Simulation and Analysis of Port Bottlenecks: The Case of Male’

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Abstract of a thesis submitted in partial fulfilment of the
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Maldives is an island nation that consists of around 1190 islands located in the Indian Ocean, southwest of Sri Lanka. The country virtually imports everything it consumes. Male' Commercial Harbour handles all international sea cargo for the country. The land area assigned for the port is small; and there are frequent bottlenecks and congestion in the port.

By using computer simulation techniques, this research investigates the situation of Male' Commercial Harbour and identifies logistic bottlenecks that exist at the port. Accordingly, a field research was conducted at Male' Commercial Harbour to collect required data. Both, qualitative and quantitative data were collected using focus group, interviews, on-site observations, and time and motion measures.

The simulation models presented in this thesis were carried out with Arena software (Academic Version of Arena 10.0). The models were used to analyse the vessel turnaround time, berth capacity, yard capacity, container dwell time, queue values, utilisation of ship cranes and other container handling equipment. The results show that berth capacity seems to be the major bottleneck that creates longer queues and ship delays at Male' Commercial Harbour.

Several scenarios were tested to identify the best scenario regarding ship waiting time at berth. Based on the best scenario, a project was proposed focusing on the development of an extended alongside berth at Male' Commercial Harbour. A cost benefit analysis was performed to see whether the project is financially feasible.

Keywords: Simulation, Utilisation, Vessel Turnaround Time, Berth Capacity, Yard Capacity, Bottlenecks.

Dedications

To my lovely, energetic, cheerful, short, and amazingly beautiful wife – Maleeha

To my, handsome, intelligent, and joyful son – Yaish. I hope I leave a legacy of learning that will encourage you to reach your goals in life.

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Glossary

AVG	Automated Guided Vehicles
BC	Berth Capacity
FL	Forklift
FT	Freight Ton
GDP	Gross Domestic Product
ha	Hectare
IMO	International Maritime Organisation
IRR	Internal Rate of Return
m	Metre
MCH	Male’ Commercial Harbour
MNSL	Maldives National Shipping Limited
MPL	Male’ Ports Limited
MRF	Maldivan Rufiyaa
NPV	Net Present Value
NZ	New Zealand
RS	Reach-stacker
RTG	Rubber Tyre Gantry
SC	Ship Crane
TEU	Twenty Foot Equivalent Unit
TR	Trailer
YC	Yard Capacity

CHAPTER 1

Thesis Introduction

1.1 Background

Maldives is a group of islands that consists of 1190 islands, which are scattered over a distance of more than 800km situated in the Indian Ocean. It has a population of about 330,000 people, living in 200 different islands (Maldives Statistical Yearbook, 2007). The Maldives is a tropical country, with very flat topography, having been built on sand dunes. Because of its strategic location it has been a crossroads of world trade and travel for centuries. The economy is based on fishing and tourism. A map of the Maldives is shown in Appendix A

The Maldives economy is expanding rapidly, driven primarily by the booming tourism industry, which makes up over 30% of GDP (Maldives Statistical Yearbook, 2007). The lack of any real domestic production and exports consisting only of fish products result in the fact that the Maldives must import nearly everything for its growing population and its tourists consumption. With the number of international tourists travelling to the Maldives growing an average of 8.4% per year between 2000 and 2007 (Statistical Yearbook, 2007), cargo traffic supporting tourist consumption has and will continue to grow.

Male’ Commercial Harbour (MCH) handles all the international sea cargo for the country except petroleum products, which are unloaded at an offshore island for reasons of safety and storage. Regular cargo services are provided to and from Europe, the Middle East, Africa, and much of Asia and the Far East. Exports are minimal so outbound international traffic via Male’ consists mostly of empty containers. The performance of MCH is particularly important because, at present, it is the sole maritime gateway to the country. Therefore, any physical capacity constraints of the port, whether internal or external, affect the country’s economic development and trade.

MCH can also significantly influence the supply chain performance and the logistics distribution of the country. Ports play an important role in the management and co-ordination of materials and information flows (Bassan, 2007). The port performance also immensely influences the lead time and the stock level of importers/distributors (Carbone & De Martino, 2003). Currently, Maldivian importers typically hold stocks for one to three months to minimise the occurrence of shortage due to problems with suppliers, port clearances, and delays in shipping. Current cycle time from order to final sale is 2-5 months ("Statistics: Lily Shipping, Male'," 2009). This longer cycle time is partly due to inefficiency of the port performance.

The important role MCH plays for the development of the country and especially the performance of the supply chains as a whole motivated me to do this research. The study attempts to examine the main constraints or bottlenecks that exist at MCH that affects the logistics performance.

1.2 Objectives of this Research

Determination of the optimum capacity of container terminals has been a major issue since the introduction of containers in the 1960s (King, 1997). The advancement of globalisation and increasing container transportation has created many problems for ports leading to higher requirements on port terminals (Blumel, 1997). Many container terminals are reaching their capacity limits, leading to traffic and port congestion (Vacca, Bierlaire, & Salani, 2007). The consequences associated with port congestion have effects on a number of agents related to container terminals.

Capacity expansion is one way of handling congestion and bottleneck problems that limit port terminal performance (Legato & Mazza, 2001). Capacity can be increased either by physical expansion or improved utilisation of the available resources (Legato & Mazza, 2001). However, in reality most of the seaports are unable to expand their terminal areas as they wish because of limited space; and often do not have enough funds to build new infrastructures.

Maldives is among the least developed countries and has fewer economic resources compared to most other countries. Land area is one of the scarcest resources. The need for area on the island (the capital) where the port is located is obvious to any visitor. The area of the island is approximately 2km² only, and it is home to more than 85,000 inhabitants. The land area assigned for the national sea port is small; and there are frequent bottlenecks and congestion in the port. The situation is negatively affecting important stakeholders as follows:

- Shipping Companies – vessel delays, extra costs, and missed feeders
- Port Terminals – extra manpower, yard congestion, and re-handling

- Trucking Companies – waiting time and loss of business
- Importers – longer lead times

The main objective of this research is to analyse the current situation of MCH and identify logistic bottlenecks that exist within the port terminal that hinder the supply chain performances of the country. Accordingly, more specific objectives of this research include:

1. To show the current status of containerisation at Male’ Port and to investigate the potential container flow pattern for the next ten years
2. To assist in better understanding of the complete container terminal operation
3. To analyse berth capacity of the port terminal
4. To analyse the yard capacity of the port terminal
5. To analyse ship working rate of the port terminal
6. To analyse dwell time of containers in the port terminal
7. To analyse the utilisation of port terminal equipment
8. To analyse and propose measures that can be taken at MCH to maximise the capacity
9. To provide a cost benefit analysis for implementation of the proposed measures

1.3 Contributions of this Research

This research will make a number of contributions to the field. Up to now, only a few studies on *‘integrated optimization’* for container terminal problems exist (Vacca et al., 2007). Although, literature concerning container terminal problems are rich, only a few studies have concentrated on complete terminals; most studies concentrate on separated decision problems, for example berth allocation, stowage planning, and vehicle dispatching (Vacca et al., 2007). This research concentrates on the complete terminal. Therefore, it is hoped that this study will, in a small way, contribute to the limited literature of complete terminal problems.

The development of MCH simulation model contributes to the area of container terminal modelling. The MCH model can be modified, depending on the level of details needed; and can be applied to most port terminals. Therefore, the methodologies used for the development of MCH model will provide a platform for stakeholders and future researchers.

Port constraints and capacity maximisation have been two major issues for MCH for many years. This research is one of the first to shed light into this subject. The findings of this research will be valuable for Maldives Port Limited, local importers, transport providers, shippers, and concerned government authorities.

1.4 Organisation of the Thesis

This thesis is divided into seven chapters presenting the main segments of this type of empirical research. First, the current chapter introduces the topic and outlines in very broad terms the objectives and contributions of the research. The second chapter proceeds to discuss the relevant theoretical literature published in the field. It does so by first introducing the concept of ‘ports’ and providing information on their developments and technological changes that took place worldwide over the years. The chapter then describes the different management approaches accompanied by different port terminals; and outlines port terminal handling equipment. Next, it reviews the common decision problems that arise in container terminals. Finally, different techniques used to analyse these problems are explained.

Chapter three furthers the literature review by providing some background information on Maldives Port Management System. In particular, it provides information on port administration structure of the country; and presents details on Maldives Port Limited (MPL) and its organisation management, MCH and handling equipment, cargo working hours, and port shutdowns. The chapter also outline and illustrates the existing shipping lines and other auxiliary services.

Chapter four delineates the major demand drivers of import cargo and seeks to forecast cargo traffic for the next ten years based on population growth and economic growth indicators.

Chapter five introduces the conceptual and empirical research models and provides a brief description of each model. The second part of the chapter explains the research design and data collection procedures of the study.

Chapter six deals with the development of the simulation model for the study. It outlines the structure of the model, the terminal logic flow, and describes input parameters used for the model. This chapter also outlines the resource simulation model and resource operational cycle model which are used to control resource operational cycles. It also addresses the validation issues of the model, as well as running setup[1].

Finally, chapter seven reports on the results in detail, and it also discuss the theoretical and managerial implications. This research concludes with a discussion of the research limitations and the implications for future research agendas.

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[1] ‘Run Setup’ is a tool where things like run length and number of replication are set in Arena. The run setup also controls number of other aspects about the run(s) such as the start date and time, Warm-up Period, time units, and terminating conditions.

CHAPTER 2

Port Terminal Operations: A Review of the Literature

2.1 Introduction

This chapter reviews the relevant literature and provides some background information on the development of marine container terminals and their operations. It aims to address topics closely related to this research and provides overview information of world trends towards container developments, technological changes, terminal operations, logistics processes, and types of resources used in container terminals. It also describes an overview of decision problems at terminals; ways in which these problems are being dealt with including computer simulation, and presents methods used in simulation modelling of container terminals.

2.2 Defining ‘Port’

A ‘port’ can be defined as a *“gateway through which goods and passengers are transferred between ships and shore”* (Wang, Cullinane, & Song, 2005, p. 14). Ports have been natural sites for transhipment in order to transfer goods from one mode of transport to another (King, 1997). They have historically provided the link between maritime and inland transport, the interface between the sea and rivers, and roads and railways (Dowd & Leschine, 1990). At present, ports play an important role in the management and co-ordination of materials and information flows, as transport is an integral part of the entire supply chain (Carbone & De Martino, 2003).

2.3 Port Terminal Development and Technological Change

Port industry is constantly evolving over time (Ircha, 2001). The evolution of the global ports sector is normally divided into three stages (Hayuth & Hilling, 1992). The first generation port constituted merely the cargo interface between land and sea transport. The second generation of ports emerged between the 1960s and the 1980s and involved their development into transport, industrial and commercial service centres. The third generation in port development emerged in the 1980s, principally due to a worldwide trend towards containerisation and greater intermodal transport, combined with growing requirements of international trade (Hayuth & Hilling, 1992).

2.3.1 Changes in Shipping

Fast-growing international seaborne trade in the 1950s and 1960s imposed demands which the shipping industry could not meet with existing technology (King, 1997). Previously, shipping was inadequate, in terms of capacity and efficiency, for transporting the growing volume of cargo across borders (Blumel, 1997). Increased demand in shipping with the existing labour intensive, low productivity cargo handling methods, resulted inevitably in longer delays, growing port congestion and rising costs (Hayuth & Hilling, 1992). Ports became the bottlenecks in the trading system and pressure for change mounted (King, 1997).

The shipping industry started changing ship design and building methods to accommodate the increase in demand, with larger dimensions for ocean carriers especially in bulk trades, with a range of new technologies for handling cargo between ship and shore (Cullinane & Song, 2007). Even though the ship designs have changed over the years, little had been done to improve cargo handling (Cullinane & Song, 2007). As shipping lines are the most important clients of a port, the revolutionary changes in shipping forced ports in recent years to change physical design, operations, organisations, and external relations (Cullinane & Song, 2007; Hayuth & Hilling, 1992).

2.3.2 Containers and Ports

The growing use of internationally standardised containers provided the basis for dramatic changes in ports (Blumel, 1997). Perhaps more than any other technological change the container has imposed itself on the internal geography of ports and on the inter-relationship between ports (Peters, 2001). In the early days small numbers of containers could be carried by conventional vessels and handled by high capacity shore cranes or ships' gear (Dekker & Verhaeghe, 2008). As the number of containers increased, specialised ships with gear were used and ports provided gantry cranes for container handling (Dekker & Verhaeghe, 2008). Simultaneously, traditional sheds were replaced by open storage space (Solomenikov, 2006). Various types of straddle carriers replaced the small forklift truck as the backbone of shore operations (Solomenikov, 2006).

2.3.3 Logistics and Supply Chain Approach towards Port Management

After two decades of massive technological change, port managements might have hoped for a period of stability to absorb the changes and gain some revenue from their investments. In the 1980s, and particularly in the later part of the decade, international freight transport embarked on a new cycle of innovations (Ircha, 2001). This new phase of development is characterised by the alteration of the organisational, logistical and regulatory structure of the transport industry (Ircha, 2001; Magableh, 2007). The new trend emphasises the greater integration and coordination of various components of the transport system and supply chain (Copacino, 1997).

Supply Chain Management can be defined as the integration of business processes from end user through original suppliers that provide products, services, and information that add value for customers (Stock & Lambert, 2001). Because of the important role ports are playing as a member of supply chains, they are now considered as part of a cluster of organisations in which different logistics and transport operators are involved in bringing value to the final consumers (O'Leary-Kelly & Flores, 2002; Song & Panayides, 2008). Thus, at present, ports expand themselves as logistics platforms rather than being a mere link between maritime and inland transport (Bichou & Gray, 2004). This requires supply chain members to consider ports as a cluster of organisations in which different logistics and transport operators are involved in bringing value to the final consumers (Bichou & Gray, 2004; Robinson, 2006).The aim is to make the supply chain function so that the right merchandise of the right quality is produced and distributed in the right quantities, to the right locations at the right time in a way that minimises system wide costs yet meet services level requirements (Tiffin & Kissling, 2007). Ports play an important role in fulfilling this aim as most of these merchandise pass through them.

2.4 Ports in the Context of Developed and Developing Countries

Recent literature has emphasised the importance of transport costs and infrastructure in explaining trade, access to markets, and increases in per capita income (UNESCAP, 2002). For most developing countries, transport costs are a greater barrier to world markets than import tariffs (UNCTAD, 2001). Port efficiency is one of the most important determinants of shipping costs (UNCTAD, 2002). Improving port efficiency reduces shipping costs (UNESCAP, 2005). In developing countries most of the port infrastructure is underdeveloped

(World Bank, 2001); and lack of comprehensive planning leads inefficiency in shipping industry (UNESCAP, 2005). Bad ports are equivalent to being 60% farther away from markets for the average country (UNCTAD, 2002). Inefficient ports also increase handling costs, which are one of the components of shipping costs (UNESCAP, 2005). According to World Bank (2001) factors explaining variations in port efficiency in developing countries and developed countries include excessive regulation, the prevalence of organized crime, and the general condition of the country's infrastructure.

2.5 Operation of Container Ports

Container port operations can be considered as one of the most complex tasks in the transport industry (Clark, Dollar, & Micco, 2004; Mennis, Platis, Lagoudis, & Nikitakos, 2008). This complexity arises due to the nature of interactions, both physical and informational, among different agents involved in container import and export (Clark et al., 2004; Mennis et al., 2008). Sanchez et al. (2003) believe that compounded operational interactions which take place among different service processes at port terminals also make container port operations one of the most difficult in the transport industry.

