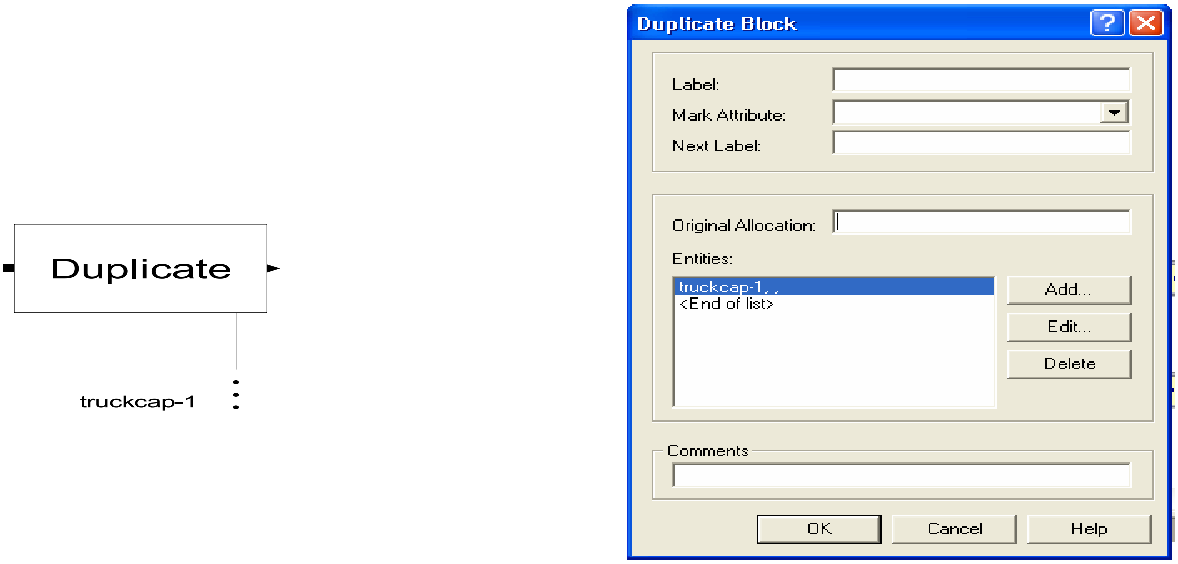

Figure 4.16. Duplicate block for products that are unloaded from the incoming trucks

4.3.1.2. Unloading Process. The fork lifts are defined as resources in the model. As the unloading operation is executed at two docks, two process modules are used.

There are 4 fork lifts in shift 1, and 2 fork lifts in shift 2 as mentioned in real system definition. One fork lift is assigned to each dock because the unloading operation is performed by only one fork lift. In shift 1, fork lift 1 is assigned to dock 1, and fork lift 3 is assigned to dock 2. The other fork lifts in shift 1 will be used for put away operations. As there are two fork lifts at shift 2, and two fork lifts should be used for the inbound process of a truck at a dock, the second dock is closed during shift 2. Therefore, only dock 1 is used at shift 2, and fork lift 5 is assigned for the unloading operation at dock 1.

According to the above paragraph, fork lift 1 and fork lift 5 are in the resource set of dock 1, and fork lift 3 is in the resource set of dock 2. Although fork lift 5 is assigned to dock 1, it is also included in the resource set of dock 2. This enables the completion of the tasks of dock 2 which could not be finished in shift 1.

Available fork lift is selected by the process module indicated in Figure 4.17. among the resource set of a dock. In the process module, the delay type is chosen as “Expression”, and time unit is chosen as “Seconds”. UNIF(62,83) distribution which is found out in input modeling is used for the expression.

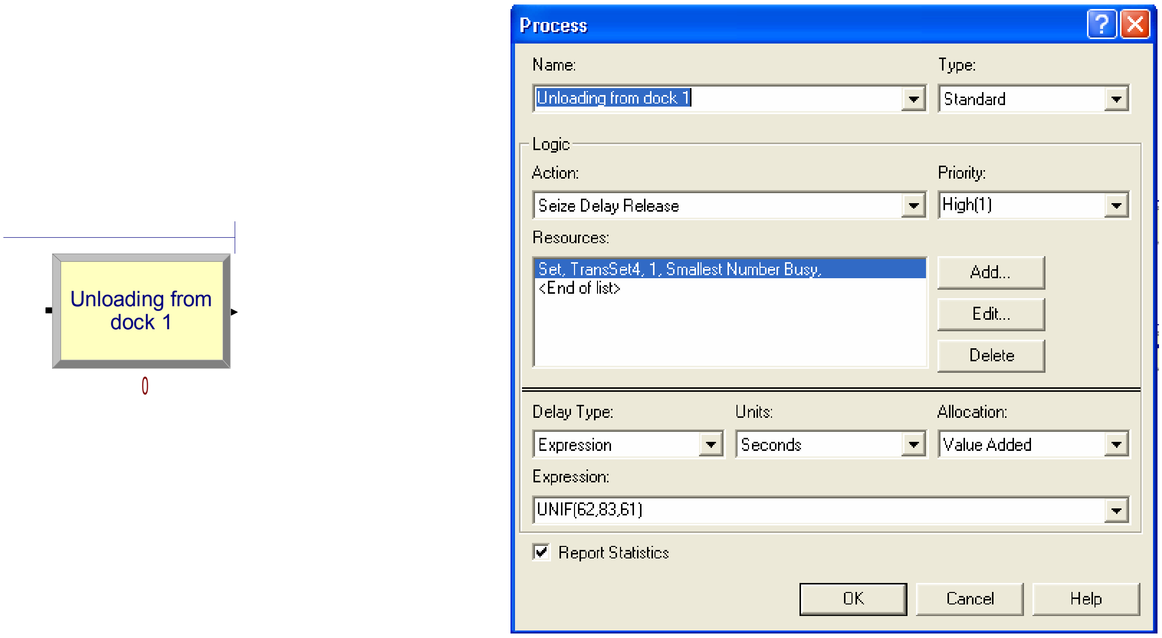

Figure 4.17. Process module for unloading operations

4.3.1.3. Put-away Process. After the trucks have been unloaded to the receiving ramp, the inbound process continues with put away operations of the products. In the put away process, every pallet of the products at the receiving ramp seizes one of the available fork lifts from the fork lift sets by the seize module given in Figure 4.18. Every set includes 6 fork lifts.

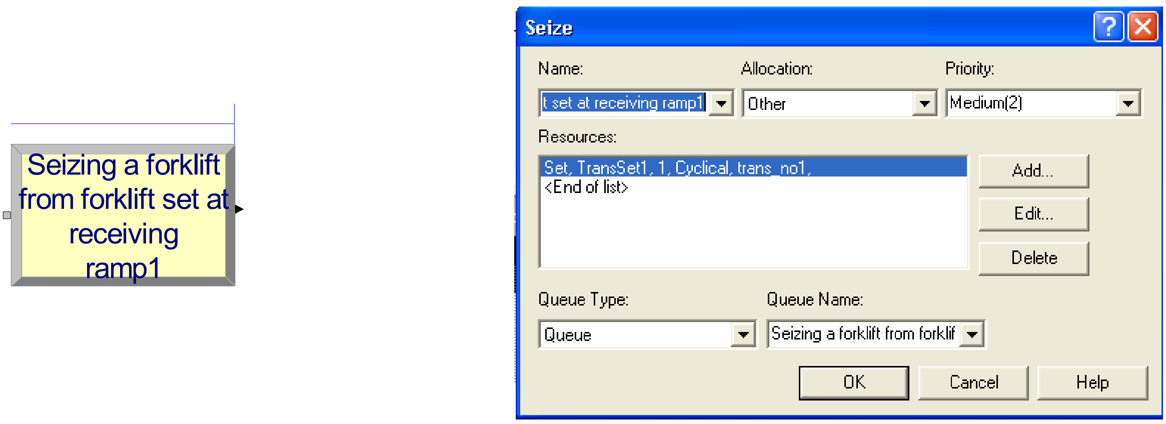

Figure 4.18. Seize module for put away operations

The pallets of the products are put away to the storage locations. Storage locations are divided into sectors. Sectors are defined as variables in the model. LocationA, LocationB, LocationC and LocationD variables represent Sector A, Sector B, Sector C and

Sector D respectively. The number of the rows of these variables is equal to the slot number at the sectors. A while loop is used to find the appropriate location for put away operation. During this operation, the policy for put away to the nearest location, the assumption for put away only one type of product to each slot, and the capacities of the slots are taken into account. Each slot of each sector is checked, the put away operation is made to the appropriate location, and the sector to which the location belongs is recorded. If there is not enough place at the slots, exceeding stocks are put to the stock1, stock2, stock3 locations with infinite capacities according to the product type. These infinite capacity locations are also defined as variables.

The system holds only the record of the products in the related variable instead of the products themselves. The transport periods of the fork lifts are realized by delay modules. If the products are put away to the slots, the appropriate slot is determined by the sector variable. The slot corresponds to the row in this variable. In order to determine the transporting distance for the product in the slot, it is checked after how many products it is located in this slot. The dock from which the put away operation begins is also known.

The length of transport is computed as explained in the Assumption 4, and is recorded in an assign module. Total time of fork lift is calculated by a regression equation found in the input modeling. In a delay module, for finding the total time of fork lift, first the length of transport is multiplied by the average speed, and then this value is added to sum of fixed time needed for taking up, transporting, and putting down the pallet and the value obtained from normal distribution with mean zero and standard deviation 7,3. The delay module is indicated in Figure 4.19. The delay time formulation for storage locations appears as below:

(Locationtype==1)*((34.521 + (0.915*distance1) + Norm(0,7.3))*2)+
(Locationtype==2)*((34.521 + (0.915*distance3) + Norm(0,7.3))*2)+
(Locationtype==3)*((34.521 + (0.915*distance5) + Norm(0,7.3))*2)+
(Locationtype==4)*((34.521 + (0.915*distance7) + Norm(0,7.3))*2)

In the formulation "Locationtype" indicates the sector type, and "distance" the length of transport." (34.521 + (0.915*distance1) + Norm (0,7.3))" gives the total time of fork lift.

Through the equation "(34.521 + (0.915*distance1)+Norm(0,7.3))" the traveling time of fork lifts from docks to storage locations is ensured. In order to include coming time of fork lifts from storage locations to docks in total time of fork lift, the result of the formula is multiplied by two.

