

A DECISION SUPPORT SYSTEM
FOR AIR CARGO WAREHOUSE DESIGN

ADNAN KARAIŞMAİLOĞLU

BOĞAZİÇİ UNIVERSITY

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A DECISION SUPPORT SYSTEM
FOR AIR CARGO WAREHOUSE DESIGN

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Adnan Karaismailoğlu

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Thesis Abstract

Adnan Karaismailoğlu, “A Decision Support System

For Air Cargo Warehouse Design”

Warehouse design is critical in the air cargo industry, where the service standards are high and the competition is getting harder. The designers of air cargo warehouses consider various criteria like costs, system failure risks, customer perception and marketing power to evaluate the alternative designs and find the optimal one. The issue of designing an air cargo warehouse is generally considered by design and consulting companies, which provide a broad experience in operational design but they lack in suggesting different alternatives based on a theoretical framework. The alternative warehouse designs are generated by allowing different combinations of resource capacities such as the number of gates, workstations and storage areas. The evaluation of these alternative designs requires the use of analytical methodologies for multi criteria decision making. At this point, simulation which is a popular tool to evaluate the operational performances and Analytical Hierarchy Process (AHP) which provides the ability to evaluate in accordance to qualitative as well as quantitative criteria, appear to be the common tools used in the literature for such problems. In this study, a flexible and user-friendly Decision Support System (DSS) is developed based on simulation and AHP approaches. The DSS is used to generate design alternatives, evaluate their performances, rank them according to a set of decision criteria and report the results. The graphical interfaces are designed in accordance with the consideration of the man-machine interaction to increase its functionality. The environment is applied with real-time data in one of the Europe’s biggest air cargo carriers and the findings are discussed.

Tez Özeti

Adnan Karaismailoğlu, “Hava Kargo Deposu Tasarımı için bir
Karar Destek Sistemi”

Hizmet standartlarının yüksek olduğu ve rekabetin gittikçe kızıştığı hava kargo taşımacılığı sektöründe depo tasarımı kritik bir konudur. Hava kargo depolarının tasarımcıları karar verme sürecinde maliyet, sistem çöküş riski, müşteri algısı ve pazarlama gücü gibi birçok kriteri göz önünde bulundurarak, alternatif tasarımları değerlendirmeye ve optimum olanı ortaya çıkarmaya çalışırlar. Hava kargo depolarının tasarımı genellikle operasyonel tasarım üzerinde geniş bir tecrübeye sahip olan; fakat teorik bir çerçeveye bağlı olarak meseleyi farklı boyutlardan ele alan alternatifler önermekte geri kalan tasarım ve danışmanlık firmaları tarafından gerçekleştirilmektedir. Alternatif depo tasarımları, körük sayısı, iş istasyonu sayısı ve depolama alanları gibi kaynakların farklı birleşimleri göz önünde bulundurularak üretilir. Bu alternatifler, çok kıstaslı karar verme süreçlerinde kullanılan analitik metodolojilere ihtiyaç duyar. Bu noktada, operasyonel performans değerlendirmesinde popüler bir araç olan benzetim ile hem niteliksel hem de niceliksel kıstaslara dayanan değerlendirmelere imkân sağlayan Analitik Hiyerarşi Süreci (AHP), bu tür problemler için literatürde oldukça yaygın olarak kullanılmaktadır. Bu çalışmada AHP yaklaşımına dayalı, esnek ve kullanıcı dostu bir karar destek sistemi geliştirilmiştir. Karar destek sistemi, tasarım alternatifleri üretmede, bu alternatiflerin performanslarını ölçmede, bir grup karar kıstasına göre bunları değerlendirmede ve raporlamada kullanılmak üzere tasarlanmıştır. Grafik arayüzler, insan-makine etkileşimi göz önünde bulundurularak tasarlanmıştır. Bu ortam, Avrupa'nın en büyük hava kargo taşıyıcılarından birine ait gerçek verilerle çalıştırılmış ve sonuçları tartışılmıştır.

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CHAPTER 1

INTRODUCTION

Warehouses are logistic facilities, which provide value-added services and storage places for various kinds of products. They can have different characteristics according to the transportation mode and business sector they serve. Air cargo warehouses are designed to support the flow of air freight by providing receiving, checking, storing and consolidating activities in a fast and safe way. They can directly affect the quality of service. Therefore, warehouse design is considered as a crucial part of air freight operations.

International Air Transport Association (IATA) lists down the reasons why air freight is preferred. These reasons are perishability, opportunity cost (i.e. capital tied up for high value product), inventory related cost, time definite requirements and emergency. Among these, perishability, time definite requirements and emergency attributes of the orders require high performance of processes in an air cargo warehouse.

Warehouse design is a multidimensional problem, which requires to consider different performance criteria such as cost, system failure risk, customer perception and marketing power independently. Cost criterion includes the investment and maintenance costs of all related expenses. System failure risk is the tendency to cause a capacity problem of any resources of the warehouse. Customer perception represents how the

customer perceives the services provided by the warehouse. And finally, marketing power is the contribution of the warehouse to the marketing activities of the company. There is a need to find a methodology to design the optimum alternative, which adds value to the marketing activities, increase customers' perceived quality, use fewer resources to achieve a high system performance and require least possible cost for implementation and maintenance.

There are two main determinants of business capacity for an air cargo carrier company: Number and capacity of aircrafts and capacity of the air cargo terminal. Pure cargo carrier companies decide on the capacity of the warehouse based on their freighter fleet capacity plans. On the other hand, passenger airlines, which also carry cargo (called belly cargo), have to decide upon passenger aircraft fleet capacity in addition to the freighter fleet capacity. This fact compels the executives of cargo departments to find an aligned solution with the executives of the passenger departments. Air cargo executives face a difficult set of challenges while designing the air cargo terminal. Providing a balance between competing interests among the design criteria is a high level issue.

The annual growth and corresponding annual tonnage are the other essential factors to be considered in air cargo terminal design. Although process and storage times, which have a significant effect on the size of the terminal design, are measurable variables, estimating the future annual tonnage is a strategic level problem. An aggressive strategy may result in an excess capacity for years, which has an effect on both investment and

maintenance costs. On the other hand, overlooking an opportunity for a rapid growth may cause to hinder the potential growth of the company because of the low capacity of the warehouse. The relatively long time to design and construct an air cargo terminal make the decision making process even harder and more delicate. Strategic level managers decide on the expected capacity and lifetime of the terminal and the designer build its project on these high-level decisions.

Cost and other design criteria like system failure risk, customer perception and marketing power are not totally independent in air cargo terminal operations. Increasing the size of the terminal, purchasing higher amount of equipment resources and hiring more labor are naturally expected to have a positive effect on the system performance. On the other hand, these increase the cost of investment and operating the terminal. Providing the balance between cost and service quality is the main purpose of these optimization efforts. Furthermore, level of automation has a more complex role in this setting. It results in an increase in the investment costs, but generally decreases the operating costs. In this study, the required annual capacity and lifetime of the terminal is provided by the executives of the company.

A cargo warehouse design is identified by the set of resources capacities allocated to maintain the air cargo operations. The main resources are transporters for transferring cargo from one process to another, workers for loading and unloading processes, officers to follow procedures and paper works, unit load devices and stock keeping units to combine various kind of

shipments into a single unit, storage racks for storing stock keeping units, special storage equipment for storing unit load devices, x-ray machines for security check, workstations for build-up and break-down operations, gates and truck ramps. Some of these resources have their own variable costs and they are easy to achieve. Labor and transporters are examples of this kind of resources. On the other hand, some resource capacities have to be defined in terminal design phase carefully, because they affect the size and height of the building, type of the equipment to use in air cargo operations and cost of operating the terminal. It is usually difficult and costly to redesign these resources. Number and type of workstations, automated storage systems, special handling equipment such as elevating transfer vehicles and flow machines, type and size of cold rooms are the examples of such resources. This relation creates a difficult challenge for designers. An imbalanced design may lead to a lack of capacity resulting in loss of opportunities or an excess capacity resulting in high investment and operating costs.

There are numerous studies in the literature on designing warehouses for land transportation whereas, designing air cargo warehouses attracts less attention. Simulation is one of the most preferred methodologies in logistics warehouse design and optimization. We combined simulation with Analytic Hierarchy Process to evaluate and rank the air cargo warehouse design alternatives.

In this thesis study, we establish a simulation model to allow a cargo warehouse designer to compare the results of different design alternatives created by changing the most effective resource on the cost and

performance of the warehouse. A Decision Support System (DSS) is developed where different alternative designs can be generated, simulated by Arena simulation software and furthermore evaluated by Analytic Hierarchy Process (AHP) to score and rank these.

The organization of the thesis is as follows: In the next Chapter 2, the background on air cargo operations and the related performance measures are provided. In Chapter 3, a literature survey is made that summarizes the findings in the design methodologies and performance measures of an air cargo warehouse, and the use of simulation in logistics industry. In Chapter 4, the design problem is introduced and a simulation model is generated to evaluate the operational performances of the alternative designs. In Chapter 5, an AHP model is developed to evaluate and rank the design alternatives in accordance to a set of decision criteria. In Chapter 6, the DSS architecture is provided and the DSS environment is illustrated with real data obtained from an air cargo company. Chapter 7 consists of the conclusion and suggestions for study.

CHAPTER 2

BACKGROUND ON AIR CARGO WAREHOUSE DESIGN

In this section, a general overview about air cargo warehouses and operations will be provided. In addition, performance measures of an air cargo warehouse, and challenges for air cargo warehouse design will be briefly explained.

Air Cargo Warehouse Overview

Warehouses are important components of modern supply chains in terms of cost and service. Within a supply chain network, products need to be physically moved from one location to another. They may be buffered or stored at certain facilities for a certain period of time. From this point of the view, warehouses are key aspects of modern supply chains and play a vital role in the success or failure, of businesses today (Frazelle, 2002).

The basic warehousing functions traditionally have been considered to be as follows (Tompkins and White, 1984);

- Receiving
- Identification and sorting
- Dispatching to storage

- Placing in storage
- Storage
- Retrieval from storage
- Order accumulation
- Packing
- Shipping
- Record keeping

Unlike traditional warehouses, air cargo terminals have special characteristics that differentiate them from the traditional warehouses. These differences require more attention in order to improve the performance of air cargo terminals. Main differences are described as follows:

- Firstly, cargo storage duration is relatively short. Customer service requires air transportation to be fast and efficient. It requires the air cargo terminal to be highly efficient and responsive.
- Secondly, although more and more automated equipment and warehouse management systems (WMS) have been introduced, most of the manual operations in air cargo terminals must still be kept. Thus, the number of workers, which has become the main cost, cannot be reduced by too much.
- Thirdly, the workload at air cargo terminals can be measured by the quantity of air cargo, which completely depends on the business contracts between airlines and cargo agents. As a ground handling agent, air cargo terminal follows the workload demand in a timely manner, without control of the quantity of cargo, or the cargo arrival

time. This uncertainty in workload demand strongly increases the difficulty of execution planning, which is very important for productivity and cost reduction (Zhiyong, 2004).

Performance Measures in an Air Cargo Terminal

There are many criteria to measure the performance of an air cargo terminal. It is crucial to select appropriate indicators to evaluate the performance of alternative designs to find out the best one. The selected performance measures for this model are explained below.

Cargo Wait Time

Cargo wait time is the most common performance measure for air cargo warehouse. It is the average of cumulative value of all waiting times from the starting point of cargo handling process to the end except regular storage times. Achieving a lower value for a wait time means to have a lower throughput time and a less space requirement for buffering. As a result, a relatively smaller air cargo warehouse area will be required. Considering high land costs, rents and construction costs in airport districts, this improvement is expected to result in a significant decline on investment and overhead costs.

This performance measure is critical to see how much the process can be improved by increasing some resources or improving some processes. The main activities having an effect on this indicator are the buffers of export acceptance, x-ray transfer, security check, export storage racks, build-up operation, ramp transfer, break-down operation, import segregation, import storage racks, delivery check and delivery to the customer.

Maximum Number of Cargo in a Queue

The most dominant characteristic of the air cargo transportation is its fast service. Without being able to send a cargo in a couple of days (or a couple of hours for the near destinations) sometimes means for customer paying more money to receive the same service as other transportation modes. From this point of view, taking the maximum number of a queue is more meaningful than taking the average. In this thesis study, we set acceptable ranges for processes which represent the acceptable amount of a queue which is not assumed to result in delays in other processes. Secondly, because of the limited space in air cargo warehouses, exceeding the capacity of a buffer area or storage may cause a snowball effect in all processes which may create an emergency situation. This is very common before special days like New Year and holidays throughout the world in some warehouses which are not designed to have excess capacity in ordinary days or seasons.

The selected specific measures of maximum number of cargo in a queue are listed below:

Maximum Number in Export Loose Storage Queue

There are two main storage areas in an air cargo warehouse: Export Storage and Import Storage. The size of the export storage depends mostly on the average connection time of export and transit cargo. Air cargo facilities are generally designed with an excess capacity to cover peak weeks' or seasons' demand. If there is overload in such periods, the queue before export storage may lock the whole operation. Security check and export acceptance processes are the most effected processes from a possible capacity problem in the export loose storage.

Maximum Number in Import Loose Storage Queue

Similar to export loose storage queue, import rack queue also affects other processes, but the direction is the opposite of the previous one. Build-up and break-down operations are affected from a backlog in the import loose storage. Unlike the export storage, storage time of import cargo is very high because of the customs clearance processes.

Maximum Number in ULD Storage Queue

Unit Load Devices, commonly called ULD, are stored on special storage equipment, which is generally automated and has multiple levels. This equipment has a big proportion in total investment and therefore, takes an important role in the air cargo warehouse design. Although unit load devices have a variety of size, the storage unit is generally around 12 square meters. Considering its size, the queue of such devices has a tremendous effect on the dedicated areas of previous processes. In addition to this, unlike the other storages devices such as export and import stock keeping units, unit load devices cannot be stored anywhere available in the warehouse. They always require a special storage equipment to be stored on it. Consequently, ULD storage queue has a direct effect on the performance of a warehouse and the maximum value of the queue size is more meaningful compared to the average. This is because the average does not give an idea about when the operation is locked.

Export Acceptance Maximum Number in Queue

The queue of the export acceptance process represents the trucks waiting to be assigned to a gate for unloading their loads. Because the cargo is not yet received from the customer, a problem at this point directly affects the customer and perceived quality of the service. Number of gates and truck

parks, export acceptance transport vehicles, operators, workers and officers are the key resources having an effect on this indicator. Among these, number of gates is the most costly and crucial one because of the area dedicated to it.

Maximum Waiting Time

Air cargo is known with its rapid transport time. It is the most valuable and important element of this service. Each individual shipment should be directed to the final destination without violating the time expectations.

Maximum waiting time arises from this point. There is a reasonable limit for some processes of air cargo operation, that represents a safe time to make a successful operation for each cargo. Among the alternative measures for this matter, two main indicators can be selected as the performance measures to show how successful the operation is and how customers affected from the operating times: Maximum waiting times of export acceptance and cold rooms.

Maximum Waiting Time in the Export Acceptance Queue

There is an interaction between the carrier and the customer through the acceptance process. Failures and inconveniences in acceptance process are directly perceived by the customer. Export acceptance maximum waiting time

is defined as the time, when trucks are ready in the air cargo terminal to be unloaded but cannot find an available gate to trigger the process. This is not only a reason for missing the connecting flight but also an additional trucking cost for the customer.

Maximum Waiting Time in the Cold Storage Queue

Cold storages are used for storing special cargo needing special temperature conditions. Pharmaceuticals, flowers, foodstuff like meat, fish, vegetables, chocolates and fruits, called perishables in general, are stored in special conditions. There are special rooms for this purpose in almost all air cargo terminals. Special cargo needing a special treatment, as listed above, may be perished under high temperature conditions after a while. There is not a common maximum exposure time defined for all kinds of perishables, but it is generally set by carriers to be applied to these cargoes according to the expectations of customers. Maximum waiting time of cold storage queue is measured to see the upper limit of the exposure time for these kind of cargo derived from the performance of the air cargo terminal.

CHAPTER 3

LITERATURE REVIEW

We made a literature survey on air cargo warehouses, logistic warehouses in general, warehouse design, warehouse optimization, the use of simulation and the multicriteria decision models. We searched for sources from 1960, but most of the cited documents are issued after 1985. We categorized the literature review in three main sections, which are the methodologies used in warehouse design and optimization, performance measures of it and the use of the simulation in logistics.

Warehouse design can be described as a structured approach of decision making at distinct decision levels in an attempt to meet a number of well-defined performance criteria.

The design of a warehouse is a highly complex problem. It includes a large number of interrelated decisions involving warehouse processes, warehouse resources and warehouse organizations (Heragu, 2005).

Warehousing is concerned with all the material handling activities that take place within the warehouse. Market competition requires higher performances from warehouses. Therefore, companies should improve the design and planning of warehouse operations continuously. Additionally, increasing variety of products, the constant changes in customer demands and the adoption of management philosophies also bring new challenges in

order to reach flexible structures that provide quality, efficiency and effectiveness of the logistic operations. In reality, warehouses have to be adaptable, accessible, modular, flexible and capable enough to respond to changing conditions, to improve space utilization and to reduce congestion and movement (Geraldes & Pereira 2011).

Air cargo terminals play a crucial role in air freight operations as a part of the logistics industry. They are located in or near to airports, where they function as a type of warehouse. Although there is a large literature on traditional warehouse operations, very few publications have discussed the operations at air cargo terminals (Zhiyong, 2004). Therefore, we analyzed the studies on warehouses in general and combined them with the industry experience to compose a proper solution for the air cargo warehouse design.

The most common methodologies used in the literature for warehouse design and optimization can be summarized as linear programming, mixed integer programming, genetic algorithm and heuristic models. Simulation and multi-stage hierarchical models like AHP are also used to support the decision making process.

Oudheusden and Boey (1994) presented a case study on the design of Thai Airways Cargo Terminal with a mathematical model based on a general model formulated by Ashayeri et al. (1985) minimizing the total cost of the storage system. The optimal design with certain flexibility for growth in the throughput rate was found (Wei, 2005).

Zhiyong (2004) makes a comprehensive review on the literature about the warehousing design and states that linear programming and mixed

integer programming have become fundamental tools in planning in the past decades, but not considered accurate for the time being.

It can be seen that studies in generating efficient warehouse designs go back to several decades. In an early study, Ashayeri and Gelders (1985) concluded that the combination of analytical and simulation tools as the most practical approach to study the complexities of a total warehousing system.

Cormier and Gunn (1992) researched the optimization of warehouse design and operation. They discussed warehouse design models specifically on the models concerning the maximization of space utilization and concluded by expressing the need for larger integrated models.

Gray et al. (1992), develop an integrated approach to the design and operation of a typical order-consolidation warehouse. This approach includes warehouse layout, equipment and technology selection, item location, zoning, picker routing, pick generation list and order batching. They develop a multi-stage hierarchical decision approach which uses a sequence of coordinated mathematical models to compare the economic trade-offs and to reduce the space. They also use simulation technique for validation of the resulting design.

Geraldes et al. (2008), adapt the mixed-integer programming model proposed by Heragu et al. (2005) to tackle the storage allocation and assignment problems.

Heragu et al. (2005), develop a mathematical model and a heuristic algorithm that jointly determines the functional areas size and the product

allocation in a way that minimizes the total material handling and storage costs based on a real-time data.

Hassan (2002) introduces a framework for the design of warehouse layout. The proposed framework accounts for several factors and operations of warehouse such as:

- Specification of warehouse type and purpose
- Analysis and forecasting demand
- Definition of operating policies
- Establishment of inventory levels
- Class formation
- Definition of functional areas and general layout
- Storage partition
- Selection of equipment for handling and storage
- Design of aisles
- Determination of space requirements
- Location and number of I/O points
- Location and number of docks
- Arrangement of storage
- Zone formation

Performance measures are used to benchmark the performance of some aspects of warehouse management and the assessment may result in a plan of action for optimizing warehouse performance. Various models for measuring warehouse performance in different measurement areas,

including cost, time and utilisation measures have been developed by many researches.

Khemavuk (2010) summarizes studies of a number of researchers and concludes that warehouse measurement areas typically consist of five measures that are labour, cost, time, utilisation and administration measures. Cost measures are considered according to Copacino and Rosenfeld (1985). Schuster (1987) evaluates distribution costs. Cohen et al. (1997) use operating cost measures to assess the performance of service parts distribution. Gunasekaran et al. (1999) study labor costs. Berry (1968) and Bassan et al. (1980) focus on minimizing handling time in order to increase performance. Berry (1968), Bassan et al. (1980) and Gunasekaran et al. (1999) propose models to maximize space utilization. Other researchers including Hausman et al. (1976) and Marsh (1979) study storage capacity in order to maximize performance. Khemavuk (2010) states that other warehouse measurement areas including warehouse complexity, warehouse automation and warehouse flexibility can be grouped into the same measurement area termed administration measures.

We use the derivatives of time and cost measures in this study as performance measures. We don't prefer utilization measures, because the effect of the utilization is already included as a cost variable in the model. These measures are explained in detail in Chapter 2.

According to the researches in the literature, simulation is a commonly used technique in evaluating the designs and the alternatives. Simulation allows evaluating the impact of new processes or changes in an organization

through the creation of different “what if” scenarios (April et al., 2005).

Therefore, simulation has become a very beneficial tool for companies to make their decisions.

Carson (1997) emphasized that when a mathematical model of a system is studied using simulation it is called simulation model. The model is run for a fixed period of time to evaluate the system behavior when different input variables are introduced. A test or series where meaningful changes are made to the input variables in order to observe and identify the changes in the output variables, called responses, is a simulation experiment. The input parameters and structural assumptions done when building the model are called factors (April et al., 2003).