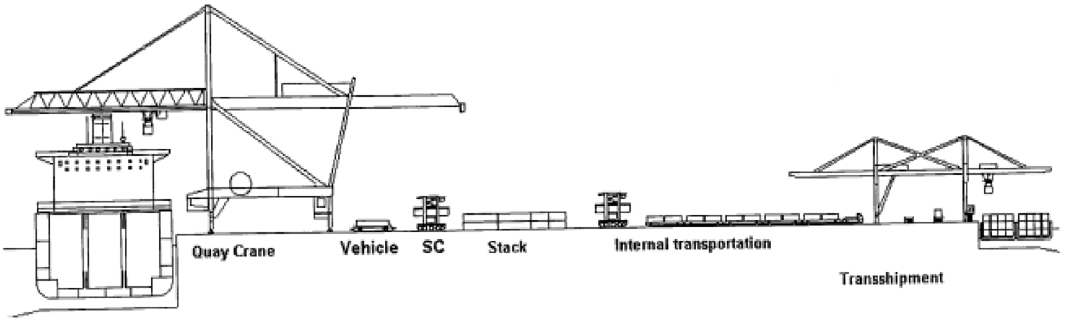
According to Vacca, Bierlaire, & Salani (2007) container port operations can be generally divided into two main operations; (1) quay transfer operations along the berth, (2) storage system in container yards. Quay transfer operation along berth primarily defines the efficiency of a port, and is important to its competitive position (J. Liu, Wan, & Wang, 2005; Ng, 2005). The quayside consists of berths for ships and quay cranes for moving containers (Imai, Chen, Nishimura, & Papadimitriou, 2007). The storage system in container yards act as a buffer between sea and inland transportation or transhipment – storage area for loading, unloading, and transhipping of containers (L. H. Lee, Chew, Tan, & Han, 2006).

Storage is normally inevitable as the sizes of ships are often thousands of times the size of land vehicle that carry cargo to and from the port (Moglia & Sanguineri, 2003). Most containers in the terminal have different properties and destinations, and are carried by different vessels (Junior, Beresford, & Pettit, 2003). The container yard is normally separated into different blocks, and each of these blocks is served by yard crane(s) (Yun & Choi, 1999).

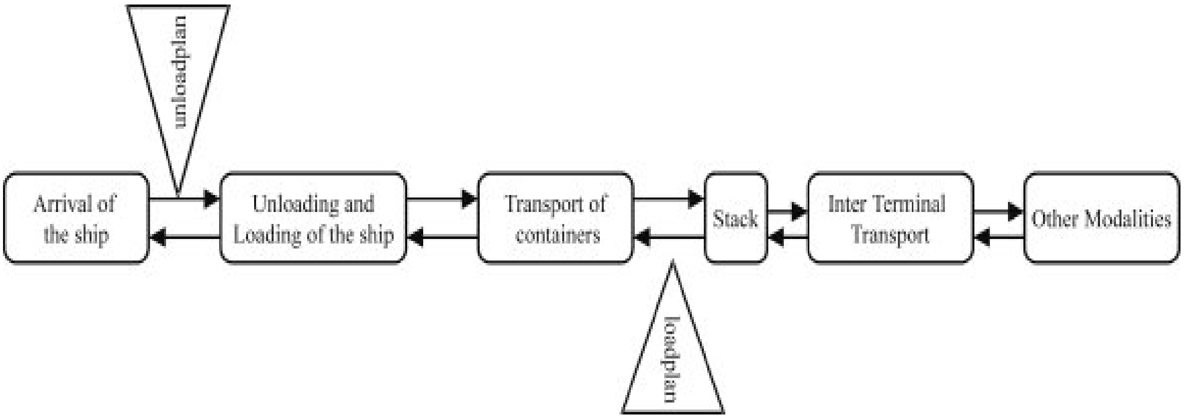
According to Vecca et al. (2007) the efficiency of a container yard utilisation depends on the operation of equipment used in the yard. The equipment determines the height level for stacking containers (Vacca et al., 2007). To achieve land utilisation and increase storage capacity, almost all container yards around the world stack their containers in tiers (Vacca et al., 2007). In concentrated terminals, containers are stacked 6-7 level high with a gap of 40cm between rows, whereas in general terminals stacks are limited to 3 – 4 level high with a gap of 150cm between rows (Vacca et al., 2007). The operations and management strategies in the container yard ultimately influence the operational efficiency and operating cost of terminal operation as a whole (L. H. Lee et al., 2006).

Figure 2.1 shows the operation process of container terminals and Figure 2.2 shows the associate transport flow.

Figure 2.1: Operation Process of Container Terminal

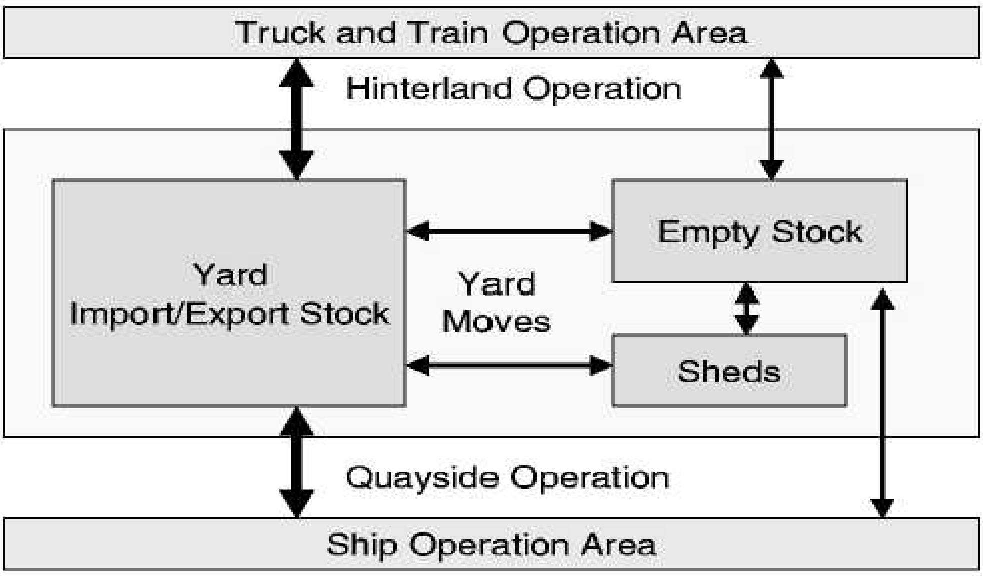


Source: (Vis & De Koster , 2003)



Source: (Vis, 2009)

Figure 2.2: Operation Area of Container Terminal and Flow of Transport



Source: Solomenikov (2006)

2.6 Terminal Handling Equipment

2.6.1 Quay Crane

Every terminal has one or more quay cranes, also referred to as gantry cranes (Solomenikov, 2006) . They are located on the shoreline of the port terminals and carry containers along arms which slide back and forth as they work a vessel. Quay cranes can winch up about 40 to 100 tons and load/unload 25 to 50 containers per hour (Huynh & Walton, 2005). The modern quay cranes can lift two containers at a time and could reach 22 rows of containers across a ship (Huynh & Walton, 2005); which is equal to about an outreach of 60 meters or more. Figure 2.3 shows a picture of a quay crane reaching out to unload goods from a waiting ship in the Port of Tacoma.

Figure 2.3: Quay Crane at the Port of Tacoma, USA

Source: (ScienceDaily, 2007)

2.6.2 Yard Crane

Yard cranes are used in container storage yards to load or unload containers onto or from prime movers such as trailers. There are three types of yard cranes: Rail Mounted Gantry Cranes (RMG), Rubber Tired Gantry Cranes (RTG), and Overhead Bridge Cranes (OBC) (Solomenikov, 2006). RTG (see Figure 2.4) is the most common type of yard crane used in chassis storage (Huynh & Walton, 2005). Straddle carriers are also used in storage yards (see Figure 2.5). They are more flexible and mobile than yard cranes, but require more land (Solomenikov, 2006). A straddle carrier can stack at most 1 container wide and 2 containers high whereas a yard crane can stack up to 7 containers wide and 5 containers high (Huynh & Walton, 2005).

Figure 2.4: Yard Crane at Male' Port, Maldives

Photo: Author, 2009

Figure 2.5: Straddle Carrier at Amsterdam Container Terminals, the Netherlands

Source: (Vis, 2009)

2.6.3 Other Equipment

Several other equipment are used for the transportation of containers at manned terminals. The most important equipment highlighted in the literature are forklifts, and trailers/trucks (Huynh & Walton, 2005; Lam, Englert, Tan, Park, & Foss, 2008; Solomenikov, 2006). Figure 2.6, Figure 2.7 and Figure 2.8 show a reach-stacker, forklift-truck, and a terminal trailer/truck respectively.

Figure 2.6: Reach-stacker at Male' Port, Maldives

Photo: (Author, 2009)

Figure 2.7: Forklift at Male' Port, Maldives

Photo: (Author, 2009)

Figure 2.8: A Yard Truck/Trailer at Male' Port, Maldives

Photo: (Author, 2009)

2.7 Containers

Containers are large boxes used to transport goods from one destination to another (Huynh & Walton, 2005). They are designed to facilitate the movement of goods without intermediate reloading. Goods in containers require less packaging, are less likely to be damaged, and result in higher productivity compared with conventional bulk (Huynh & Walton, 2005). Containers are fitted with devices permitting their ready handling by terminal equipment and the transportation system (Lam et al., 2008). The dimensions of containers are standardised by International Standards Organisation (ISO) (Huynh & Walton, 2005). The ISO recommended lengths are 10, 20, 30, 40 foot, but most containers are 20 and 40 foot ("Containers and services," 2009). Figure 2.9 shows pictures of 40-foot (on the left) and 20-foot (on the right) containers.

Figure 2.9: 40-Foot and 20-Foot Containers

Source: (Huynh & Walton, 2005)

2.8 Common Decision Problems

2.8.1 Berth Allocation Problem

The Berth Allocation Problem can be identified as a problem of allocating ships to berths or to quays (Jean-François Cordeau, Laporte, Legato, & Moccia, 2005). In the berth allocation problem the aim is to plan and assign ships to berthing area along a quay in order to achieve the maximum utilisation possible (Jean-François Cordeau et al., 2005). The objective is to minimise the total service time for all ships which is defined as the time elapsed between the arrival in the harbour and completion of handling (Jean-François Cordeau et al., 2005). There are many constraints and issues when allocating ships to berth. The constraints and issues includes the length of ship, depth of berth, time frame, priorities assigned to the ship, and shippers favourite berthing areas (Jean-François Cordeau et al., 2005; Imai, Nishimura, Hattori, & Papadimitriou, 2007; Yusin Lee & Chen, 2009; Legato & Mazza, 2001; Vacca et al., 2007).

The berth allocation problem can be modelled either as a discrete or a continuous event (Jean-François Cordeau et al., 2005). Jean-François Cordeau et al., (2005) considered two versions of berth allocation problem in their studies: the discrete case and the continuous case. The discrete case worked with a finite set of berthing points and in the continuous case ships berthed anywhere along the quay. Two formulations and a tabu[2] search heuristic are presented and tested on realistic traffic and berth allocation data obtained from the port of Gioia Tauro, Italy. Imai, Nis himura, Sun, & Papadimitriou (2005) presented a continuous model of the berth allocation problem to minimise the total service time of ships. The authors presented a

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[2] Tabu search is a metaheuristic algorithm that is used for solving combinatorial optimisation problems.

heuristic algorithm which solves the problem in two stages, by improving the solution for the discrete case.

Yusin Lee & Chen (2009) present an optimisation based approach for the berth scheduling problem. The main purpose of the study was to determine the berthing time and space for incoming ships. The neighbourhood-search based heuristic treats the quay as a continuous space. In addition to the basic physical requirements, the model they presented takes several factors important in practice into consideration, including the first-in-first-out (FIFO) rule, clearance distance between ships, and the possibility of ship shifting.

Imai, Chen et al., (2007) address the berth allocation problem at a multi-user container terminal with indented berths for fast handling of small containerships. The problem is formulated as an integer linear problem and the formulation is then extended to model the berth allocation problem at a terminal with indented berths, where both mega-containerships and feeder ships are to be served for higher berth productivity. The berth allocation problem at the indented berths is solved by genetic algorithms. The solutions are evaluated by comparing the indented terminal with a conventional terminal of the same size.

Legato & Mazza (2001) propose a queuing network model of the logistics activities related to the arrival, berthing and departure process of vessels at container terminals. Wang and Lim (2007) propose a stochastic beam search scheme for the berth allocation problem. The implemented algorithm is tested on real-life data from the Singapore Port Terminal.

2.8.2 Quay Crane Scheduling Problem

The Quay Crane Scheduling Problem refers to the allocation of a fixed number of quay cranes to a ship or to a task and it also refers to the scheduling of loading and unloading container moves (Vacca et al., 2007). The quay crane scheduling problem aims at finding a schedule for the quay cranes with respect to a given objective function (Bierwirth & Meisel, 2009). This helps in assigning a particular quay crane and a starting time to every intended loading and unloading operation. Most often, the purpose is to minimise the vessel service time (J. Liu et al., 2005).

Ng, (2005) examines the problem of scheduling multiple yard cranes to perform a given set of jobs with different ready time in a yard zone. The research develops a dynamic programming based heuristic to solve the scheduling problem and an algorithm to find lower bounds for benchmarking the schedules found by the heuristic. Computational tests are carried out to evaluate the performance of the heuristic. The results demonstrate that the heuristic can find efficient solutions for the scheduling problem.

Imai, Chen et al., (2007) propose a dynamic programming algorithms and a probabilistic tabu search to solve the quay scheduling problem. The algorithms are tested on the actual situation in the port of Singapore.

Kim & Park, (2004) discuss the problem of scheduling quay cranes using a mixed integer programming model which considers various constraints related to the operation of quay cranes. The study proposes a branch and bound method to obtain the optimal solution of the quay crane scheduling problem and a heuristic search algorithm called greedy randomise adoptive search procedure. Both solutions are tested on generated instances.

2.8.3 Yard Operations Problem

The management of yard operations involves several problems: the decision of container storage location, the planning and sequencing of stacking or un-stacking, and the allocation of yard cranes and other resources in terms of space and in accordance with container size, weight, destination, import/export and so on (C. Chen, Hsu, & Huang, 2007). Yard cranes play one of the most important roles in the yard and perhaps are the most popular handling equipment for loading and unloading containers in yards (Park, Choi, Kwon, Lee, & Lee, 2007). However, such equipment is bulky, and often generates bottlenecks in the container yard because of the slow operation (Ng & Mak, 2005). Therefore, they highlighted the importance of developing a good work schedule for yard cranes to ensure high terminal throughput.

Ng & Mak, (2005) propose a solution to the scheduling of different jobs assigned to a yard crane to perform a given set of loading/unloading jobs with different ready times. The aim is to reduce the sum of job waiting times. The authors propose a branch and bound algorithm to solve the scheduling problem optimally. Efficient and effective algorithms are formulated to find lower and upper bounds. The algorithm is evaluated and tested on generated instances based on real life data collected from Singapore and Hong Kong. The results show that the algorithm works well in finding the optimal sequence for most problems of realistic sizes. Ng (2005) also addresses the same scheduling problem with extra constraints because of the interference among yard cranes.