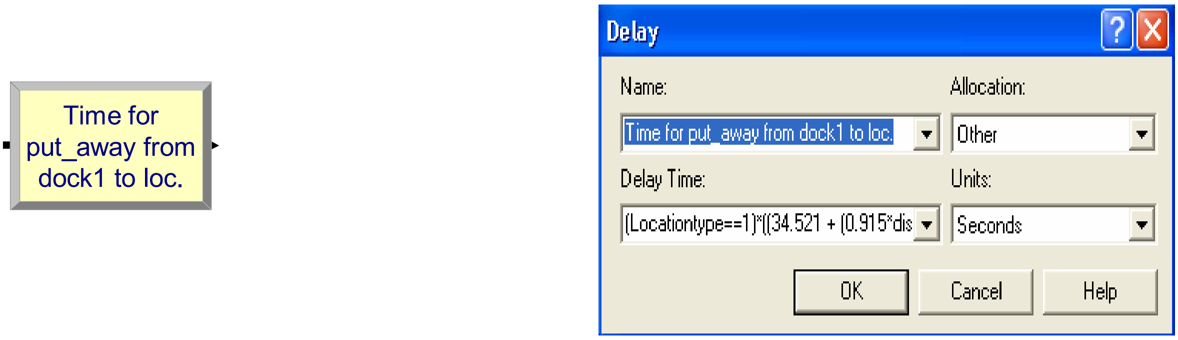

Figure 4.19. Delay module for determining put away time of products from dock1 to locations

If the products are put away to the infinite capacity locations, the length of transport is assumed as a constant value, "averagedistance". The total time of fork lift is calculated by a regression equation found in the input modeling. In another delay module for infinite capacity locations, for finding the total time of fork lift, first the "averagedistance" is multiplied by the average speed, and then this value is added to sum of fixed time needed for taking up, transporting, and putting down the pallet and the value obtained from normal distribution with mean zero and standard deviation 7.3. The delay time formulation for infinite capacity locations appears as below:

((34.521 + (0.915*averagedistance)+Norm(0,7.3))*2)

In the formulation "averagedistance" indicates the constant value, and "(34.521 + (0.915*averagedistance)+Norm(0,7.3))" gives the total time of fork lift. Through the equation "(34.521 + (0.915*averagedistance)+Norm(0,7.3))" the traveling time of the fork lifts from docks to infinite capacity locations is found. In order to include coming time of fork lifts from infinite capacity locations to docks in the total time of fork lift, the result of the formula is multiplied by two.

Put away operations for dock2 are same as those for dock1.

After the put away operations are completed at dock 1, the seized fork lift is released with the release block given in Figure 4.20. There is also another release block to release the seized fork lift for put away operations at dock 2.

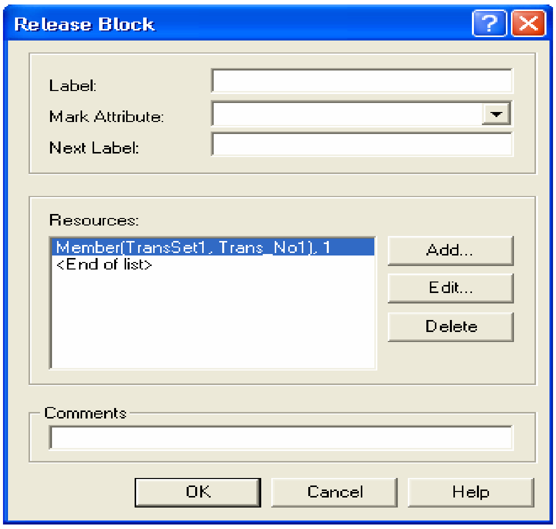

Figure 4.20. Release block for releasing the fork lift seized for put away operation

For each dock, the materials which are already put away are counted one by one with a variable in an assign block. After a material has been counted, it is disposed by a dispose module. The model only holds the record of the materials. When the value of the count variable becomes equal to the truck capacity, the dock seized by the truck is released. This control is performed by a decide module. After the dock has been released by a release module, the value of the count variable is set to zero in an assign module.

The releasing process of dock 2 is same as that of dock 1. Finally, the entities are made to leave the system by a dispose module.

4.3.2. Outbound Process

4.3.2.1. Creation of Outgoing Trucks and Seizing Available Docks. At the beginning of each day, an entity is created for each shift of each product type in a create module. This entity is used to determine how many outgoing trucks will arrive for a product type in a shift. There are 3 product types and 2 shifts.

Entities come to a decide module. In this decide module, the entities for each shift are separated according to shift period.

The entities separated for each shift get the information of how many outgoing trucks will arrive at the day in the assign module. Discrete empirical distributions which have been computed in input modeling are entered to the value area of the assign module. Through these distributions, the number of the outgoing trucks is determined randomly.

According to the number of the outgoing trucks, the entities follow different paths in the model. There are three possibilities for the number:

1. Number = 0: No truck arrives
2. Number = 1: One truck arrives
3. Number > 1: More than one truck arrive

The entities which represent the trucks from now on are sent to their paths by a decide module.

If the number of outgoing trucks is zero which means no truck will arrive, the entity is made to leave the system by a dispose module. If the number of outgoing trucks is one, then the entity, here the truck is directed to a process module. If the number of outgoing trucks is more than one, then the entity is duplicated as many times as 1 less than the determined number by a separate module. All entities, here the trucks are directed to the same process module mentioned above.

In the process module the delay type is chosen as “Expression”, and time unit is chosen as “Hour”. An exponential distribution with the average of $1/\lambda$ is used for the expression. Herein λ represents the number of outgoing trucks for a specific product type in each shift span, as explained in the input modeling. Through this module, the outgoing trucks are provided to arrive at the warehouse in intervals. Separate and process modules for shift 2 also exist in the model.

Finally, an attribute is defined for the outgoing trucks to make them demonstrate the product type with which they are loaded by an assign module.

The process of creating the outgoing trucks through the modules explained until now is repeated for each of the 3 product types. Consequently, it is provided that outgoing trucks to be loaded with different product types arrive at the warehouse.

The amount of products that will be loaded to the outgoing trucks is assigned with an attribute named "ordersize" in an assign module. The trucks can be loaded with 8 pallets of only one product type.

The outgoing trucks enter the "outgoing truck queue" that is named "shipmentdockqueue" in the model. The block for "shipmentdockqueue" is selected among the siman blocks in the siman-level panel as indicated in Figure 4.21. In order to use this block, "shipmentdockqueue" has been defined in queues element.

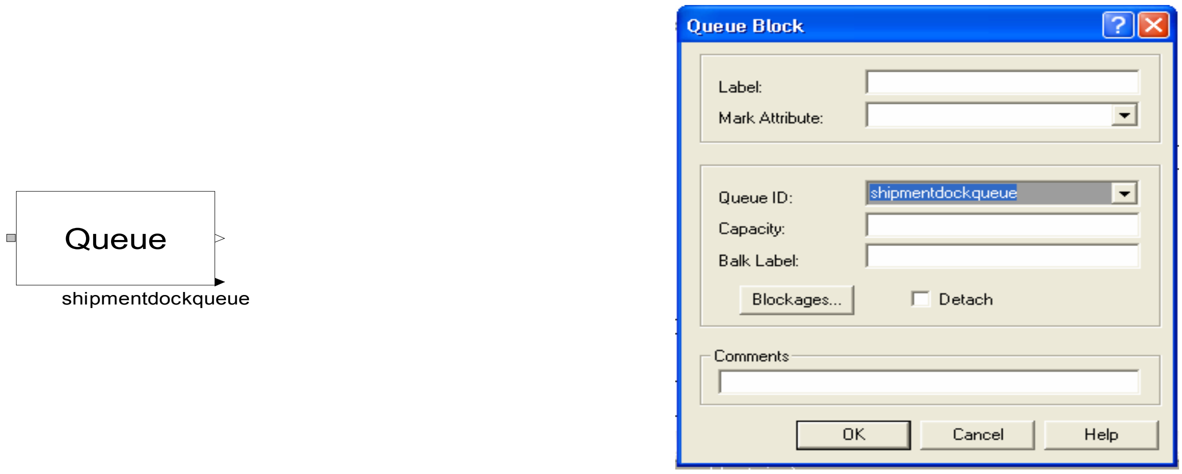

Figure 4.21. Queue block for outgoing trucks

There are two docks in the model. These docks are defined as resources, and they form the resource set called "S_Docks". LRC is used as resource selection rule in this set. According to this rule, the outgoing trucks seize one of the two docks in a seize block. The dock remains seized until the products are picked for the order from the storage locations and the trucks are loaded. As the same docks are used in the inbound process and the outbound operations have the higher priority than the inbound operations, the seize block for the outgoing trucks is given the higher priority which is equal to 1.

The entity which was known as truck until now is transformed into demand for one pallet of products in the order. As there is demand for 8 pallets of products in an order, the entity is duplicated seven times, and these 8 entities are considered to be the total demand for 8 pallets of the products which will be picked for the order.

4.3.2.2. Order Picking Process. After the entities have been duplicated to constitute the total demand for 8 pallets of the products which will be picked for the order, the pick up process begins. The sector variable has the information about how many products of which product type have been placed in every slot of every sector. Pick up operations are performed according to the policy that orders should be picked up from the closest appropriate storage location. A while loop is used for order picking process. In this while loop, each slot of the sector variable is checked one by one considering the product type.

When a pallet of the order for a product type is picked from a slot of a sector, the amount of product in the first column of sector variable is reduced by 1. The sector type is assigned as an attribute to the product in an assign module. If the products are picked up from the slots, the length of transport is computed as explained in the assumptions, and is recorded in an assign. If the products are picked up from the infinite capacity locations, the length of transport is assumed as a constant value.

In the order picking process, the demand for one pallet of products in the order seizes one of the available fork lifts from the fork lift sets by a seize module. Every fork lift set includes 6 fork lifts.

If the products are picked up from the storage locations, for finding total time of fork lift, first the length of transport recorded in the assign module is multiplied by average speed, and then this value is added to sum of the fixed time needed for taking up, transporting, and putting down the pallet and the value obtained from normal distribution with mean zero and standard deviation 7.3 in the delay module. If the products are picked up from the infinite capacity locations, delay time is calculated by first multiplying the constant value for the length of transport by the average speed, and then adding this value to sum of fixed time needed for taking up, transporting, and putting down the pallet and the value obtained from normal distribution with mean zero and standard deviation 7.3 in the delay module. The calculated value includes only the traveling time of the fork lifts from locations to docks. In order to include traveling time of fork lifts from docks to locations in the total time of fork lift, this value is multiplied by two.

When the products are carried from storage locations to docks, the seized fork lift is released by a release module.

Order picking operations for dock2 are same as those for dock1.

4.3.2.3. Loading Process. The pick up operation of each order is performed to the shipment docks seized by outgoing trucks' of that order. There are 4 fork lifts in shift 1, and 2 fork lifts in shift 2 as mentioned in real system definition. One fork lift is assigned to each dock because the loading operation is performed by only one fork lift. In shift 1, fork lift 1 is assigned to dock 1, and fork lift 3 is assigned to dock 2. As there are two fork lifts at shift 2, and two fork lifts should be used for the outbound process of a truck at a dock, the second dock is closed during shift 2. Therefore, only dock 1 is used at shift 2, and fork lift 5 is assigned to dock 1 for the loading operation. Fork lift 1 and fork lift 5 are in the resource set of dock 1, and fork lift 3 is in the resource set of dock 2. Although fork lift 5 is assigned to dock 1, it is also included in the resource set of dock 2. This enables the completion of the tasks of dock 2 which could not be finished in shift 1. Available fork lift is selected among the resource set of a dock by a process module. In the process module, the delay type is chosen as "Expression", and time unit is chosen as "Seconds". UNIF(62,83) distribution which is found out in input modeling is used for the expression. Another process module with the same characteristics exists for loading operations that are done at dock 2.