On the other hand, 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. Senko and Suskind (1990) suggested that the risk in a warehouse designed without proper planning is poor customer service and high operating costs. They stated that this poor customer service and high operating costs result from inefficiencies related to material handling, space utilization, inventory, throughput, equipment, and labor. They related the success or failure of a warehouse with whether or not the design reflects the nature of the business. They stated that “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".

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.

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

- 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).

Peng (2005) focuses on the vital role of the simulation technique. He summarizes the studies on this area, which describe simulation as a more clear and straightforward image of the system as in Gambardella et al.

(1998), Marco and Salmi (2002), and Yun and Choi (1999). Gambardella et al. (1998) presented a decision support system for the operations management of an inter-modal container terminal in order to maximize the performance of the system, which focused on the efficient allocation of resources. This problem was further solved with other techniques like genetic algorithm and mixed-integer linear programming. Peng (2005) states that similar applications of simulation tools provided by Marco and Salmi (2002) and Yun and Choi (1999) contributed to prompt the thought of using simulation in warehouse operations.

Luk (1990) modeled Hong Kong Air Cargo Terminals Limited (HACTL) Terminal II via simulation. Models were built for both the Bulk Storage System (BSS), which is also called Automated Storage and Retrieval System, and Container Storage System (CSS), also called Pallet and Container Handling System (PCHS). The simulation models are designed to represent the complex distribution and storage systems rapidly and less costly. Deficiencies are identified in the design stage and corrected easily and inexpensively.

Although there is a large literature on traditional warehouse operations, very few publications have discussed the operations at air cargo terminals. The differences between traditional and air cargo warehouses are resulted from the following reasons:

- Short durations (require highly efficient and responsive facilities)
- Need for manual works besides the automation
- No control over the quantity and time of the cargo

It is also important to state as a difference that cargo rejection case which is common in traditional logistics is excluded, because there is a reservation phase in air cargo processes which prevents inappropriate cargo to enter the system.

Consequently, we benefited from the literature on traditional warehouse operations and decided to establish a decision support system based on multicriteria decision model and simulation techniques.

CHAPTER 4

DEVELOPMENT OF THE SIMULATION MODEL

This section introduces a simulation model for air cargo operations. The simulation model handles truck arrival schedule for export demand, ULD arrival rates for inbound cargo operations and process times as inputs and it reports the performance measures such as the maximum waiting times and maximum sizes in the queues for export acceptance, export and import loose storage, cold room and ULD storage and finally the average waiting time of cargo in the system. The developed simulation model is used as the base of a Decision Support System (DSS) for the design of an air cargo warehouse. The data and processes used in this model are based on a real time project in one of the biggest European Air Cargo Carriers.

In the following subsections, first the company will be introduced. Secondly, problem definition and objectives will take place. Explanation of required inputs and their statistical analysis will follow this section. Finally, development of the simulation model with Rockwell Arena Simulation Software will be described and it will be validated.

Company Overview

Company A is one of the biggest air cargo carriers in Europe with more than half a million tons of annual cargo volume. As of Dec 2012, around 1400 white-and-blue collar employee in more than 200 countries have been working for cargo processes of this company. The Company operates in one main hub, which shows transit hub characteristics. There is a work flow from landside to airside for export operation and airside to landside for import operation. Transit operations, which have a volume around two-third of the total operations, take place in the middle of these two main processes.

The company has decided to make a temporary air cargo terminal investment for five years. Although the usual lifetime of a terminal is around 10 to 20 years, the company needs an urgent action for a transition period. The simulation model is developed for this case, but it is flexible to be modified for different cargo warehouse design problems.

Problem Definition and Objective

Company A faces a capacity problem in its hub because of tremendous and stable growth in its businesses in a small period of time. Although government of the country announced a new airport project, the capacity in the current hub needs to be increased because it is not capable of handling the additional volume until the start of use of the new airport.

They have a tradeoff between cost and functionality of this temporary warehouse. Although the targeted capacity is decided by the strategic level managers, the main criteria of the warehouse design which have the highest influence on the cost and performance of the whole system should be decided by the designer and a high performance alternative should be found out with the lowest possible cost. Figure 1 illustrates a sample design layout of an air cargo warehouse.

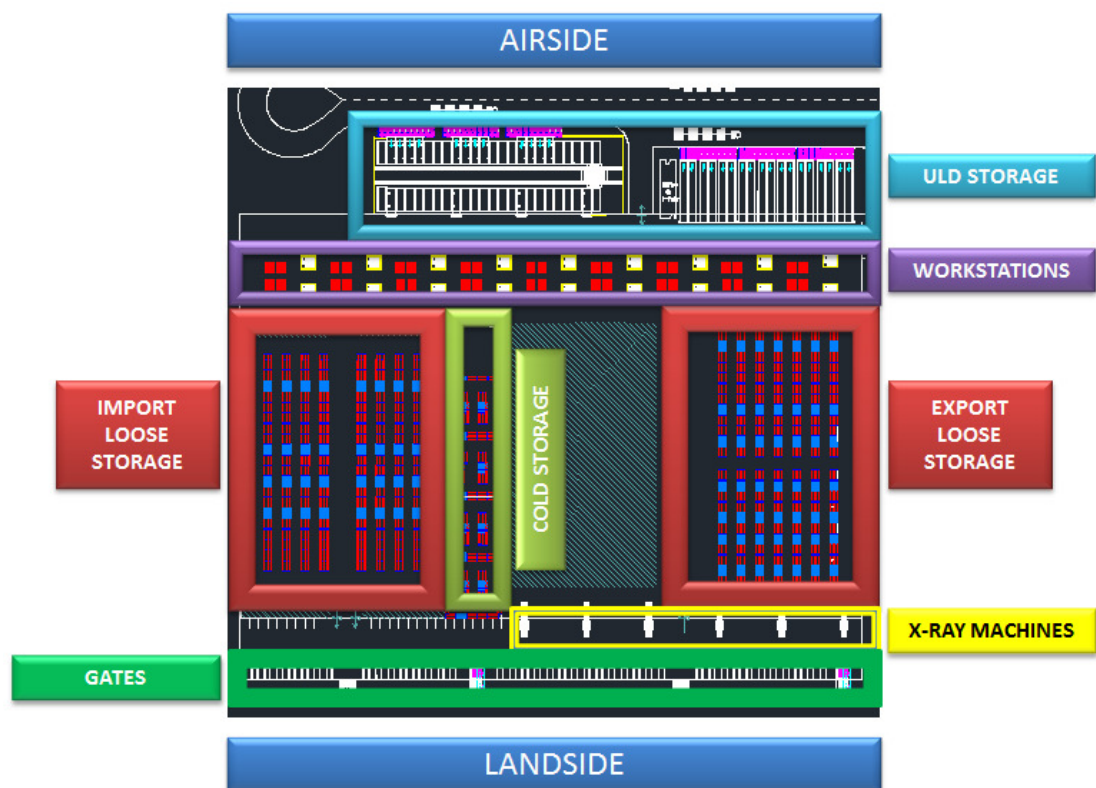


Figure 1: Layout of a sample warehouse design

Scope of the Study and Assumptions

Considering the regulations of the country and the preferences of the company, RFS (Road Feeder Service), known-agent regulation related processes and excess baggage operations are not included in the scope of the study. Domestic cargo operations are also excluded because of its small proportion, independent flow and minor role in the whole process. The flow between domestic and international flights is included in the international operations. Document flow is also not considered because it is assumed that it does not have a significant effect on the design of the warehouse. It may have an effect on the process design, which is accepted as it remains.

Demand forecasting is not in the scope of this project. Future capacity expectations are obtained from the company.

Required Inputs for Simulation Model

In order to develop the simulation model, three-month (thirteen weeks) input data have been gathered. Company A provided their future growth plans and expected capacities with a safety level as well. . The main inputs used in the model are listed below:

1. Arrival Types: Export Acceptance Truck Arrivals and Inbound Cargo Arrivals are the entry points of the system from airside to landside and vice versa. The arrival rates show high fluctuation rates

within days and hours of a day. Export truck arrival rate is the number of trucks arrived from the landside to the gates of the warehouse in one hour period. Similarly, import truck arrival rate is the number of ULDs arrived from the airside to the warehouse in the same period of time.

2. Unit Loads: Cargo is not in the same form at each step in the model. In export stream, firstly it arrives as “truckload”, and then it is held on stock keeping units (SKU) or large storage pallets (LSP). Finally it becomes unit load device (ULD). Figure 2 and 3 illustrate LSP and ULD. The flow is the opposite of this in the import stream. Average unit loads and corresponding probability distributions are used as inputs to the simulation model.



Figure 2: LSP (Large Storage Pallet)



Figure 3: An air cargo container called AKH, as an example of ULD

3. Process Times: At least 1000 record have been gathered for each process type.
4. Storage Times: Storage time is the time of cargo waiting for the scheduled flight or the delivery to the customer in the loose storage racks or in ULD storage area. Export, import, transit and special cargo storage times are mainly based on the decision of customer, who also takes flight availability into account. Therefore, current storage times are directly used as obtained from the company.

Air cargo operation generally has a push system instead of a pull system. Air cargo carriers have a limited flexibility of changing the scheduled flight and the storage time of the cargo. They have to comply with the reservation requested by customers. Therefore, storage time is not a part of the decision and also not possible to be improved to a better and more desired amount. Consequently, storage times for export, import, transit and special cargoes are obtained from the company and used without any corrections or improvements.

5. Resources: Three main resources, which are building, equipment and labor have been identified. Labor size has been used as input. The others are used as the variables.

Statistical Analysis of the Input Data

Statistical Analysis of Arrival Types

There are two main streams in an air cargo terminal: One from landside to airside and one from airside to landside. The first stream from landside includes export cargos departing from the country. The second one represents cargos from an arrival flight, which are received from the airside. Although import cargo and transit cargo follow different processes after break-down operations, they arrive from the airside in the same units together.

The arrival rates for both import and export cargo are assumed to follow Poisson distributions. The average arrival rates are calculated by using the data obtained from the company as explained below.

Export Truck Arrival Schedule

This type of cargo is received from trucks of customers at the gates of the landside of the warehouse. Independent from the type of the truck, each truck arrives at a random gate and unloads its cargo onto specific storage units called SKU or LSP. The main trigger of the system from the landside stream is the arrival of these trucks. A historical data set for thirteen weeks is obtained from Company A. The data set includes truck arrivals per hours of each day of week. The percentage of each day and hour in total amounts has been calculated and the preset growth rate is applied to it. The results of these calculations have been used as the input data of truck arrivals.

Air cargo has its specific characteristics about time schedules of operations, which are dependent on the working hours and working days of Customs. While analyzing export arrival rates, we checked whether their patterns differ on a weekly basis. Initially, the thirteen-week data set has been plotted for each day of week. In Figures 4 to 10 the arrival rates are plotted for each day of the week for thirteen weeks.

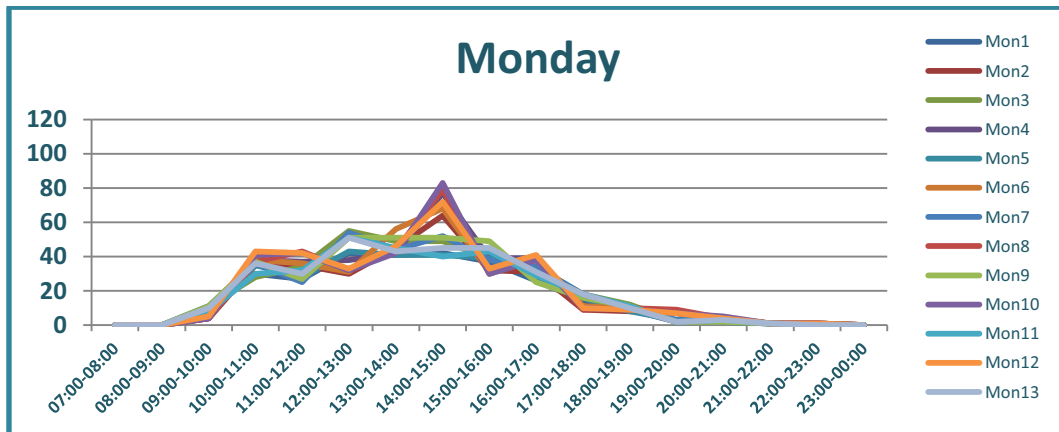


Figure 4: Schedule of arrival rates of export acceptance - Monday

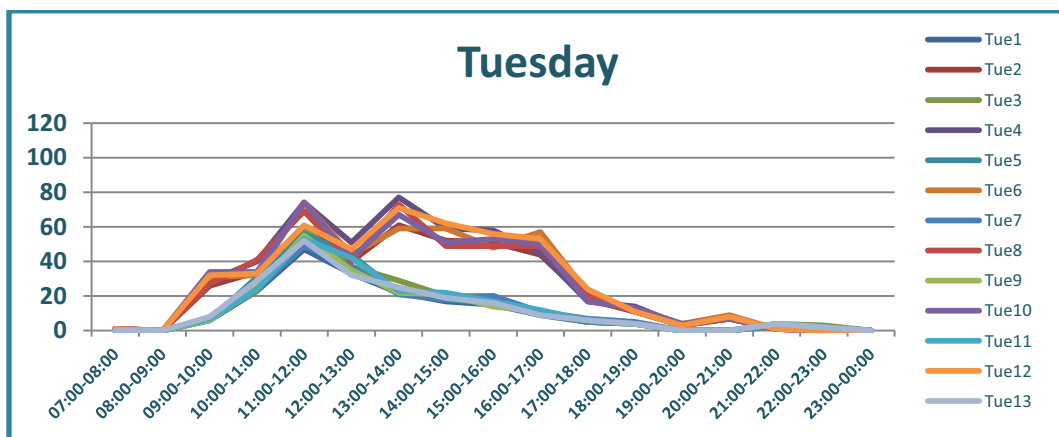


Figure 5: Schedule of arrival rates of export acceptance - Tuesday

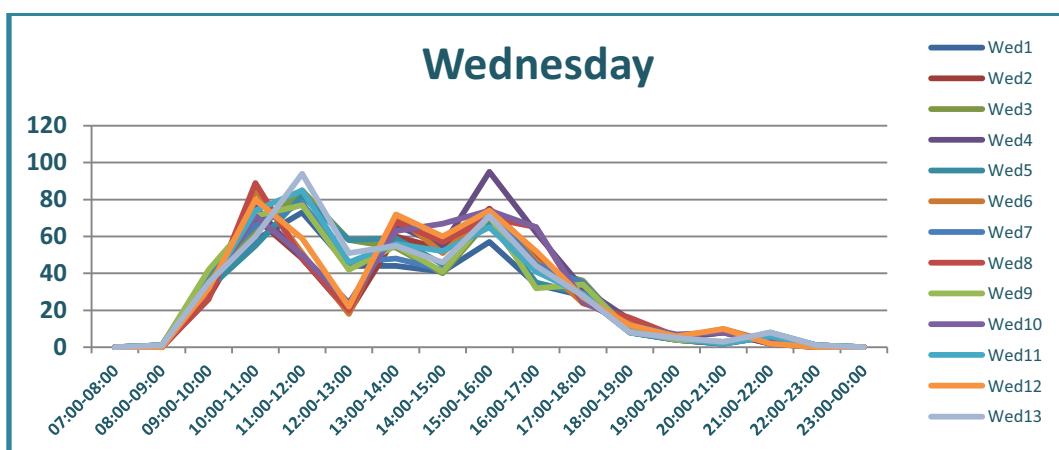


Figure 6: Schedule of arrival rates of export acceptance - Wednesday

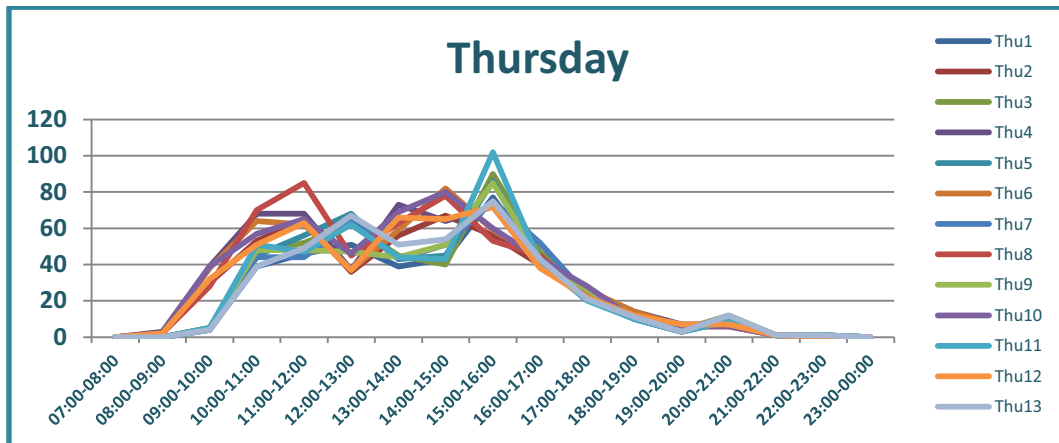


Figure 7: Schedule of arrival rates of export acceptance - Thursday

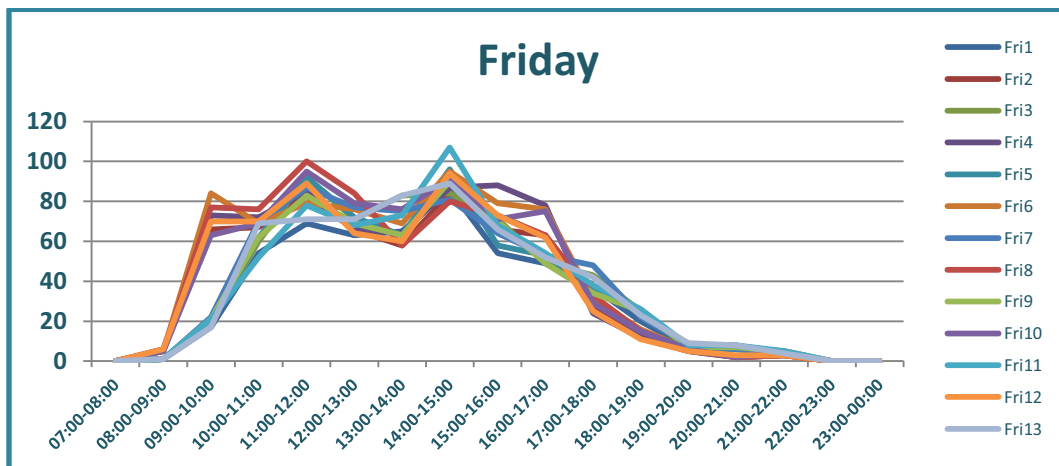


Figure 8: Schedule of arrival rates of export acceptance - Friday

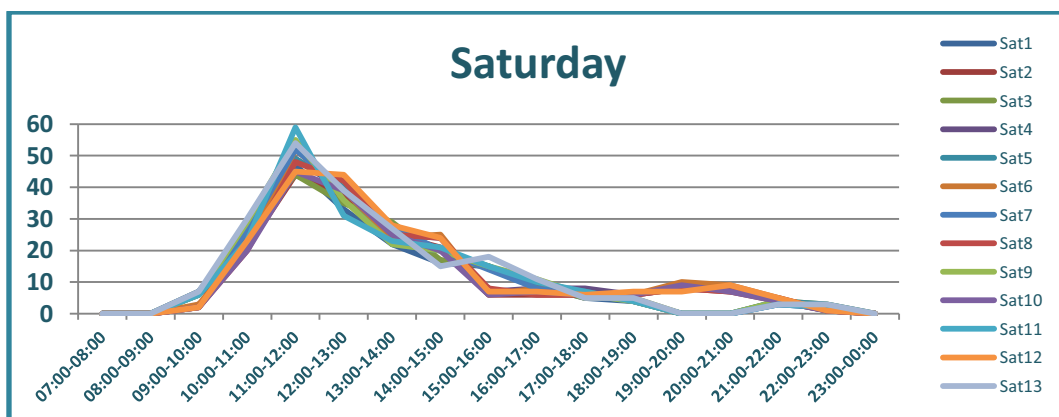


Figure 9: Schedule of arrival rates of export acceptance - Saturday

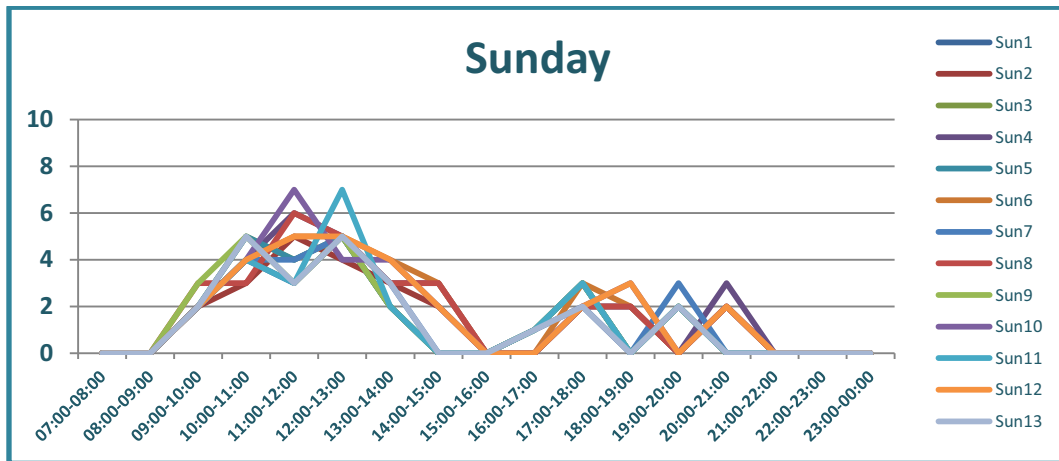


Figure 10: Schedule of arrival rates of export acceptance - Sunday

Similar patterns in different weeks can be seen obviously for Wednesdays, Thursdays, Fridays, Saturdays and Sundays. On Mondays, a different pattern is observed in weeks two, six, eight, ten and twelve. Similarly, fifth, seventh, ninth, eleventh and thirteenth weeks are similar within themselves but different from other weeks.