Kang, Ryu, & Kim, (2006) examine stacking strategies for export containers when weight information is not available. They propose a method based on a simulated annealing search to derive a good stacking strategy for containers with uncertain weight information. The experiments show that the strategies proposed by authors work more effectively in reducing the number of re-handlings than the traditional methods. It also shows that accuracy can be improved by applying machine learning techniques.

L. H. Lee et al., (2006) study a yard storage allocation problem in a transhipment hub with a great number of loading and unloading activities. The purpose is to minimise reshuffling and traffic congestion by efficiently shifting containers between the vessels and the storage area. A mixed integer-programming model is proposed to determine the minimum number of yard cranes deployment. Two heuristics are developed and tested on generated instances. The first is a sequential method while the second is a column generation method.

Y. Lee & Hsu, (2007) present a mathematical model for the container pre-marshalling problem in order to minimise the number of container movements during pre-marshalling. The model formulated is an integer programming model consisting of a multi-commodity flow problem and a set of side constraints. A solution heuristic and a number of possible variations of the model are also discussed and computation results are provided.

Jean-François Cordeau, Gaudioso, Laporte, & Moccia, (2007) presented the service allocation problem, which is a tactical problem arising in yard management of container terminals. The purpose of the study is to minimise container re-handling inside the yard. The study was done on Gioia Tauro port which is located in Italy. The authors formulated a quadratic mathematical model for the problem. Two mixed integer linear programming formulations are presented. The result shows that for small size instances the heuristic always yields optimal solutions.

2.8.4 Transfer Operations

Once containers have arrived to ports, they are transported from the quayside to the yard, from the yard to the gate and vice-versa by internal trucks, straddle carriers, and reach-stackers (Vacca et al., 2007). The objective of optimising transfer operations is usually to minimize the vehicle fleet size (Vacca et al., 2007).

Yun & Choi, (1999) propose a simulation model for container terminal system analysis. The simulation model is developed using an object-oriented approach, and using SIMPLE++, object oriented simulation software. The authors consider a simple container terminal - a reduced system of a real terminal in Pusan, Korea. The authors assume that the container terminal consists of gate, container yard, and berth. The facilities used in the container terminal are transfer cranes, gantry cranes, trailers, and yard tractors.

C.-I. Liu, Jula, Vukadinovic, & Ioannou, (2004) develop a simulation model and this model is used to demonstrate the impact of two commonly used yard layouts on the terminal performance when Automated Guided Vehicles (AGV) are used. A multi attribute decision making method is used to asses the performance of the two terminals and to decide the optimal number of deployed AGVs in each terminal. The simulation results show that high performance can be achieved using AGVs. Lam et al., (2008) developed a simulation model to sequence container deliveries to road trucks from yard stacks. The purpose is to examine the effect of container delivery methods of Los Angles/Long Beach Seaport on the mean truck time, as volume of container increases. They believe that the methodology is applicable to a large number of other container ports as well.

2.9 Trends in the Literature

Analysing the recent literature concerning container terminal operations, the following trends regarding port management problems are identified.

2.9.1 Concentration on a Single Problem

Most of the available literature mainly concentrates in developing sophisticated models for single decision problems at container terminals. These models provide accurate details and information to provide more reliable solutions to specific problems. For example, J. Liu et al., (2005), and Ng, (2005) concentrate on the quay crane scheduling problem. Imai et al., (2005), Imai, Nishimura et al., (2007), and Yusin Lee & Chen, (2009) investigate the berth allocation problem under different scenarios. Finally, Kang et al., (2006), L. H. Lee et al., (2006), Y. Lee & Hsu, (2007), and Ng & Mak, (2005) modelled yard operations.

2.9.2 Combination of Problems and Amalgamation

Here, authors with experience on single decision problems aim to combine the problems and the solution methods into a unique approach. For instance, Imai, Chen et al., (2007) focus on the integration of berth allocation and quay crane scheduling problems. L. Chen, Bostel, Dejax, Cai, & Xi, (2007) and C.-I. Liu et al., (2004) examine the integrated scheduling of handling equipment in a container terminal. Goodchild & Daganzo, (2006) study the impact of double cycling of quay cranes on loading/unloading operations.

2.9.3 Computer Simulation for Complete Terminal

"Computer simulation refers to methods for studying a wide variety of models of real world systems by numerical evaluation using software designed to imitate the system's operations or characteristics, often over time" (Kelton, Sadowski, & Sturrock, 2007, p. 7)

The maritime sector has been a thriving area for simulation, especially for training equipment and ship design support (Kelton et al., 2007). The use of simulation techniques in this area has been justified for many years because of the costs and the complexity of both harbours and vessels (Huynh & Walton, 2005). Steeken, Vob, & Stahlbock, (2004) argue that analytical models, especially queuing models, cannot be used to analyse terminal operations in the estimation of port performance indicators. They believe this because queuing models are valid only if the probability distribution of the arrival time of ships and their service time belong to the Erlang family of distribution functions. Ramani, (1996) also argued that analytical models themselves cannot be used wholly to model terminal operations, but they can be used to model certain aspects of terminal operation.

When simulating, authors consider a container terminal as a system; therefore, instead of concentrating on single terminal problem the entire flow of containers are considered and optimised (Nevins, Macal, Love, & Bargen, 1998).

Hayuth et al., (1994) developed one of the most comprehensive simulation software for analysis of port operations, at that time (Huynh & Walton, 2005). The model dealt with coordination between terminals in more than one part. Nevins et al., (1998) developed another comprehensive port model called PORTSIM. It is a discrete-event, time-stepped simulation that facilitates the analysis of movements of military equipment through worldwide seaports and allows for detailed infrastructure analysis. Merkuryeva, Merkuyev, & Tolujev, (2002) developed a simulation model of the Baltic Container Terminal, within the Riga Commercial

Port. The purpose of the study was to regulate transportation routes within the terminal by segregating different traffic flows, to improve layout utilisation, and to analyse the impact of weather conditions on terminal operations. They used Arena and SLX to build their model. C. Chen et al., (2007) and Legato & Mazza, (2001) developed a simulation model for integration of berth planning at a container terminal. Lam et al., (2008) developed a simulation model on sequencing of container deliveries to road trucks from yard stacks. Kofjac, Kljajic, & Rejec, (2009) proposed a concept of warehouse optimisation using simulation. Yun & Choi, (1999) built a simulation model to see whether the existing terminal in Pusan, Korea is efficient enough to handle a high number of container flows or whether the system is more effective by using transfer cranes and gantry cranes. Their simulation model was not applied to a full size terminal but rather a reduced one.

It is evident from the literature that different authors have used different simulation software and models for their studies. Some authors built their models from scratch using programming languages such as FORTRAN, Pascal, and C/C++ (Huynh & Walton, 2005). Others used simulation languages like SLAM II, GPSS, and SIMAN to build their models (Huynh & Walton, 2005). For this research, simulation software called Arena is used to analyse some of the objectives of the research.

2.10 Simulation with Arena

Arena is a simulation software manufactured by Rockwell Automation about a decade ago. First released in 1993, it was designed to provide a general purpose collection of modelling features for all types of applications. According to (Kelton, Sadowski, & Sturrock, 2007) it is being increasingly applied to transportation systems. Arena can be used to build systems, either continuous or discrete, or both (Kelton et al., 2007). Arena uses the SIMAN processor and simulation language. This software integrates very well with other software such as Microsoft. Researchers interested in learning Arena software may study the textbook written by Kelton et al., (2007).

2.11 Chapter Summary

In summary, a ‘port’ is a gateway through which goods and passengers are transferred between ships and shore. The port industry has been evolving constantly over time. The fast growing international seaborne trade, changing of ship design and building methods, standardisation of containers, regulatory structure of transport industry, integration and coordination of various components of the transport systems have contributed to the development of the port industry over the years.

Container port operations can be considered as one of the most complex tasks in the transport industry. These tasks can be generally divided into quay transfer operations along berth, storage system in container yards, and transfer operation from yard to final destinations. Managing these processes efficiently and effectively reduces the decision problems that arise at port terminals; for example, berth allocation problem, quay crane scheduling problem, yard operations problem, and transfer operations problem. Various methods are used in identifying and analysing these decision problems. Some methods focus on single decision problem while others concentrate on combinations of problems. The most modern methods concentrate on using computer simulations for the complete terminal.

CHAPTER 3

Background Information on Maldives Port Management System

3.1 Introduction

The Maldives consists of numerous far-flung, often sparsely populated, atoll communities. Due to the geographic spread and the physical diversity of economic nodes throughout the Maldives, a fragmented network of maritime landing points has evolved. These range from the international gateway (Male’ Commercial Harbour), to southern and northern regional ports, to facilities built to receive goods and passengers at local islands and resorts. This chapter provides background information on port management systems currently existing in the Maldives.

3.2 Port Administration Structure

There is no clear port administration structure in the Maldives. A variety of public and private parties are engaged in terminal management and operations, namely:

(i) Transport Authority of the Ministry of Housing, Transport and Environment which mainly deals with land and maritime transportation. The Transport Authority functions on the basis of a Presidential Decree broadly describing the tasks of the organization.

(ii) The Ministry of Economic Development, with regard to foreign investments.

(iii) The Ministry of Tourism Arts and Culture, dealing with resort development.

(iv) The Maldives Ports Limited operating and managing the international harbour at Male' which includes the container berth and the adjacent basins which are mainly used by small local vessels. MPL is also responsible for operating and managing the two regional ports - one located in South (Hithadhoo) and other in North (Kulhudhuffushi) of the Republic.

(v) The Public Works Services Division, a semi-independent part of the Ministry of Housing, Transport and Environment, operating and managing the local ports at Male', which are mainly used for distribution of break-bulk cargo to other islands. This department is financially independent, covers its own costs and expenses from harbour dues and other related income.

(vi) The Ministry of Home Affairs, in charge of the harbours and landing places on smaller islands.

(vii) A number of private terminal operators which provide generally proprietary port services for port industries, for example Thilafushi port.

3.3 Maldives Ports Limited

Maldives Ports Limited was established in September 1986 under a Presidential Decree, to manage and operate all ports within the country ("Welcome to Maldives Ports Limited," 2009). For privatisation purposes, the organisation was changed from Maldives Ports Authority to Maldives Port Limited in 2008. Currently, it is 100% owned by the government of the Maldives and functions under the Ministry of Housing, Transport and Environment ("Welcome to Maldives Ports Limited," 2009). MPL is administered and managed by a board whose members are appointed by the President of the Maldives ("Welcome to Maldives Ports Limited," 2009). The managing director appointed by the board is in charge of managing the operations of the port ("Welcome to Maldives Ports Limited," 2009).

3.3.1 Management Organisation of Maldives Port Limited

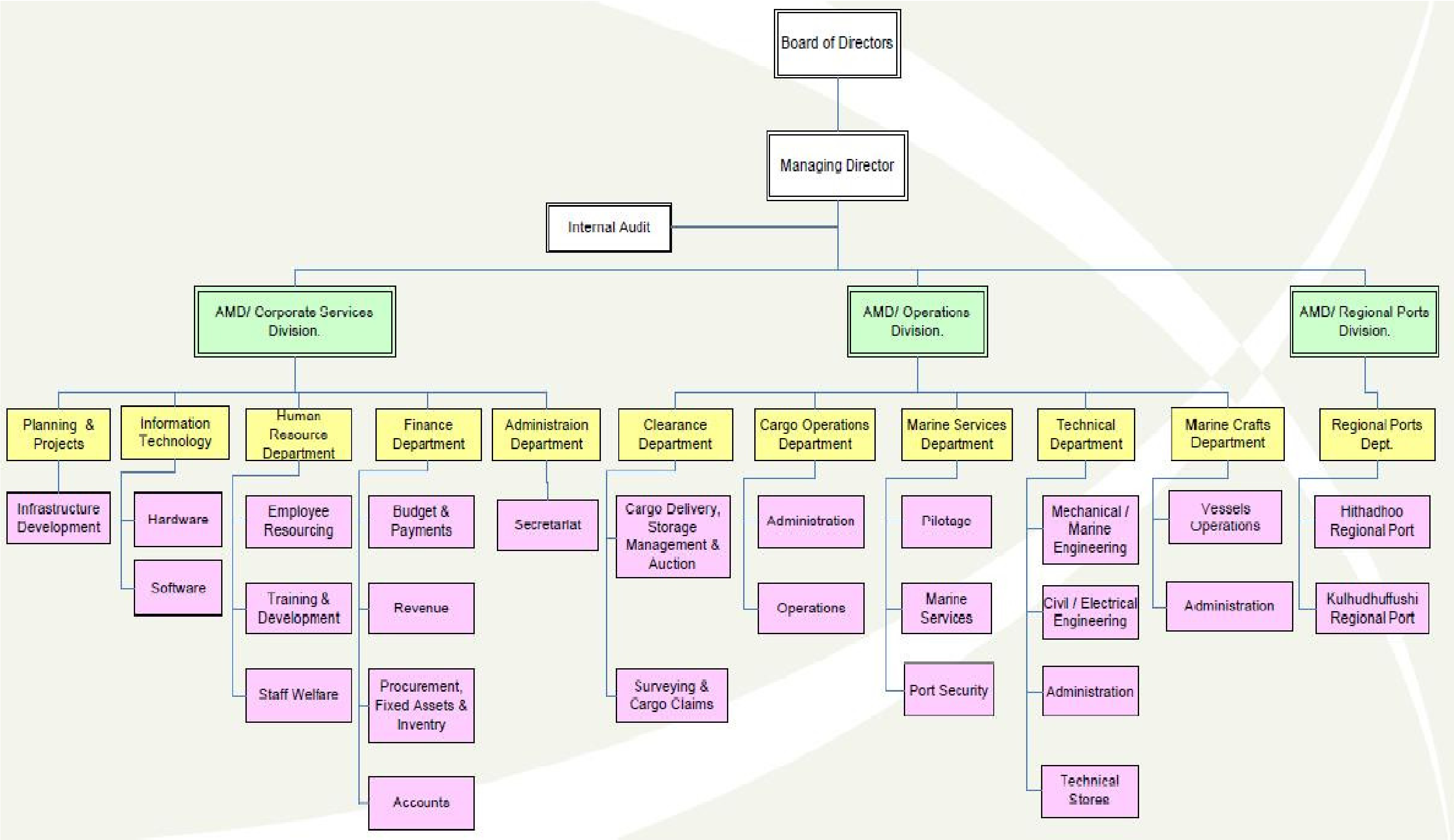
MPL has 150 officers and 450 workers for the direct operation. Detailed numbers of employee for each department are shown in Table 3.1. Figure 3.1 show the organisation chart of MPL.