For each dock, the products which are loaded to the outgoing truck are counted one by one with a variable in an assign block. When the value of this variable becomes equal to the order size, the dock seized by the outgoing truck is released which means that the outgoing trucks leave the warehouse with their loads. The counting control is performed by a decide module. After the dock has been released by a release module, the value of the counting variable is made equal to zero in an assign module.

The releasing process of dock 2 is same as that of dock 1. Finally, the entities are made to leave the system by a dispose module.

5. SIMULATION STUDY FOR STRATEGIC DECISION MAKING

5.1. Running the First Model with One Standard Customer

The first model is constituted by considering a warehouse of a third party Logistics Company within the simplifying assumptions indicated in section 4. The warehouse has a lot of customers. The model covers only one of these customers. In this thesis, this customer is called as standard customer from now on. The number of the equipments used in the model equals that of the real system.

In order not to start the simulation study with an empty system, warm-up period of 309 days is added to the replication length. In addition to that, the model is run for another 365 days. So, the replication length of the model covers 674 days. The model is run 100 times for this replication length. While the model is being run for 100 times, the utilization results of the fork lifts which can be seen in Table 5.1. are collected. No statistics are collected for the warm-up period.

Table 5.1. Utilization results of fork lifts for the first model

Fork lifts	Mean	Standard Deviation	95% Confidence Interval	
			Lower Bound	Upper Bound
Fork lift 1	11.830	1.002	11.633	12.026
Fork lift 2	5.298	0.615	5.178	5.419
Fork lift 3	6.039	0.663	5.909	6.169
Fork lift 4	5.226	0.598	5.109	5.344
Fork lift 5	8.355	0.878	8.183	8.527
Fork lift 6	6.644	0.729	6.501	6.787

In third party logistics companies, fork lifts and fork lift operators are used for more than one customer’s receiving and shipment operations. It is observed that the utilization values of the fork lifts are low. The reason for that is accomplishing receiving and shipment operations of only one customer with all of the equipments used in the real warehousing system.

5.2. Designing a New Warehouse

The model can be useful for designing a new warehouse if business is forecasted to grow in the near future. While designing a new warehouse, strategic decisions can be taken with the support of this model. These strategic decisions can be summarized as determining the required amount of location capacity, docks, equipment, and labor.

In designing a new warehouse according to business growth forecasts, the most important issue is predicting the number of customers with their inbound and outbound traffics. For the sake of simplicity it is assumed that there will be five standard customers in the new warehouse. In the first model with one standard customer, the receiving and shipment processes that form the basic of the warehousing system were constituted. This construction is maintained in the new model. However, since the new warehouse will consist of five standard customers, only inbound and outbound traffic of the first model is changed. To provide this, the modules in which the incoming and outgoing trucks are created in the first model are replicated five times.

The assumptions of the first model with one standard customer are maintained. Furthermore, the following properties are equal to those in the first model:

- The number of sectors and the pallet capacity of each slot in each sector
- Distances of the slots from the docks, distances between slots, and the length of the slot
- The types of the three products of the customer
- Average speeds of fork lifts during put away and order picking processes
- Time distribution of loading a pallet into a truck and unloading it from a truck
- Pallet capacity of the incoming and outgoing trucks

5.2.1. Determining Required Location Capacity

Firstly, the necessary location capacity is calculated according to the assumptions mentioned above. Then, considering this location capacity and the slot capacities, the number of slots in each sector is computed. During these calculations, at the beginning, the number of the equipments is assumed to be equal to that of the first model with one standard customer.

Moreover, at the beginning, the number of slots is taken 100, warm-up period which is required not to start with empty system is taken as 309 days and replication length is taken as 674 days as much as in the first model. Before running the model, it is estimated that a warehouse with 100 slots in each sector won't respond to the demand. But, it doesn't create a problem for running the simulation because infinite capacity locations have been defined in order to put away the products exceeding the capacity.

After running the model for 100 times, mean, standard deviation, and 95% confidence interval of maximum stock levels observed in each run has been calculated. These results can be seen in Table 5.2. Upper bound level of 95% confidence intervals which is equal to 6010 has been taken as location capacity for this model.

Table 5.2. Results for determining required location capacity

	Mean	Standard Deviation	95% Confidence Intervals	
			Lower Bound	**Upper Bound**
Max. stock	5583.380	2177.053	5156.686	6010.074

The pallet capacity of a slot in sector A and sector B is 5, and of a slot in sector C and sector D is 8. Total capacity of slots in the same range of the four sectors is 26 pallets. The number of required slots for the location capacity of 6010 pallets is computed as 231,153. This number is rounded to 231. Therefore, the required location capacity is taken as 6006 which equals to 231 times 26. The warm-up period for the location capacity of the new warehouse with 231 slots is calculated as 161 days. The aim of using a warm-up period is to start with a semi-full system. The replication length for each run is taken as 526 days which is found by adding warm-up period of 161 days to 365 days. Finally, the model has been run for 100 times with replication length of 526. In order to obtain the percentage of exceeded stock levels, firstly differences between maximum stock values and location capacity are computed. Then, these values have been divided by location capacity. The calculations can be seen in Appendix B. Average of percentage of maximal exceeded stock levels is 10,523%.

When this result is analyzed and compared to the exceeding stock levels in real system, it can be seen that this result is acceptable. Sometimes if there is not any empty storage location in the warehouse, products can be put on the fork lift paths, receiving and shipment ramps, and outside of the warehouse in order not to send the incoming trucks back. Seeing there are products outside of the storage locations which are allocated to them in the contract can cause dissatisfaction of customers.

5.2.2. Determining the Number of Required Resources

After determining the required location capacity for a new warehouse with the assumed inbound and outbound traffic, it’s necessary to calculate the number of required resources. In this calculation, we assumed that the permissible dissatisfaction level is that the percentage of outgoing trucks which are leaving the warehouse after more than 45 minutes does not exceed 5%.

For determining the required number of docks and fork lifts, different alternative models are developed. Among these alternatives, the model which does not exceed permissible dissatisfaction level with minimum labor cost is selected. There are no breaks at the shifts in the models. These alternative models are explained below:

Model_NB_4F_2D_2F_1D (No break, 4 fork lifts and 2 docks in the first shift, 2 fork lifts and 1 dock in the second shift) :

- Four fork lifts and six fork lift operators are used at the model.
- Four fork lifts and four fork lift operators work at the first shift, and two fork lifts and two fork lift operators work at the second shift.
- As there are two fork lifts at the second shift, and two fork lifts should be used for the inbound or outbound process of a truck at a dock, the second dock is closed during the second shift.

Model_NB_3F_2D_2F_1D (No break, 3 fork lifts and 2 docks in the first shift, 2 fork lifts and 1 dock in the second shift):

- Three fork lifts and five fork lift operators are used at the model.
- Three fork lifts and three fork lift operators work at the first shift, and two fork lifts and two fork lift operators work at the second shift.
- As there are two fork lifts at the second shift, and two fork lifts should be used for the inbound or outbound process of a truck at a dock, the second dock is closed during the second shift.

Model_NB_3F_1D_2F_1D (No break, 3 fork lifts and 1 dock in the first shift, 2 fork lifts and 1 dock in the second shift):

- Three fork lifts and five fork lift operators are used at the model.
- Three fork lifts and three fork lift operators work at the first shift and two fork lifts and two fork lift operators work at the second shift.
- Only dock 1 is open during all shifts.

These models have been run for 100 times. In order not to start with empty system, warm-up period is taken as 161 days for all models. In addition to that, the models are run for another 365 days. So, the replication length of the models covers 526 days. For each run of every model, the percentage of outgoing trucks which are leaving the warehouse after more than 45 minutes has been calculated. Then; mean, standard deviation, and 95% confidence intervals of these 100 percentages are computed for each model. The results are shown in Table 5.3.

Table 5.3. Dissatisfaction level results of alternative models for determining required number of resources

Alternative Models	**Mean of Dissatisfaction Level**	**Standard Deviation of Dissatisfaction Level**	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
Model_NB_4F_2D_2F_1D	4.462	1.127	4.241	4.683
Model_NB_3F_2D_2F_1D	4.880	1.287	4.628	5.132
Model_NB_3F_1D_2F_1D	6.482	1.228	6.241	6.722

The results of dissatisfaction level are examined. From Table 5.3., it can be seen that Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D do not exceed the permissible dissatisfaction level.

“Two sample T-Test” has been made for determining if there is certain difference between two alternative models. In order to perform this test, Minitab has been used. Null hypothesis for this hypothesis test is that the means of these two alternative models are equal. On the other hand, alternative hypothesis is that the means of these two alternative models are not equal. Outputs of this test, box plot of Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D, and individual value plot of Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D can be seen in the Appendix B. According to these outputs, there is significant difference between Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D as it is expected.

Although both of the models do not exceed the permissible dissatisfaction level, Model_NB_3F_2D_2F_1D with less fork lifts has been chosen to reduce the labor cost. So, required number of fork lifts is 3 and required number of fork lift operators is 5, and the number of required docks is 2.

6. SIMULATION STUDY FOR OPERATIONAL DECISION MAKING

6.1. Obtaining Operational Characteristics of the Warehouse

The simulation model provides valuable knowledge about the operational characteristics of a warehouse during operational decision making process. These operational characteristics are determined with the use of defined statistics recorded in output text files. Some of these statistics are as follows:

- Mean, standard deviation, and 95% confidence intervals of utilization percentages of fork lifts and docks
- Mean, standard deviation, and 95% confidence intervals of waiting times of outgoing trucks in the shipment queue
- Mean, standard deviation, and 95% confidence intervals of times for outgoing trucks to pick an order at different docks
- Mean, standard deviation, and 95% confidence intervals of time to load an outgoing truck at different docks
- Mean, standard deviation, and 95% confidence intervals of time that outgoing trucks spent in the warehouse

The results for the operational characteristics of the warehouse are indicated in Table 6.1., 6.2., 6.3., 6.4., 6.5.