When arrival rate averages of these thirteen weeks are compared for weekdays, it is observed that the arrival rates of days differ significantly between them as shown in Figure 11. Therefore, each day is represented independently in the arrival schedule.

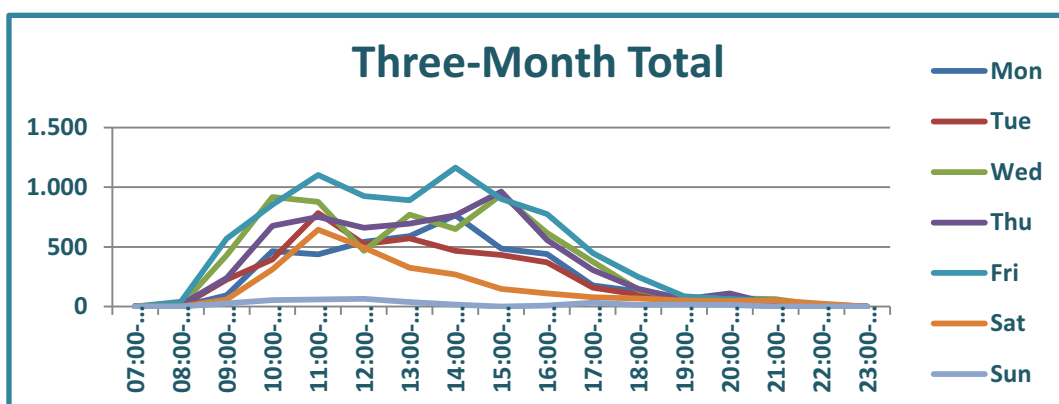


Figure 11: 13-weeks total arrival rates of export acceptance

A table has been prepared with the total number of arrivals per hours of the days. The percentage of each hour of each day in total amounts has been calculated as a percentage. Then the future projection for the expected number of arrivals per week are calculated by multiplying the current average arrival rates with the expected future growth rate obtained from Company A. Accordingly, the future projections for the export acceptance truck arrivals are plotted as follows in Figures 12 to 18:

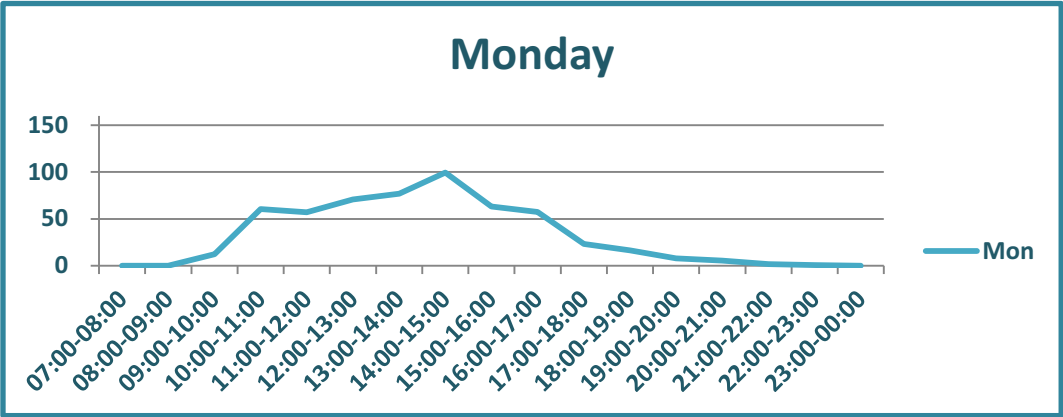


Figure 12: Future estimates of arrival rates of export acceptance - Monday

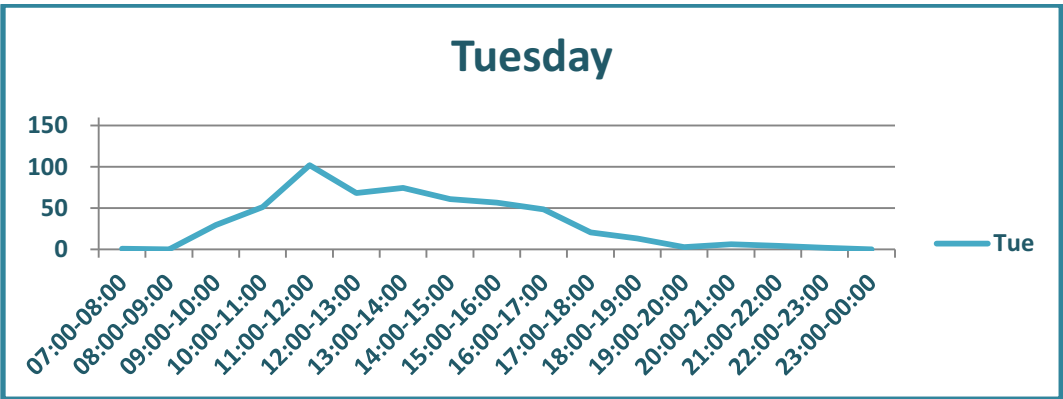


Figure 13: Future estimates of arrival rates of export acceptance - Tuesday

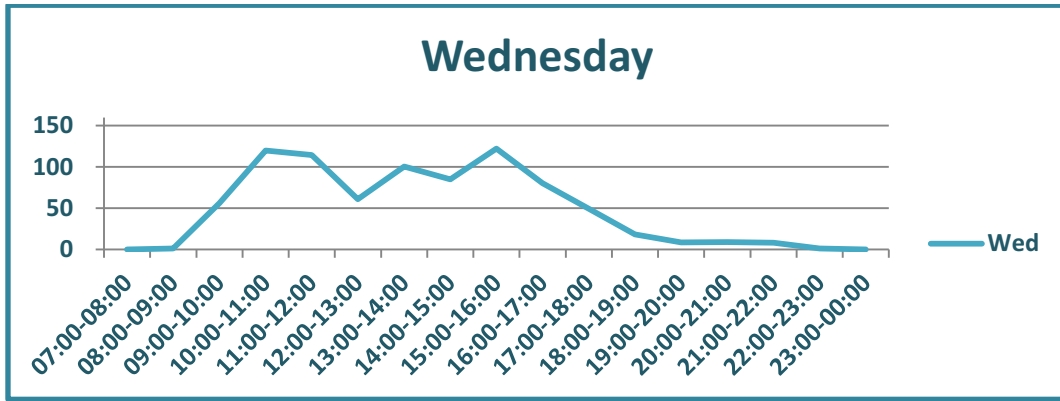


Figure 14: Future estimates of arrival rates of export acceptance-Wednesday

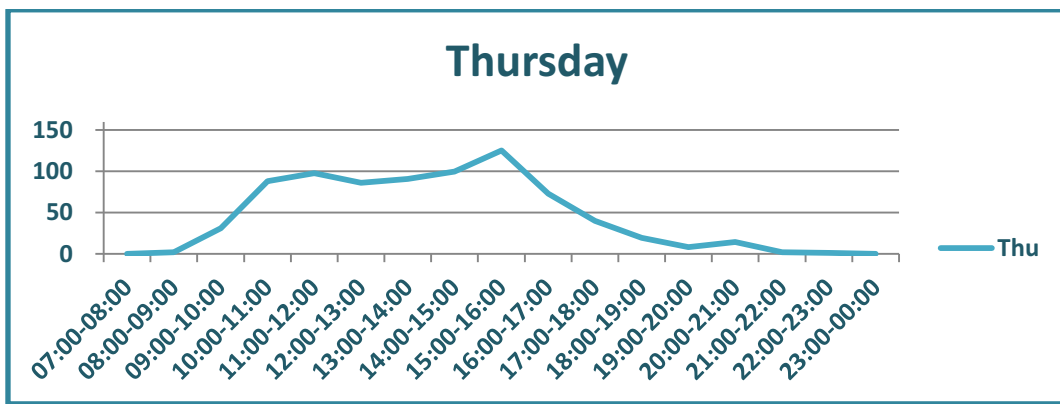


Figure 15: Future estimates of arrival rates of export acceptance - Thursday

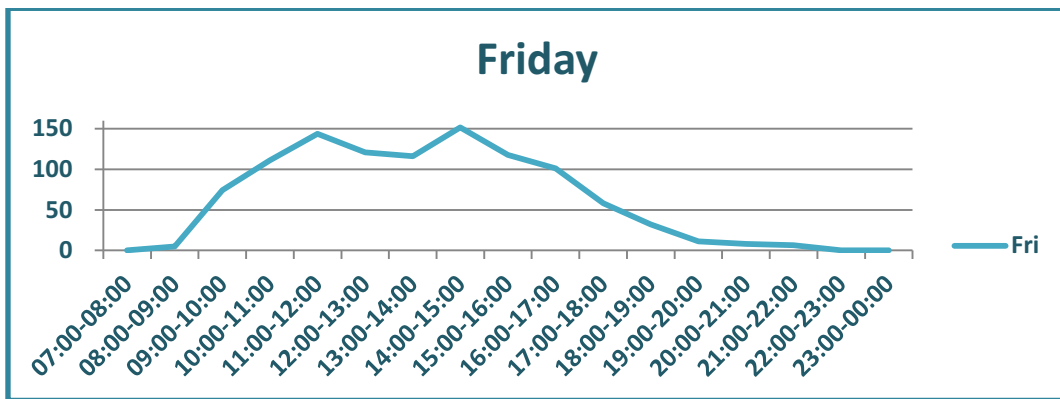


Figure 16: Future estimates of arrival rates of export acceptance - Friday

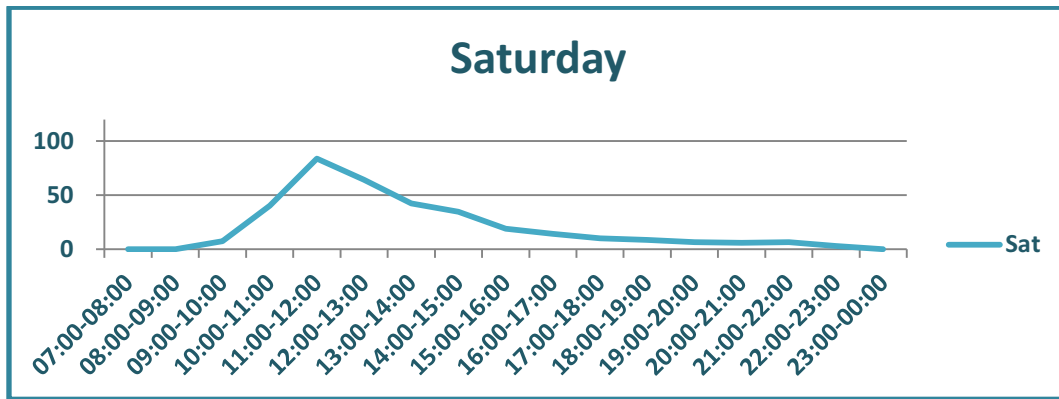


Figure 17: Future estimates of arrival rates of export acceptance - Saturday

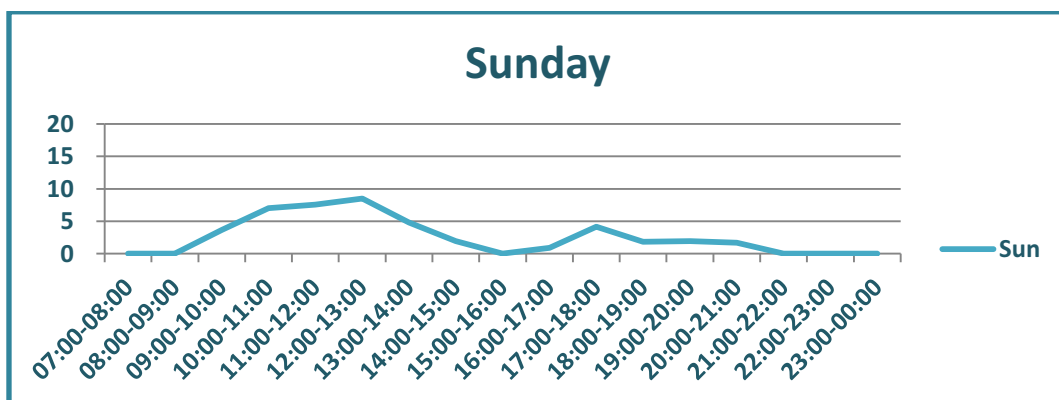


Figure 18: Future estimates of arrival rates of export acceptance - Sunday

Inbound Arrival Schedule

The second stream is from the airside to the landside. Import cargo, whose final destination is the hub and the transit cargo. Transit cargos are processed and stored in the air cargo warehouse, and then they depart from the airside. A historical data set of the last three-months average of arrivals are obtained from Company A. The data set includes arrivals per hours of each day of week for import and transit cargo. The percentage of each day

and hour within total has been calculated. The current average arrival rates are multiplied by the estimated growth rate obtained from the company to predict the future arrival rates. The results of these calculations are used as the input rates of truck arrivals.

Company A uses a specialized policy to coordinate connected flights. The flights coming from Far East arrive almost at the same time (within a couple of hours) and Europe flights depart almost at the same time as well. As a result of this scheduling policy, the arrival rates of inbound cargo, which includes import and transit, fluctuate as shown below in Figure 19:

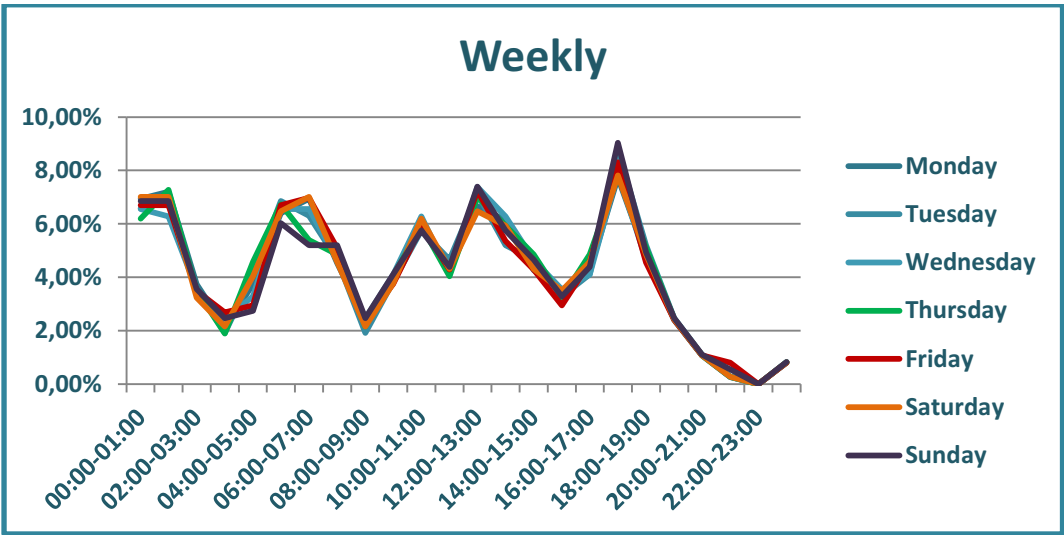


Figure 19: Distribution of inbound arrivals

As it is obviously seen in this graph, the arrival rates in each time period in a day are stable, so period averages are used to estimate the arrival rates for import cargo.

In the next step, the future arrival rates are to be estimated for import cargo. Table 1, provides the daily distribution of the total weekly arrival rates among days of a week in the form of percentages:

Table 1: Distribution of Inbound Arrivals within Days of Week

Daily Inbound Arrivals			
	2011	2012	Future
Monday	9,5%	10,4%	10,2%
Tuesday	11,5%	12,5%	12,2%
Wednesday	16,5%	16,1%	16,2%
Thursday	16,2%	15,0%	15,3%
Friday	14,6%	15,8%	15,4%
Saturday	16,3%	16,8%	16,6%
Sunday	15,5%	13,5%	14,1%
TOTAL	100%	100%	100%

In the above Table 1, the future percentages in the third column are calculated according to a simple linear equation after interviews with executives of Company A. Thirty percent of the value coming from 2011 is summed with seventy percent of the value coming from the nearest year 2012. Total expected arrivals are distributed to days according to this table and to hours according to Table 1. The resulting schedule as in the Table 2 is used in the model.

Table 2: Inbound Arrival Schedule

	Inbound Arrival Distribution						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
00:00-01:00	57	65	93	86	84	98	91
01:00-02:00	59	67	89	101	84	98	91
02:00-03:00	30	35	50	49	44	45	47
03:00-04:00	17	19	35	26	34	30	33
04:00-05:00	30	40	46	64	37	57	37
05:00-06:00	52	67	93	94	84	91	80
06:00-07:00	57	62	93	75	87	98	69
07:00-08:00	37	46	66	67	64	64	69
08:00-09:00	20	19	35	30	30	30	33
09:00-10:00	33	38	58	56	47	53	55
10:00-11:00	48	57	89	82	74	87	77
11:00-12:00	35	46	58	56	54	60	58
12:00-13:00	54	70	104	97	91	91	99
13:00-14:00	50	51	89	82	67	83	77
14:00-15:00	35	46	66	67	54	60	62
15:00-16:00	28	32	50	45	37	49	44
16:00-17:00	35	40	58	67	57	64	58
17:00-18:00	63	86	112	109	104	110	121
18:00-19:00	39	51	66	71	57	68	66
19:00-20:00	20	24	35	34	30	34	33
20:00-21:00	9	11	15	15	13	15	15
21:00-22:00	2	3	4	4	10	4	7
22:00-23:00	0	0	0	0	0	0	0
23:00-00:00	7	8	12	11	10	11	11
Total	816	984	1416	1388	1253	1402	1333

Process and Storage Times

The process times of all processes in the scope of the study such as Reservation Check, Export Acceptance, Unloading to LSP, Transfer to X-ray machine, Security Check, Transfer to Racks, Transfer to Workstation, Build-up, Break-down, Import Segregation, Delivery Check and Delivery Loading has been gathered.

Average processing times for each process are obtained from Company A. Thereby, at least 1000 data per each process have been analyzed. Analyses have been made according to the following steps:

1. Data Filtering: Entries above an unrealistic level has been removed from each input data list.
2. Descriptive Statistical Analysis: Mean, standard deviation, maximum and minimum values for each process duration are calculated. Histograms are plotted and shapes of the distributions are observed.
3. Significance Tests to Theoretical Distributions: Compliance of the data to the theoretical distribution is analyzed with Easy Fit 5.0 Distribution Fitting Software. Chi-square, Kolmogorov-Smirnov and Anderson-Darling tests are performed.

As an example, analysis of the export acceptance times is explained below. Other results of tests are given in the Appendices A to D.

Chi-square test is performed for the export acceptance processing time. The chi-square test divides the range of the data into k intervals and checks whether the number of observations that fall in each interval is close to the expected number that should fall in the interval given the hypothesized distribution. So we have the following hypothesis test:

Ho: The data follows the theoretical distribution with the estimated parameters

Ha: Otherwise

The test statistic is Chi square $\chi^2 = \sum_{i=1}^k \frac{(N_i - np_i)^2}{np_i}$ which can be simplified as $\chi^2 = \sum \frac{(\text{observed} - \text{expected})^2}{\text{expected}}$ with k-s-1 degrees of freedom where k is the number of intervals and s is the number of estimated parameters. The chi-square value is evaluated by using the resulting p-value as follows:

If the p-value > α , then do not reject H_0 .

If the p-value < α , then reject H_0 .

Where α denotes the significance level of the hypothesis test and conventionally taken 0.05. If the p-value of the distribution is higher than 0.05, this distribution will be an input for the simulation model. But in applications, if the data set includes high amount of data, no theoretical distribution can pass all the significance tests. In such cases, empirical distributions can be used.

As an example of the application of this methodology, analysis of export acceptance processing times is explained below.

According to the results of Easy Fit Software, average processing time for export acceptance is 12.1 minutes and standard deviation is 4.3 minutes. Minimum and maximum values for this process are 0.3 minutes and 29.4 minutes respectively. The histogram of this deviation is shown in Figure 20. This deviation is tested for its compliance to the theoretical distributions and it is found out that normal distribution passed all tests.

Table 3: Results of Significance Tests to Theoretical Distributions

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,03816				
P-Value	0,10591				
Rank	4				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	1,4478				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	14,266				
P-Value	0,11318				
Rank	6				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	No	No	No	No

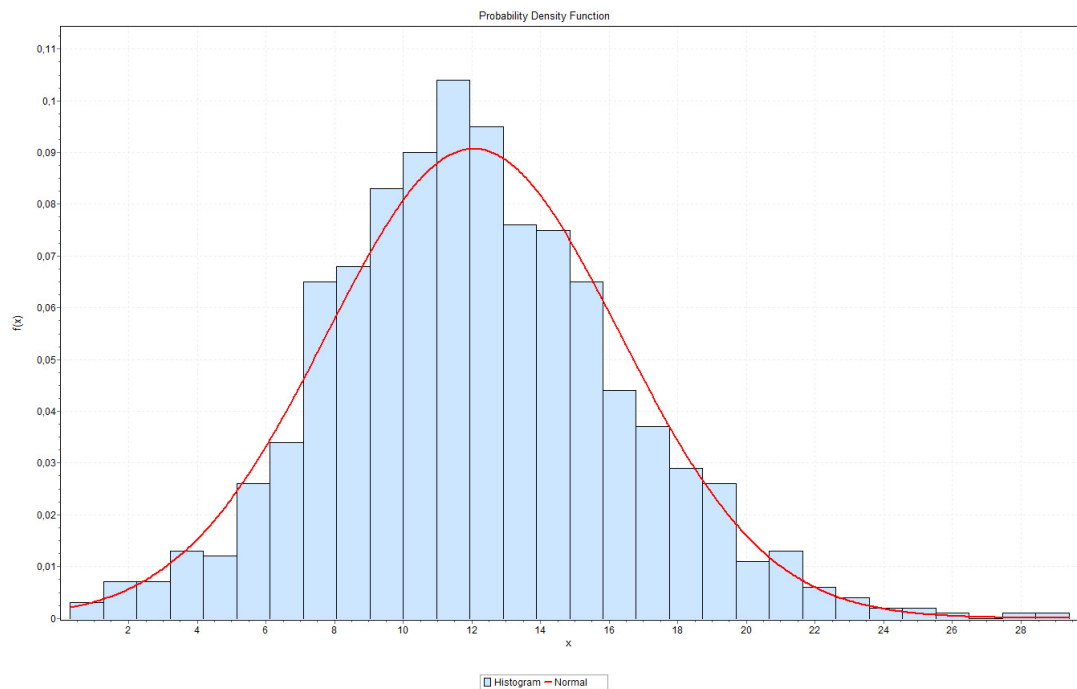


Figure 20: 30-tile histogram of the fitting distribution

Kolmogorov Smirnov and Anderson Darling tests are also applied to find the fitting distribution of the data set.