Table 3.1: Management and Operational Staff of MPL

Operational Department	**Maldivian**	**Expatriate**	**Total**
Cargo Operation	199	90	289
Clearance	45	2	47
Marine Services	58	0	58
Marine Crafts	46	8	54
Engineering Department			
Technical	62	4	66
Other Department			
Administration	17	2	19
Finance	28	4	32
Human Resources	16	12	28
Others	14	2	16

Source: ("Maldives Ports Limited," 2009)

Figure 3.1: Organisation Chart of Maldives Port Limited



Source: ("Organisation chart," 2009)

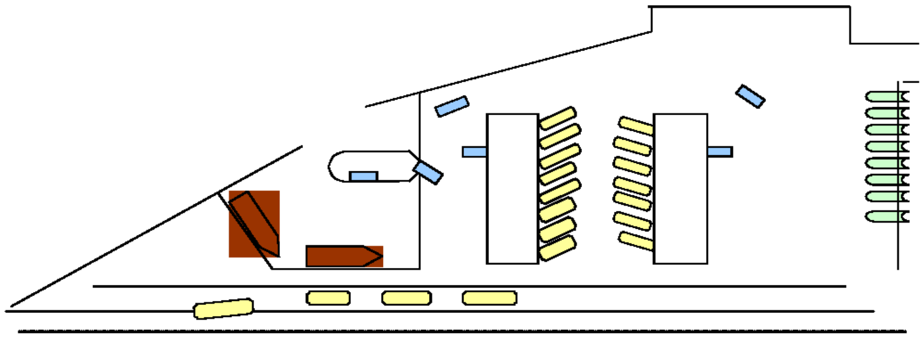
3.3.2 Male' Commercial Harbour

Male' Commercial Harbour, also commonly referred as Male' Port is managed and operated by MPL. It consists of a main berth 101 m in length with an alongside depth of 9.5 m. This is backed up by an area of approximately 1.6 ha used for the storage of containers and break-bulk cargo. The latter are stored in a transit shed having an area of approximately 3500 m². On the eastern side of the storage area is a 100-meter quay facing the Eastern Lighter Basin. This is used for loading empty containers to be transferred to the off-dock storage area in Hulhumale' as well as for loaded containers to be transhipped directly to the resorts or the bonded storage area at the International Airport. At the western edge of the terminal is a 140 m quay with alongside depth of approximately 3.5 m. This is used by traditional boats unloading break-bulk cargo, primarily foodstuffs, from Tuticorin and other Indian ports. It is also used by smaller vessels for unloading various break-bulk cargo. On the other side of the West Lighter Basin from this quay is a quay for mooring the tugboats and barges and an open area for storing empty 40-foot containers and construction material ("Maldives Ports Limited," 2009). The harbour basins on either side of the port are protected by breakwater walls built on reef edge. Figure 3.2 and Figure 3.3 show a picture and layout of MCH respectively.

Figure 3.2: Male' Commercial Harbour

Source: (Google earth, 2009)

Figure 3.3: Layout of Male' Commercial Harbour



3.3.3 Characteristics of Male' Commercial Harbour

3.3.3.1 Employing Expatriate Workers

MCH is run by a labour force of about 180 persons comprising a considerable number of imported unskilled labour. After their arrival, MPL trains these workers and once they are trained and experienced they are able to leave and obtain better paid jobs elsewhere. Consequently, MPL is left with costs of frequent damage to equipment and cargo by inexperienced labourers. Furthermore, MPL is burdened with the cost of providing training to workers without being able to harvest long term benefits from those trained workers (personal conversation with Assistant Managing Director of MPL, 2009).

3.3.3.2 Willing to Accept Only 20 Foot Containers

Male' Commercial Port is willing to accept only 20 foot containers or less. The decision is made by MPL due to lack of capacity of unloading equipment and additional shipping requirements. However, with the rapidly increasing containerisation and repeated requests from stakeholders MPL is now accepting some 40 foot containers (personal conversation with Assistant Managing Director of MPL, 2009).

3.3.3.3 No Container Leaves from the Port to the City

It is another characteristic that the containers are not expected to leave the port. They are stripped in the port and unstuffed cargo is loaded on small trucks immediately and taken to the first point of destination, which is most often a trader's storage in town.

3.3.4 Container Handling Equipment

3.3.4.1 Harbour Crane

MCH has one large mobile crane having 150 ton capacity which is used to load/unload containers from Lighters and well as break-bulk cargo from smaller vessels.

3.3.4.2 Rubber Tyred Gantry Crane

MCH has one RTG having the capacity for seven rows, one over four containers stacking. Currently the RTG is used to stack 40 foot laden containers only.

3.3.4.3 Other Handling Equipment

- 01 Terminal Trailer (used to transport 40 foot containers)
- 01 Terminal Trailer (used to transport 20 foot containers)
- 03 Reach-stackers
- 2 Forklifts

A list of cargo handling equipment are shown in Appendix B

3.3.5 Cargo Working Hours

Cargo working hours of MCH is as follows:

- Saturday to Thursday - 07:30 hrs to 24:00 hrs by two shifts
- Friday - 14:30 hrs to 22:30 hrs by one shift

Net working time is 100 hours per week or on average 14.3 hours per day.

3.3.6 Port Holidays

Port holidays are as follows.

1) 1st Day of Ramazaan (Islamic Calendar)
2) Fithr Eid Day (Islamic Calendar)
3) Hajj Day (Islamic Calendar)
4) Al’Haa Eid Day (Islamic Calendar)

5) 1st Day of Muharram (Islamic Calendar)
6) 26th July, Independence Day
7) 12 Rabee-ul Awwal - Prophet Muhammad's Birthday (Islamic Calendar)
8) 11th November, Republic Day
9) 1st Day of Rabee-ul Awwal (Islamic Calendar)

3.3.7 Port Shutdowns

The days of port shutdown at MCH due to waves, strong wind, or other unfavourable weather conditions are very rare according to the port management. However, barge operations (lighterage) are affected by the weather condition. Such shutdown is estimated as less than 10 days per year (Personal conversation with Assistant Managing Director of MPL, 2009).

3.4 Customs Services

The smooth flow of imports through the major gateways to the consignees requires coordination between customs and other agencies involved in regulation of trade (Song & Panayides, 2008). A similar requirement applies to exports but the controls are usually less stringent and, in the case of Maldives, there are few exports.

At present, customs procedures do not appear to be an impediment to efficient trade logistics. The Customs Department has made substantial efforts in implementing the reforms identified in the Revised Kyoto Conventions ("Maldives Customs Service," 2009). Customs operational data are classified on the Harmonized Commodity Description and Coding System and processed through ASYCUDA++ ("Maldives Customs Service," 2009). As part of implementation of ASYCUDA, it has introduced a single administrative document consistent with the UN key layout ("Maldives Customs Service," 2009). It allows for direct trader input of customs declarations either through Customs operated centres or over the Internet.

Customs allows 24 hour per day clearance at the airport and provides clearance for seaport outside of the 16 hours per day that the port routinely operates ("Import procedure," 2009). It allows loaded marine containers to be moved in bond to the resorts for clearance and unloading at final destination. However, this is on a case-by-case basis and requires escort by a customs official and a security official. With current policies, it completes clearance procedures within 48 hours for normal cargo and 24 hours for perishables and other time-sensitive goods ("Import procedure," 2009).

3.4.1 Custom Duties

Customs levies import duties on all goods entering the country, except items brought by passengers for personal use in non commercial quantities. Import duty is levied on the CIF (Cost + Insurance + Freight) value of the goods ("Import procedure," 2009).

3.4.2 Port Tariff

MPL also levies a charge for individual services and resources provided to its customers ("Port tariff," 2009). The tariff was first imposed in 1997 ("Port tariff," 2009).

3.5 Port Cargo Traffic

Table 3.2 presents a summary of total cargo traffic at Male’ Commercial Port for the period from 1995-2008. The total cargo has been growing at the annual growth rate of about 9% on average for the period. The total cargo throughput exceeded 1.1 million Freight Tons in 2008.

Since Maldives imports virtually everything it consumes, almost all of the cargo handled by MCH is imported cargo. The inbound cargo accounts for around 96% of the total cargo throughput at Male’ Commercial Port.

Table 3.2: Cargo Traffic at Male’ Commercial Port for the Period, 1995-2008

Year	Cargo Throughput (FT)	Growth Rate (%)	Cargo Inbound (FT)	Share (%)	Cargo Outbound (FT)	Share (%)
1995	368,348		361,757	98%	6,591	2%
1996	431,606	17%	417,251	97%	14,355	3%
1997	484,479	12%	465,337	96%	19,142	4%
1998	589,048	22%	572,138	97%	16,910	3%
1999	590,742	0%	569,802	96%	20,940	4%
2000	522,722	-12%	497,989	95%	24,733	5%
2001	485,251	-7%	454,273	94%	30,978	6%
2002	498,632	3%	468,378	94%	30,254	6%
2003	591,103	19%	560,389	95%	30,714	5%
2004	743,585	26%	708,323	95%	35,262	5%
2005	812,101	9%	771,972	95%	40,129	5%
2006	906,633	12%	869,531	96%	37,102	4%
2007	1,086,297	20%	1,051,099	97%	35,198	3%
2008	1,139,808	5%	1,092,377	96%	47,431	4%

Source: ("Maldives Ports Limited," 2009)

Table 3.3 presents the summary of container traffic at Male' Commercial Port for the same period, 1995-2008. Over the period container throughput has been growing at an annual growth rate of 15% on average. Container handling at the Port has exceeded 50 thousand TEUs (Twenty Foot Equivalent Units) in 2008. Although the volumes of inbound containers and outbound containers are seen as balanced in Table 3.3; most of the outbound volume is that of empty containers.

Table 3.3: Container Traffic at Male' Commercial Port for the Period, 1995-2008

Year	Containers Throughput ((TEU))	Growth Rate (%)	Containers Inbound ((TEU))	Share (%)	Containers Outbound ((TEU))	Share (%)
1995	7,842		4,215	54%	3,627	46%
1996	9,553	22%	4,866	51%	4,687	49%
1997	11,246	18%	5,762	51%	5,484	49%
1998	14,375	28%	7,240	50%	7,135	50%
1999	16,531	15%	8,329	50%	8,202	50%
2000	19,081	15%	9,381	49%	9,700	51%
2001	18,598	-3%	9,492	51%	9,106	49%
2002	19,249	4%	9,624	50%	9625	50%
2003	21,729	13%	11,059	51%	10,670	49%
2004	30,666	41%	15,606	51%	15,060	49%
2005	33,860	10%	16,838	50%	17,022	50%
2006	38,359	13%	19,776	52%	18,583	48%
2007	47,703	24%	24,350	51%	23,353	49%
2008	53,650	12%	27,045	50%	26,605	50%

Source: ("Maldives Ports Limited," 2009)

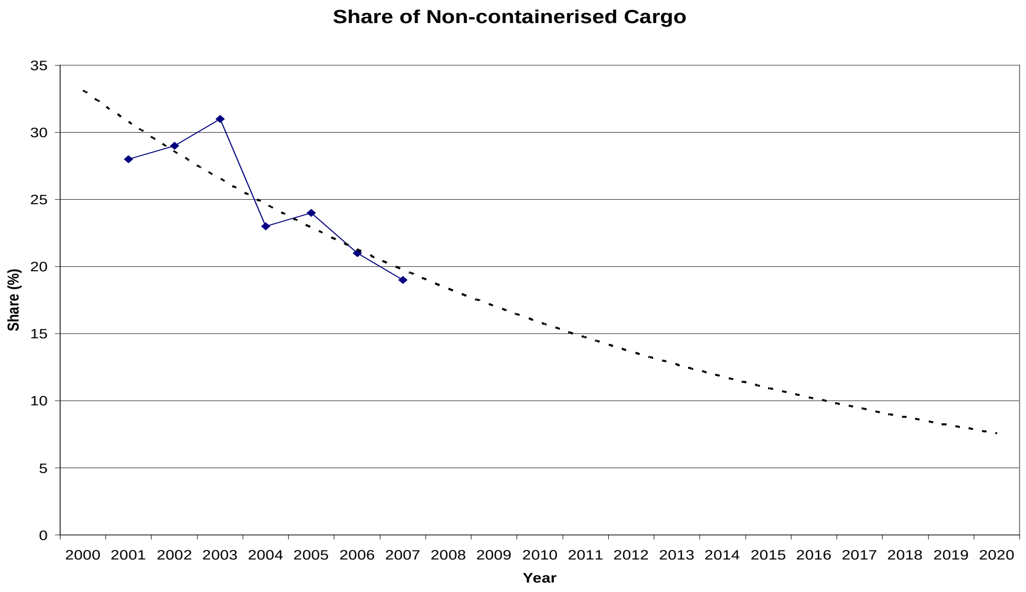
A summary of the Import/Inbound Cargo traffic is presented in Table 3.4 for the period 2001 - 2007. The volume of Non-containerised cargo has accounted for about 25% of the total cargo throughput on average in the 7 year period; meaning that 75% of the Import/Inbound cargo has been containerised. Currently, Non- containerised imported cargo represents only about 19% of the total cargo. The share of Non-containerised cargo (Import) has a trend presented in Figure 3.4 converging to about less that 10% by 2020. Since Non-containerised cargo represents a relatively smaller percentage of total cargo, it was decided to analyse only containerised cargo in this study.

Table 3.4: Import/Inbound Cargo Traffic 2001-2007

Year	(a) Total Cargo (FT)	(b) General Cargo (FT)	(c) Total Bulk Cargo (MT)	(d) Container Cargo (FT)	(b)+(c) Non-container Cargo (FT)	[(b)+(c)]/(a)
		Import/Inbound Cargo				
2007	1,051,099	178,786	24,155	848,158	102,941	19%
2006	869,531	144,068	35,963	689,500	180,031	21%
2005	771,972	143,966	40,636	587,370	184,602	24%
2004	708,323	122,530	41,403	544,390	163,933	23%
2003	560,389	108,180	66,754	385,455	174,934	31%
2002	468,378	95,151	38,557	334,670	133,708	29%
2001	454,273	97,533	30,925	325,815	128,458	28%

Source: ("Maldives Ports Limited," 2009)

Figure 3.4: Share of Non- Containerised Cargo



3.6 Existing Shipping Services

According to MPL the pattern of liner shipping services to and from the Maldives can be classified in three categories:

(i) A dedicated shuttle service from Colombo operated with smaller ships on a fast rotation

(ii) An intra-Asian service originating in Singapore and stopping at various ports with Male' as the end of the line

(iii) An Asia –East Africa route which is calling at Maldives along the way

3.6.1 The Shipping Lines

Currently, there are four shipping companies operating container shipping services to and from Maldives. A brief description of the 4 companies and the vessels they employ on the different routes is provided below.

3.6.1.1 Lily Shipping

Lily shipping is a Maldivian privately owned company specialised in shipping to and from the Maldives. The company presently owns 3 vessels, 2 of which operate between Singapore, Port Klang, and Male’, with occasional trips via Colombo ("Statistics: Lily Shipping, Male'," 2009). The third vessel operates on a feeder service between Colombo and Male’. The company calls at Male’ from South East Asia once every three weeks; and from Colombo once a week ("Statistics: Lily Shipping, Male'," 2009). Lily is the largest Maldivian shipping line with agencies in Malaysia, Singapore and Colombo. It is also a major forwarding and receiving agent in the Maldives. Lily averaged about 310 TEU of cargo discharged per trip in Male’ in 2008, which reflects the small sizes of their container ships ("Maldives Ports Limited," 2009). Its year-accumulated discharge of 3,724 TEU accounted for roughly 42% of all goods imported to Male’ ("Statistics: Lily Shipping, Male'," 2009).