Table 6.1. Utilization percentages of fork lifts and docks at Model_NB_3F_2D_2F_1D

Docks/Fork lifts	**Mean (%)**	**Standard Deviation (%)**	**95% Confidence Interval**	
			Lower Bound (%)	**Upper Bound (%)**
Dock 1	59.003	1.997	58.612	59.394
Dock 2	43.196	2.211	42.716	43.675
Fork lift 1	58.888	1.950	58.506	59.270
Fork lift 2	49.775	2.211	49.341	50.208
Fork lift 3	52.664	2.182	52.237	53.092
Fork lift 5	59.409	2.088	59.000	59.819
Fork lift 6	49.043	1.982	48.654	49.431

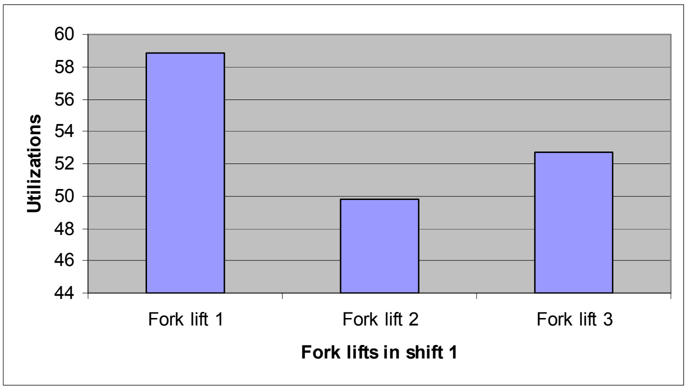

Figure 6.1. Utilization results of fork lifts in shift 1

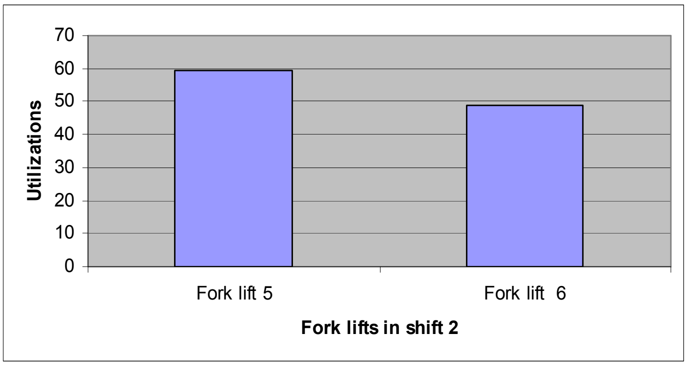

Figure 6.2. Utilization results of fork lifts in shift 2

When the utilization results in Figure 6.1. and Figure 6.2. are analyzed, it can be seen that total utilization of fork lifts in shift 1 is more than total utilization of fork lifts in shift 2. However, the duration of shift 2, 14 hours, is more than the duration of shift 1, 10 hours. Considering both duration of shifts and utilization of fork lifts, it can be concluded that total warehouse traffic in shift 1 is greater than in shift 2.

Table 6.2. Waiting times of outgoing trucks in the shipment queue at Model_NB_3F_2D_2F_1D

	Mean (min)	Standard Deviation (min)	95% Confidence Interval	
			Lower Bound (min)	Upper Bound (min)
Waiting time of trucks that left the shipment queue to be loaded at dock 1	7.382	1.186	7.149	7.614
Waiting time of trucks that left the shipment queue to be loaded at dock 2	4.489	1.277	4.239	4.739

Table 6.3. Times to pick the orders of outgoing trucks at different docks at Model_NB_3F_2D_2F_1D

	Mean (min)	Standard Deviation (min)	95% Confidence Interval	
			Lower Bound (min)	Upper Bound (min)
Time to pick an order at dock 1	9.930	0.355	9.860	10.000
Time to pick an order at dock 2	10.884	0.454	10.795	10.973

Table 6.4. Time to load an outgoing truck at different docks at Model_NB_3F_2D_2F_1D

	Mean (min)	Standard Deviation (min)	95% Confidence Interval	
			Lower Bound (min)	Upper Bound (min)
Time for loading at dock 1	11.791	0.199	11.752	11.831
Time for loading at dock 2	11.622	0.169	11.589	11.655

Table 6.5. Time that outgoing trucks spent in the warehouse at Model_NB_3F_2D_2F_1D

	Mean (min)	Standard Deviation (min)	95% Confidence Interval	
			Lower Bound (min)	Upper Bound (min)
Time that outgoing trucks loaded from dock 1 spent in the warehouse	21.284	1.396	21.011	21.558
Time that outgoing trucks loaded from dock 2 spent in the warehouse	19.655	1.499	19.361	19.949

In Table 6.5. mean of times that outgoing trucks spent in the warehouse is calculated without considering shifts. More detailed analysis is performed including shifts and time intervals for total times that outgoing trucks spent in the system. Following histograms show the results of this analysis.

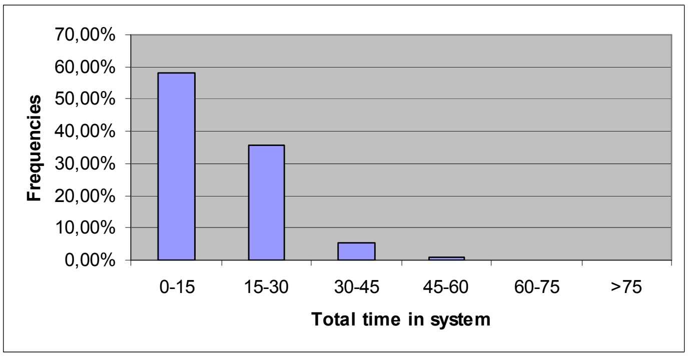

Figure 6.3. Histogram of total time spent in system versus percentages of frequencies for outgoing trucks loaded from dock 1 in shift 1

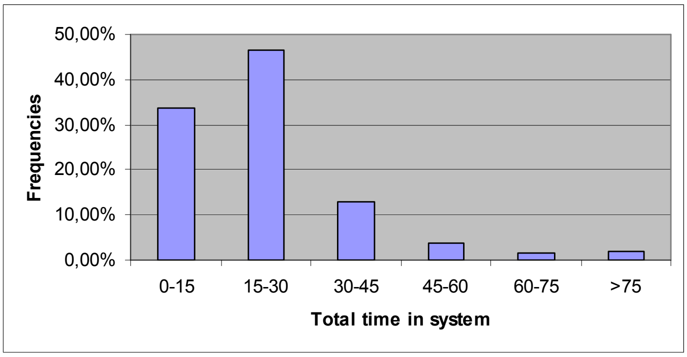

Figure 6.4. Histogram of total time spent in system versus percentages of frequencies for outgoing trucks loaded from dock 1 in shift 2

Figure 6.3. shows that most of the outgoing trucks loaded from dock 1 in shift 1 spend less than 15 minutes in the system. In the other hand, the times that most of the outgoing trucks loaded from dock 1 in shift 2 spend in the system are between 15 minutes and 30 minutes as it can be seen from Figure 6.4. The reason of this result is that the number of fork lifts used in shift 2 is less than the number of fork lifts used in shift1.

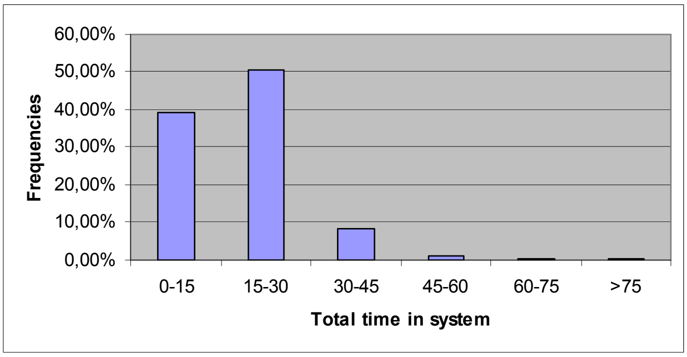

Figure 6.5. Histogram of total time spent in system versus percentages of frequencies for outgoing trucks loaded from dock 2 in shift 1

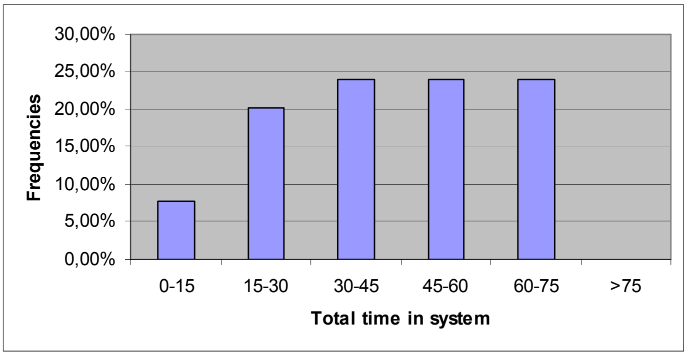

Figure 6.6. Histogram of total time spent in system versus percentages of frequencies for outgoing trucks loaded from dock 2 in shift 2

In Figure 6.5., it can be seen that total times that outgoing trucks loaded from dock 2 in shift 1 spend in the system are mostly between 15 minutes and 30 minutes. The main reason here is that dock 2 is started to be used only while there is already a truck at dock 1, and because of this the available fork lifts are separated for operations at each dock. In shift 2, dock 2 is closed. While a truck is being loaded or unloaded at dock 2 in the time shift 1 finishes and shift 2 starts, fork lift operators who start to work at shift 2 continue the operation remained from shift 1 at dock 2. So, there can be a few outgoing trucks loaded from dock 2 in shift 2. In addition to that, total times that these trucks spend in the system are too high since the number of fork lifts is decreased in shift 2.

If the above operational characteristics of the system are analyzed, it can be concluded that different statistics can be collected by the model. All of these statistics can be used for comparing alternative models. In this study, as a matter of convenience, the percentage of outgoing trucks which are leaving the warehouse after more than 45 minutes is taken as performance measure while comparing alternative models.

6.1.1. An Attempt of Validation

The behavior of different types of specific entities in the model has been traced through the model and it has been seen that model's logic is correct. For validation, Model_NB_3F_2D_2F_1D and the real system are compared. Results of total times outgoing trucks spend in the warehouse are used to determine whether the model behaves similar to the real system. Although the two systems are not equal, we want to see if they are comparable. Two hundred results were taken from historical data for calculating mean of times that outgoing trucks spent in the warehouse. The average of these data given in Appendix C is close to 28. Compared to a mean time in system of approximately 20 minutes for outgoing trucks we may say that although the simulation model is a clearly simplified version of the real system they do not behave too different.

6.2. Fork Lifts and Labor Force Planning In Case Of Decrease in the Traffic

The simulation model can be utilized for determining required changes in the amount of fork lifts and labor in case of decrease in warehouse traffic if some customers are closed during a time period. In this study, it is assumed that two of the standard customers are closed during one month. To provide this, the modules in which the incoming and outgoing trucks are created for these two customers are removed from the model. Beside this change all parameters of the system remained the same as in the Model_NB_3F_2D_2F_1D.

Firstly, the new model with decreased traffic, Model DecT_3F_2D_2F_1D (Model with decreased traffic, 3 fork lifts and 2 docks in the first shift and 2 fork lifts and 1 dock in the second shift), is run for 100 times. It is analyzed if the percentages of outgoing trucks which are leaving the warehouse after more than 45 minutes show the desired level or not. Mean, standard deviation, and 95% confidence intervals of these percentages for 100 runs are obtained as indicated in Table 6.6.