The Anderson-Darling test is used to test if a sample of data came from a population with a specific distribution. It is an alternative to the chi-square and Kolmogorov-Smirnov goodness-of-fit tests. The Anderson-Darling test is defined as:

H₀: The data follow a specified distribution

H_a: The data do not follow the specified distribution

Test Statistic: The Anderson-Darling test statistic is defined as

$$A^2 = -N - S$$

where

$$S = \sum_{k=1}^n \frac{2k-1}{n} [\ln(F(Y_k)) + \ln(1 - F(Y_{n+1-k}))]$$

F is the cumulative distribution function of the specified distribution. and Y_i is the ordered data.

The Kolmogorov-Smirnov (K-S) test is based on the empirical distribution function (ECDF). Given N ordered data points Y₁, Y₂, ..., Y_N, the ECDF is defined as

$$E_N = n(i)/N$$

where n(i) is the number of points less than Y_i and the Y_i are ordered from smallest to largest value. This is a step function that increases by 1/N at the

value of each ordered data point (NIST/SEMATECH e-Handbook of Statistical Methods).

Resources

There are three main resource categories for an air cargo warehouse:
Building area, equipment and labor.

When Automated Storage and Retrieval Systems (ASRS) and Pallet and Container Handling Systems (PCHS) alternatives are considered, labor resources and their cost have to be taken into account. In this study on the other hand, ASRS and PCHS alternatives are not considered and consequently, labor resources are identified as infinite. Company A assumes that they have a fixed number of labor and does not plan to alter this quantity in the future.

Simulation Model Development with Arena

Arena Simulation Software basic process panels are used for this study. It does not include a specific panel for logistic terminal operations. The final simulation model is demonstrated in Figures 21 and 22.

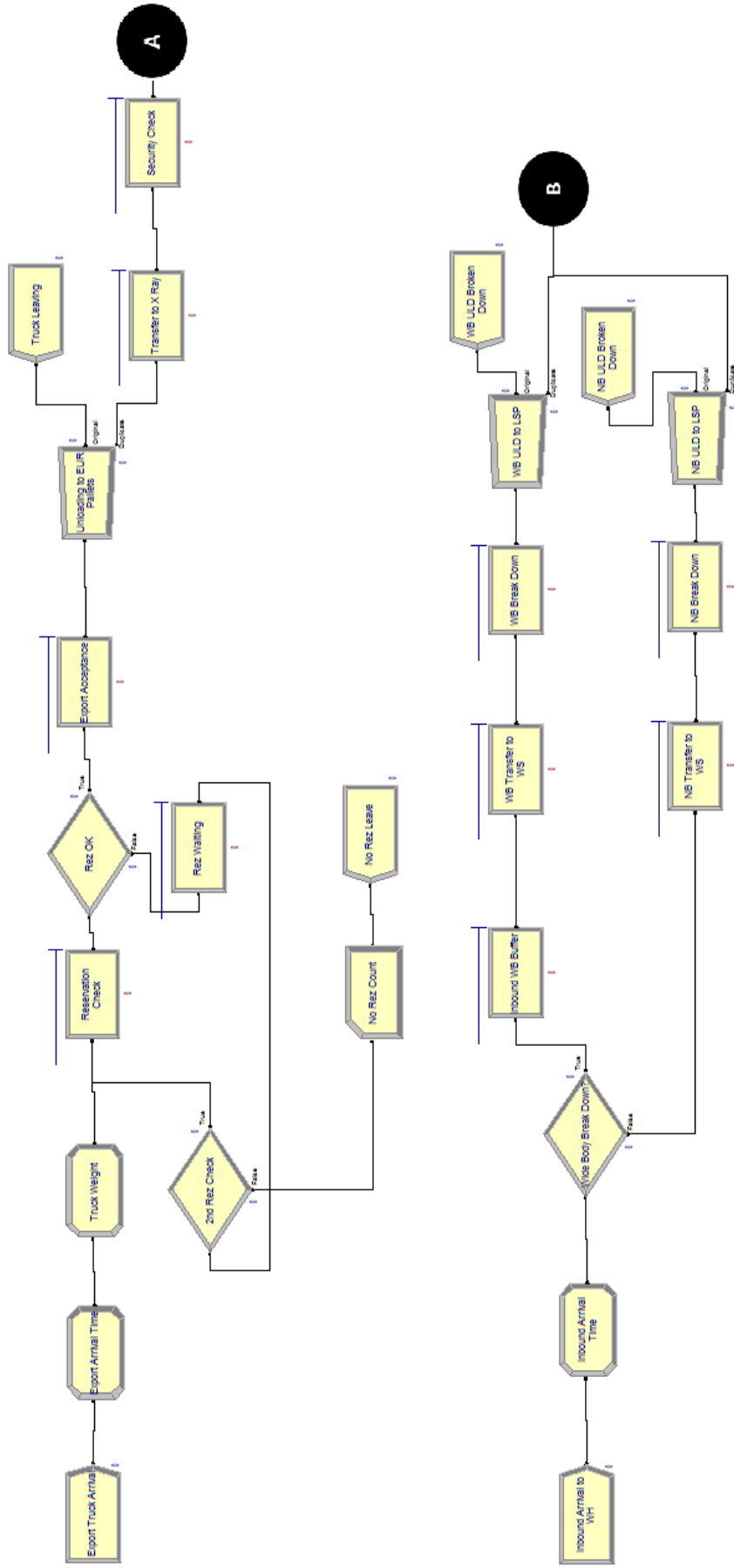


Figure 21: Simulation model – part 1

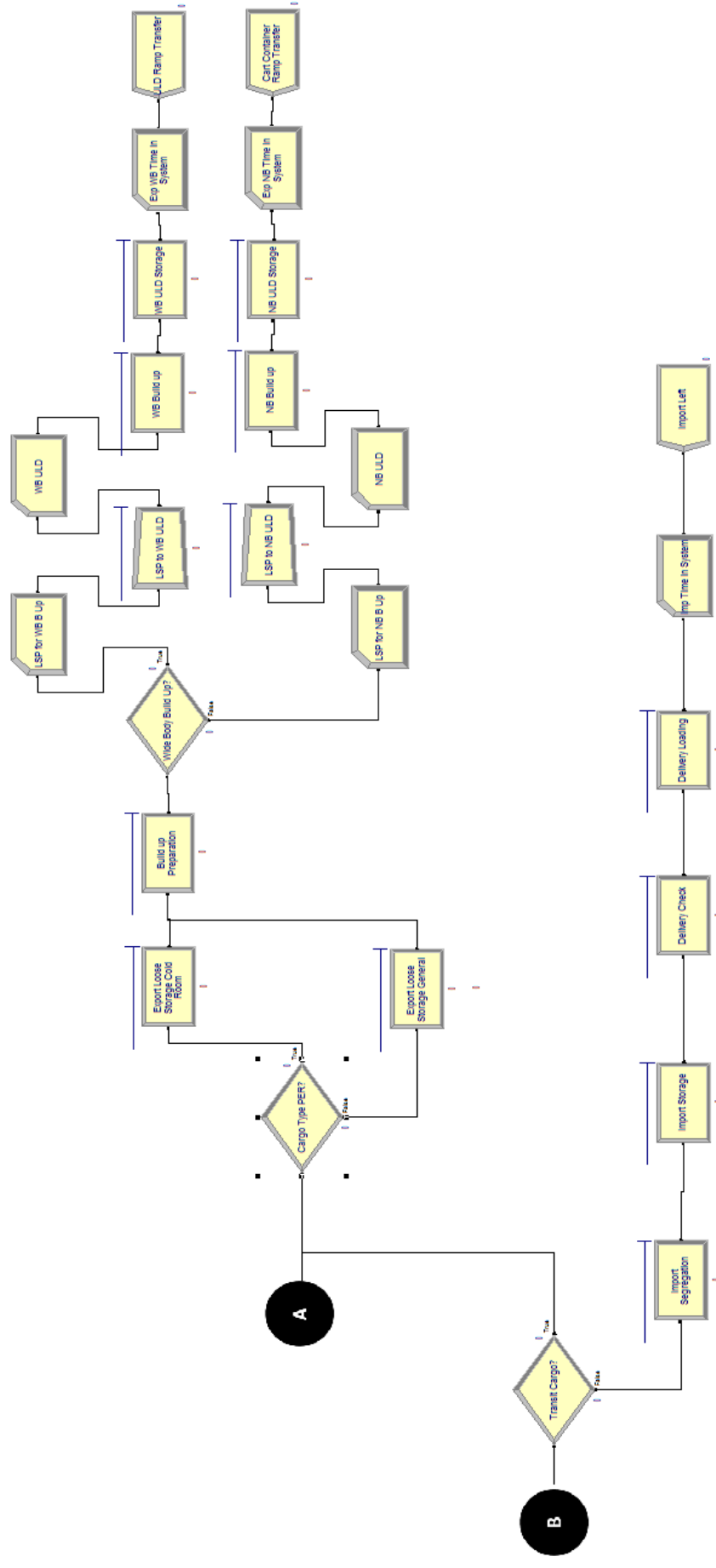


Figure 22: Simulation model – part 2

Simulation Results of the Alternative Scenarios

The simulation model is run with the real process flow of an air cargo warehouse and the distributions and parameters of these processes which is based on the real data obtained from Company A. Firstly, the length and the number of replications are decided. The proper length and number are achieved after some attempts with 14 days and 21 days and 10, 30, 50, 100, 500 and 1000 runs. The interval estimations are made in accordance to n=1000 runs by using the following formula:

$$\text{Confidence interval} = \bar{X} \pm z_{(\alpha/2)} \frac{s}{\sqrt{n}}$$

$$\text{Half width} = z_{(\alpha/2)} \frac{s}{\sqrt{n}}$$

where α denotes the probability of type 1 error, s variance (the average of the squared differences from the Mean) and n the sample size. Because the sample size is greater than thirty, z test is used instead of t test.











Rockwell Arena Simulation tool gives mean, half width, minimum and maximum values for each item in the overview report. We have found the ratio between the “half width” and “mean” that provided all relative precisions to be under 0.01. In other words, after 1000 simulation runs for 3 weeks, the interval estimations for each performance measure are within 1% of their mean values.

After the length and the number of replications are decided, Rockwell Arena Process Analyzer Tool (PAN) is used to compare the results of

different scenarios. These scenarios are created by changing the amounts of the seven main resources. These resources are called “controls”. As the “responses” of these control variables, seven performance indicators which are explained in Chapter 2 are calculated by PAN after 1000 replications per each. These results are applied to a table, which feeds the AHP model.

The scenarios generated in DSS environment (explained in chapter 6) are integrated to the simulation model. “Controls” shown in PAN are provided from CargoSim.

Table 4: Process Analyzer (PAN) Outputs – Controls

	S	Scenario Properties			Controls						
		Name	Program File	Reps	Gate	X ray machine	Workstation	Export Rack	Import Rack	Export Rack Cold Room	ULD Position
1		Base Case	5 : Air Cargo	1000	55	6	40	7500	8000	700	700
2		Min	3 : Air Cargo	1000	45	4	30	5500	6500	400	500
3		Max	3 : Air Cargo	1000	70	8	50	8000	9000	800	800
4		Alt1	3 : Air Cargo	1000	60	6	42	6750	7750	550	650
5		Alt2	3 : Air Cargo	1000	55	5	40	6750	7750	550	600
6		Alt3	3 : Air Cargo	1000	60	5	42	6750	7750	500	700
7		Alt4	3 : Air Cargo	1000	50	5	42	6750	7250	450	650
8		Alt5	3 : Air Cargo	1000	50	4	40	6750	7500	500	650
9		Alt6	3 : Air Cargo	1000	50	4	36	6500	7500	475	625
10		Alt7	5 : Air Cargo	1000	55	6	40	6750	7750	550	650

The simulation model is run for three weeks with one week warm-up period. 1000 replications per each scenario are run to achieve the best fit to statistical requirements. The system and collected statistics are initialized between replications in order to obtain one thousand statistically independent and identical replications each starting at time zero. The results appear in PAN as in Table 5. These results are integrated with the AHP tables to calculate the corresponding scores.

Table 5: Process Analyzer (PAN) Outputs – Responses

Responses						
Cargo.WaitTime	Export Acceptance.Queue.NumberInQueue	Export Acceptance.Queue.WaitingTime	WB ULD Storage.Queue.NumberInQueue	Export Loose Storage General.Queue.NumberInQueue	Import Storage.Queue.NumberInQueue	Export Loose Storage Cold Room.Queue.WaitingTime
0.037	14	0.0841	2	0	0	0.000
4.645	88	0.7390	750	1271	573	4.822
0.037	1	0.0054	0	0	0	0.000
0.050	8	0.0440	28	93	1	0.058
0.116	14	0.0847	93	70	1	0.051
0.076	9	0.0455	2	88	1	0.335
0.288	27	0.1852	25	91	268	1.733
0.101	27	0.1833	26	97	49	0.333
0.171	27	0.1848	50	302	50	0.738
0.050	14	0.0841	28	86	1	0.056

Validation of the Simulation Model

Validation of the model is performed to check whether the model represents the current system correctly. The results of the model are expected to be aligned with the real system performance. To check the validity of the model, we run the simulation with the resources of the current state and compared the results with the real data provided by the company. The results are mainly consistent with the real reports, but it is not possible to conclude if there are any irregularities in model outputs for the maximum waiting time in cold storage queue, cargo average waiting time and maximum waiting time in export acceptance queue, because such data doesn't exist in the reporting history of Company A.

The results of maximum number in export loose storage queue are illustrated in Figure 23. Other comparisons can be found in the Appendix.

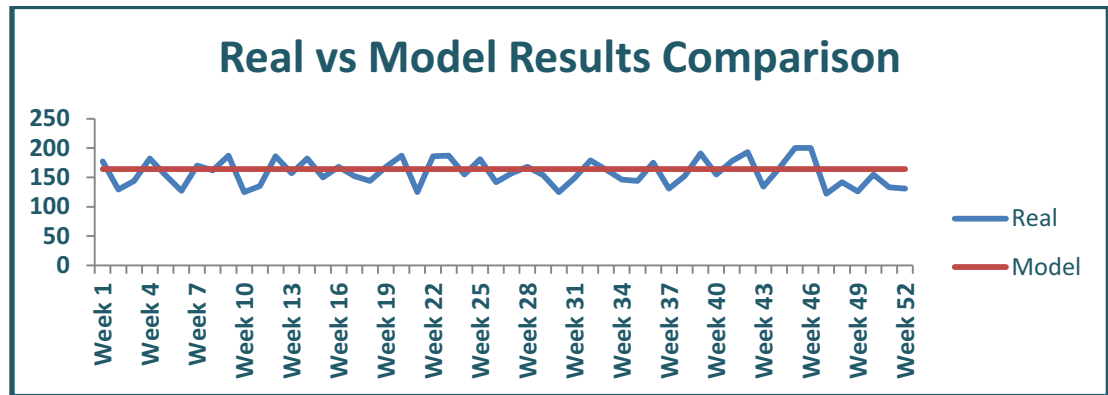


Figure 23: Real results of export loose storage queue

CHAPTER 5

DEVELOPMENT OF THE ANALYTIC HIERARCHY PROCESS (AHP) MODEL

The simulation model itself, as explained in the previous chapter, may not be sufficient to measure the performance of an air cargo terminal because simulation is a tool for multicriteria decision making but it does not allow qualitative evaluation. Furthermore there are multiple alternative designs that are to be evaluated and ranked according to multiple criteria. Therefore, we used the Analytic Hierarchy Process to establish a multicriteria decision model. In this chapter, the steps of the AHP model development will be described.

Criteria of the AHP Model

We established an Analytic Hierarchy Processing (AHP) Model to evaluate the results of scenarios and select the best alternative according to the criteria weights in the AHP model. We made interviews with the top executives of Company A to extract the most effective criteria of an air cargo warehouse performance. These criteria are identified as Cost, System Failure Risk, Customer Perception and Marketing Power. Figure 24 illustrates the criteria tree of the AHP model.

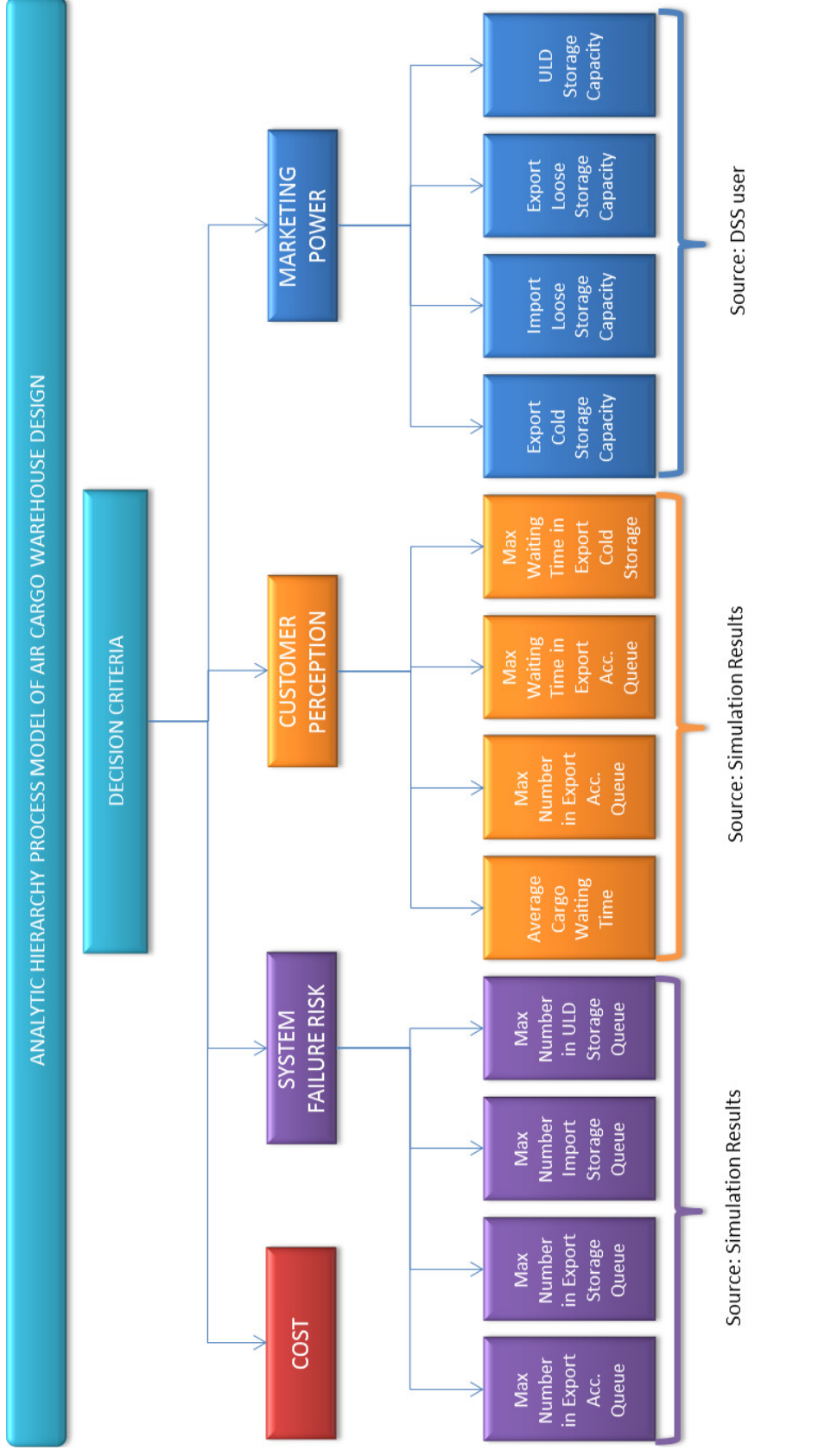


Figure 24: AHP model of the air cargo warehouse design DSS

Cost

“Cost” is the first criterion of the AHP Model. Its subcriteria are Direct Costs and Indirect Costs. Direct Costs include purchasing and maintenance costs, which are directly related with the acquirement and sustainability of the resources. Purchasing cost is, as the name implies, the cost of acquiring a resource. It is obtained from the suppliers in the market for the case study. Maintenance cost is the cost incurred during the use of a resource for a specific time. Spare part costs and breakdown service costs are the examples of maintenance costs. There is not a common rule for calculating the maintenance cost of equipment used in the air cargo processes. We obtained these costs from Company A, who use their own cost calculations based on the experiences earned from the use of this equipment for decades.

Indirect costs include construction and rental costs, which are not directly related with the purchasing or use of the resources, but affected by the amount and size of them. Increasing size of a resource result in a requirement to build a bigger place. The construction cost is calculated according to the space requirement of a resource. Construction cost is the cost of building the warehouse, of which size is defined according to the dedicated area of defined resources. Similarly, rental cost is the rent of this dedicated area through the lifetime of the resource. Because this study is mainly based on the construction and implementation of a new air cargo

terminal, construction and rental costs take a large share from the total investment and have to be considered for all related criteria.