3.6.1.2 Maldives National Shipping Limited (MNSL)

Maldives National Shipping Limited (MNSL) was established in 1957 under the name Maldivian National Trading Corporation (Ceylon) Limited ("Maldives National Shipping," 2009). The company's routes are concentrated around the triangle formed by Sri Lanka, Maldives, and the South-East Asian ports. It specialises in shipping to Maldives, and operates shuttle services through Singapore, Port Kelang, Colombo and Male’ using small container ships under 500 TEU ("Statistics: Maldives National Shipping," 2009). MNSL operates a service from Singapore through Port Kelang to Male’ for containers/break-bulk and then returns through Colombo, Kelang and Singapore with break-bulk using multipurpose vessels and calling at Northport in Port Kelang and Pasir Pajang in Singapore ("Maldives National Shipping," 2009). The break-bulk cargo carried to Male’ is primarily timber from East Malaysia which is moved conventionally up to Port Kelang and then picked up as break-bulk cargo. MNSL also operate a dedicated container service between Colombo and Male’ on a weekly basis (more like 10 days) which continues to the Northern regional port or Southern regional port on alternating basis using multipurpose vessels equipped with hydraulic cranes to handle containers ("Maldives Ports Limited," 2009). Their nominal capacity is 350 TEU but they typically offload 175 and load 225 ("Maldives Ports Limited," 2009); and the latter is the empty repositioning service.

3.6.1.3 Delmas

Delmas is a premier French liner company engaged in north-south trades. Delmas has 76 regular lines spanning Europe, Asia, Africa, and South America and traversing the Atlantic Ocean, Indian Ocean, and several smaller waterways ("Delmas: Asia - East Africa line," 2008). Altogether, Delmas calls at 350 ports in over 150 countries. It has a container fleet of 242 vessels with a total capacity of 886 thousand, TEUs ("Delmas: key figures," 2009). Delmas calls at Male' on their way back to East Africa from the Far East bringing shipments from Colombo and Singapore. There are currently five 700 TEU-class container ships servicing this route, making a total of 10 calls per voyage and 52 voyages per year ("Delmas: Asia - East Africa line," 2008). Their average load/discharge in Male' is around 100 TEUs ("Maldives Ports Limited," 2009).

3.6.1.4 Maersk

Maersk is one of the leading container ship operators in the world. The company, based in Copenhagen, Denmark, owns and charters over 500 container carriers and number of containers corresponding to more than 1,900,000 TEU ("Maersk: About us," 2009). Maersk is relatively a small player for the time being on the Maldivian market. Maersk does not currently have its own ships calling at the Maldives. Instead, it tranships to MNSL and Lily vessels in Colombo which provides 8-10 trips each month ("Maldives Ports Limited," 2009).

3.7 Chapter Summary

In summary, there is no clear port administration structure in the Maldives. A variety of public and private parties are engaged in terminal management and operations. MCH is the country's only international sea port where almost all international cargo are handled. The Harbour is managed and run by MPL.

MCH has its own characteristics which are quite distinct from other standard ports. First, unlike other ports where containers are transported to final destination by importers, containers never leave the Male' port premises. They are stripped in the port and unstuffed cargo is loaded on small trucks right away and taken to the first point of destination, leaving containers in Port. Second, MCH is only willing to accept 20 foot containers; however, with rapid increasing containerisation and the repeated requests from stake holders, especially shipping companies; MCH is now accepting some 40 foot containers as well. There are four shipping companies operating container shipping services to and from Maldives.

In 2008, MCH handled more than 50 thousand TEU’s. The containerised cargo accounted for about 75% of the total cargo. The non-containerised cargo has a converging trend and it is forecasted that this would represent less than 10% of the total cargo in 2010.

CHAPTER 4

Demand Drivers of Import Cargo, and Estimation of Cargo Traffic

4.1 Introduction

The Maldivian economy is anchored on the rapid growth of the tourist and fishing industries. It is expanding rapidly, driven primarily by the booming tourism industry, which makes up over 30% of GDP (*Seventh national development plan 2006-2010*, 2008). The lack of any real domestic production with exports consisting only of fish products result in the fact that the Maldives must import nearly everything for its growing population (currently at approximately 359,000, (*Population and housing census 2006*, 2007)) and its tourists consumption. With the number of international tourists travelling to the Maldives growing at an average of 6.8% per year between 2000 and 2005 (*Seventh national development plan 2006-2010*, 2008), cargo traffic supporting tourist consumption has and will continue to grow.

This chapter seeks to outline the major demand drivers of import cargo and tries to forecast cargo traffic for the next ten years based on population growth and economic growth indicators using correlation techniques. The aim is to realise cargo traffic trends and understand possible future capacity requirements.

4.2 Demand Drivers

The major demand drivers influencing import growth for the Maldives consist of GDP, population, and tourism growth.

4.2.1 Real Gross Domestic Product

The real GDP growth was strong, with an average of 7.7% per year between 1995 and 2004, prior to the 2004 tsunami. Since the tsunami, the economy has recovered quickly and real GDP grew at an average annual rate of 7% between 2005 and 2007. The real GDP is expected to grow at an average annual rate of 5.2% between 2010 and 2015 (*Statistical year book of*

Maldives 2008, 2008). The 13 year history of GDP of the Maldives industrial sector is presented in Table 4.1 and Figure 4.1 for the years 1995–2007. Figure 4.2 shows the annual growth rate of GDP from 1995 to 2007.

Table 4.1: GDP by Industry Sector, 1995-2007

Year	Primary Sector (Million Rf)	Secondary Sector (Million Rf)	Tertiary Sector (Million Rf)	GDP at Basic Prices (Million Rf)	Annual Growth Rate	GDP/Capita at Basic Prices (Rf)	GDP/Capita at Basic Prices (USD)	Average Exchange Rate
1995	520.6	547.0	3,379.0	4,271.6	7.8	17,449.0	1,482.5	11.77
1996	530.1	567.0	3,752.1	4,659.7	9.1	18,628.0	1,582.7	11.77
1997	541.2	683.4	4,126.4	5,144.6	10.4	20,139.0	1,711.0	11.77
1998	578.8	801.2	4,493.5	5,648.2	9.8	21,659.0	1,840.2	11.77
1999	599.2	900.2	4,798.7	6,056.6	7.2	22,761.0	1,933.8	11.77
2000	595.2	914.8	5,084.6	6,345.5	4.8	23,380.0	1,986.4	11.77
2001	625.5	989.0	5,205.4	6,564.4	3.5	23,786.0	2,020.9	12.24
2002	724.8	1,091.7	5,448.8	6,992.8	6.5	24,925.0	2,117.7	12.80
2003	738.0	1,182.6	5,969.2	7,589.9	8.5	26,625.0	2,262.1	12.80
2004	759.1	1,335.1	6,549.3	8,311.2	9.5	28,711.0	2,439.3	12.80
2005	848.9	1,374.2	6,010.9	7,926.2	-4.6	26,983.0	2,292.5	12.80
2006	846.5	1,592.1	7,292.6	9,354.8	18.0	31,182.0	2,649.0	12.80
2007	718.8	1,770.5	7,975.5	10,063.3	7.6	33,009.0	2,804.0	12.80

Source: (*Statistical yearbook of Maldives, 2008*)

Figure 4.1: GDP by Industry Sector, 1995-2007

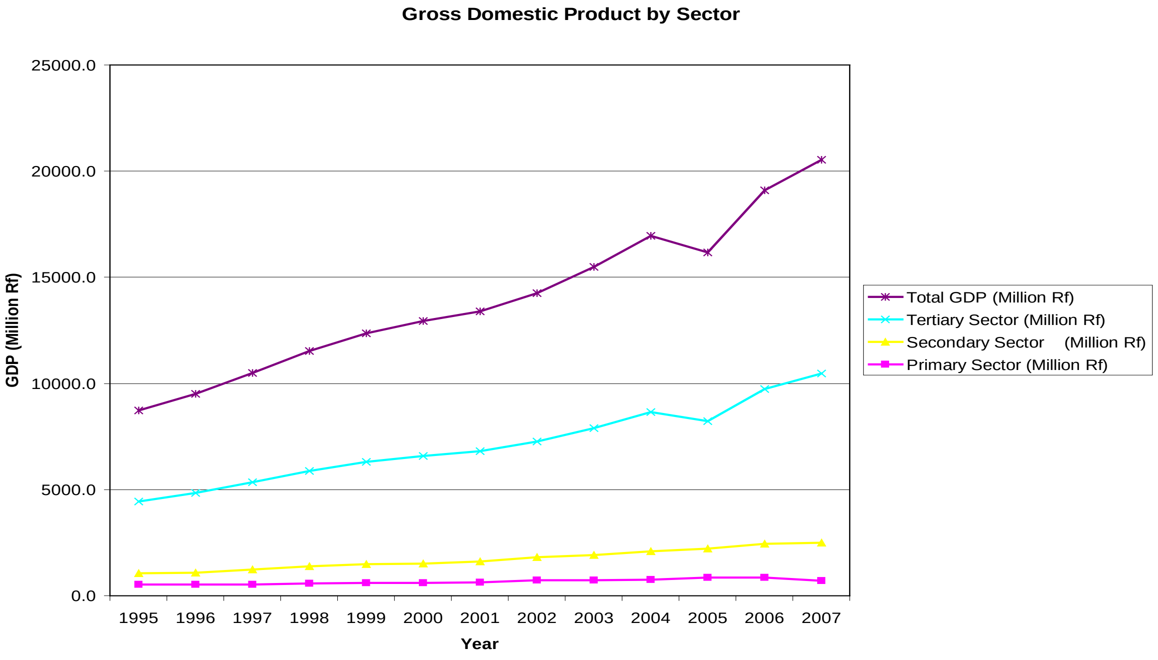
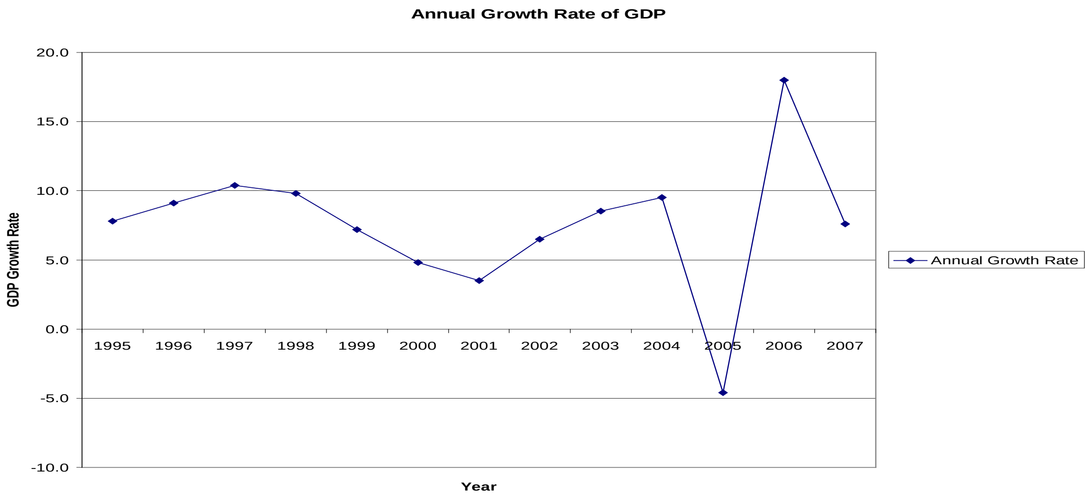


Figure 4.2: Annual Growth Rate of GDP



4.2.2 Population

The population of the Maldives increased from 143,000 in 1977 to 270,000 in 2000 and passed 300,000 in the year 2006. The population grew slowly at an annual average of 1.8% per year from 1995 to 2007 and is expected to grow at an annual rate of 2.3% between 2010 and 2015. The long-term growth rate of population is estimated at 1.5% per year. The overall growth rate has a declining trend (*Statistical year book of Maldives 2007*, 2007). Table 4.2 shows the population growth from 1977 to 2007 and growth estimation from 2008 to 2025. Figure 4.3 shows the population growth rate for the same period.

Figure 4.3: Population Growth Rate

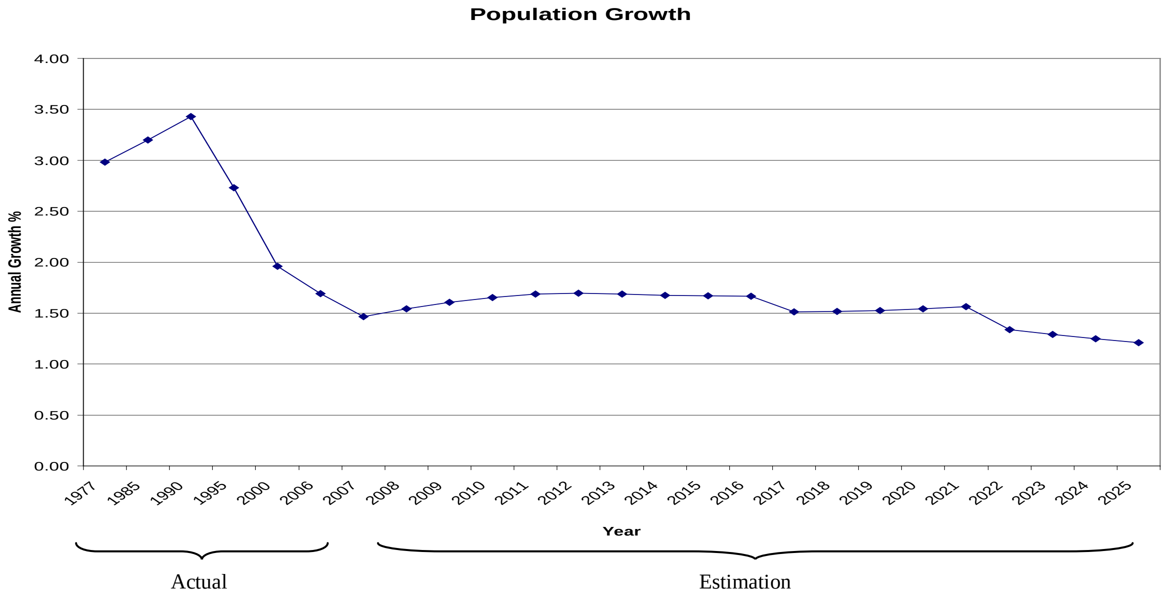


Table 4.2: Population Growth

	Year	Total Population	Annual Growth
Actual	1977	142,832	2.98
	1985	180,088	3.20
	1990	213,215	3.43
	1995	244,814	2.73
	2000	270,101	1.96
	2006	300,466	1.69
	2007	304,869	1.47
Projected	2008	309,575	1.54
	2009	314,542	1.60
	2010	319,738	1.65
	2011	325,135	1.69
	2012	330,652	1.70
	2013	336,224	1.69
	2014	341,848	1.67
	2015	347,552	1.67
	2016	353,334	1.66
	2017	358,679	1.51
	2018	364,120	1.52
	2019	369,674	1.53
	2020	375,367	1.54
	2021	381,229	1.56
	2022	386,330	1.34
	2023	391,321	1.29
	2024	396,205	1.25
	2025	400,996	1.21

Source: (*Statistical yearbook of Maldives 2007*)

4.2.3 Tourism

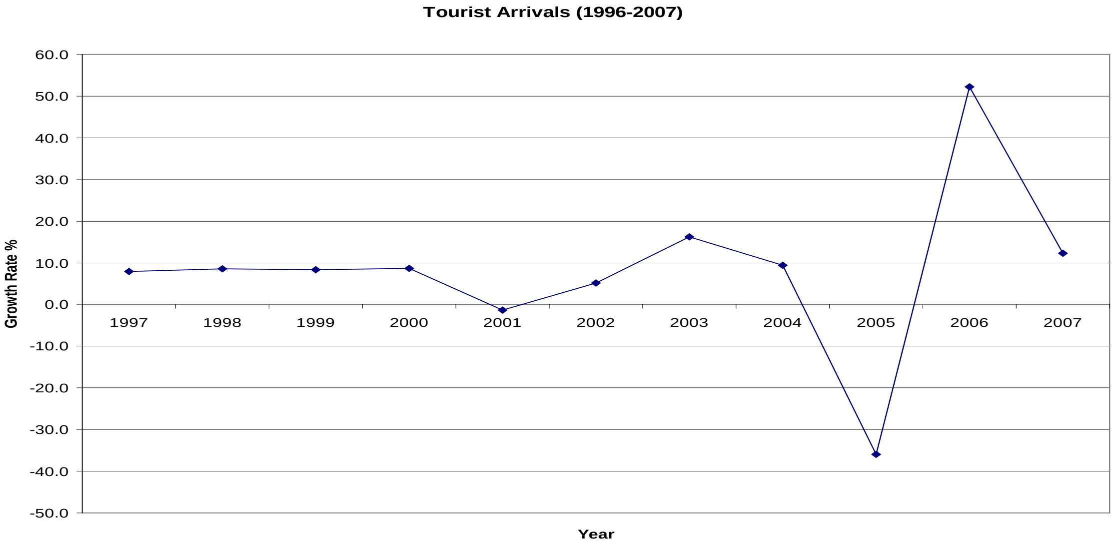
The contribution of tourism to the national GDP is immense, accounting for around 30% (34.5% in 1995, 33% in 2000, 22.7% in 2005, and 27.4% in 2008) (*Statistical year book of Maldives 2008*, 2008). The tourism sector showed steady growth until the September 11, 2001 and recovered promptly before having a massive fall of 35% in 2005, (effect caused by the Asian tsunami), (*Statistical year book of Maldives 2007*, 2007). Since the tsunami the tourism sector has recovered and the tourist arrivals have increased. Table 4.3 presents the total number of tourist arrivals, average duration of stay, and growth rate for the period from 1996-2007. Figure 4.4 shows the growth trend for the same period.