Table 6.6. Results for percentages of outgoing trucks which are leaving the warehouse after more than 45 minutes at Model DecT_3F_2D_2F_1D

Percentages of Outgoing Trucks Which Are Leaving The Warehouse After More Than 45 Minutes For Model DecT_3F_2D_2F_1D	Mean of Dissatisfaction Level	Standard Deviation of Dissatisfaction Level	95% Confidence Interval	
			Lower Bound	Upper Bound
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock1	1.395	0.508	1.296	1.495
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock2	0.628	0.390	0.551	0.704

When the run results are examined, the mean of percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 1 is 1,395%. This value is below the permissible dissatisfaction level of 5% which indicates that there is still opportunity for decreasing the number of fork lifts in order to reduce labor cost. Therefore, two alternative models, Model DecT_2F_1D_2F_1D, Model DecT_2F_1D_1F_1D are developed in being attentive to not exceeding the permissible dissatisfaction level.

Model DecT_2F_1D_2F_1D (Model with decreased traffic, 2 fork lifts and 1 dock in the first shift, 2 fork lifts and 1 dock in the second shift):

- Two fork lifts and four fork lift operators are used for inbound and outbound processes.
- Two fork lifts and two fork lifts operators work at the first shift, and two fork lifts and two fork lifts operators work at the second shift.
- The second dock is not opened during all shifts, as there are two fork lifts at the first shift, and two fork lifts should be used for the inbound or outbound process of a truck at a dock.

Model DecT_2F_1D_1F_1D (Model with decreased traffic, 2 fork lifts and 1 dock in the first shift, 1 fork lift and 1 dock in the second shift):

- Two fork lifts and three fork lift operators are used in the model.
- Two fork lifts and two fork lift operators work at the first shift, and one fork lift and one fork lift operator work at the second shift.
- Only dock 1 is open during all shifts.

These models have same inbound and outbound processes. As explained above, the only difference between the models lies in the amount of fork lifts at shifts. These models have been run for 100 times, and the percentages of outgoing trucks which are leaving the warehouse after more than 45 minutes are analyzed for each model. Mean, standard deviation, and 95% confidence intervals of these percentages for 100 runs of each model are obtained. The run results for Model DecT_2F_1D_2F_1D and Model DecT_2F_1D_1F_1D can be seen in Table 6.7. and Table 6.8. respectively.

Table 6.7. Results for percentages of outgoing trucks which are leaving the warehouse after more than 45 minutes at Model DecT_2F_1D_2F_1D

Percentages of Outgoing Trucks Which Are Leaving The Warehouse After More Than 45 Minutes For Model DecT_2F_1D_2F_1D	**Mean of Dissatisfaction Level**	**Standard Deviation of Dissatisfaction Level**	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock1	2.822	0.810	2.663	2.981

Table 6.8. Results for percentages of outgoing trucks which are leaving the warehouse after more than 45 minutes at Model DecT_2F_1D_1F_1D

Percentages of Outgoing Trucks Which Are Leaving The Warehouse After More Than 45 Minutes For Model DecT_2F_1D_1F_1D	**Mean of Dissatisfaction Level**	**Standard Deviation of Dissatisfaction Level**	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock1	18.523	1.968	18.137	18.908

When the models are examined, it is observed that mean results of Model DecT_2F_1D_1F_1D is far above the permissible dissatisfaction level. This outcome supports the work policy that two fork lifts should be used for the inbound or outbound process of a truck at a dock. During the inbound process, while one fork lift unloads the truck, the second fork lift puts away the materials to the storage locations. During the outbound process, while one fork lift picks up the materials, the second fork lift loads the truck. When only one fork lift is dedicated to an inbound process or an outbound process, the completion times of the processes increase so much that the permissible dissatisfaction level is exceeded.

As conclusion, Model DecT_2F_1D_2F_1D is chosen as the most appropriate solution to the decreased traffic problem as the permissible dissatisfaction level is not exceeded. According to Model DecT_2F_1D_2F_1D; required number of fork lifts is two and required number of fork lift operators are four, two for the first shift and two for the second shift.

While in the model for five standard customers, Model_NB_3F_2D_2F_1D, three fork lifts and five fork lift operators are required, the numbers of fork lifts and fork lift operators decrease by one in the model for decreased traffic with three standard customers, Model DecT_2F_1D_2F_1D. The company can plan the holidays of its fork lift operators in the month when such labor force deduction happens as two of the customers are closed.

6.3. Planning the Shifts with Breaks

The simulation model can also be used for finding an optimal break schedule. In the models considered until now, no meal break is included. With adding breaks to Model_NB_3F_2D_2F_1D, the number and times of breaks are determined.

In real system, there is a lunch break of one hour between 12:30 p.m. and 13:30 p.m. during the first shift. The times allocated for meal breaks during the second shift are not predetermined. The workers decide about their break times based on their work loads. Therefore, breaks are planned only for the first shift.

Three alternative models are developed for planning the breaks in the first shift. Model_W1B_3F_2D_2F_1D (Model with one break, three fork lifts and two docks in the first shift, two fork lifts and one dock in the second shift) has one break, Model_W2B_3F_2D_2F_1D (Model with two breaks, 3 fork lifts and 2 docks in the first shift, 2 fork lifts and 1 dock in the second shift) has two breaks, and Model_W6B_3F_2D_2F_1D (Model with six breaks, 3 fork lifts and 2 docks in the first shift, 2 fork lifts and 1 dock in the second shift) has six breaks.

At Model_W1B_3F_2D_2F_1D, the meal break for all fork lifts is between 12:30 and 13:30. If break time starts while a truck is in process, fork lifts can’t have breaks until they finish their operations. These processes are unloading and put away operations for incoming trucks, and pick up and loading operations for outgoing trucks. Since the inbound and outbound processes last 21 minutes in average, there will remain time for the meal. However, all fork lifts end the break at 13:30.

At Model_W2B_3F_2D_2F_1D, the meal break for fork lift 1 and fork lift 2 is between 11:30 and 12:30, and the meal break for fork lift 3 is between 12:30 and 13:30. While fork lift 1 and fork lift 2 are in the break, fork lift 3 continues with their unfinished work. While fork lift 3 is in the break, fork lift 1 and fork lift 2 continue with its unfinished work.

At Model_W6B_3F_2D_2F_1D, fork lifts use their break in two 30 minutes parts. The first part of the break of fork lift 1 is between 11:30 and 12:00, and the second part is between 13:00 and 13:30. While fork lift 1 is in the break, fork lift 2 is assigned to dock 1, and fork lift 3 is assigned to dock 2. The first part of the break of fork lift 2 is between 12:00 and 12:30, and the second part is between 13:30 and 14:00. While fork lift 2 is in the break, fork lift 1 is assigned to dock 1, and fork lift 3 is assigned to dock 2. The first part of the break of fork lift 3 is between 12:30 and 13:00, and the second part is between 14:00 and 14:30. While fork lift 3 is in the break, fork lift 1 is assigned to dock 1, and fork lift 2 is assigned to dock 2. Namely, it is provided that always two fork lifts remain working as two fork lifts are needed for the inbound or outbound process of a truck at a dock.

These models have been run for 100 times, and the waiting times of the trucks in the shipment queue and the percentages of outgoing trucks which are leaving the warehouse after more than 45 minutes are analyzed for each model. Mean, standard deviation, and 95% confidence intervals of these waiting times and percentages for 100 runs of each model are obtained. The run results for Model_W1B_3F_2D_2F_1D, Model_W2B_3F_2D_2F_1D, and Model_W6B_3F_2D_2F_1D can be seen in Table 6.9., Table 6.10., Table 6.11., Table 6.12., Table 6.13., and Table 6.14. respectively.

Table 6.9. Waiting times of the trucks in the shipment queue at Model_W1B_3F_2D_2F_1D

	Mean	Standard Deviation	95% Confidence Interval	
			Lower Bound	Upper Bound
Waiting time of trucks loaded from dock 1 in the shipment queue	9.009	1.262	8.762	9.256
Waiting time of trucks loaded from dock 2 in the shipment queue	9.640	1.399	9.366	9.914

Table 6.10. Waiting times of the trucks in the shipment queue at Model_W2B_3F_2D_2F_1D

	Mean	Standard Deviation	95% Confidence Interval	
			Lower Bound	Upper Bound
Waiting time of trucks that are loaded from dock 1 in the shipment queue	8.562	1.336	8.300	8.824
Waiting time of trucks that are loaded from dock 2 in the shipment queue	8.039	1.572	7.731	8.347

Table 6.11. Waiting times of the trucks in the shipment queue at Model_W6B_3F_2D_2F_1D

	Mean	Standard Deviation	95% Confidence Interval	
			Lower Bound	Upper Bound
Waiting time of trucks loaded from dock 1 in the shipment queue	8.125	1.356	7.859	8.391
Waiting time of trucks loaded from dock 2 in the shipment queue	6.826	1.535	6.525	7.127

Table 6.12. Percentages of outgoing trucks which are in the system more than 45 minutes at Model_W1B_3F_2D_2F_1D

	Mean (%)	Standard Deviation (%)	95% Confidence Interval	
			Lower Bound (%)	Upper Bound (%)
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 1	7.494	1.294	7.241	7.748
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 2	11.396	1.167	11.168	11.625

Table 6.13. Percentages of outgoing trucks which are in the system more than 45 minutes at Model_W2B_3F_2D_2F_1D

	Mean (%)	Standard Deviation (%)	95% Confidence Interval	
			Lower Bound (%)	Upper Bound (%)
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 1	7.839	1.401	7.565	8.114
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 2	12.375	1.570	12.067	12.682

Table 6.14. Percentages of outgoing trucks which are in the system more than 45 minutes at Model_W6B_3F_2D_2F_1D

	Mean (%)	Standard Deviation (%)	95% Confidence Interval	
			Lower Bound (%)	Upper Bound (%)
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 1	6.753	1.425	6.474	7.032
percentage of outgoing trucks that are in the system more than 45 minutes and loaded from dock 2	8.324	1.496	8.031	8.617

When the results are analyzed, it can be seen that Model_W6B_3F_2D_2F_1D that has six breaks is more advantageous than the other alternatives. The underlying reason is that Model_W6B_3F_2D_2F_1D reduces average waiting times of outgoing trucks in the shipment queues and percentages of outgoing trucks that are in system more than 45 minutes. Such a solution was to be expected as letting only one fork lift operator to go to the break at a time provides two active fork lifts in the warehouse. In other alternatives, number of active fork lifts is less than two, which causes an increase of the waiting time and not achieving not to exceed the permissible dissatisfaction level. However, the trade off will be worker satisfaction in such a situation because people don't like to eat alone. To force fork lift operators to have their meal break on their own may have negative effects as dissatisfied workers may slow down the business on purpose. The decision about having six meal breaks in order to optimize waiting times has to be taken after a test period or/and in conferring with the fork lift operators.