System Failure Risk

“System Failure Risk” is the second criterion of the AHP model. It represents the main resources which can cause bottlenecks because of their insufficient amounts for a specific time and affect the performance of the whole system resulting in huge buffers on previous processes or storages. There are four subcriteria for this criterion:

- Maximum number in export acceptance queue,
- Maximum number in export loose storage queue,
- Maximum number in import loose storage queue
- Maximum number in ULD storage queue

We identified a standard range including lower and upper limits for each of these subcriteria. Then a table of rules is created to score the alternatives. Results are calculated according to this table of rules based on these limits. Results above the upper limit are dismissed and the scenario such a result is disapproved.

Maximum number in export acceptance queue is one of the factors of these criteria. Export acceptance is the entrance of the system from the landside of the air cargo terminal. If there is a bottleneck caused by the insufficient resources at this point, air cargo handler or carrier company will

not be able to accept any other cargoes to the system. We don't define a capacity for the queues, because arrivals are not blocked in an overload situation and additional places around the warehouse are to be used for different purposes, according to the experiences faced in real cases.

Furthermore, an overload situation may cause an unexpected disorder in the traffic flow of the whole airport. Consequently, it will probably result in loss of business, customer dissatisfaction or simply an overcapacity in the following processes. Therefore, it is selected as one of the subcriteria.

The second and third subcriteria are the maximum queue numbers in export and import loose storages. Export and import loose storages are generally the biggest sections in an air cargo warehouse. Their dedicated areas have a significant effect on the cost and performance of the whole terminal. If there is not enough space in one of these storages, there will be a buffer in the previous processes. If the volume of this buffer exceeds the acceptable range, which is defined previously, the system will be locked and a backlog will occur. This, therefore, is defined as a system failure risk.

The final subcriterion of the system failure risk is the maximum number in the queue of the ULD storage. When the ULD storage is full, built-up export ULD's won't be able to be kept there. This will have a negative effect in the performance of the in-warehouse operations. In addition to this, inbound ULD's will not be able to be accepted to the warehouse and airside entrance will be locked. This is also called a system failure risk.

Customer Perception

“Customer Perception” criterion of the AHP model includes the customer related performances that have a direct effect on the performances of the processes. Cargo average waiting time, maximum waiting time of the export acceptance, maximum queue number of the export acceptance and maximum waiting time of the cold storage rooms are the subcriteria of the customer perception. These factors have a direct effect on the perceived quality of cargo processes. Except the maximum waiting time of the cold storage rooms, the other three factors result in additional time and costs to the own processes of the customers. On the other hand, the maximum waiting time of the cold storage rooms cause the ingredients of the cargo to be perished. This will return back to the company as a claim or dissatisfied customer. These will affect the customers’ perception on the service quality of the handler or the carrier.

Marketing Power

There are some sections or resources of an air cargo warehouse, which can be used as a marketing tool. Air cargo carriers generally invite their current or potential customers to their warehouses to present their facilities and services. During these visits, the existence of advanced storage systems like Automated Storage and Retrieval System (ASRS) and Pallet and Container

Handling System (PCHS) improve the marketing power of the company. However in our case, ASRS and PCHS systems do not exist due financial limits. Instead, manual SKU and ULD storages are used in the air cargo terminal,. These are categorized as Export Loose Storage, Import Loose Storage and ULD storage in our model. These, so called “resources”, are also used as a contributor to the marketing activities.

Additionally, special cargo facilities or sections are also interesting for customers. Cold storage rooms for perishable cargoes, which are in the scope of this study, are used as the guarantee of the cool chain. If customers believe that the capacity of the cold rooms and cool chain operations are sufficient, they will tend to use this service after evaluating other factors of their decisions such as cost and network. In the opposite situation, they will never prefer the company as the carrier of their goods, if they do not believe that they will survive until the end of the supply chain.

Development of the AHP Model

Each criterion of the AHP model, as explained in the previous section, has its own calculation method. In this section, each of them will be explained and the resulting tables will be illustrated.

Cost

Cost of a project is always a part of a decision making process. In the air cargo warehouse design, there are four main elements of the cost equation.

$$TCI = TCC + TRC + TPC + TMC$$

Where

$$TCI = \text{Total cost of investment}$$

$$TCC = \text{Total construction cost}$$

$$TRC = \text{Total rental cost}$$

$$TPC = \text{Total purchasing cost}$$

$$TMC = \text{Total maintenance cost}$$

TCI, TCC, TRC, TPC and TMC are calculated via the following formula:

$$TCI = \sum_{i=1}^7 CI_i$$

$$TCC = \sum_{i=1}^7 CC_i$$

$$TRC = \sum_{i=1}^7 RC_i$$

$$TPC = \sum_{i=1}^7 PC_i$$

$$TMC = \sum_{i=1}^7 MC_i$$

Here CI_i , CC_i , RC_i , PC_i and MC_i denote the respective costs for the i th resource, where

1 = Gates,

2 = X-ray Machines,

- 3 = Workstations,
- 4 = Export Racks,
- 5 = Import Racks,
- 6 = Cold Room Racks and
- 7 = ULD positions.

After the total costs are calculated for each design alternative, the resulting scores are calculated through the following rule by taking the reciprocals of the costs:

RULE
$\text{Score} = 100.000.000 / \text{Total Cost of the Scenario}$

This calculation allows the lower costs to have higher scores in the further AHP analysis.

Construction Cost

A dedicated area is identified for each design alternative. The unit construction cost is obtained from the warehouse project of Company A. The construction cost related with the specified resource is calculated from the multiplication of the unit cost and the dedicated area.

The following formula is used to calculate construction cost of each design alternative..

$$CC_i = UC_i \times DA_i$$

Where

CC = Construction cost

UC = Unit construction cost for resource i, i=1, 2, ... , 7

DA = Dedicated area for resource i, i=1, 2, ... , 7

Rental Cost

In the main page of the DSS interface, the user identifies the lifetime of the terminal. This is used in the calculation of the rental costs. Considering the five-year cargo terminal, rental costs are around 40% of the construction costs and have a significant impact on the total investment costs because of the scarce and expensive lands of the airports. As the lifetime increases, the proportion of the rental cost in total investment also increases.

Rental costs are calculated using the following formula:

$$RC_i = UR \times DA_i \times LT \times 12$$

Where

RC = Rental cost per resource through the lifetime of the terminal

UR = Unit rent per area per month

DA = Dedicated area for the resource i, i=1, 2, ... , 7

LT = Lifetime of the terminal

Purchasing and Maintenance Cost

Purchasing cost and estimated maintenance cost of each design alternative are obtained from Company A.

The table of the AHP model is prepared with the inputs from the DSS user and the results from the PAN tool. Table 6 illustrates the unit costs of each variables. These costs are inputs for the cost calculation formula of each scenario, which is shown in Table 7.

Table 6: Cost of Each Variable

Unit Costs					
Input Variables	Direct Cost (Purchasing & Maintenance)	Area	Indirect Cost (Construction)	Indirect Cost (Rent)	TOTAL
Gate	6.500 USD	80	56.000 USD	24.000 USD	86.500 USD
X-ray machine	250.000 USD	50	35.000 USD	15.000 USD	300.000 USD
Workstation	40.000 USD	100	70.000 USD	30.000 USD	140.000 USD
Export Rack	55 USD	0,2	140 USD	60 USD	255 USD
Import Rack	55 USD	0,2	140 USD	60 USD	255 USD
Export Rack Cold Room	55 USD	1,2	1.920 USD	360 USD	2.335 USD
ULD Position	7.500 USD	12	8.400 USD	3.600 USD	19.500 USD

Table 7: Cost of Each Scenario

Scenario Analysis - Costs									
	Gate	X-ray Machine	Workstation	Export Loose Storage Capacity (SKU)	Import Loose Storage Capacity (SKU)	Cold Storage Capacity (SKU)	ULD Storage Capacity (ULD)	TOTAL	SCORE
Scenario 1	4.757.500 USD	1.800.000 USD	5.600.000 USD	1.912.500 USD	2.040.000 USD	1.634.500 USD	13.650.000 USD	31.394.500 USD	31,85
Scenario 2	3.892.500 USD	1.200.000 USD	4.200.000 USD	1.402.500 USD	1.657.500 USD	934.000 USD	9.750.000 USD	23.036.500 USD	43,41
Scenario 3	6.055.000 USD	2.400.000 USD	7.000.000 USD	2.040.000 USD	2.295.000 USD	1.868.000 USD	15.600.000 USD	37.258.000 USD	26,84
Scenario 4	4.757.500 USD	1.500.000 USD	5.600.000 USD	1.721.250 USD	1.976.250 USD	1.284.250 USD	11.700.000 USD	28.539.250 USD	35,04
Scenario 5	5.190.000 USD	1.500.000 USD	5.880.000 USD	1.721.250 USD	1.976.250 USD	1.167.500 USD	13.650.000 USD	31.085.000 USD	32,17
Scenario 6	4.757.500 USD	1.800.000 USD	5.600.000 USD	1.721.250 USD	1.976.250 USD	1.284.250 USD	12.675.000 USD	29.814.250 USD	33,54

Table 8: Normalized Cost of Each Scenario

NORMALIZED SCORES	
COST	Cost
Scenario 1	0,26
Scenario 2	0,00
Scenario 3	0,22
Scenario 4	0,00
Scenario 5	0,26
Scenario 6	0,27
	1,00

System Failure Risk

For the calculations of the “system failure risk” criterion, the DSS uses a table of rules for the evaluation of the related performance measures. After the performance measures on maximum queue sizes are obtained from the simulation runs, these values are transformed into the scores to be used in further AHP analysis. Table 9 illustrates these rules.

Table 9: Rules for the Calculation of the System Failure Risk Score

RULE								
	Max Number in Exp. Acc. Queue		Max Number in Exp. Loose Storage Queue		Max Number in Imp. Loose Storage Queue		Max Number in ULD Storage Queue	
Score	Interval		Interval		Interval		Interval	
100	0	5	0	20	0	20	0	5
90	6	10	21	40	21	40	6	10
80	11	15	41	60	41	60	11	15
70	16	20	61	80	61	80	16	20
60	21	25	81	100	81	100	21	25
50	26	30	101	120	101	120	26	30
0	31	9.999	121	9.999	121	9.999	31	9.999

In the AHP analysis, if any of the scenarios get a score of zero from any of the subcriteria, it is disapproved and excluded from the following steps. The proper scenarios are labeled with “APPLY AHP” and the rest with “DISAPPROVE”. Table 10 and 11 illustrates the calculation of the scores and shows the algorithm of the selection of the proper scenarios on an example.

Table 10: Simulation Results of Sample Scenarios

Scenario Analysis - Results				
	Max Number in Exp. Acc. Queue	Max Number in Exp. Loose Storage Queue	Max Number in Imp. Loose Storage Queue	Max Number in ULD Storage Queue
Scenario 1	14	0	0	2
Scenario 2	88	1271	573	750
Scenario 3	1	0	0	0
Scenario 4	14	70	1	93
Scenario 5	9	88	1	2
Scenario 6	14	86	1	28

Table 11: AHP Scores for System Failure Risk Criterion

Scenario Analysis - Scores					
	Max Number in Exp. Acc. Queue	Max Number in Exp. Loose Storage Queue	Max Number in Imp. Loose Storage Queue	Max Number in ULD Storage Queue	RESULT
Scenario 1	80	100	100	100	APPLY AHP
Scenario 2	0	0	0	0	DISAPPROVE
Scenario 3	100	100	100	100	APPLY AHP
Scenario 4	80	70	100	0	DISAPPROVE
Scenario 5	90	60	100	100	APPLY AHP
Scenario 6	80	60	100	50	APPLY AHP

The scores in the above table are converted into normalized scores by dividing each value by the sum of its column as in Table 12.

Table 12: Normalized System Failure Risk Results of Each Scenario

NORMALIZED SCORES				
SYSTEM FAILURE	Max Number in Exp. Acc. Queue	Max Number in Exp. Loose Storage Queue	Max Number in Imp. Loose Storage Queue	Max Number in ULD Storage Queue
Scenario 1	0,23	0,31	0,25	0,29
Scenario 2	0,00	0,00	0,00	0,00
Scenario 3	0,29	0,31	0,25	0,29
Scenario 4	0,00	0,00	0,00	0,00
Scenario 5	0,26	0,19	0,25	0,29
Scenario 6	0,23	0,19	0,25	0,14
	1,00	1,00	1,00	1,00

In the AHP analysis, a weight is determined for all subcriteria of the system failure risk criterion. The higher the weight is, the more the measure affects the general formula. These weights are calculated through the pairwise comparison method of AHP. Accordingly, four executives from the company

have evaluated the weights of the subcriteria for system failure risk by making pairwise comparisons as seen in Table 13.

Table 13: Pairwise Comparison Tables of Each Executive for System Failure Risk

Executive 1					Executive 2					Executive 3					Executive 4				
	EA	ES	IS	US		EA	ES	IS	US		EA	ES	IS	US		EA	ES	IS	US
EA	1	1	1	1/3	EA	1	2	2	1/2	EA	1	1	1	1	EA	1	1	1	1/2
ES	1	1	1	1/3	ES	1/2	1	1	1/4	ES	1	1	1	1	ES	1	1	1	1/2
IS	1	1	1	1/3	IS	1/2	1	1	1/4	IS	1	1	1	1	IS	1	1	1	1/2
US	3	3	3	1	US	2	4	4	1	US	1	1	1	1	US	2	2	2	1

EA: Export Acceptance Queue Max Number
ES: Export Storage Queue Max Number
IS: Import Storage Queue Max Number
US: ULD Storage Queue Max Number

The weights in the pairwise comparison above are given according to Saaty's Rating Scale Table.

Table 14: Saaty's Rating Scale Table

RATING SCALE TABLE	
Rating (R)	Description of Relative Rating
1	Equal
3	Weak preference
5	Essential or strong preference
7	Demonstrated preference
9	Absolute preference
2, 4, 6, 8	Intermediate values
Reciprocals of the above	If for criterion x, option A has a rating of one of the above when compared to option B (R_{xAB}), then option B has the reciprocal rating when compared to option A (R_{xBA})

These four matrices are combined in one matrix by taking the averages of each cell as seen in Table 15.

Table 15: Pairwise Comparison Summary Table for System Failure Risk

	Max Number in Exp. Acc. Queue	Max Number in Exp. Loose Storage Queue	Max Number in Imp. Loose Storage Queue	Max Number in ULD Storage Queue	Weights Priority Vector
Max Number in Exp. Acc. Queue	0,22	0,22	0,22	0,22	0,22
Max Number in Exp. Loose Storage Queue	0,19	0,19	0,19	0,19	0,19
Max Number in Imp. Loose Storage Queue	0,19	0,19	0,19	0,19	0,19
Max Number in ULD Storage Queue	0,41	0,41	0,41	0,41	0,41
Sum	1,00	1,00	1,00	1,00	

The weights priority vector is found in the following way: Within each column in Table 15, the cell values are divided by the sum of the column entries to normalize the proportion of each criterion. Then the arithmetic mean of each row in the comparison matrix has been taken to find the weights priority vector.

System failure risk score of each scenario is found through the matrix multiplication as illustrated below in Table 16.

Table 16: Matrix Multiplication to Find Final Results for System Failure Risk Criterion

NORMALIZED SCORES						
SYSTEM FAILURE	Max Number in Exp. Acc. Queue	Max Number in Exp. Loose Storage Queue	Max Number in Imp. Loose Storage Queue	Max Number in ULD Storage Queue	Criteria Weights	Matrix Calculation Result
Scenario 1	0,23	0,31	0,25	0,29	0,22	0,27
Scenario 2	0,00	0,00	0,00	0,00	0,19	0,00
Scenario 3	0,29	0,31	0,25	0,29	0,19	0,28
Scenario 4	0,00	0,00	0,00	0,00	0,41	0,00
Scenario 5	0,26	0,19	0,25	0,29		0,25
Scenario 6	0,23	0,19	0,25	0,14		0,19
	1,00	1,00	1,00	1,00		

Customer Perception

The method of calculating the customer perception score is the same as the system failure risk. Scores are calculated according to the predefined rules as in the Table 17.

Table 17: Rules for the Calculation of the Customer Perception Score

RULE								
	Average Cargo Waiting Time		Max Number in Exp. Acc. Queue		Max Waiting Time in Exp. Acc.		Max Waiting Time in Cold Storage Queue	
Score	Interval		Interval		Interval		Interval	
100	0,000	0,015	0	5	0,000	0,025	0,000	0,060
90	0,016	0,030	6	10	0,026	0,050	0,061	0,120
80	0,031	0,045	11	15	0,051	0,075	0,121	0,180
70	0,046	0,060	16	20	0,076	0,100	0,181	0,240
60	0,061	0,075	21	25	0,101	0,125	0,241	0,300
50	0,076	0,090	26	30	0,126	0,150	0,301	0,360
0	0,091	9,999	31	9,999	0,151	9,999	0,361	9,999

The results of the experimented simulation results are entered to a table (shown in Table 18) and the scores are calculated according to the table of rules as seen in Table 19.

Table 18: Simulation Results of Sample Scenarios

Scenario Analysis - Results				
	Average Cargo Waiting Time (hours)	Max Number in Exp. Acc. Queue	Max Waiting Time in Exp. Acc.	Max Waiting Time in Cold Storage Queue
Scenario 1	0,037	14	0,0841	0
Scenario 2	4,645	88	0,739	4,822
Scenario 3	0,037	1	0,0054	0
Scenario 4	0,116	14	0,0847	0,051
Scenario 5	0,076	9	0,0455	0,335
Scenario 6	0,05	14	0,0841	0,056

Table 19: Scores of Each Scenario for Customer Perception Criterion

Scenario Analysis - Scores					RESULT
	Average Cargo Waiting Time (hours)	Max Number in Exp. Acc. Queue	Max Waiting Time in Exp. Acc.	Max Waiting Time in Cold Storage Queue	
Scenario 1	80	80	70	100	APPLY AHP
Scenario 2	0	0	0	0	DISAPPROVE
Scenario 3	80	100	100	100	APPLY AHP
Scenario 4	0	80	70	100	DISAPPROVE
Scenario 5	50	90	90	50	APPLY AHP
Scenario 6	70	80	70	100	APPLY AHP

The table of rules of Customer Perception in Table 17 defines an upper limit for each subcriteria. The scenarios below this limit gets a score of zero. If one scenario gets a zero from one of the subcriteria, it is “DISAPPROVED” immediately and not included in the AHP process. The others, which pass the limit, are labeled with “APPLY AHP” result and included in the AHP process.

The scores in the above table are converted into normalized scores by dividing each value by the sum of its column as in Table 20.

Table 20: Normalized Customer Perception Results of Each Scenario

CUSTOMER PERCEPTION	NORMALIZED SCORES			
	Average Cargo Waiting Time (hours)	Max Number in Exp. Acc. Queue	Max Waiting Time in Exp. Acc.	Max Waiting Time in Cold Storage Queue
Scenario 1	0,29	0,23	0,21	0,29
Scenario 2	0,00	0,00	0,00	0,00
Scenario 3	0,29	0,29	0,30	0,29
Scenario 4	0,00	0,00	0,00	0,00
Scenario 5	0,18	0,26	0,27	0,14
Scenario 6	0,25	0,23	0,21	0,29
	1,00	1,00	1,00	1,00

Weights of the subcriteria for customer perception are also calculated according to the AHP analysis. Table 21 figures out the process.

Table 21: Pairwise Comparison Summary Table for Customer Perception

	Average Cargo Waiting Time (hours)	Max Number in Exp. Acc. Queue	Max Waiting Time in Exp. Acc.	Max Waiting Time in Cold Storage Queue	Weights Priority Vector
Average Cargo Waiting Time (hours)	0,12	0,12	0,12	0,13	0,12
Max Number in Exp. Acc. Queue	0,18	0,17	0,16	0,20	0,18
Max Waiting Time in Exp. Acc.	0,21	0,20	0,18	0,17	0,19
Max Waiting Time in Cold Storage Queue	0,48	0,52	0,54	0,50	0,51
Sum	1,00	1,00	1,00	1,00	

The procedure to calculate the final scores for this criterion is the same as the analysis used for system failure risk as illustrated in Table 22.

Table 22: Matrix Multiplication to Find Final Results for Customer Perception Criterion

NORMALIZED SCORES					Criteria Weights	Matrix Calculation Result
CUSTOMER PERCEPTION	Average Cargo Waiting Time (hours)	Max Number in Exp. Acc. Queue	Max Waiting Time in Exp. Acc.	Max Waiting Time in Cold Storage Queue		
Scenario 1	0,29	0,23	0,21	0,29	0,12	0,26
Scenario 2	0,00	0,00	0,00	0,00	0,18	0,00
Scenario 3	0,29	0,29	0,30	0,29	0,19	0,29
Scenario 4	0,00	0,00	0,00	0,00	0,51	0,00
Scenario 5	0,18	0,26	0,27	0,14		0,20
Scenario 6	0,25	0,23	0,21	0,29		0,25
	1,00	1,00	1,00	1,00		

Marketing Power

The scores of each subcriteria are calculated through the following rule:

RULE
Score = (Amount of the Resource in Scenario) / (Average Amount of the Resource in all Scenarios)

The results are calculated as follows:

Table 23: Input Table of Sample Scenarios (fed from the inputs of CargoSim)

Scenario Analysis - Input				
	Export Cold Storage Capacity	Import Loose Storage Capacity	Export Loose Storage Capacity	ULD Storage Capacity
Scenario 1	700	8000	7500	700
Scenario 2	400	6500	5500	500
Scenario 3	800	9000	8000	800
Scenario 4	550	7750	6750	600
Scenario 5	500	7750	6750	700
Scenario 6	550	7750	6750	650

Table 24: Marketing Power Scores before Normalization

Scenario Analysis - Scores				
	Export Cold Storage Capacity	Import Loose Storage Capacity	Export Loose Storage Capacity	ULD Storage Capacity
Scenario 1	1,20	1,03	1,09	1,06
Scenario 2	0,69	0,83	0,80	0,76
Scenario 3	1,37	1,16	1,16	1,22
Scenario 4	0,94	0,99	0,98	0,91
Scenario 5	0,86	0,99	0,98	1,06
Scenario 6	0,94	0,99	0,98	0,99

The scores in the above table are converted into normalized scores by dividing each value by the sum of its column.