Table 4.3: Tourist Arrivals from 1996 to 2007

Year	Total Arrival	Average duration of stay (days)	Growth Rate
	Tourist Arrivals (1996-2007)		
1996	338,733	9.0	
1997	365,563	8.9	7.9
1998	396,725	8.8	8.5
1999	429,666	8.7	8.3
2000	467,154	8.4	8.7
2001	460,984	8.5	-1.3
2002	484,680	8.4	5.1
2003	563,593	8.3	16.3
2004	616,716	8.3	9.4
2005	395,320	8.3	-35.9
2006	601,923	8.0	52.3
2007	675,889	8.5	12.3

Source: (*Statistical yearbooks of Maldives 2001-2008*)

Figure 4.4: Tourist Arrival Growth Rate from 1997 to 2007



4.3 Correlation Analyses of Macro-economy and Port Cargo Traffic

As stated earlier, the Maldives national GDP has been growing rapidly with an average growth rate of 7.6% per year (refer Table 4.1, Figure 4.1, and Figure 4.2). The national population and tourist arrivals have also been increasing consistent with the economic development of the Maldives (refer Table 4.3 and Figure 4.4). Correlation analysis techniques are used to determine the relationship between container throughput and GDP, Population, and Tourist arrivals.

4.3.1 Correlation Analysis between GDP and Container Throughput

Figure 4.5 presents correlation of total container throughput at Male' Commercial Harbour against GDP of the Maldives for the period, 1996-2007. The Container Throughput contains all import (inbound) containers and all export (outbound) containers.

The correlation of the total container versus GDP shows a fairly linear relationship and the square of coefficient of correlation (R^2) is given as 0.9578.

Hence, an assumption is made that the container throughput can be estimated as the function of national GDP of the Maldives based on the following formula.

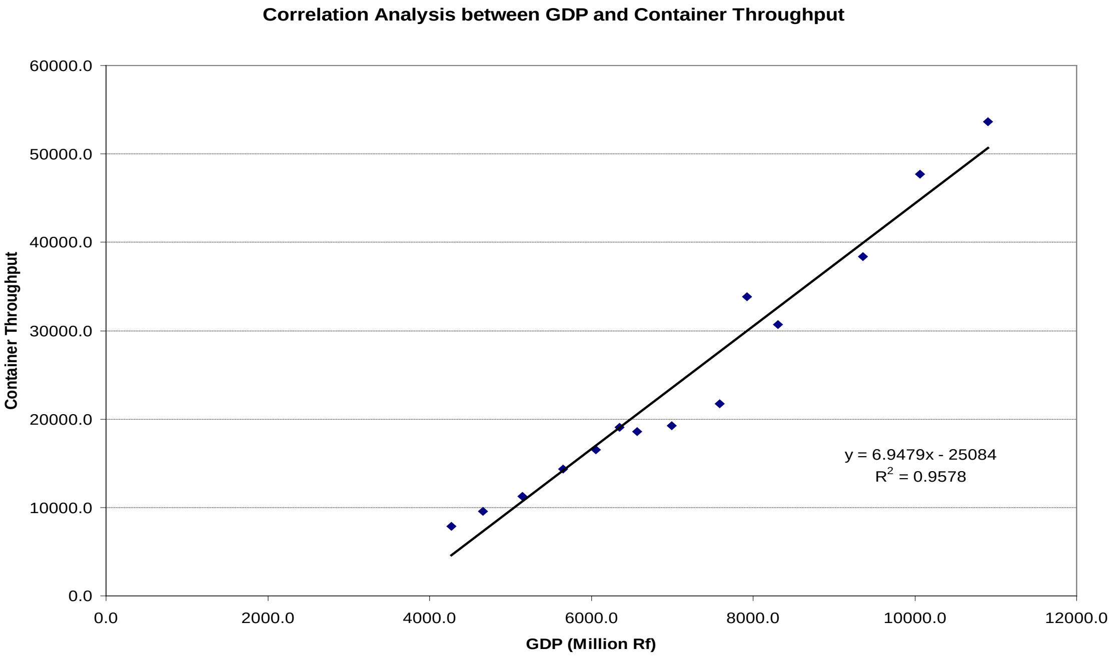
$Y = 6.9479X – 25,084$

Where:

X: GDP (in million Rf), and

Y: Total Container Throughput (TEU per year)

Figure 4.5: Correlation Analysis between GDP and Container Throughput



4.3.2 Correlation Analysis between Population and Container Throughput

Correlation analysis performed for the period 1995 – 2007 for Population and Container Throughput shows a linear relationship with the square of correlation coefficient (R^2) of 0.89 (see Figure 4.6).

Thus, an assumption is made that the container throughput can be estimated as the function of Population of the Maldives based on the following formula.

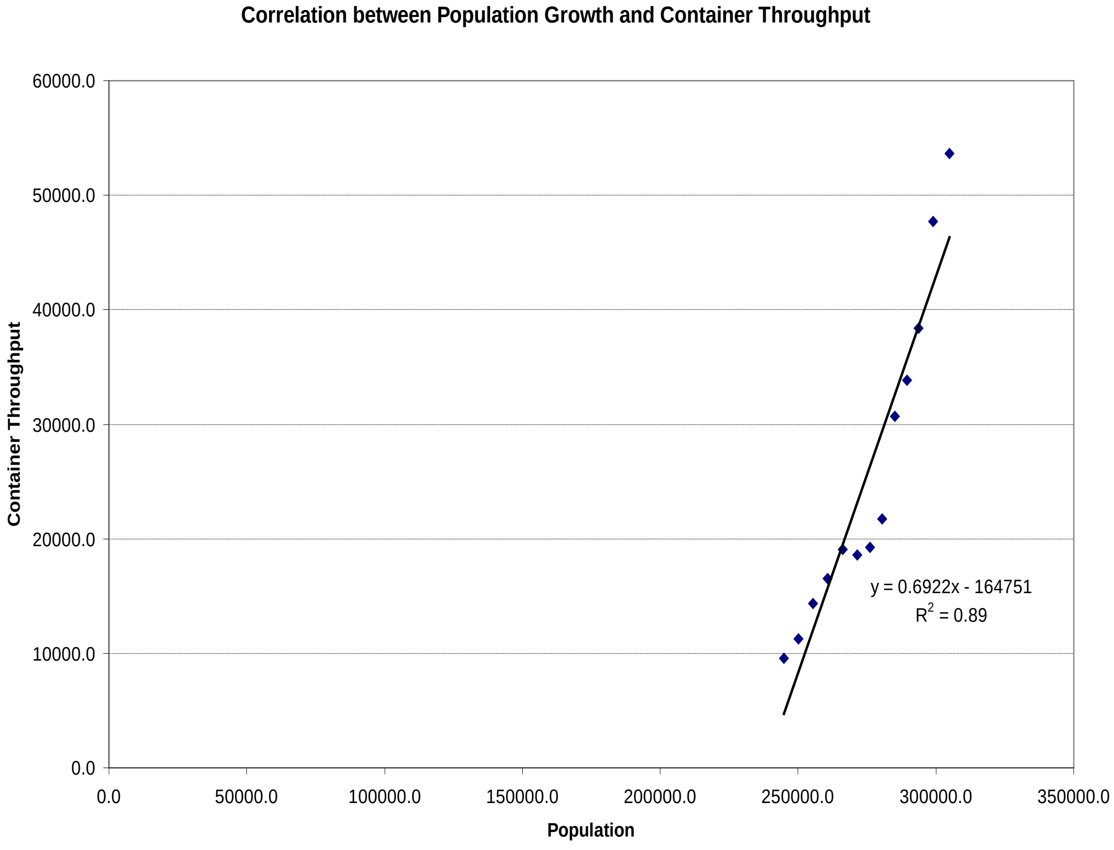
$Y = 0.6922X - 164751$

Where:

X: Population of Maldives, and

Y: Total Container Throughput (TEU per year)

Figure 4.6: Correlation between Population Growth and Container Throughput



4.3.3 Correlation Analysis between Tourist Arrival and Container Throughput

Tourism is the big important driver of the economic growth of the Maldives which accounts for around 30% share of contribution to the national GDP. Tourist arrivals to the Maldives have been increasing consistently, except for the year 2005 (effects of Tsunami). The annual total arrival has exceeded 600,000 in 2006 and this figure is far beyond the national population of the Maldives (*Statistical year book of Maldives 2007*, 2007). The average duration of stay of these tourists is reported as 8.5 days (see Table 4.3).

To analyse the correlation between container throughput and tourist arrival, the average duration of stay of tourist is taken into consideration (Tourist Days = Annual Tourist Arrival x 8.5/365).

The correlation of the tourist arrival versus the container throughput shows a fairly linear relationship and the square of the coefficient correlation (R^2) is given as 0.6365 (see Figure 4.7).

Therefore, an assumption is made that the container throughput of MCH can be estimated as the function of tourist arrivals based on the following formula.

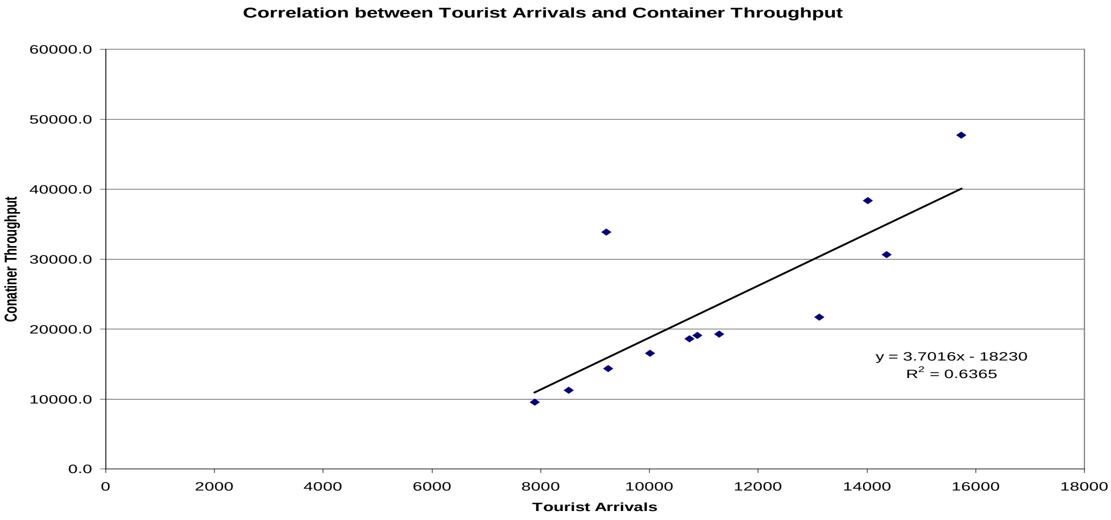
$Y = 3.7016X – 18230$

Where:

X: Tourist Days [Tourist Days = Annual Tourist Arrival x 8.5/365]

Y: Total Container Throughput (TEU per year)

Figure 4.7: Correlation between Tourist Arrivals and Container Throughput



4.4 Container Traffic Forecast

The forecast scenario of container throughput is estimated based on the GDP growth forecasted by the Department of National Planning of the Maldives and using the result of correlation analyses discussed above. The growth rate of GDP is obtained for Low, Medium, and High Case from the department (see Table 4.4). Using these estimations container throughput for each case (Low, Medium, and High Case) is estimated using the correlation formula given below. The GDP and Container Throughput correlation is used to estimate container traffic because it confers the strongest correlation ($R^2 = 0.9578$) compared to population ($R^2 = 0.89$) and tourist arrivals ($R^2 = 0.6365$)

$Y = 6.9479X – 25{,}084$

Where:

X: GDP (in million Rf), and

Y: Total Container Throughput (TEU per year)

Table 4.4: GDP Growth Rate for Low, Medium, and High Case for the Period 2009-2012

Cases	**Assumptions**	**Up to 2008**	**2009**	**2010**	**2011**	**After 2012**
Low Case	GDP	Average 7.50%	4.4%	4.5%	4.7%	4.6 ¬ 3.8%
Medium Case	GDP		5.9%	6.0%	6.1%	6.0 ¬ 5.6%
High Case	GDP		7.50%			

Source: (*Statistical year book of Maldives 2008*)

4.4.1 Container Throughput (Low Case)

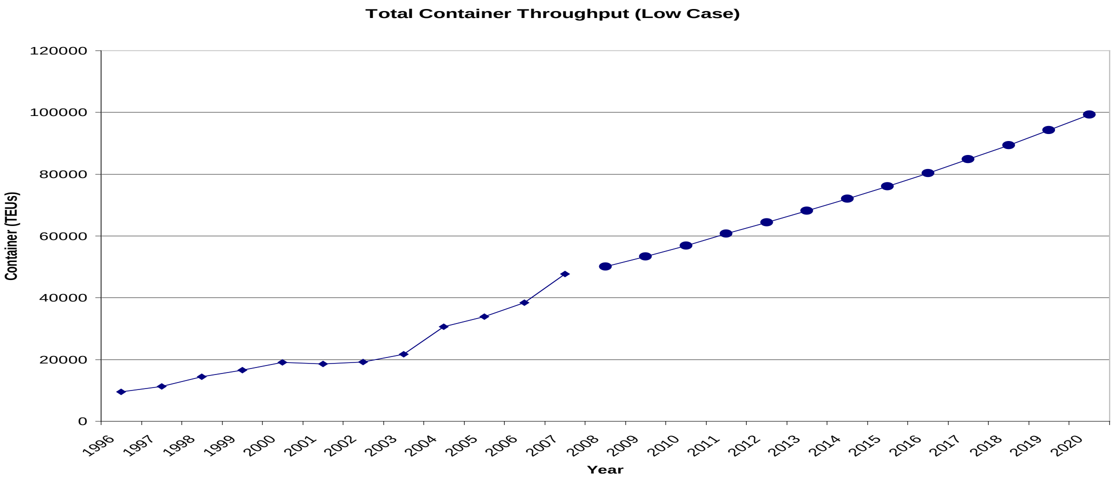
The Low Case of cargo traffic forecast is given by the Low Case of GDP growth. It is estimated that GDP would grow at the rate of 4.2% for the period from 2012 to 2020.