6.4. Model with Scheduled Arrivals

There are some possibilities to reduce waiting times without increasing costs. One of these possibilities is planning the number of trucks that will come to the warehouse for inbound or outbound process at each hour of a day. The main practical problems related to this possibility are as follows:

- Will the customers be able and willing to give the information about the number of incoming and outgoing trucks at each hour of a day?
- It is likely that the precision of the arrival time information depends on the location of the warehouse and the company of the customer.

A second possibility to reduce waiting times without increasing costs is that there are extra fork lift drivers who normally do a different work. These workers are called when there are trucks in the queues.

We will here try the first of the two possibilities. Although optimization of the number of necessary forklifts is out of the scope of this thesis, we want to show in a simple example how simulation could be used to decide about the necessary number of forklifts when the arrivals of the trucks are known.

If there are scheduled arrivals with definite number of incoming and outgoing trucks per hour, the model can also be utilized in investigating equipment and labor requirements for each hour of a day. If the third party logistics company knows the number of incoming and outgoing trucks per hour for the following day, they can plan the resource requirements for each hour for a specific customer, and direct the idle fork lifts to the other customers' operations.

In this subsection, required number of fork lifts and labor requirements are found in case of scheduled arrivals per hour. Utilizations of the fork lifts are taken as performance measure for evaluating the resource requirements for each hour. The scheduled numbers of incoming and outgoing trucks per hour is given in Appendix C.

In the model, time in busy state for each fork lift is stored for each hour and percentage of time in busy state is calculated by dividing this time by 60 minutes. The model is run for 100 times. Replication length except warm up period is taken as 365 days.

If the number of fork lifts is not adequate in a specific time interval, trucks that come to warehouse in this time interval are postponed to the following time interval. Therefore, although the scheduled numbers of incoming and outgoing trucks do not change in a specific time interval, the utilizations of the forklifts increase for that interval because of remaining trucks from previous time interval. This issue of fact makes scheduled arrivals a multi-dimensional optimization problem. With the simulation study in this thesis, optimal solutions cannot be obtained. But, it can support operational decision making processes to find close to optimal solutions.

Utilizations of fork lifts for each hour are given in Table 6.15. for different number of fork lifts. Some other analysis results for different number of fork lifts for each hour are indicated in Appendix C. Required number of fork lifts are determined considering the performance measure. These numbers can be seen in Table 6.16. In the 14th time interval, although the number of fork lifts is increased, the utilizations of fork lift which are especially being used for loading and unloading activities do not decrease to the desired level. It can be concluded that the number of docks are inadequate for this interval.

Table 6.15. Utilizations of fork lifts for Scheduled Arrivals

		Number of Fork lifts																			
		f1	f2	f3		f1	f2	f3	f4		f1	f2	f3	f4	f5		f1	f2	f3	f4	f5
Hours	1	82.75	74.33	78.13		77.55	71.42	67.01			80.24	74.96	70.95				87.83	85.08	80.71		
	2	86.59	79.79	83.49		84.32	80.65	76.66			85.10	81.63	77.73				87.89	85.08	81.54		
	3	87.00	79.52	83.45		85.53	81.50	77.44			86.00	82.10	78.08				87.66	84.26	80.38		
	4	84.52	77.48	81.30		82.89	79.43	75.38			83.29	79.89	75.90				84.73	81.68	77.82		
	5	85.40	76.95	81.06		84.20	79.43	75.23			84.51	79.81	75.65				85.46	81.08	76.96		
	6	84.56	77.13	81.06		83.31	79.45	75.40			83.53	79.71	75.73				84.36	80.78	76.81		
	7	71.38	61.80	65.98		69.22	63.37	59.09			75.35	61.70					79.58	68.96			
	8	84.66	76.49	80.34		83.70	79.11	75.13			89.54	88.42	82.60				88.82	86.27	82.00		
	9	80.20	72.20	76.37		79.17	75.05	70.83			82.20	78.79	74.83				82.19	78.85	74.84		
	10	91.34	85.41	88.57		91.00	88.15	84.93			82.20	78.79	74.83	67.27			88.86	85.16	67.53	67.35	
	11	94.17	92.61	88.72		90.65	88.19	72.46	71.11		86.30	82.71	52.84	51.87	50.56		86.41	82.90	52.97	52.00	50.68
	12	91.15	89.19	85.82		82.51	78.00	63.39	62.93		80.26	75.15	60.52	59.78			80.43	75.40	60.79	60.02	
	13	92.36	90.56	88.11		84.42	79.94	61.81	61.90		83.58	78.81	60.65	60.72			83.74	79.03	60.86	60.89	
	14	97.53	96.74	94.61		93.79	91.71	72.53	71.88		92.26	89.79	54.06	53.84	53.60		92.33	89.87	54.11	53.85	53.60
	15	93.81	92.71	89.72		81.66	77.81	62.17	61.68		79.67	75.36	59.43	58.59			79.78	75.50	59.52	58.72	
	16	94.48	92.96	90.31		85.51	80.77	63.32	62.93		84.87	79.85	62.41	61.98			84.96	79.99	62.49	62.10	
	17	90.46	88.45	84.91		75.10	68.72	54.30	53.84		79.78	75.29	70.14				79.89	75.43	70.27		
	18	92.23	90.21	86.80		81.53	75.56	60.94	60.40		83.10	77.64	63.38	63.03			83.19	77.81	63.57	63.20	
	19	93.16	91.54	88.56		82.10	77.05	60.23	59.85		82.61	77.68	60.95	60.61			82.75	77.84	61.07	60.74	
	20	89.65	87.37	84.48		75.27	68.56	51.92	51.98		75.65	69.06	52.42	52.42			80.51	75.98	71.36		
	21	86.20	82.90	79.60		71.64	63.45	47.77	47.74		76.66	70.90	65.71				79.61	74.74	70.74		
	22	74.29	69.06	65.24		56.45	45.47	33.77	33.83		64.86	57.71	53.48				76.53	66.39			
	23	82.07	7716	72.93		71.57	62.00	47.40	47.18		78.03	71.86	67.34				83.78	79.74	74.89		
	24	78.13	73.18	68.99		64.83	55.06	41.92	41.81		74.33	68.45	64.05				85.01	74.55			

Table 6.16. Required number of fork lifts for scheduled arrivals

Hours	Number of fork lifts
1	3
2	3
3	3
4	3
5	3
6	3
7	2
8	3
9	3
10	4
11	5
12	4
13	4
14	5
15	4
16	4
17	3
18	4
19	4
20	3
21	3
22	2
23	3
24	2

7. CONCLUSION AND FUTURE RESEARCH

This thesis has shown the usefulness of the developed simulation model both in strategic and operational decision making processes of logistics companies. One of the main findings is that the model in this thesis is able to assist in the strategic decision making process of designing new warehouses according to the near future business growth forecasts. If the number of customers and amounts of inbound and outbound traffic are forecasted, the required location capacity and required amount of equipments and headcounts to be used in warehouse operations considering both permissible dissatisfaction level of the customers and equipment and labor cost are determined through the simulation model. According to the results of this simulation model, logistics companies are capable of taking proper strategic decisions in order to design more efficient warehouses.

It is also possible to obtain valuable knowledge about the operational characteristics of the current warehouse using the simulation model.

Logistics companies can utilize the simulation model in fork lifts and labor force planning during their operational decision making process in case of decrease in warehouse traffic if some customers are closed during a time period. If the results of the simulation model indicate that the numbers of fork lifts and fork lift operators can be decreased when these customers are closed, the logistics companies can plan the holidays of its workers in this time of period. The simulation model can also be used with the idea of finding optimal break schedule which is again part of the operational decision making process. Logistics companies are able to investigate equipment and labor requirements for each hour of a day with the help of the model if there are scheduled arrivals with definite number of incoming and outgoing trucks per hour. In taking utilizations of the fork lifts as performance metric for evaluating the resource requirements for each hour, near optimal plans for fork lift and labor requirements can be made.

In conclusion, this study presents a beneficial tool for a decision maker in warehousing systems in the light of the above stated findings. Future work of the study will include investigating and modeling of warehousing systems with more customers with different inbound and outbound traffic. The model in this study can be improved in handling flexible order and truck sizes. Thereby, different storage systems such as rack systems can be analyzed. Different put away and order picking policies can be examined.

APPENDIX A: DATA AND RESULTS OF INPUT MODELING

A.1. Input and Output Distributions of Materials

Table A.1. Discrete empirical distribution of incoming Soda trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.772	0.772
2	0.005	0.777
4	0.011	0.788
5	0.022	0.810
6	0.011	0.821
7	0.011	0.832
8	0.038	0.870
9	0.016	0.886
10	0.005	0.891
11	0.016	0.908
12	0.016	0.924
13	0.011	0.935
14	0.011	0.946
16	0.005	0.951
17	0.011	0.962
18	0.011	0.973
22	0.005	0.978
23	0.005	0.984
27	0.011	0.995
32	0.005	1.000

Table A.2. Discrete empirical distribution of outgoing Soda trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.332	0.332
1	0.054	0.386
2	0.114	0.500
3	0.207	0.707
4	0.152	0.859
5	0.087	0.946
6	0.038	0.984
7	0.005	0.989
8	0.005	0.995
10	0.005	1.000

Table A.3. Discrete empirical distribution of incoming Soda trucks at shift 2

# Of Trucks	Probability	Cum. Probability
0	0.810	0.810
1	0.011	0.821
2	0.011	0.832
4	0.016	0.848
5	0.005	0.853
6	0.011	0.864
7	0.016	0.880
8	0.005	0.886
9	0.005	0.891
10	0.011	0.902
11	0.011	0.913
12	0.005	0.918
13	0.005	0.924
14	0.005	0.929
15	0.011	0.940
16	0.005	0.946
18	0.016	0.962
20	0.011	0.973
23	0.005	0.978
26	0.005	0.984
28	0.005	0.989
29	0.005	0.995
36	0.005	1.000

Table A.4. Discrete empirical distribution of outgoing Soda trucks at shift 2

# Of Trucks	Probability	Cum. Probability
0	0.315	0.315
1	0.092	0.408
2	0.098	0.505
3	0.179	0.685
4	0.152	0.837
5	0.092	0.929
6	0.060	0.989
7	0.011	1.000

Table A.5. Discrete empirical distribution of incoming Phosphate trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.924	0.924
1	0.005	0.929
2	0.011	0.940
6	0.005	0.946
8	0.005	0.951
9	0.011	0.962
15	0.011	0.973
16	0.005	0.978
17	0.005	0.984
18	0.005	0.989
19	0.005	0.995
21	0.005	1.000

Table A.6. Discrete empirical distribution of outgoing Phosphate trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.674	0.674
1	0.043	0.717
2	0.065	0.783
3	0.027	0.810
4	0.109	0.918
5	0.054	0.973
6	0.027	1.000