Table 25: Normalized Marketing Power Results of Each Scenario

NORMALIZED SCORES				
MARKETING POWER	Export Cold Storage Capacity	Import Loose Storage Capacity	Export Loose Storage Capacity	ULD Storage Capacity
Scenario 1	0,27	0,25	0,26	0,25
Scenario 2	0,00	0,00	0,00	0,00
Scenario 3	0,31	0,28	0,28	0,28
Scenario 4	0,00	0,00	0,00	0,00
Scenario 5	0,20	0,24	0,23	0,25
Scenario 6	0,22	0,24	0,23	0,23
	1,00	1,00	1,00	1,00

Coefficients of marketing power criterion are defined by the executives.

Hence it is not related with the simulation model and has no relation with the operational performance; there is not an available scale to apply to it except

the opinions of the executives. Again pairwise comparison is used to give weights.

Table 26: Pairwise Comparison Summary Table for Marketing Power

	Export Cold Storage Capacity	Import Loose Storage Capacity	Export Loose Storage Capacity	ULD Storage Capacity	Weights Priority Vector
Export Cold Storage Capacity	0,57	0,54	0,54	0,60	0,56
Import Loose Storage Capacity	0,12	0,11	0,12	0,10	0,12
Export Loose Storage Capacity	0,12	0,12	0,12	0,11	0,12
ULD Storage Capacity	0,18	0,22	0,22	0,19	0,20
Sum	1,00	1,00	1,00	1,00	

The results are calculated through matrix multiplication between the score table and the priority matrix of Marketing Power criterion as in Table 27.

Table 27: Matrix Multiplication to Find Final Results for Marketing Power Criterion

MARKETING POWER	NORMALIZED SCORES				Criteria Weights	Matrix Calculation Result
	Export Cold Storage Capacity	Import Loose Storage Capacity	Export Loose Storage Capacity	ULD Storage Capacity		
Scenario 1	0,27	0,25	0,26	0,25	0,56	0,25
Scenario 2	0,00	0,00	0,00	0,00	0,12	0,00
Scenario 3	0,31	0,28	0,28	0,28	0,12	0,29
Scenario 4	0,00	0,00	0,00	0,00	0,20	0,00
Scenario 5	0,20	0,24	0,23	0,25		0,23
Scenario 6	0,22	0,24	0,23	0,23		0,23
	1,00	1,00	1,00	1,00		

Overall AHP Score

The overall score of each scenario in the AHP model is calculated after the normalization of the results coming from each individual table of criteria.

While converting these results into final scores, the status of the scenario is checked from the table, which shows if the scenario is disapproved by one of the subcriterion or not. If the scenario is disapproved, the score is set to zero for all measures. This allows the user to exclude the scenario completely from the AHP model.

The weights priority vectors of the AHP main criteria are developed. Firstly, four evaluators from the company are asked to make pairwise comparisons between the main criteria of cost, system failure risk, customer satisfaction and marketing power. Then the steps similar to the analysis in the above subsections are followed to calculate the overall weights priority matrix as seen in the below Table 28.

Table 28: Pairwise Comparison Tables of Each Executive for the Criteria

Executive 1					Executive 2					Executive 3					Executive 4				
	C	SFR	CP	MP		C	SFR	CP	MP		C	SFR	CP	MP		C	SFR	CP	MP
C	1	1/2	3	5	C	1	1/3	5	7	C	1	1	3	3	C	1	1/3	2	3
SFR	2	1	5	7	SFR	3	1	7	9	SFR	1	1	3	3	SFR	3	1	5	6
CP	1/3	1/5	1	2	CP	1/5	1/7	1	1	CP	1/3	1/3	1	1	CP	1/2	1/5	1	2
MP	1/5	1/7	1/2	1	MP	1/7	1/9	1	1	MP	1/3	1/3	1	1	MP	1/3	1/6	1/2	1

Table 29 shows overall results, after a matrix multiplication process between the matrix of scores and the priority matrix.

Table 29: Matrix multiplication to find the final overall scores

NORMALIZED SCORES					Criteria Weights	Matrix Calculation Result
OVERALL	COST	SYSTEM FAILURE	CUSTOMER PERCEPTION	MARKETING POWER		
Scenario 1	0,26	0,27	0,26	0,25	0,30	0,263
Scenario 2	0,00	0,00	0,00	0,00	0,51	0,000
Scenario 3	0,22	0,28	0,29	0,29	0,11	0,263
Scenario 4	0,00	0,00	0,00	0,00	0,08	0,000
Scenario 5	0,26	0,25	0,20	0,23		0,247
Scenario 6	0,27	0,19	0,25	0,23		0,223
	1,00	1,00	1,00	1,00		

The DSS user is able to compare the scores of each scenario regarding each criterion and also see the overall score of each. These results show that Scenario 2 and Scenario 4 are excluded before AHP process because of their poor performance.

Adding huge amount of resources may not affect the performance of the system. Instead of this, the optimum amounts should be found by trying different alternatives, which helps to avoid implementing surplus resources resulting in excess capacity. This can be interpreted from the comparison of scenarios 1 and 5. The fifth scenario has the same score with the first in terms of cost, but the system failure risk score of the first is higher. This means that some resources are not used as effective as in the first scenario and there are both surpluses and deficits in the resources.

The interrelation between cost and customer perception is also worth to think about. As interpreted in this study, not all inconvenient situations and failures in the system result in a decline in the customer perception. There is

not a consistent relation between “system failure risk” and “customer perception”. This can be said considering the comparison between the fifth and the sixth scenarios. While the system failure risk score is 0.25 in the fifth scenario, the customer perception is 0.20. Inversely, while the system failure risk score decreases to 0.19, the customer perception goes up to 0.25.

Finally, the correlation between the cost and the marketing power is also interesting. Increasing the cost of the design does not directly support the marketing power. Investing in more accurate and effective resources may affect the overall result, which can be supported by the marketing power criterion.

CHAPTER 6

DEVELOPMENT OF THE DECISION SUPPORT SYSTEM ENVIRONMENT

In this section, a DSS is developed based on the data coming from simulation, data provided by the user and the calculations made according to the AHP model.

Illustrative Application Example of DSS

In this section, an example is given to demonstrate the execution of CargoSim. The data set for this example is provided by Company A.

Main Page

The main page is shown below in Figure 25. Firstly, the user sees a brief introduction to CargoSim. After the introduction, there are interactive fields for the user. These fields include the run specifications for the simulation model such as number of replications, replication length and annual capacity, which allows the user to change the export and inbound arrival rates of the model. The arrival rates are recalculated automatically by multiplying the current arrival rates with the component entered by the user. Additionally, the input

for the lifetime of the terminal, which is needed for the rental cost calculation in the AHP analysis, is also gathered from the DSS user.

These fields have to be filled by the user via selecting the required value from a list in a combo box. There is a default value for each selection. In each page of the interface, there is a “Back” and “Next” button except the first and the last screens. In the first screen, there is a button to exit the program. In the last screen, it is possible to use “Start over” button to go to the main screen.

CargoSim

CargoSim is a DSS software which enables the users to create alternative designs for an air cargo warehouse by changing the key factors. Design alternatives are evaluated and ranked by a simulation and Analytic Hierarchy Process (AHP) analysis.

Run Specifications

Annual Capacity	1.000.000	tonnes	<i>*Default 1.000.000</i>
Replication Length	14	days	<i>*Default 21</i>
Number of Replications	1		<i>*Default 1000</i>

AHP Model Inputs

Lifetime of the Terminal*	7	years	<i>*Default 5</i>
---------------------------	---	-------	-------------------

**This information will be used in cost calculations.*

Exit **Next**

Figure 25: The main page of CargoSim

If the user tries to enter an invalid input instead of selecting from the list in the combo box, an error message appears in the screen to warn the user that he has to check his selection as in Figure 26.

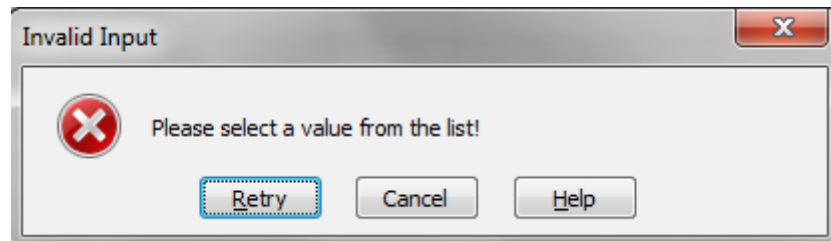


Figure 26: Error message for an invalid coefficient

Generating Alternative Warehouse Designs

In the second screen of CargoSim in the below Figure 27, the DSS user defines resources to create different warehouse designs. The amount of each resource has to be an integer value.

The amount of resources is the key part to create scenarios. The user can change the amounts of seven main resources and create up to twenty different scenarios. It is not allowed to leave fields blank. Figure 27 illustrates the screen of resource allocations.

CargoSim

Generating Alternative WH Designs

Please enter the amounts of the resources for each scenario.

	Gate	X-ray Machine	Workstation	Export Loose Storage Capacity (SKU)	Import Loose Storage Capacity (SKU)	Cold Storage Capacity (SKU)	ULD Storage Capacity (ULD)
Scenario 1	70	8	50	8.000	9.000	800	800
Scenario 2	50	6	50	10.000	500	100	2.000
Scenario 3	70	8	50	8.000	9.000	800	800
Scenario 4	55	5	66	6.750	7.750	550	600
Scenario 5	60	5	42	6.750	7.750	500	700
Scenario 6	55	6	40	6.750	7.750	550	650

Back
Run

Figure 27: Generating alternative designs with CargoSim

Running the Simulation Model

After all inputs are entered by the user through the described screens and the “Run” button is clicked, the input data in the data repository are written automatically to the simulation model and the program starts running the model with the number and length of replications as described by the user.

The interface sends the resource data as an input to the simulation model and receives the results after the run of Arena. The results in the below Figure 28 are used in the AHP model to calculate the score of each scenario and to find the best design.

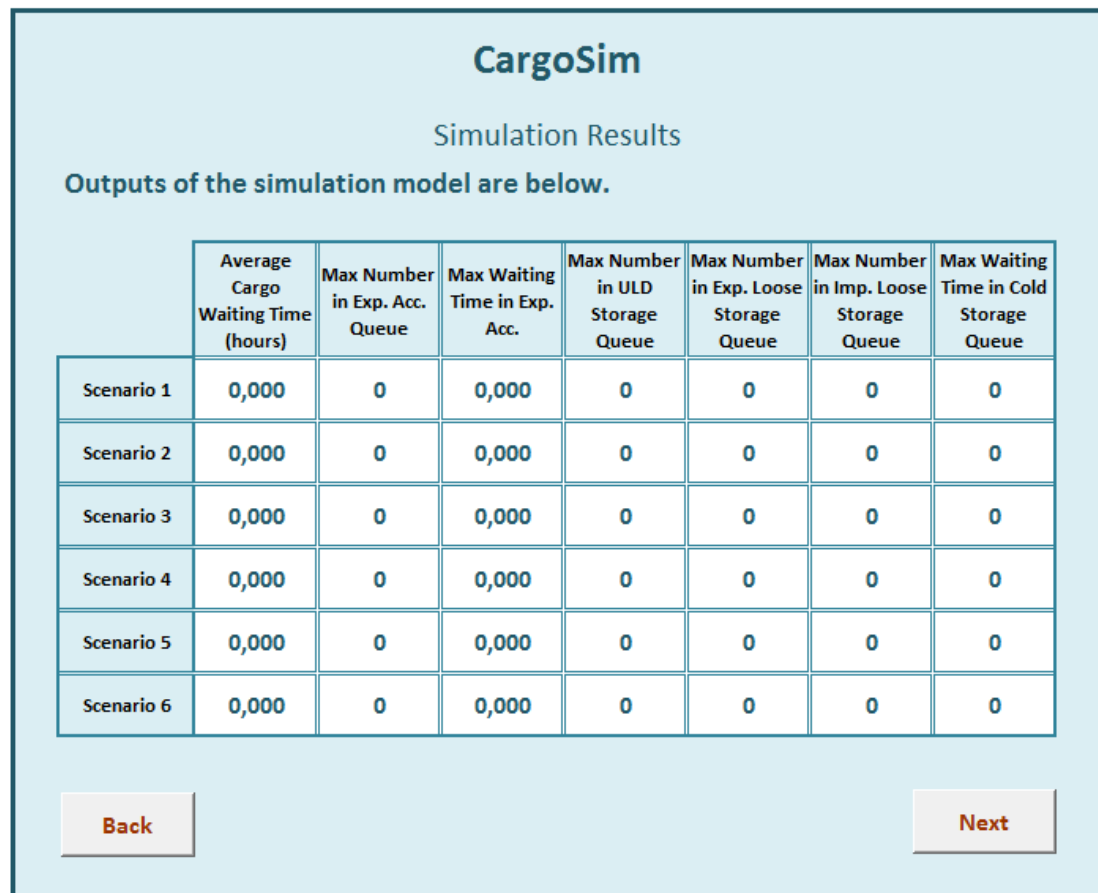


Figure 28: Simulation Results

AHP Results

When the run is completed, AHP results page appears and shows the comparison of all scenarios. Scores are calculated according to the Analytic Hierarchy Process Model and written to tables shown in Figure 29. The scores of each criterion can be seen in these tables.

After this screen, the DSS user sees the overall scores of the scenarios. Cost of each scenario is also available on the screen. At the bottom of the page, the best scenario according to this model is illustrated. Figure 30 illustrates the overall results and the best scenario.

CargoSim

AHP Results

First Criteria: COST (weight = 0.30)

	TOTAL COST
Scenario 1	0,16
Scenario 2	0,11
Scenario 3	0,16
Scenario 4	0,18
Scenario 5	0,19
Scenario 6	0,20

Second Criteria: SYSTEM FAILURE (weight = 0.51)

	Max Number in Exp. Acc. Queue	Max Number in Exp. Loose Storage Queue	Max Number in Imp. Loose Storage Queue	Max Number in ULD Storage Queue
Weights	0,22	0,19	0,19	0,41
Scenario 1	0,17	0,17	0,17	0,17
Scenario 2	0,17	0,17	0,17	0,17
Scenario 3	0,17	0,17	0,17	0,17
Scenario 4	0,17	0,17	0,17	0,17
Scenario 5	0,17	0,17	0,17	0,17
Scenario 6	0,17	0,17	0,17	0,17

Third Criteria: CUSTOMER PERCEPTION

	Average Cargo Waiting Time (hours)	Max Number in Exp. Acc. Queue	Max Waiting Time in Exp. Acc.	Max Waiting Time in Cold Storage Queue
Weights	0,12	0,18	0,19	0,51
Scenario 1	0,17	0,17	0,17	0,17
Scenario 2	0,17	0,17	0,17	0,17
Scenario 3	0,17	0,17	0,17	0,17
Scenario 4	0,17	0,17	0,17	0,17
Scenario 5	0,17	0,17	0,17	0,17
Scenario 6	0,17	0,17	0,17	0,17

Fourth Criteria: MARKETING POWER

	Export Cold Storage Capacity	Import Loose Storage Capacity	Export Loose Storage Capacity	ULD Storage Capacity
Weights	0,56	0,12	0,12	0,20
Scenario 1	0,24	0,22	0,17	0,14
Scenario 2	0,03	0,01	0,22	0,36
Scenario 3	0,24	0,22	0,17	0,14
Scenario 4	0,17	0,19	0,15	0,11
Scenario 5	0,15	0,19	0,15	0,13
Scenario 6	0,17	0,19	0,15	0,12

Back

Next

Figure 29: AHP Results screen

While the screen in Figure 29 shows the detailed scores of each scenario in terms of subcriteria, the following screen as shown in Figure 30 gives the overall results and the best decision. If there is a tie between two or more scores, all the scenarios having the highest score is represented as the best.

CargoSim					
AHP Results					
Overall					
	COST	SYSTEM FAILURE	CUSTOMER PERCEPTION	MARKETING POWER	OVERALL
Scenario 1	0,16	0,17	0,17	0,18	0,165
Scenario 2	0,11	0,17	0,17	0,20	0,151
Scenario 3	0,16	0,17	0,17	0,18	0,165
Scenario 4	0,18	0,17	0,17	0,14	0,169
Scenario 5	0,19	0,17	0,17	0,15	0,171
Scenario 6	0,20	0,17	0,17	0,15	0,174

Back

Start over

Figure 30: Overall results and the best scenario

CHAPTER 7

CONCLUSION

As a result of higher competition in the air cargo industry,, air cargo warehouses has become more and more important. Designing a warehouse which operates cost efficiently while maintaining high competencies provide the air cargo carrier a competitive advantage in this industry.

In this thesis, we study the problem of designing an air cargo warehouse with the considerations of low costs, high operational performance, high level of customers' perceived quality and high marketing effectiveness.

We develop a DSS interface which allows the designer to create alternative air cargo terminal designs and evaluate the results in terms of four main criteria which are cost, system failure risk, customer perception and marketing power. Simulation and Analytical Hierarchy Process methodologies are used together to evaluate and rank the design alternatives. In order to develop this model, the input data is obtained from one of the Europe's biggest air cargo carrier company. Additionally, the results are discussed with the executives.

The DSS is used to generate multiple alternative designs, evaluate their operational performances by simulation and rank them according to multiple criteria by using the AHP approach.

In the pilot study of the DSS, we observe that the DSS provides an effective and efficient environment to compare alternative designs of an air cargo terminal. It provides the user to create his own scenarios using an interactive and user-friendly interface, obtain simulation results, see AHP criteria and their weights, achieve the scores of each scenario in terms of each criterion and find out the best scenario among these alternatives. The DSS guarantees effectiveness of the design by eliminating the alternatives with high error rates. There is a list of rules to set a score for each criteria. The score of a criteria below a defined limit is set as zero. If one of the criteria gets a zero, the alternative is eliminated completely. This process avoids the alternatives which perform badly. The DSS provides an efficient solution by leading to find the best alternative with lower consumption of resources. These resources are mainly the constructional resources, special handling equipment and land which are very expensive and rare around airports. The DSS gives poor scores to the alternatives with high consumption of resources. Consequently, the DSS helps improving the productivity by increasing the effectiveness and efficiency.

The DSS allows the user to change the general conditions of the warehouse design. Simple interfaces and interactive fields are developed to improve the interaction between the software and the user. The DSS is flexible in defining various alternatives with different number of resources, annual tonnages, replication length and lifetime of the cargo terminal.

As a future study, the effectiveness, efficiency and flexibility of this DSS should be evaluated and enhanced by survey analysis after a pilot study

by the users. At last, the graphical user interfaces might be improved according to the feedbacks of the users. Additionally, more input fields can be provided to allow a more customized model. In this model, daily and monthly demands are decided based on the historical data. A forecast model can be developed and integrated with the software as an addition to the output of this study. Finally, the interface can be redesigned to be more responsive to the changes in the AHP decision criteria, weights and simulation processes.