Table 4.5 and Figure 4.8 present the results of the Port Cargo Throughput. The Container Throughput is estimated to reach 99,000 (TEUs) in 2020. The annual growth rate of Container Throughput is given at the higher growth rate (5.5% on average from 2009-2020) than that of GDP growth rate of 4.3% on average for the same period.

Table 4.5: Container Throughput Estimation (Low Case)

Year	GDP Growth Rate	GDP Estimation	Estimated Container Throughput (TEU/year)
2007	7.6	10,063	47,703
2008	7.5	10,818	50,079
2009	4.4	11,294	53,386
2010	4.5	11,802	56,917
2011	4.7	12,357	60,771
2012	4.2	12,876	64,377
2013	4.2	13,417	68,134
2014	4.2	13,980	72,050
2015	4.2	14,567	76,129
2016	4.2	15,179	80,380
2017	4.2	15,817	84,810
2018	4.2	16,481	89,425
2019	4.2	17,173	94,234
2020	4.2	17,895	99,246

Figure 4.8: Container Throughput Growth Rate (Low Case)



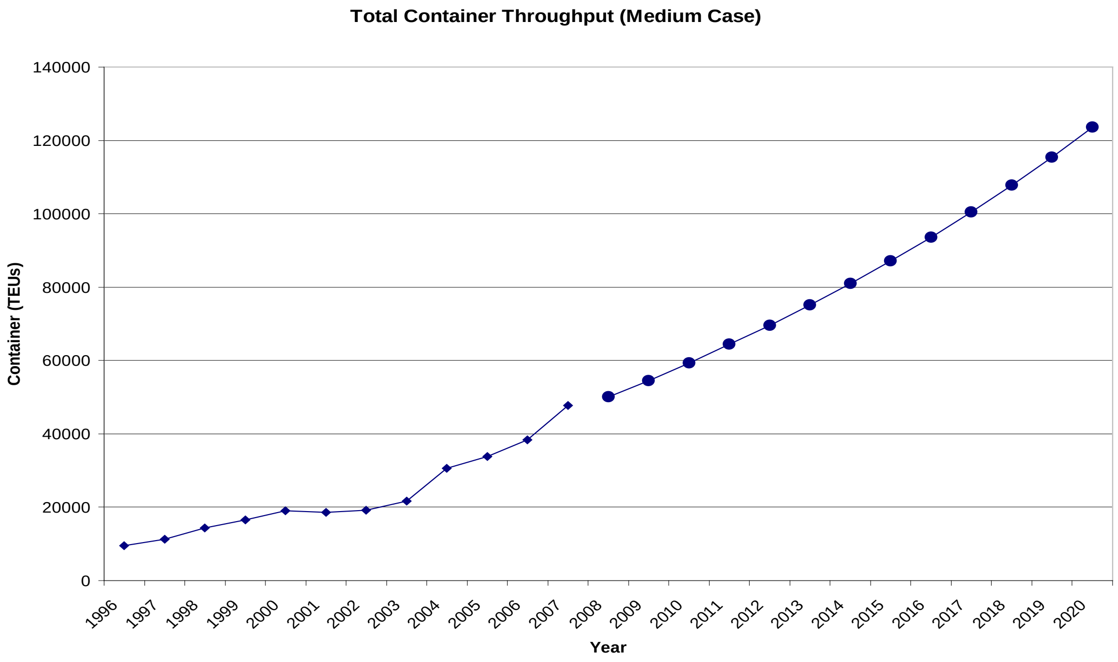
4.4.2 Container Throughput (Medium Case)

Medium Case of cargo traffic forecast is presented in Table 4.6 and Figure 4.9. The container throughput is estimated to exceed 100,000 (TEUs) in 2020. The annual growth rate of Container Throughput is given at a larger growth rate of 7.3% on average from 2009-2020 than that of GDP 5.9% on average for the same period.

Table 4.6: Container Throughput Estimation (Medium Case)

Year	GDP Growth Rate	GDP Estimation	Estimated Container Throughput (TEU/year)
2007	7.6	10,063	47,703
2008	7.5	10,818	50,079
2009	5.9	11,456	54,513
2010	6.0	12,144	59,289
2011	6.1	12,884	64,436
2012	5.8	13,632	69,628
2013	5.8	14,422	75,121
2014	5.8	15,259	80,933
2015	5.8	16,144	87,082
2016	5.8	17,080	93,588
2017	5.8	18,071	100,471
2018	5.8	19,119	107,753
2019	5.8	20,228	115,458
2020	5.8	21,401	123,609

Figure 4.9: Container Throughput Growth Rate (Medium Case)



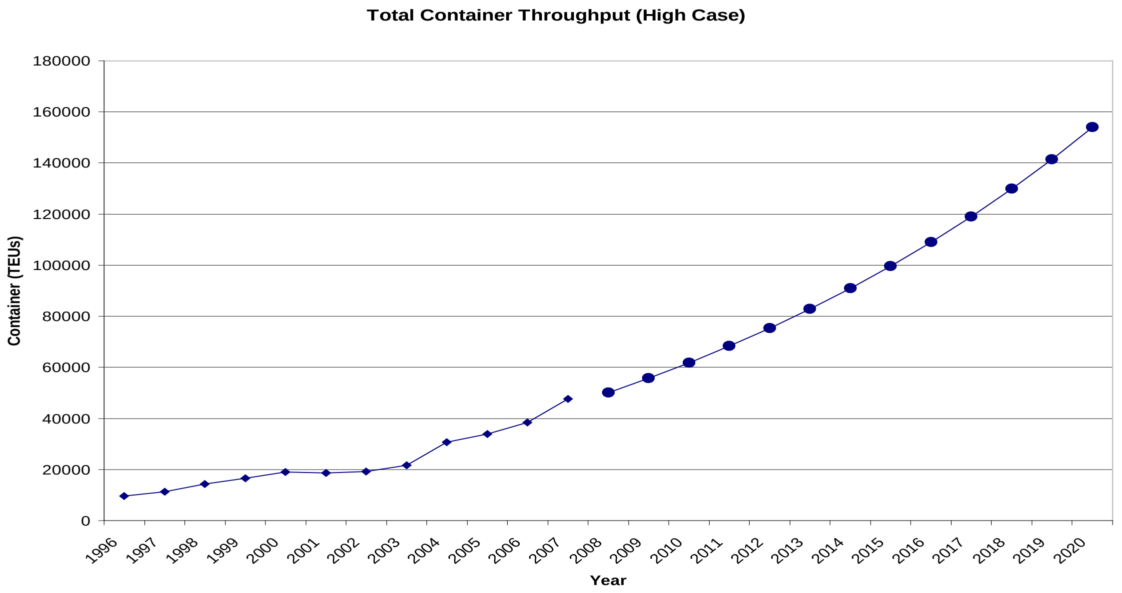
4.4.3 Container Throughput (High Case)

High Case of cargo traffic forecast is presented in Table 4.7 and Figure 4.10. The container throughput is forecasted to increase with 9-10% annual growth rate. The container throughput is estimated to reach 150,000TEUs in 2020. The annual growth rate of total Container Throughput is given at a larger growth rate of 8.9% on average from 2009-2020 compared to a 7.5% average growth rate of GDP for the same period.

Table 4.7: Container Throughput Estimation (High Case)

Year	GDP Growth Rate	Estimated GDP	Estimated Container Throughput (TEU/year)
2007	7.6	10,063	47,703
2008	7.5	10,818	50,079
2009	7.5	11,629	55,716
2010	7.5	12,502	61,776
2011	7.5	13,439	68,290
2012	7.5	14,447	75,293
2013	7.5	15,531	82,822
2014	7.5	16,696	90,915
2015	7.5	17,948	99,615
2016	7.5	19,294	108,967
2017	7.5	20,741	119,021
2018	7.5	22,296	129,829
2019	7.5	23,969	141,447
2020	7.5	25,766	153,937

Figure 4.10: Container Throughput Growth Rate (High Case)



4.5 Chapter Summary

In summary, the major demand drivers influencing import growth for the Maldives consist of GDP, Population, and Tourism growth. The effects of these demand drivers on Container Throughput is analysed using correlation techniques. Correlations of Container Throughput versus the demand drivers show fairly linear relationships, and the relationship between GDP and Container Throughput is the strongest. Thus, GDP growth estimation of Low, Medium, and High Case are used to estimate Container Throughput for each of these cases.

CHAPTER 5

Research Design and Methodology

5.1 Introduction

The main objective of developing a conceptual model is to explain the research objectives more clearly by extracting essential information from the literature review (Zikmund, 2003). This chapter introduces the conceptual and the empirical research model and explains the methodology and the research design used for the study.

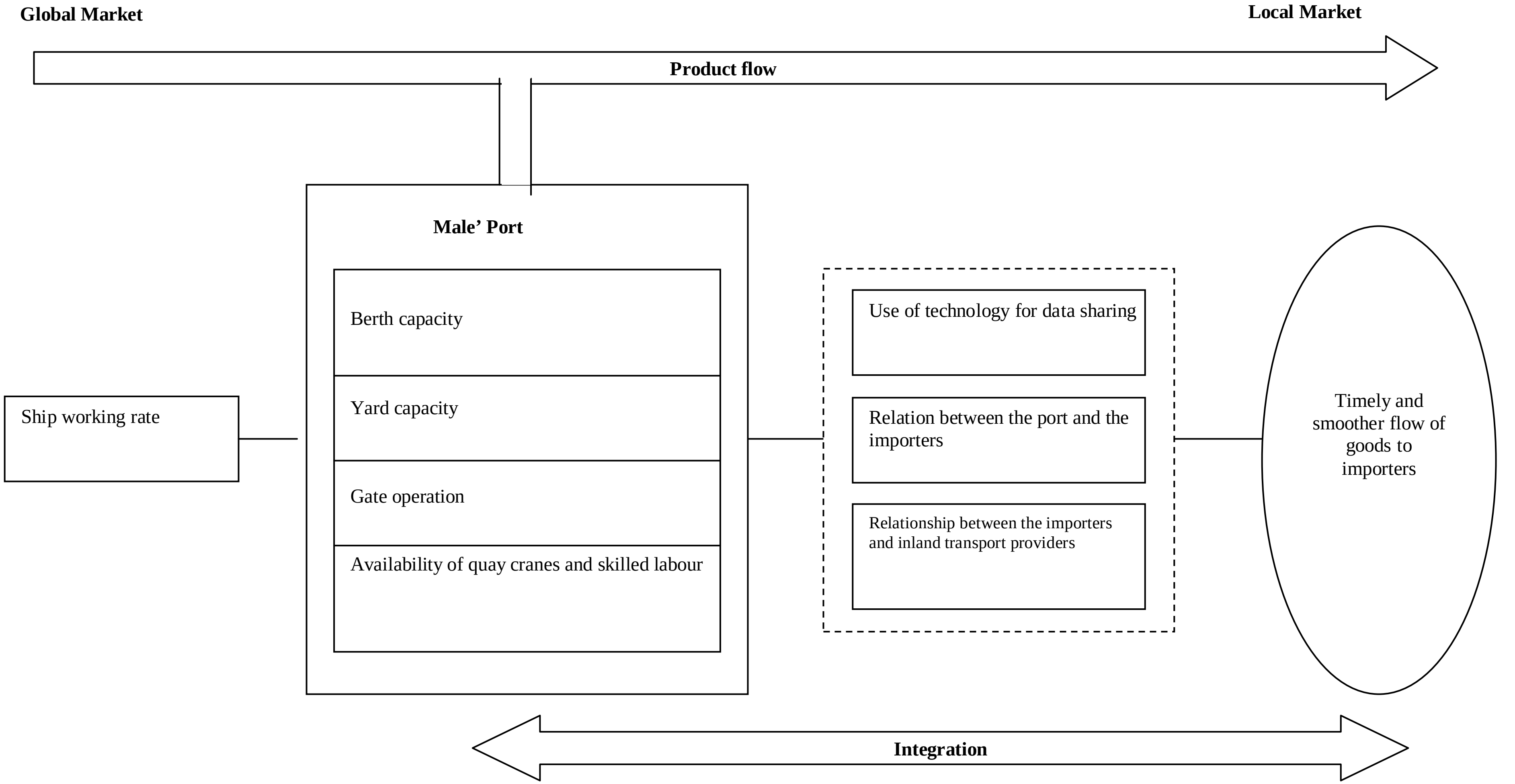
5.2 The Conceptual Research Model

There are several factors that affect port performance and create management problems. Port/terminal throughput capacity is a major factor that affects the movement of goods within supply chains (De Langen & Pallis, 2007; Paixao & Marlow, 2003). According to Bassan (2007) either physical or institutional factors may limit the productivity of container terminals. Physical limiting factors include berth capacity, yard capacity, amount of equipment available, vessel type and characteristics, berthage type and its correlation to the vessels, and road access. Lack of cranes, insufficient land, poor configuration of container yards, inadequate berth system, gate facilities and access limitations are all other potential physical limiting factors (Bassan, 2007). Institutional factors include union work rules, customs regulations, safety rules and various requirements imposed on terminal operators by the carrier (Bassan, 2007). Cronje (2006) argues that an absence of a capable yard management computer system may also affect port throughput. He believes that this complicates the yard control task, resulting in slower stacking-down and access times, and misplaced containers. This also impacts on the ship-working rate leading to an increased berth occupancy and ship turnaround time (Cronje, 2006). Carbone and De Martino (2003) identified four variables in his study that affect port/terminal integration in a global supply chain. They are: (1) relationships between the port operators and the focal firm, (2) information and communication technologies; (3) value added supplied services, (4) performance measurement indicators common to supply chain partners.

These variables can be placed under four main categories; berth operations, quay crane operations, yard operations, and gate operations (Vacca et al., 2007).

Management of these processes create management problems such as berth allocation problem, quay crane scheduling problem, stowage planning problem, yard crane scheduling problem, and gate operation problem. The following model, Figure 5.1, illustrates the major bottlenecks identified in the literature that affect port performance and create management problems.

Figure 5.1: The Conceptual Research Model for Understanding the Bottlenecks



5.2.1 Conceptual Model Description

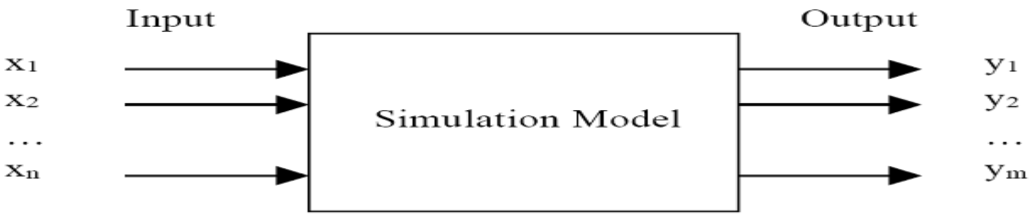
There are several ways to identify and measure port bottlenecks depending on which aspects of the port operation are being evaluated (L. H. Lee et al., 2006). For example, the ship working rate proposed by Dowd and Leschine (1990), berth capacity, yard capacity, proposed by Cronje (2006), degree of congestion, availability of quay cranes and labour proposed by Bassan (2007), use of technology for information sharing and relationships between port and respondent firms proposed by Carbone and De Martino (2003), and relationship between the importers and inland transport providers proposed by Bichou and Gray (2004) are all factors that can create operational problems and thus lead to a port bottleneck. This research looks at terminal operational functions, such as ship working rate, berth capacity, yard capacity, gate operation, and availability of quay cranes and skilled labour; and examines these functions in detail in order to locate possible bottleneck(s).