Table A.7. Discrete empirical distribution of incoming Phosphate trucks at shift 2

# Of Trucks	Probability	Cum. Probability
0	0.929	0.929
1	0.005	0.935
7	0.011	0.946
8	0.011	0.957
12	0.011	0.967
15	0.005	0.973
17	0.005	0.978
19	0.005	0.984
21	0.005	0.989
27	0.005	0.995
28	0.005	1.000

Table A.8. Discrete empirical distribution of outgoing Phosphate trucks at shift 2

# Of Trucks	Probability	Cum. Probability
0	0.663	0.663
1	0.043	0.707
2	0.054	0.761
3	0.092	0.853
4	0.038	0.891
5	0.054	0.946
6	0.027	0.973
7	0.022	0.995
9	0.005	1.000

Table A.9. Discrete empirical distribution of incoming Sulphate trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.848	0.848
1	0.011	0.859
2	0.022	0.880
3	0.022	0.902
4	0.033	0.935
5	0.027	0.962
6	0.011	0.973
7	0.016	0.989
8	0.005	0.995
10	0.005	1.000

Table A.10. Discrete empirical distribution of outgoing Sulphate trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.842	0.842
1	0.049	0.891
2	0.033	0.924
3	0.011	0.935
4	0.027	0.962
5	0.016	0.978
6	0.016	0.995
7	0.005	1.000

Table A.11. Discrete empirical distribution of incoming Sulphate trucks at shift 2

# Of Trucks	Probability	Cum. Probability
0	0.848	0.848
1	0.016	0.864
2	0.011	0.875
3	0.038	0.913
4	0.033	0.946
5	0.027	0.973
6	0.016	0.989
8	0.005	0.995
10	0.005	1.000

Table A.12. Discrete empirical distribution of outgoing Sulphate trucks at shift 1

# Of Trucks	Probability	Cum. Probability
0	0.723	0.723
1	0.082	0.804
2	0.065	0.870
3	0.038	0.908
4	0.033	0.940
5	0.049	0.989
6	0.011	1.000

A.2. Transportation Times of Fork lifts for Different Distances

Table A.13. Transportation times of fork lifts for different distances

Number	Time for transportation (sec)	Distance (m)
1	119	90
2	130	91
3	125	92
4	111	93
5	128	94
6	74	38
7	70	39
8	64	40
9	75	41
10	77	42
11	142	115
12	143	116
13	129	117
14	131	118
15	136	119
16	74	46
17	86	47
18	77	48
19	78	49
20	80	50
21	97	70
22	103	71
23	107	72
24	106	73
25	107	74
26	138	112
27	135	113
28	126	114
29	136	115
30	156	116
31	95	52
32	86	53
33	99	54
34	76	55

Table A.13. Transportation times of fork lifts for different distances (continued)

Number	Time for transportation (sec)	Distance (m)
35	78	56
36	48	30
37	60	31
38	51	32
39	62	33
40	63	34
41	133	100
42	125	101
43	135	102
44	123	103
45	128	104
46	93	65
47	92	66
48	93	67
49	102	68
50	103	69
51	136	120
52	149	121
53	164	122
54	139	123
55	142	124
56	100	72
57	96	73
58	108	74
59	104	75
60	103	76

A.3. Loading and Unloading Times

Table A.14. Unloading time observations of fork lifts

Number of Observations	Time (sec)
1	73
2	67
3	63
4	80
5	74
6	64
7	78
8	76
9	79
10	68
11	71
12	81
13	62
14	81
15	70

Table A.14. Unloading time observations of fork lifts (continued)

Number of Observations	**Time (sec)**
16	63
17	71
18	70
19	73
20	65
21	67
22	62
23	78
24	83
25	66

Table A.15. Loading time observations of fork lifts

Number of Observations	Time (sec)
26	78
27	70
28	69
29	65
30	83
31	66
32	63
33	73
34	78
35	82
36	75
37	78
38	83
39	82
40	64
41	67
42	66
43	78
44	76
45	75
46	78
47	76
48	68
49	75
50	62

Table A.16. Outputs of T-Test for loading and unloading time observation values

Analysis		**Results**
Estimate for difference		-1.800
95% confidence for difference	Upper Bound	1.994
	Lower Bound	-5.593
T-Value		-0.95
P-Value		0.345
DF		47

It can be seen from above results that 95% confidence interval for difference of means includes zero. And p-value "0.345" is higher than 0.05. According to these outputs, it can be concluded that there is no difference between loading and unloading times.

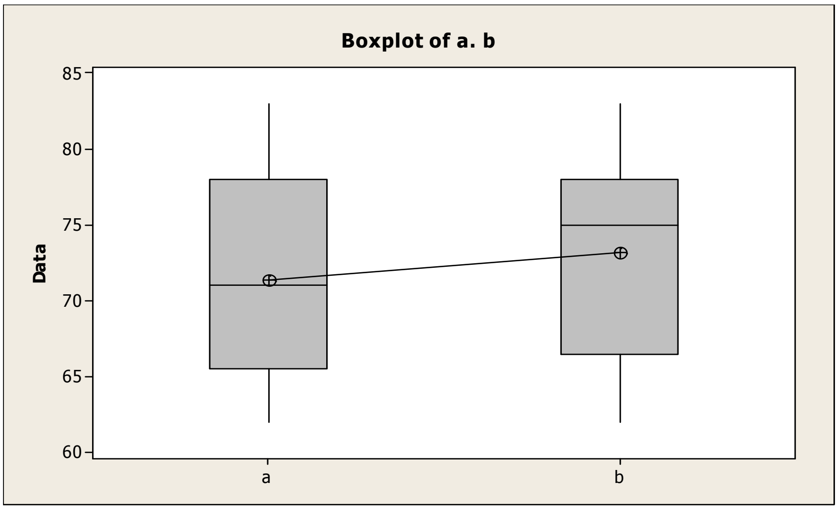

Figure A.1. Boxplot of unloading and loading time observations

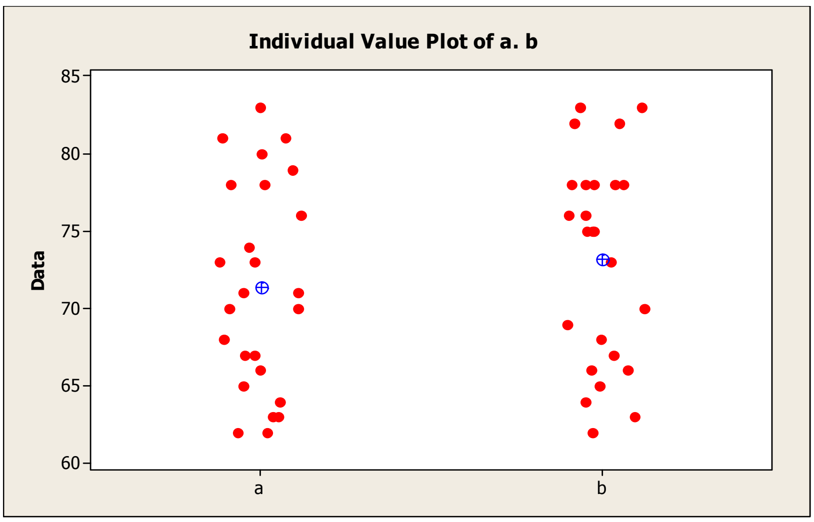

Figure A.2. Individual value plot of unloading and loading times observations

APPENDIX B: STRATEGIC DECISION MAKING RESULTS

B.1. Results of New Warehouse Design

Table B.1. Results of exceeded stock levels for new designed warehouse

Rep. no	Max. stock levels	Stock capacity	Exceeded amount	Percentage of exceeded stock levels
1	3438	6006	0	0.000
2	6064	6006	58	0.966
3	6296	6006	290	4.829
4	4720	6006	0	0.000
5	4800	6006	0	0.000
6	8192	6006	2186	36.397
7	3696	6006	0	0.000
8	8336	6006	2330	38.795
9	4566	6006	0	0.000
10	6980	6006	974	16.217
11	6952	6006	946	15.751
12	6080	6006	74	1.232
13	3864	6006	0	0.000
14	5768	6006	0	0.000
15	3856	6006	0	0.000
16	6848	6006	842	14.019
17	5232	6006	0	0.000
18	5032	6006	0	0.000
19	6392	6006	386	6.427
20	4272	6006	0	0.000
21	7088	6006	1082	18.015
22	3288	6006	0	0.000
23	11360	6006	5354	89.144
24	4496	6006	0	0.000
25	8705	6006	2699	44.938
26	4384	6006	0	0.000
27	4336	6006	0	0.000
28	2832	6006	0	0.000
29	4744	6006	0	0.000
30	8280	6006	2274	37.862
31	3704	6006	0	0.000
32	8384	6006	2378	39.594
33	5552	6006	0	0.000
34	8168	6006	2162	35.997
35	12520	6006	6514	108.458
36	3396	6006	0	0.000
37	9187	6006	3181	52.964
38	3848	6006	0	0.000
39	5464	6006	0	0.000
40	3912	6006	0	0.000

Table B.1. Results of exceeded stock levels for new designed warehouse (continued)

Rep. no	Max. stock levels	Stock capacity	Exceeded amount	Percentage of exceeded stock levels
41	5928	6006	0	0.000
42	8872	6006	2866	47.719
43	3952	6006	0	0.000
44	5344	6006	0	0.000
45	2944	6006	0	0.000
46	6040	6006	34	0.566
47	6024	6006	18	0.300
48	3568	6006	0	0.000
49	4384	6006	0	0.000
50	6648	6006	642	10.689
51	2848	6006	0	0.000
52	5200	6006	0	0.000
53	6504	6006	498	8.292
54	4552	6006	0	0.000
55	6397	6006	391	6.510
56	3136	6006	0	0.000
57	3568	6006	0	0.000
58	5584	6006	0	0.000
59	8928	6006	2922	48.651
60	5165	6006	0	0.000
61	7024	6006	1018	16.950
62	12272	6006	6266	104.329
63	6512	6006	506	8.425
64	4568	6006	0	0.000
65	3472	6006	0	0.000
66	6032	6006	26	0.433
67	8240	6006	2234	37.196
68	6256	6006	250	4.163
69	3472	6006	0	0.000
70	4976	6006	0	0.000
71	6776	6006	770	12.821
72	6564	6006	558	9.291
73	8120	6006	2114	35.198
74	5120	6006	0	0.000
75	5408	6006	0	0.000
76	5112	6006	0	0.000
77	4152	6006	0	0.000
78	7464	6006	1458	24.276
79	8488	6006	2482	41.325
80	7560	6006	1554	25.874
81	5368	6006	0	0.000
82	3736	6006	0	0.000
83	5104	6006	0	0.000
84	5656	6006	0	0.000
85	6320	6006	314	5.228
86	5480	6006	0	0.000
87	4184	6006	0	0.000
88	3848	6006	0	0.000

Table B.1. Results of exceeded stock levels for new designed warehouse (continued)

Rep. no	**Max. stock levels**	**Stock capacity**	**Exceeded amount**	**Percentage of exceeded stock levels**
89	5720	6006	0	0.000
90	6968	6006	962	16.017
91	5968	6006	0	0.000
92	3808	6006	0	0.000
93	4296	6006	0	0.000
94	3744	6006	0	0.000
95	3624	6006	0	0.000
96	3664	6006	0	0.000
97	4328	6006	0	0.000
98	4600	6006	0	0.000
99	3528	6006	0	0.000
100	7592	6006	1586	26.407

Table B.2. Outputs of T-Test for Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D

Analysis		**Results**
Estimate for difference		-0.418
95% confidence for difference	Upper Bound	-0.08
	Lower Bound	-0.755
T-Value		-2.44
P-Value		0.016
DF		194

It can be seen from above results that 95% confidence interval for difference of means does not contain zero. And p-value is smaller than 0.05. Thus the null hypothesis can be rejected. It can be concluded that these two alternatives are different from each other.