APPENDICES

A. DISTRIBUTION ANALYSIS OF UNIT LOADS

Table 30: Results of Significance Tests to Theoretical Distributions- LSP

Weight

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,03956				
P-Value	0,08511				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	Yes	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	2,7201				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	Yes	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	22,661				
P-Value	0,007				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	Yes	Yes

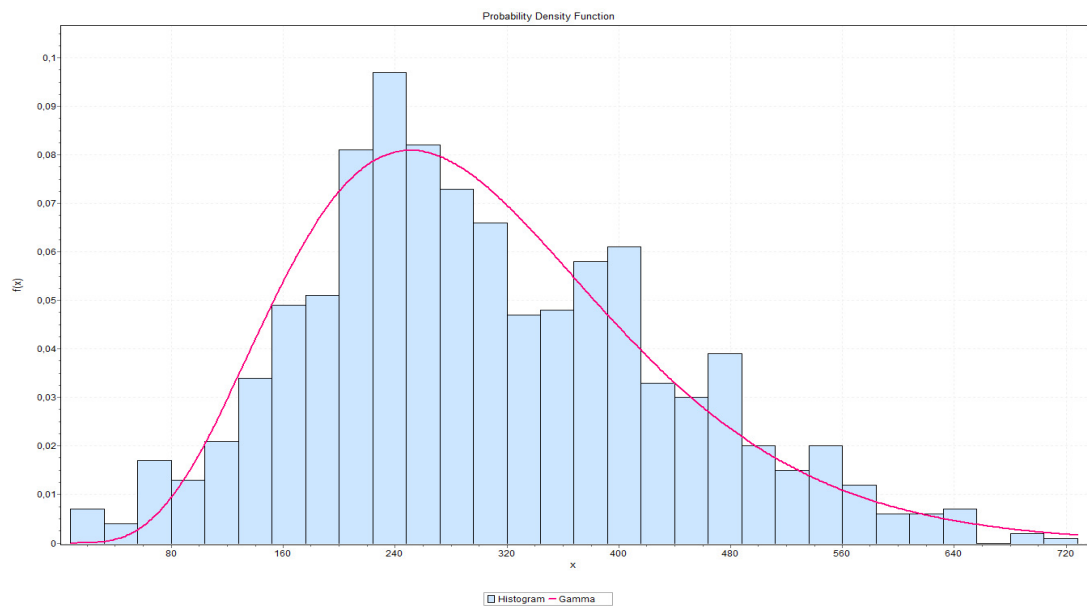


Figure 31: 30-tile histogram of the fitting distribution – LSP Weight

Table 31: Results of Significance Tests to Theoretical Distributions- Truck Load

Gamma [#5]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,02585				
P-Value	0,50796				
Rank	4				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	1,377				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	12,186				
P-Value	0,20302				
Rank	4				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

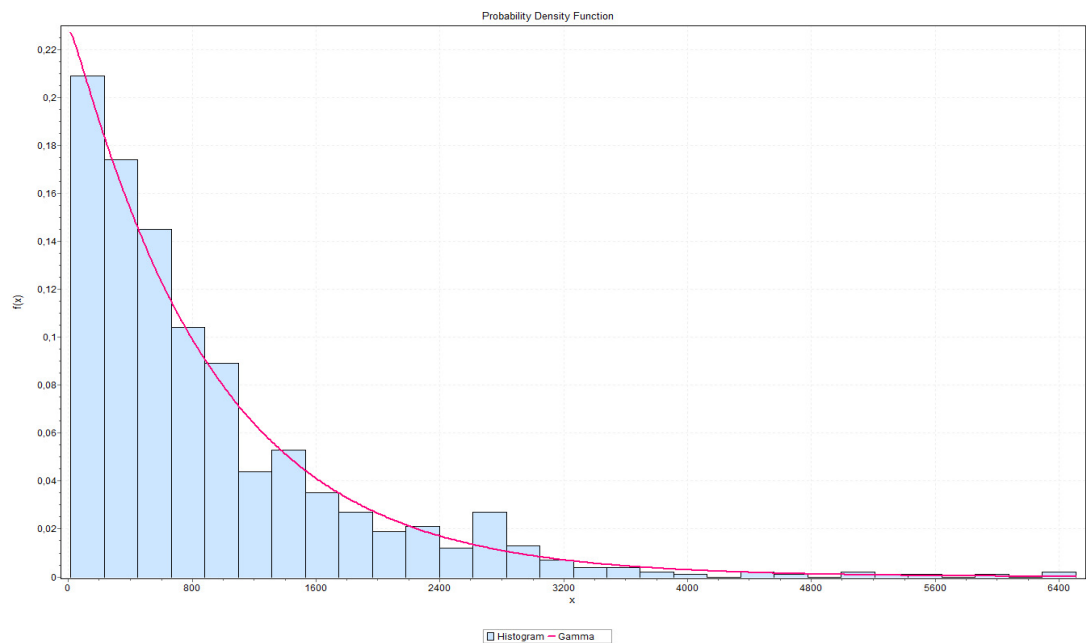


Figure 32: 30-tile histogram of the fitting distribution – Truck Load

Table 32: Results of Significance Tests to Theoretical Distributions- Wide
Body ULD Load

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,02791				
P-Value	0,40966				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	1,0066				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	12,574				
P-Value	0,18287				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	No	No	No	No

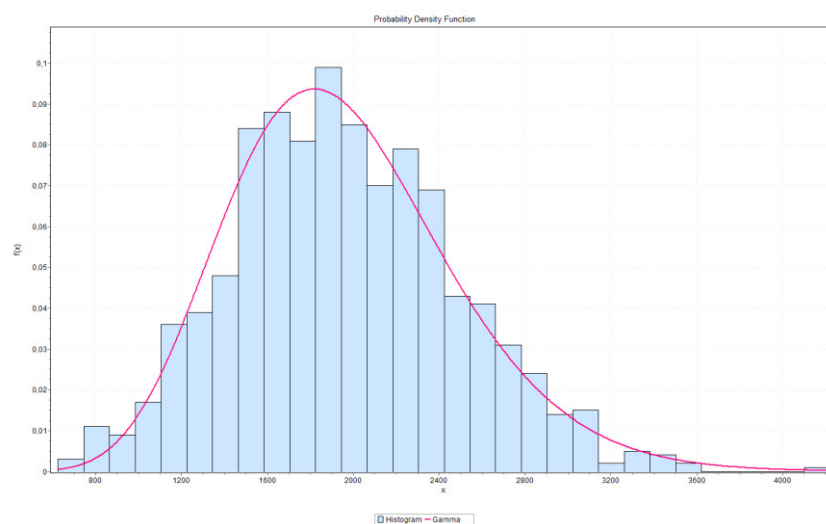


Figure 33: 30-tile histogram of the fitting distribution–Wide Body ULD Load

Table 33: Results of Significance Tests to Theoretical Distributions- Narrow Body ULD Load

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	887				
Statistic	0,02855				
P-Value	0,45646				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03603	0,04106	0,0456	0,05097	0,0547
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	887				
Statistic	1,1682				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	13,912				
P-Value	0,12548				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	No	No	No	No

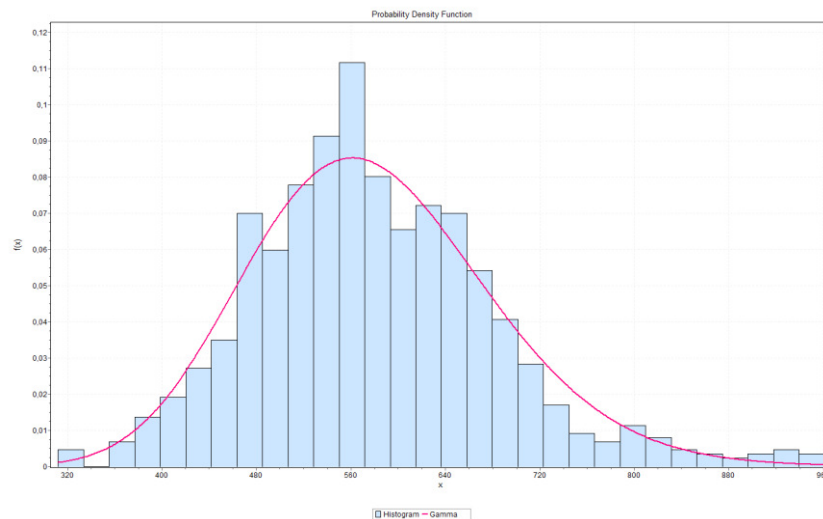


Figure 34: 30-tile histogram of the fitting distribution–Narrow Body ULD Load

B. DISTRIBUTION ANALYSIS OF PROCESS TIMES

Table 34: Results of Significance Tests to Theoretical Distributions- Export

Acceptance

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,03816				
P-Value	0,10591				
Rank	4				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	1,4478				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	14,266				
P-Value	0,11318				
Rank	6				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	No	No	No	No

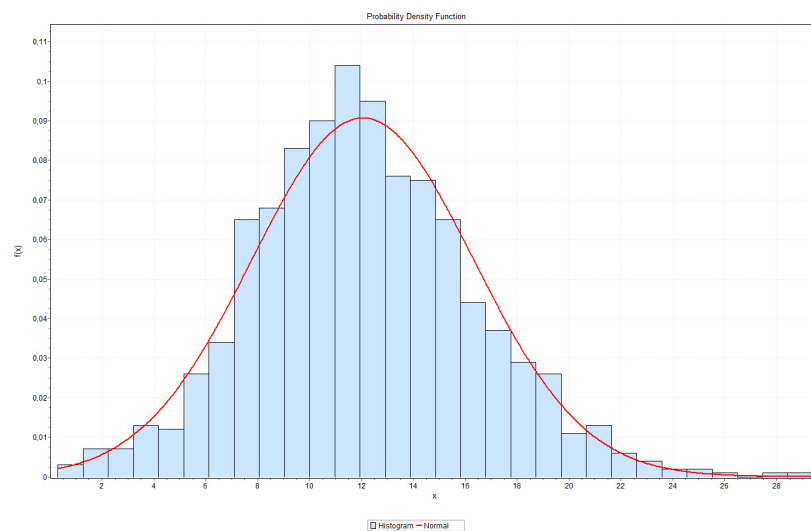


Figure 35: 30-tile histogram of the fitting distribution – Export Acceptance

Table 35: Results of Significance Tests to Theoretical Distributions – Security Check

Weibull [#11]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,04066				
P-Value	0,07127				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	Yes	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	3,0809				
Rank	4				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	Yes	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	19,829				
P-Value	0,019				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	Yes	No

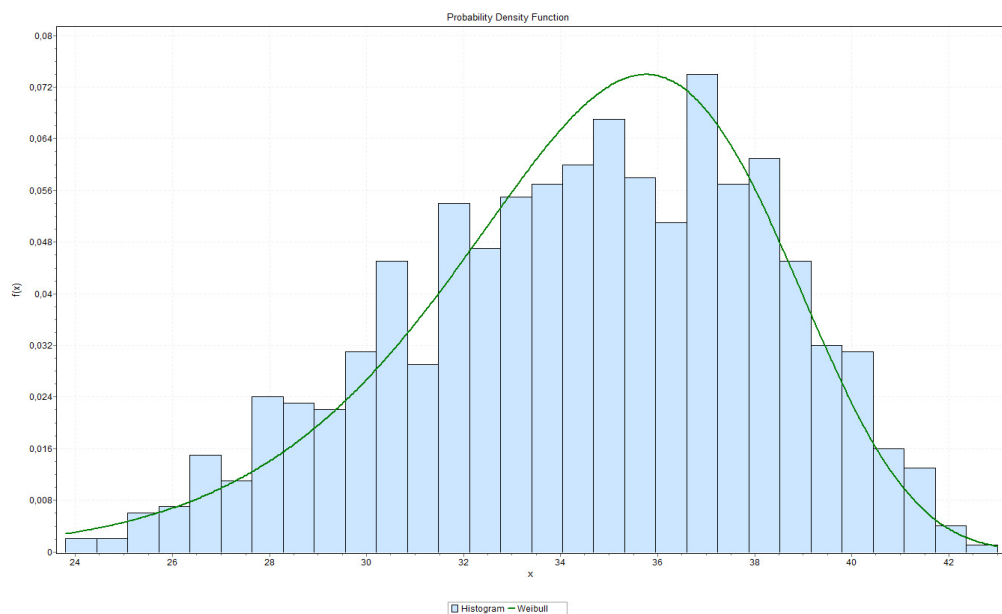


Figure 36: 30-tile histogram of the fitting distribution – Security Check

Table 36: Results of Significance Tests to Theoretical Distributions –
Build-up Preparation

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,0273				
P-Value	0,43766				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	0,73818				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	11,007				
P-Value	0,27521				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

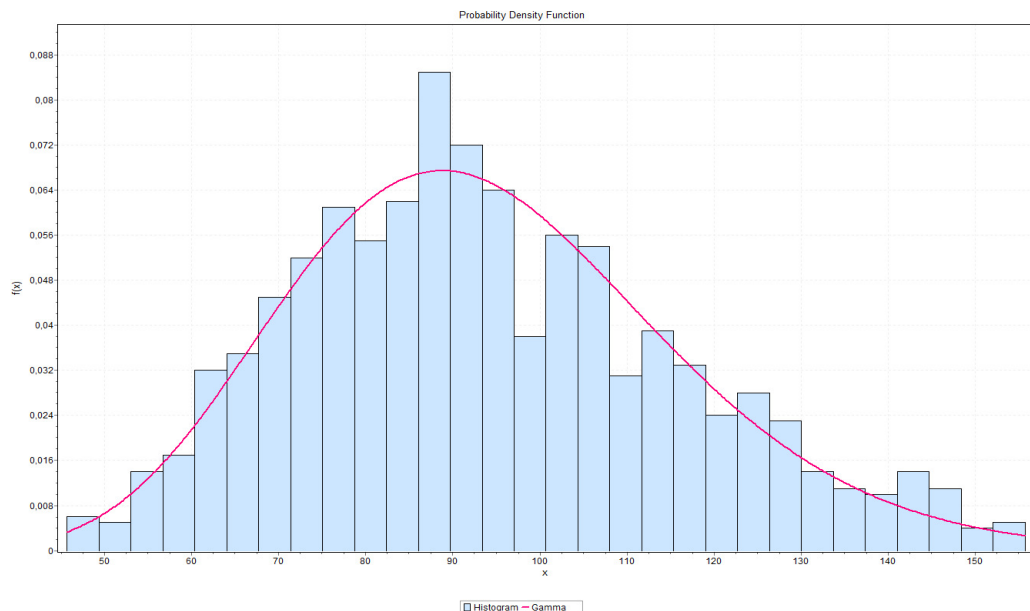


Figure 37: 30-tile histogram of the fitting distribution – Build-up Preparation

Table 37: Results of Significance Tests to Theoretical Distributions – Wide Body Build Up

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	996				
Statistic	0,04902				
P-Value	0,01612				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,034	0,03875	0,04303	0,0481	0,05162
Reject?	Yes	Yes	Yes	Yes	No
Anderson-Darling					
Sample Size	996				
Statistic	3,2516				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	Yes	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	29,991				
P-Value	4,4022E-4				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	Yes	Yes

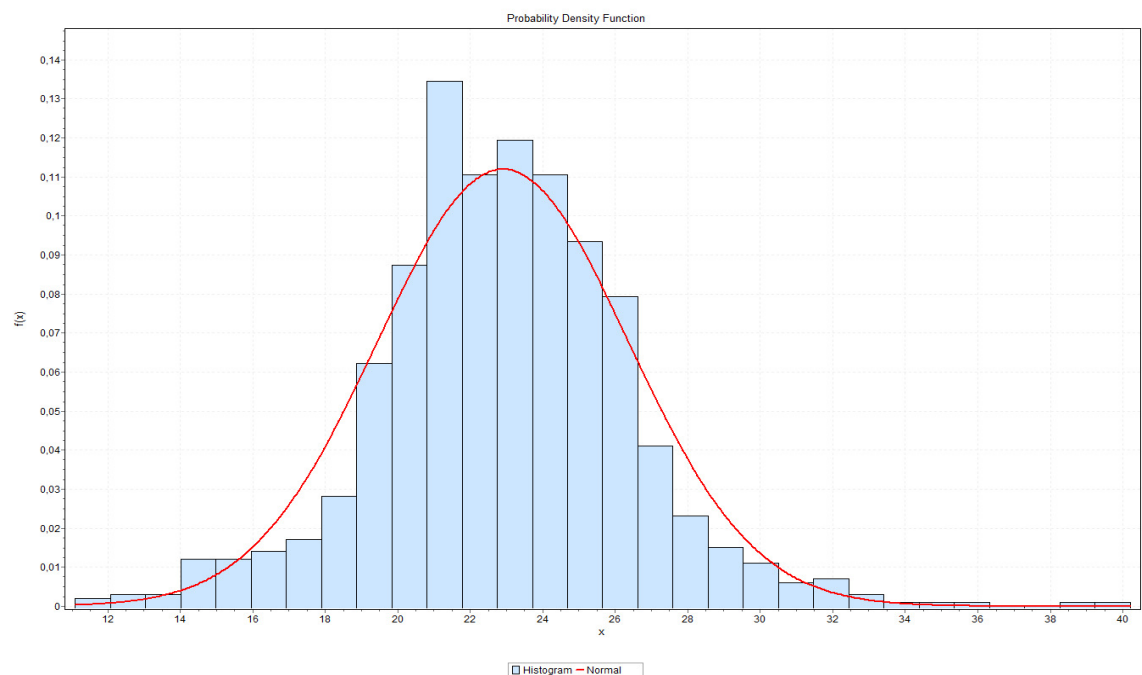


Figure 38: 30-tile histogram of the fitting distribution – Wide Body Build Up

Table 38: Results of Significance Tests to Theoretical Distributions –
Narrow Body Build Up

Weibull [#11]					
Kolmogorov-Smirnov					
Sample Size	887				
Statistic	0,04188				
P-Value	0,08653				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03603	0,04106	0,0456	0,05097	0,0547
Reject?	Yes	Yes	No	No	No
Anderson-Darling					
Sample Size	887				
Statistic	1,7832				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	17,36				
P-Value	0,04337				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	No	No

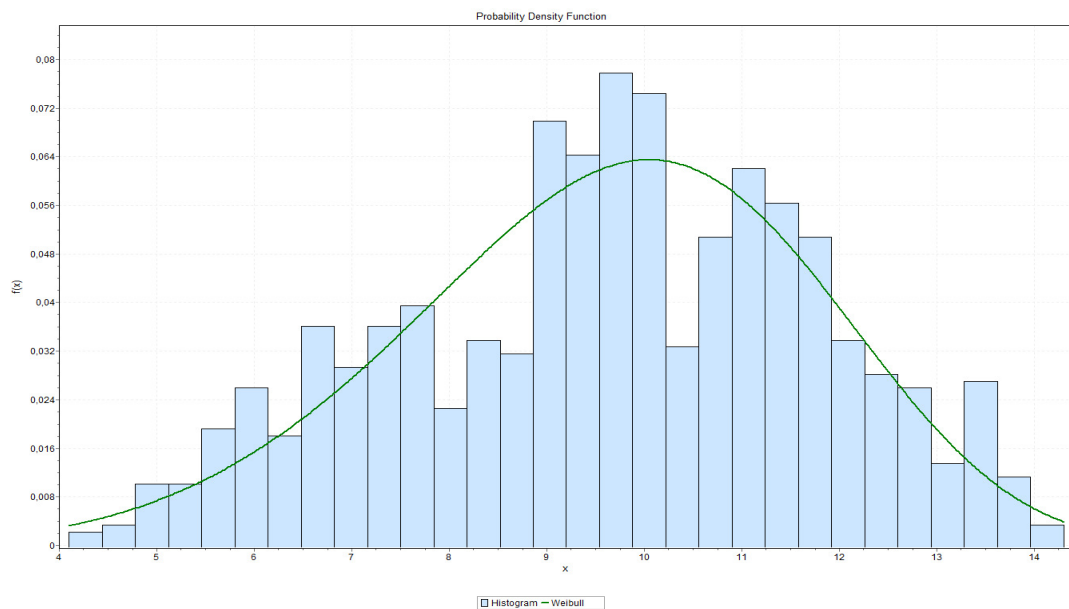


Figure 39: 30-tile histogram of the fitting distribution – Narrow Body Build Up

Table 39: Results of Significance Tests to Theoretical Distributions – Wide Body Break Down

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	996				
Statistic	0,03111				
P-Value	0,28411				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,034	0,03875	0,04303	0,0481	0,05162
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	996				
Statistic	0,69931				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	15,073				
P-Value	0,08894				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	No	No	No

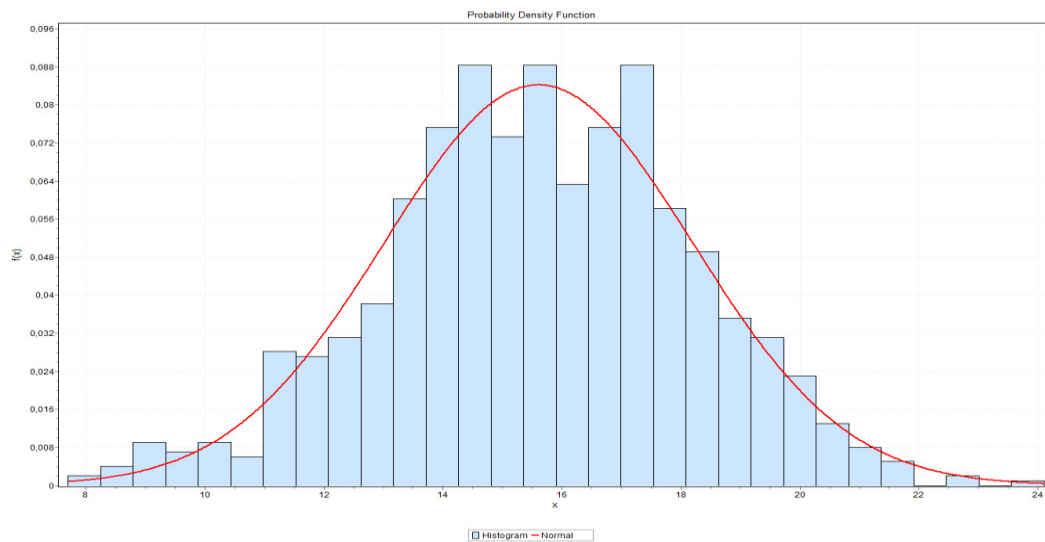


Figure 40: 30-tile histogram of the fitting distribution – Wide Body Break Down

Table 40: Results of Significance Tests to Theoretical Distributions –
Narrow Body Break Down

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	887				
Statistic	0,02666				
P-Value	0,54479				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03603	0,04106	0,0456	0,05097	0,0547
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	887				
Statistic	0,48189				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	10,119				
P-Value	0,34091				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

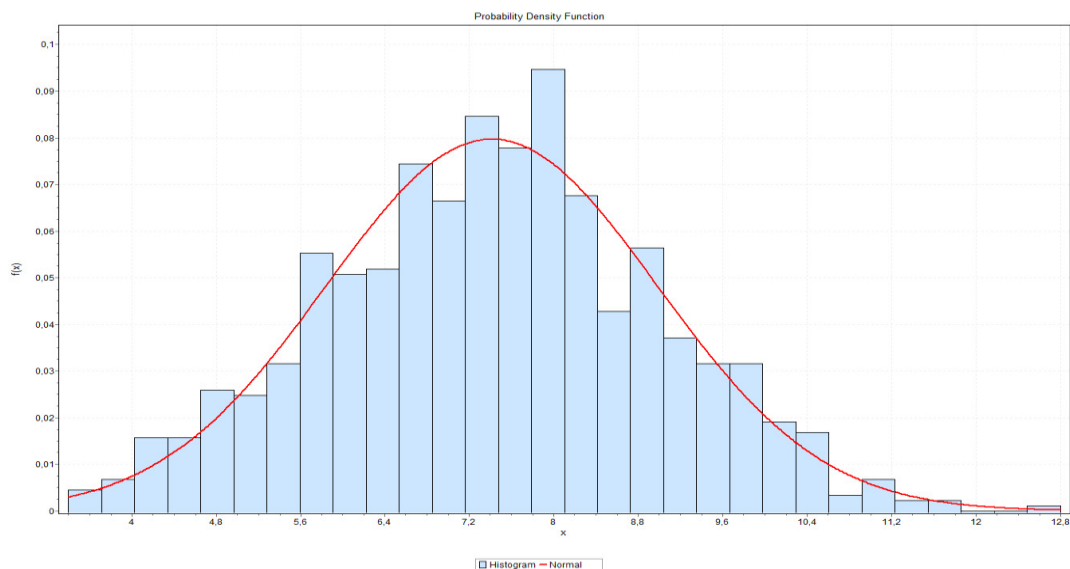


Figure 41: 30-tile histogram of the fitting distribution – Narrow Body Break
Down