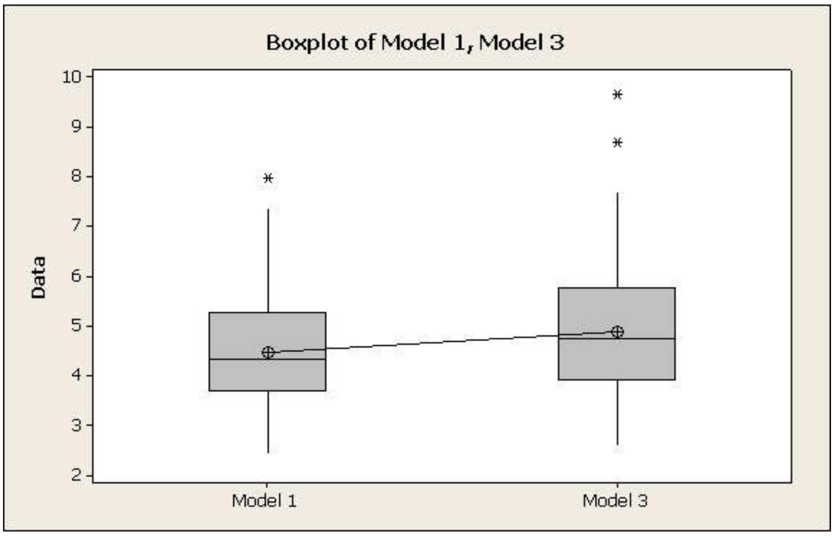

Figure B.1. Box plot of Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D

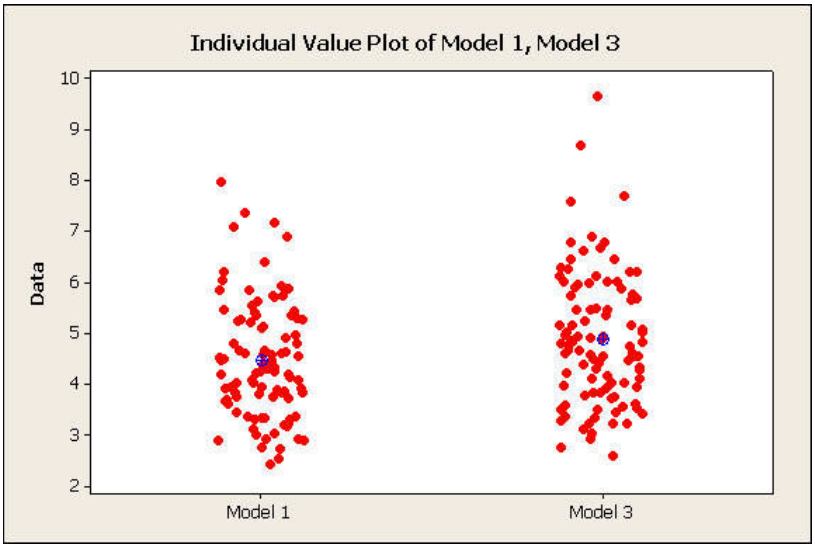

Figure B.2. Individual value plot of Model_NB_4F_2D_2F_1D and Model_NB_3F_2D_2F_1D

APPENDIX C: OPERATIONAL DECISION MAKING

C.1. Total times that outgoing trucks spent in the real system

Table C.1. Total times that outgoing trucks spent in the real system

Total times that outgoing trucks spent in the real system (min)				
20	30	30	20	40
15	25	20	40	15
25	35	25	30	65
20	30	35	20	40
25	40	40	25	45
40	25	15	15	25
35	20	25	20	30
25	30	30	20	30
20	30	20	30	20
30	25	15	20	25
35	45	35	25	30
25	25	35	20	15
45	30	20	25	25
25	30	15	20	25
30	25	20	15	30
35	35	20	20	20
20	25	25	55	20
20	20	20	20	40
30	50	30	30	25
15	35	40	15	15
40	25	15	20	15
15	55	25	30	20
50	30	20	25	15
25	35	25	35	20
40	15	20	30	20
25	35	40	15	15
30	30	20	25	30
35	50	10	20	20
25	30	30	20	15
20	35	20	20	30
40	30	20	25	35
35	25	25	25	25
15	25	60	30	20
30	30	20	60	25
35	25	20	35	20
25	65	25	55	25
20	30	20	15	30
40	45	35	35	30
35	20	30	20	25
20	25	25	75	20

C.2. Data for Scheduled Arrivals

Table C.2. The number of incoming and outgoing trucks per hour in case of scheduled arrivals

Hours	Number of incoming trucks	Number of outgoing trucks	Total truck number
1	4	3	7
2	2	5	7
3	5	2	7
4	1	5	6
5	6	1	7
6	3	3	6
7	2	2	4
8	4	4	8
9	1	4	5
10	5	5	10
11	7	1	8
12	3	3	6
13	1	7	8
14	8	4	12
15	2	2	4
16	4	5	9
17	4	1	5
18	5	3	8
19	3	4	7
20	1	5	6
21	2	4	6
22	2	2	4
23	4	3	7
24	3	2	5

C.3. Analysis Results for Scheduled Arrivals

Table C.3. Analysis results for different fork lift numbers in case of scheduled arrivals

Hours	# of fork lifts	mean of largest three	max	average	median	%75 percentile	%90 percentile	%95 percentile	# of trucks
1	3	51.84	67.79	16.58	13.94	19.41	23.7	26.54	84.553
2	3	53.54	64.71	18.55	16.61	21.87	26.85	30.57	129.926
3	3	70.06	82.48	21.59	18.6	24.91	33.55	40.07	92.688
4	3	76.76	94.29	18.63	16.23	21.68	26.44	30.3	124.358
5	3	76.09	93.64	22.43	18.83	25.85	35.31	42.3	71.701
6	3	77.41	100.72	18.11	15.76	20.94	25.01	28.03	75.545
7	2	66.80	72.47	19.73	17.76	23.45	30.22	35.48	98.827
8	3	74.78	119.95	26.12	18.03	23.2	29.17	34.23	114.934
9	3	66.11	81.43	19.94	17.58	23.15	29.17	34.07	125.685
10	4	73.18	85.70	18.45	16.16	20.67	26.41	31.48	144.117
11	5	68.34	82.39	19.04	16.43	20.7	27.38	33.25	68.391
12	4	47.46	67.45	15.77	13.77	17.59	21.26	23.68	77.233
13	4	46.50	55.37	16.76	14.65	19.42	23.99	27.4	173.275
14	5	60.66	68.37	19.35	16.72	21.88	29.67	35.3	149.840
15	4	64.02	76.67	17.43	15.32	18.86	23.17	27.62	81.134
16	4	47.31	59.04	16.07	14.39	18.47	22.1	24.77	126.057
17	3	56.49	66.79	18.98	16.89	21.71	27.53	32.42	67.073
18	4	53.83	72.84	15.99	14.24	18.42	22.13	24.62	78.739
19	4	43.26	50.29	16.33	14.76	18.81	22.64	25.62	116.639
20	4	45.18	51.04	16.06	13.55	18.23	22.57	25.95	150.731
21	3	56.81	65.73	17.40	13.84	19.69	25.3	29.71	131.878
22	3	69.17	82.54	18.61	13.67	20.6	27.63	33.88	88.496
23	3	67.52	90.28	16.64	13.24	18.69	23.34	26.32	86.315
24	3	58.53	75.46	17.78	14.79	20.44	25.15	29	75.049

Table C.4. Analysis results for different fork lift numbers in case of scheduled arrivals

Hours	# of fork lifts	mean of largest three	max	average	median	%75 percentile	%90 percentile	%95 percentile	# of trucks
1	3	120.89	134.18	24.77	19.22	25.74	44.36	72.63	110.636
2	3	81.82	97.43	19.44	18.13	23.22	28.33	32.46	149.043
3	3	86.75	98.23	22.28	19.78	26.41	35.83	42.96	110.474
4	3	98.14	109.21	19.06	17.34	22.63	27.58	31.85	140.253
5	3	96.81	107.34	22.87	20.01	27.36	37.54	44.9	84.926
6	3	102.06	115.18	18.37	16.51	21.52	25.78	29.35	85.257
7	2	75.29	87.79	21.91	20.06	26.58	34.48	39.76	67.356
8	3	113.47	125.19	23.62	18.99	25.11	37.29	70.49	130.636
9	3	78.84	91.52	19.88	18.23	23.78	29.84	34.95	144.280
10	4	85.09	93.37	18.43	16.45	21.18	27.16	32.64	167.917
11	5	78.05	84.13	18.97	16.74	21.27	28.32	34.57	82.036
12	4	60.00	70.12	15.82	14.32	18.04	21.77	24.4	87.353
13	4	53.20	58.61	16.81	15.12	19.85	24.59	28.12	199.138
14	5	65.43	70.62	19.33	16.97	22.43	30.62	36.32	179.160
15	4	70.37	75.78	17.42	15.78	19.31	23.93	28.96	95.205
16	4	52.83	59.78	16.06	14.65	18.66	22.45	25.14	143.558
17	3	61.95	67.86	18.99	17.29	22.22	28.13	33	77.624
18	4	63.14	73.74	15.99	14.39	18.57	22.45	25.17	87.679
19	4	47.27	50.84	16.34	15.01	19	23.05	26.13	132.791
20	3	52.02	56.17	17.62	15.77	21.04	26.29	30.14	159.224
21	3	70.17	76.15	19.73	17.18	23.76	31.58	37.65	153.678
22	2	86.82	94.71	23.40	20.49	28.58	39.08	47.31	76.192
23	3	120.53	128.89	26.27	18.68	26.59	67.3	76.31	114.242
24	2	89.61	103.31	22.77	20.67	27.11	35.37	41.22	66.344

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