Table 41: Results of Significance Tests to Theoretical Distributions – Import Segregation

Triangular [#9]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,02389				
P-Value	0,60927				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	0,664				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	10,82				
P-Value	0,28822				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

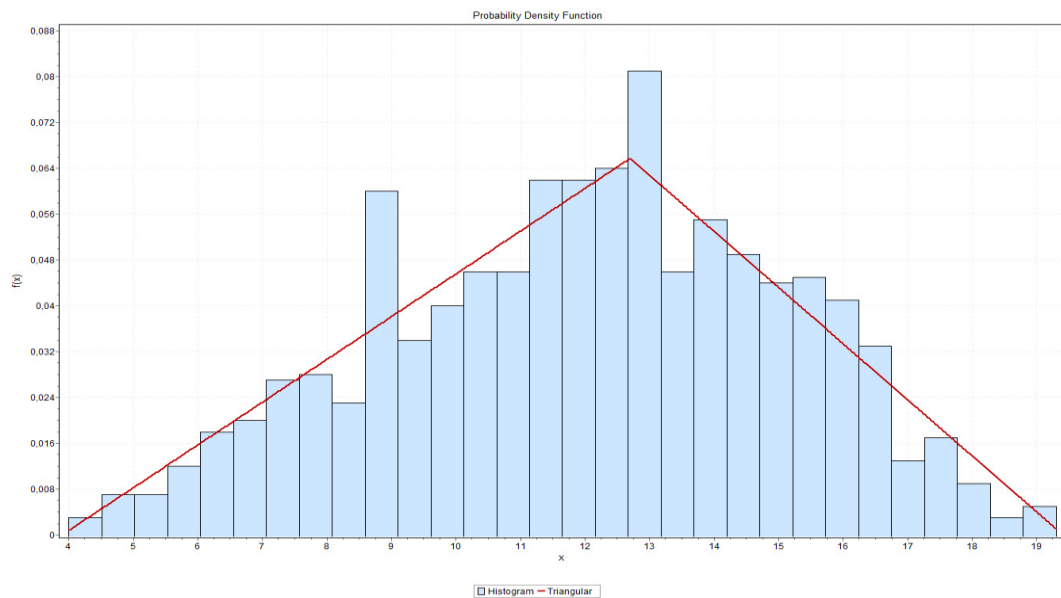


Figure 42: 30-tile histogram of the fitting distribution – Import Segregation

Table 42: Results of Significance Tests to Theoretical Distributions – Delivery Check

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,04012				
P-Value	0,07777				
Rank	5				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	Yes	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	2,4849				
Rank	6				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	22,573				
P-Value	0,00723				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	Yes	Yes

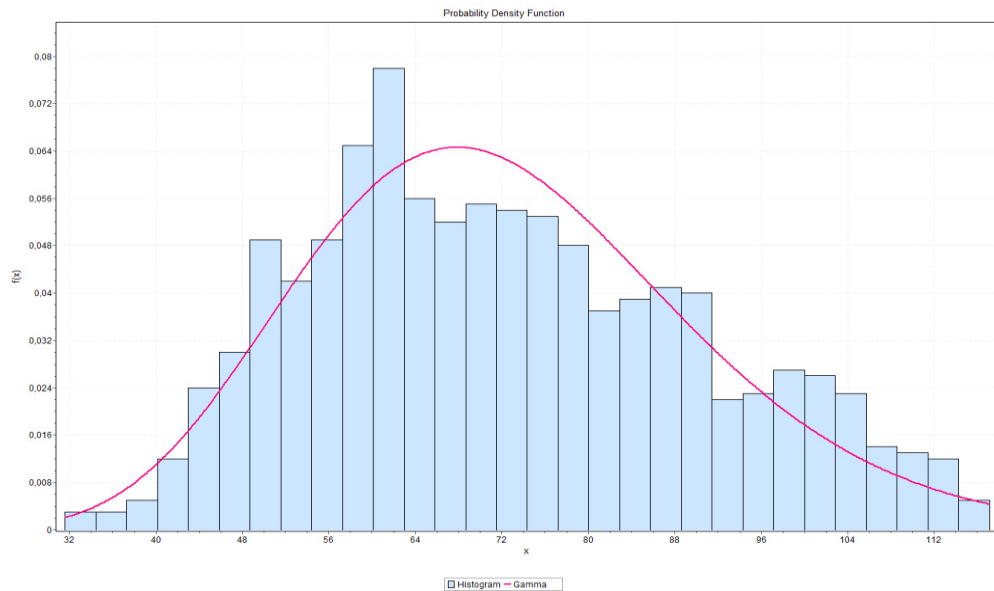


Figure 43: 30-tile histogram of the fitting distribution – Delivery Check

Table 43: Results of Significance Tests to Theoretical Distributions –
Delivery Loading

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,04972				
P-Value	0,01375				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	Yes	Yes	Yes	No
Anderson-Darling					
Sample Size	1000				
Statistic	3,5379				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	Yes	Yes	No
Chi-Squared					
Deg. of freedom	9				
Statistic	30,44				
P-Value	3,6907E-4				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	Yes	Yes

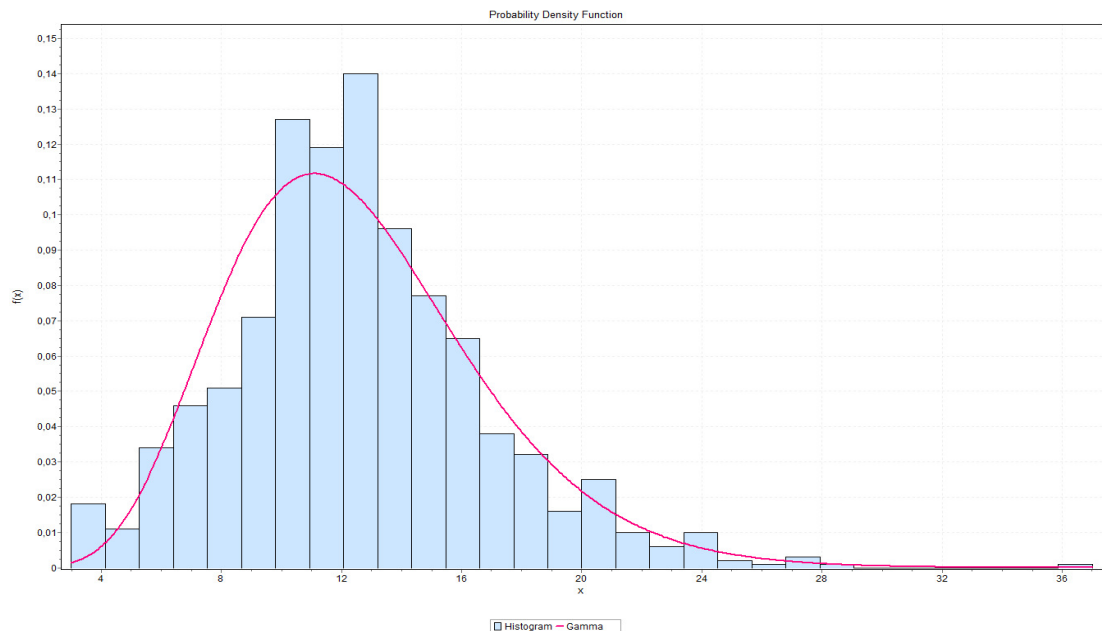


Figure 44: 30-tile histogram of the fitting distribution – Delivery Loading

C. DISTRIBUTION ANALYSIS OF TRANSPORTATION TIMES

Table 44: Results of Significance Tests to Theoretical Distributions –
Transfer to X-ray

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,01987				
P-Value	0,81704				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	0,57974				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	10,402				
P-Value	0,31891				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

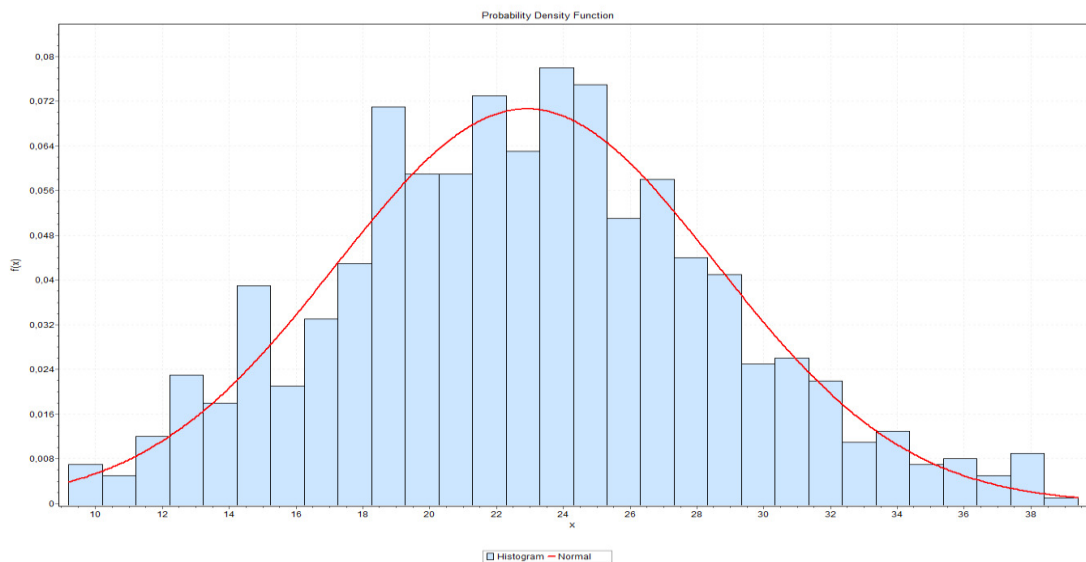


Figure 45: 30-tile histogram of the fitting distribution – Transfer to X-ray

Table 45: Results of Significance Tests to Theoretical Distributions –
Transfer to Workstation

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,02145				
P-Value	0,73865				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	0,48789				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	6,5029				
P-Value	0,68872				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

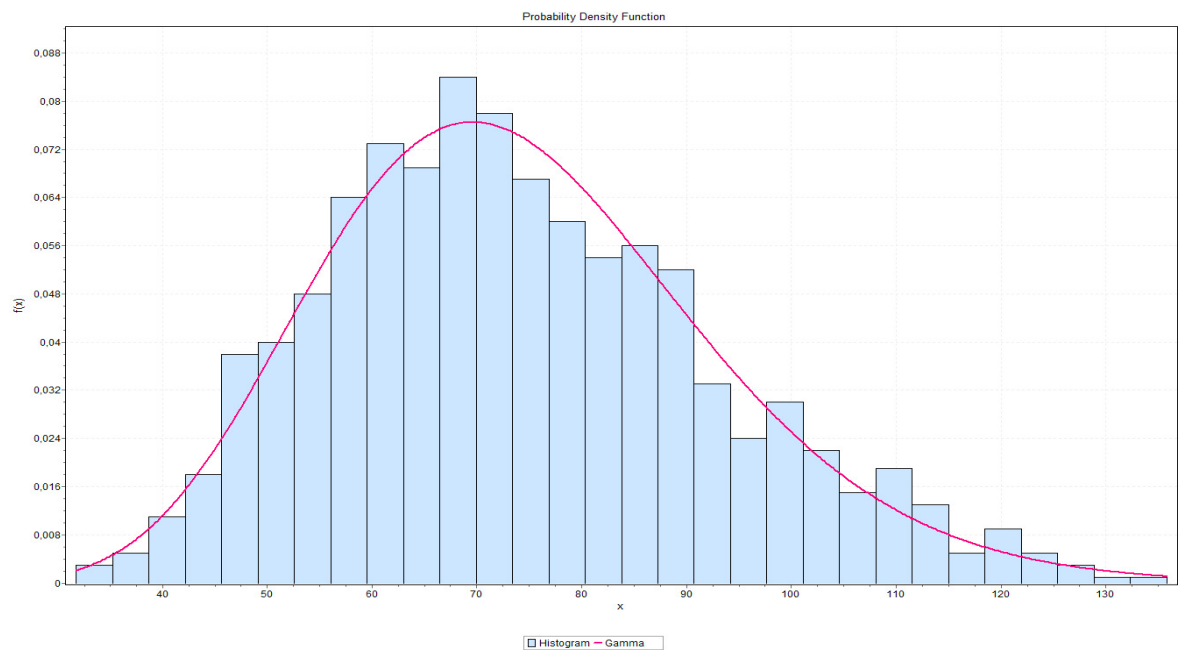


Figure 46: 30-tile histogram of the fitting distribution – Transfer to Workstation

D. DISTRIBUTION ANALYSIS OF DESIRED STORAGE TIMES

Table 46: Results of Significance Tests to Theoretical Distributions – ULD Storage

Gamma [#4]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,02717				
P-Value	0,44361				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	19,654				
Rank	3				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom	9				
Statistic	13,635				
P-Value	0,13592				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	No	No	No	No

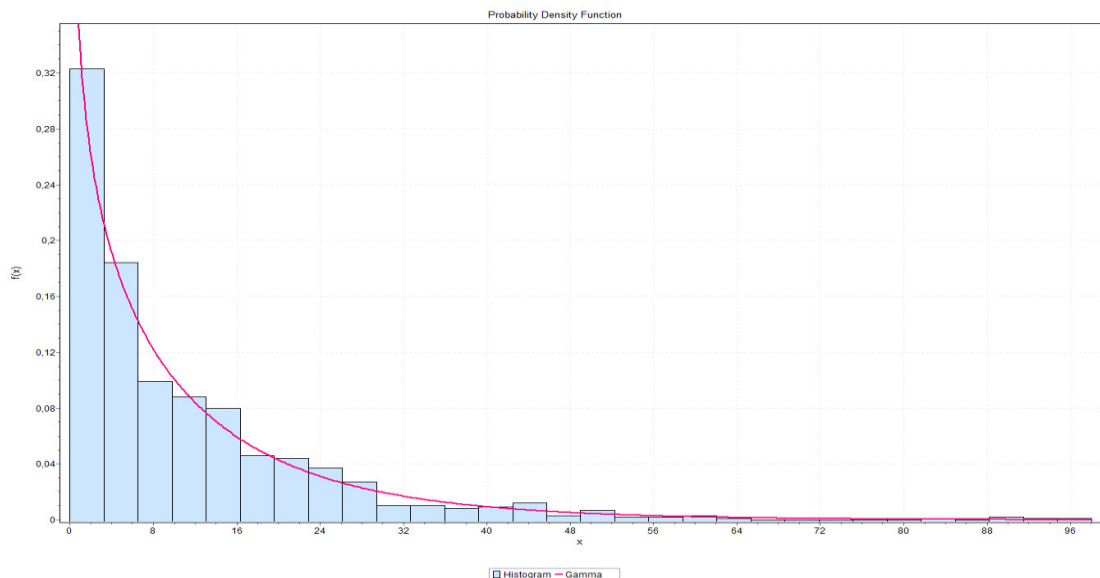


Figure 47: 30-tile histogram of the fitting distribution – ULD Storage

Table 47: Results of Significance Tests to Theoretical Distributions –
Export Loose Storage

Gamma [#6]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,01786				
P-Value	0,9014				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	0,5697				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	3,7784				
P-Value	0,92538				
Rank	1				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	No	No	No	No	No

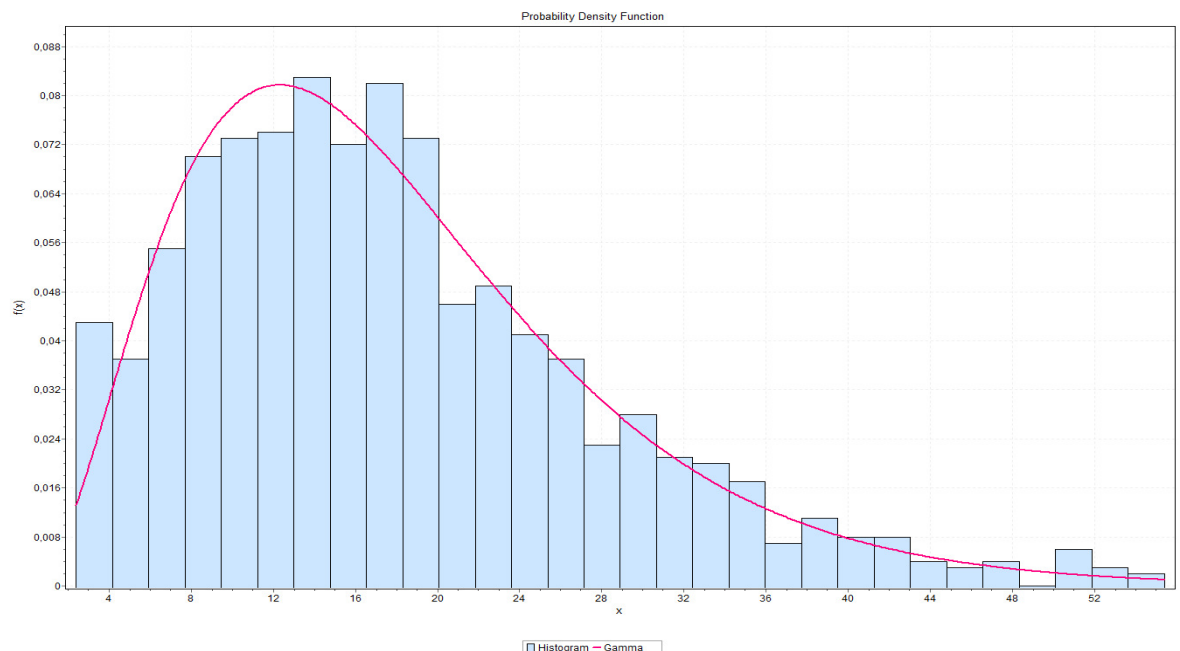


Figure 48: 30-tile histogram of the fitting distribution – Export Loose Storage

Table 48: Results of Significance Tests to Theoretical Distributions –
Import Loose Storage

Normal [#8]					
Kolmogorov-Smirnov					
Sample Size	1000				
Statistic	0,04735				
P-Value	0,02183				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	0,03393	0,03867	0,04294	0,048	0,05151
Reject?	Yes	Yes	Yes	No	No
Anderson-Darling					
Sample Size	1000				
Statistic	2,6374				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	1,3749	1,9286	2,5018	3,2892	3,9074
Reject?	Yes	Yes	Yes	No	No
Chi-Squared					
Deg. of freedom	9				
Statistic	21,484				
P-Value	0,01067				
Rank	2				
α	0,2	0,1	0,05	0,02	0,01
Critical Value	12,242	14,684	16,919	19,679	21,666
Reject?	Yes	Yes	Yes	Yes	No

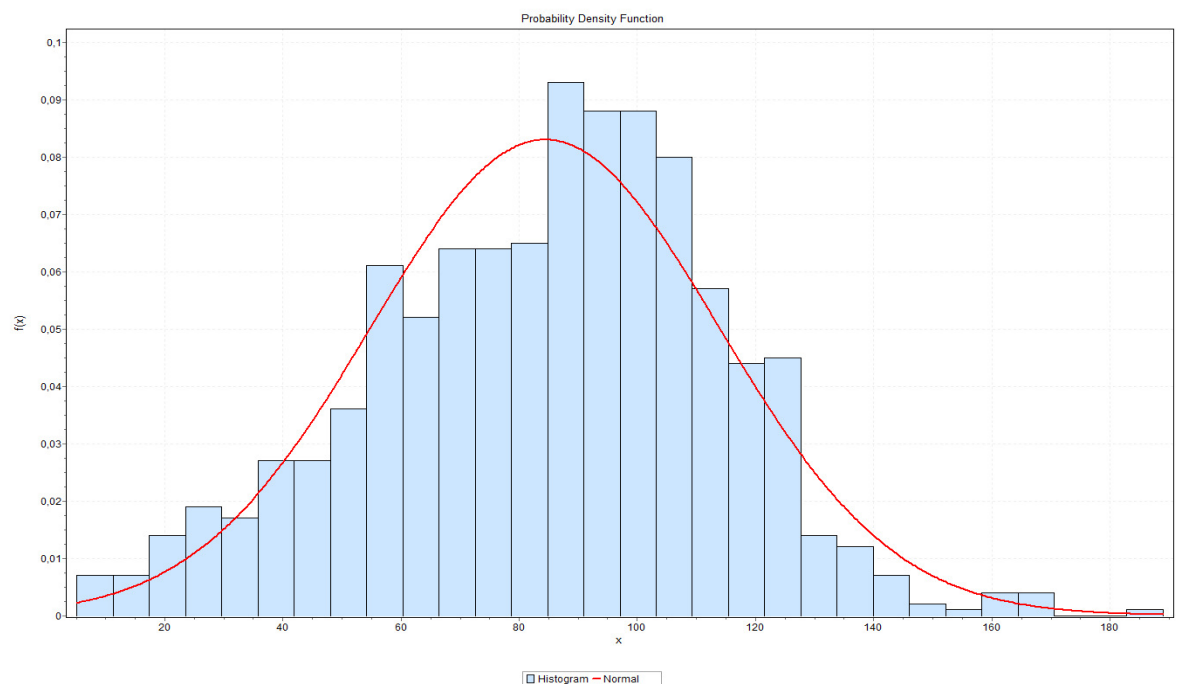


Figure 49: 30-tile histogram of the fitting distribution – Import Loose Storage

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