5.3 The Empirical Research Model

Ports have a complex structure due to their complex functions and dynamics. Complex structures are investigated through simulation techniques instead of analytical methods. Ports simulation can be used for different goals such as design, planning, capacity increase, and productivity. In this study port bottlenecks are investigated using computer simulation techniques.

According to Kelton et al., (2007) a general simulation model comprises n input variables ($x_1, x_2, x_3, \ldots\ldots, x_n$) and m output variables ($f_1(x), f_2(x), f_3(x), \ldots\ldots, f_n(x)$). Simulation optimisation entails finding the optimal setting of input variables ($x_1, x_2, x_3, \ldots\ldots, x_n$) which optimise output variable(s) (Solomenikov, 2006). Figure 5.2 shows a graphical illustration of a simulation model.

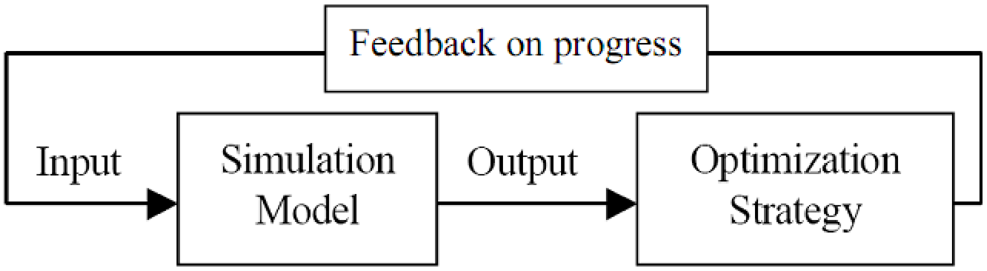
Figure 5.2: Graphical Illustration of a Simulation Model



Source: (Solomenikov, 2006)

Once a simulation model is developed the output of the model is often used to optimise strategy to provide feedback on the progress of the search for the optimal solution. This in turn directs simulation and provides further input to the simulation model. Figure 5.3 shows a graphic illustration of a simulation optimisation model.

Figure 5.3: Graphical Illustration of a Simulation Optimisation Model



Source: (Solomenikov, 2006)

The development of the simulation model for this research is discussed in detail in Chapter 6.

5.4 Research Design

The research design consisted of a field research conducted at Male' Port Terminal. This research strategy clearly corresponds to an exploratory research initiative. This appears appropriate since it enables researchers to capture a real picture of the port (Zikmund, 2003). Furthermore, a *“case study is a research strategy which focuses on understanding the dynamics present within single settings”* (Eisenhardt, 2004, p. 533). A case study allows researchers to fully understand the dynamic within a given situation, focus on emerging phenomena and eventually induce theories (Benbasat, Goldstein, and Mead, 1987). Case studies are also well suited to answer research questions such as “why” and “how” things are done (Yin, 1994).

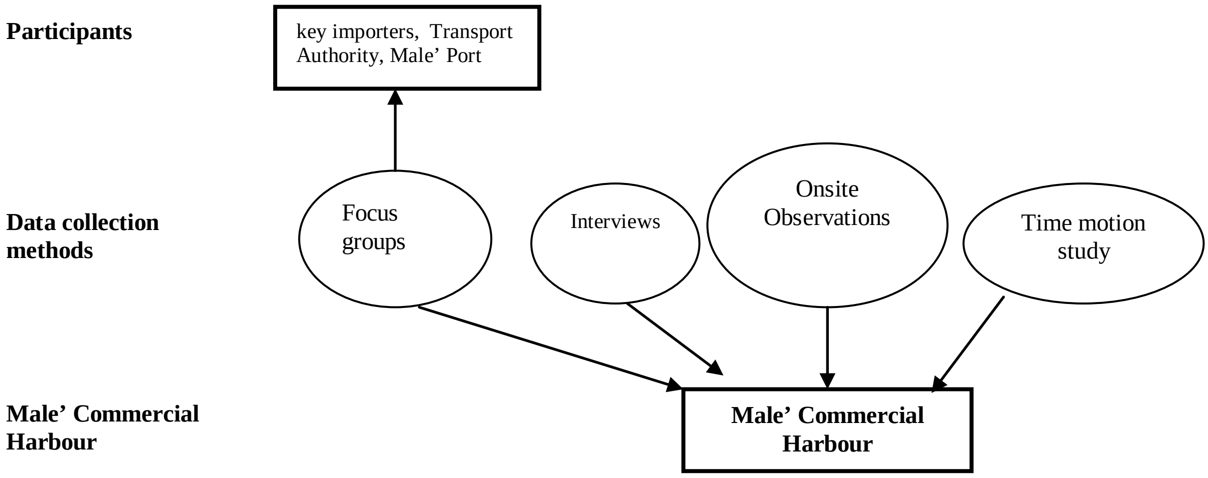
Observation technique was considered the most appropriate data collection method for this study as the research requires a good understanding of Male' Port logistics processes and terminal operations for the development of a simulation model. Observation technique also helps in obtaining complete and precise information (Yin, 1994). Two sets of semi-structured questionnaires, one for the focus group, and the other for port authority personnel were prepared. The latter was used to collect the factual information needed to determine variables such as inter-arrival time of ships, ship cranes hook-cycle time, yard crane cycle time, and processing time of container transport equipment. Interviews were conducted with key personnel of MPL.

On-site observation was another method used to collect data for this research. About a month (from 14 June to 9 July 2009) was spent at Male’ Port to observe the logistics processes and to analyse the current situation of the Male’ Port. The following section explains in detail the data collection methods used in this research.

5.5 Data Collection

This study collects both qualitative and quantitative data using: (i) focus groups, (ii) interviews, (iii) on-site observations, and (iv) time and motion measures. Figure 5.4 shows the corresponding data collection methods.

Figure 5.4: Data Collection Methods



5.5.1 Focus Group

A focus group discussion was conducted with functional managers from key importing firms, key personnel from MPL and Transport Authority of the Ministry of Housing, Transport and Environment. The main objective of this focus group was to understand policies and strategies in place for the future port and logistics development of the Maldives. Participants of focus group are listed in Appendix C.

5.5.2 Interviews

Interviews were conducted with key personnel of MPL. These interviews allowed open-ended probing. Data gathered during these interviews were used for the mapping of existing logistics processes at Male' Port.

5.5.3 On-Site Observations

On-site observations were performed to analyse the current layout of the port and to understand the logistics processes and information flow relating to the container and break-bulk cargo movements. All logistic processes were analysed in detail in order to develop a simulation model.

5.5.4 Time and Motion Measurements

Time and motion measures were conducted to collect processing times of ship cranes, yard cranes, forklifts, and trailers. These data were used to map the movement of cargo within the port.

5.6 Research Site

MCH is the field involved in the research. It is the only international sea port in the Maldives and therefore handles all the international sea cargo for the country. A detailed description of the research site is presented in Chapter 3 Section 3.3.2.

5.7 Chapter Summary

In summary, there are several factors (both physical and institutional) that affect port performance and create management problems. These factors create management problems such as berth allocation problem, quay crane scheduling problem, stowage planning problem, yard crane scheduling problem, and gate operation problem. To manage a port terminal efficiently and effectively it is vital to investigate and analyse these decision problems thoroughly.

Ports have a complex structure due to their complex functions and dynamics. Complex structures are investigated through simulation techniques instead of analytical methods. This study investigates these problems and identifies possible bottleneck(s) using computer simulation techniques.

The research design of the study consists of field research conducted at Male' Port Terminal. The observation technique is considered the most appropriate data collection method for the study as the research requires a good understanding of the site. The study collects both qualitative and quantitative data using focus groups, interviews, on-site observations, and time and motion measures.

CHAPTER 6

Development of Simulation Model

6.1 Introduction

The chapter concentrates on the development of a simulation model using Rockwell Software Arena. Simulation refers to a *"broad collection of methods and applications to mimic the behaviour of real systems, usually on a computer with appropriate software"* (Kelton at al., 2007, p. 1). The simulation parameters for the model were estimated using the historical data of MCH. The aim was to analyse the port situation in detail and identify bottleneck(s) that hinders the logistics activities within the port terminal.

Simulation studies require understanding the system, being clear about goals, formulating model representation, translating it into modelling software, verifying the representation with conceptual model, validating the model, designing experiments, running the experiments, analysing results, obtaining insight from the analysis, and documentation of the findings (Kelton et al., 2007). Close attention was paid to these and similar issues while the simulation model was being developed.

6.2 The Model

MCH handles all international sea cargo for the country. Currently, it handles more than 53000 TEUs per year with a strong escalating tendency. The terminal consists of a 101 meter quay used for container berth and an area of approximately 1.6 hectares of land used for the storage of containers and break-bulk cargo. Transportation of containers within the terminal is carried out in a circular route: import containers → un-stuff container in port → export empty containers (containers do not leave the port). The imported cargoes (un-stuffed in the port) are transported on small trucks to importers' warehouses in the city or local jetties to be transported to other islands. Generally, all inbound or dispatched containers stay at a corresponding container storage yard for a certain time. The MCH handles break-bulk cargo as well. However, the volume of this type of cargo is small (see Table 3.4 and Figure 3.4). Hence, it was decided to describe only the container flow processing process in the simulation model.

6.2.1 The Structure of the Model

The model consists of ship arrivals, loading and unloading of containers from vessels, movement of containers within terminal and stacking area. The model did not take into account the exit/entry gate connection because at MCH containers do not leave the port terminal.

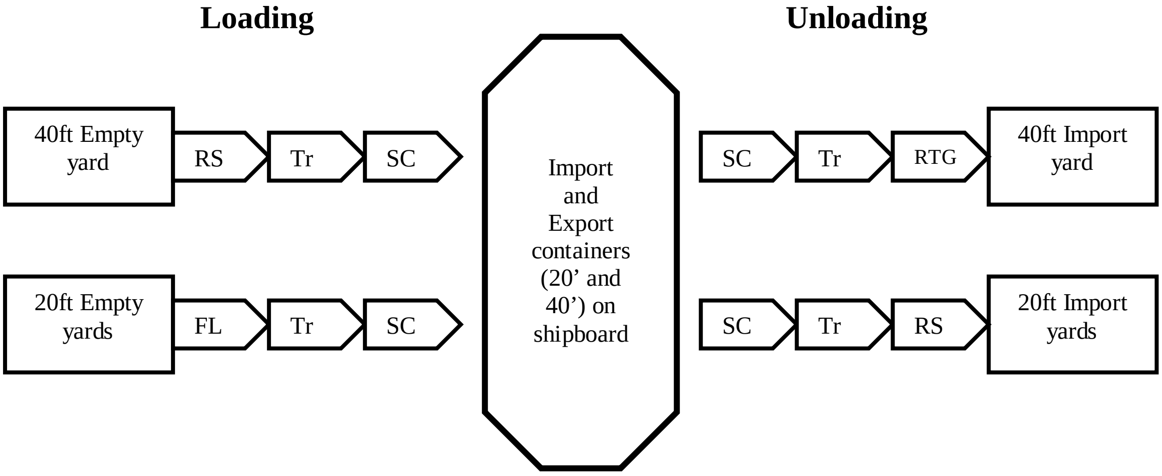
6.2.1.1 System Description

When a ship arrives at MCH it waits until the berth is available. If the berth is available the ship is barged to the berth and sets up for loading/unloading containers. If the berth is not available the ship anchors at sea and waits for lighterage services or the availability of berth, whichever occurs first. MCH offers lighterage services to load/unload containers at anchorage using barges to ease congestion. When loading/unloading is done the ship is barged away by tugboats and leaves the port.

After ship berths at quay, ship cranes (ship’s own gear) start unloading containers off the ship and places them on the quay. Unloaded containers are checked and discrepancies are fixed (if any) before loading onto a trailer by a forklift (20 foot) and a reach-stacker (40 foot). Next, the container is transported on trailer to import yard. This yard consists of a number of lanes where containers are stored for a certain period. From the trailer the container is lifted by a reach-stacker (20 foot containers) or RTG (40 foot containers) and stacked in the yard. After a certain period, when importers request for container clearance, the requested container is retrieved from the stack by RTG or reach-stacker and transported by trailers to un-stuffing yard. Here, the container is stripped open in the presence of importer, Port, Customs, and National Security Services. The unstuffed goods are transported by small trucks by the importer. The empty container is then placed onto a trailer by forklift (20 foot) or reach-stacker (40 foot) and transported to empty yard. Once all the imported containers are unloaded the loading of empty containers (export containers) begins. To load export containers onto a ship, the above processes are executed in reverse order.

Figure 6.1 shows resource allocation structure of logistic activities for loading and unloading containers. The flowchart logic of these logistics processes are shown in Appendix D.

Figure 6.1: Resource Allocation Structure



Key: *RS – Reach-stacker, Tr – Trailer; FL – Forklift, RTG – Rubber Tired Gentry crane, SC-Ship Crane.*

Source: Idea obtained from Solomenikov (2006)

6.2.2 Input Parameter

As the procedure displayed in Figure 6.2, distribution estimation and empirical distribution for input parameters are fitted using the Input Analyser. The Input Analyser is a standard tool that accompanies Arena and is designed specifically to fit distributions to observed data, provide estimates of their parameters, and measure how well they fit the data (Kelton et al., 2007). Input Analyser requires text files (see Figure 6.3) containing basic data to fit probability distributions to data. These input distributions are used as input variables in the model. Goodness-of-fit test was evaluated, for all tested data, by both Chi-square and Kolmogorov-Smirnov test at a 5% significance level.

Figure 6.2: Analysis Procedure

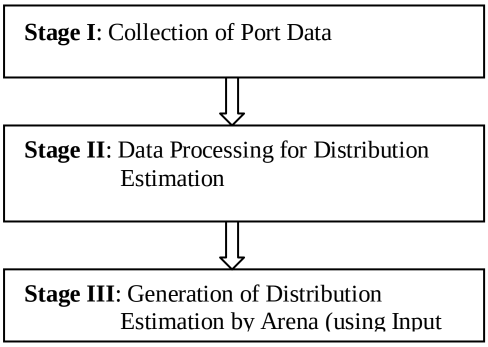
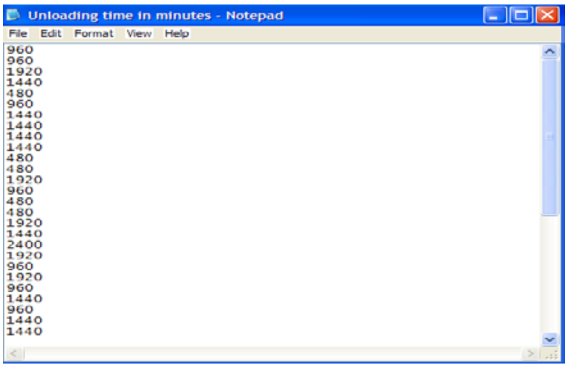


Figure 6.3: Text File



```
960
960
1920
1440
480
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1440
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480
1920
960
480
480
1920
1440
2400
1920
960
1920
960
1440
960
1440
1440
```
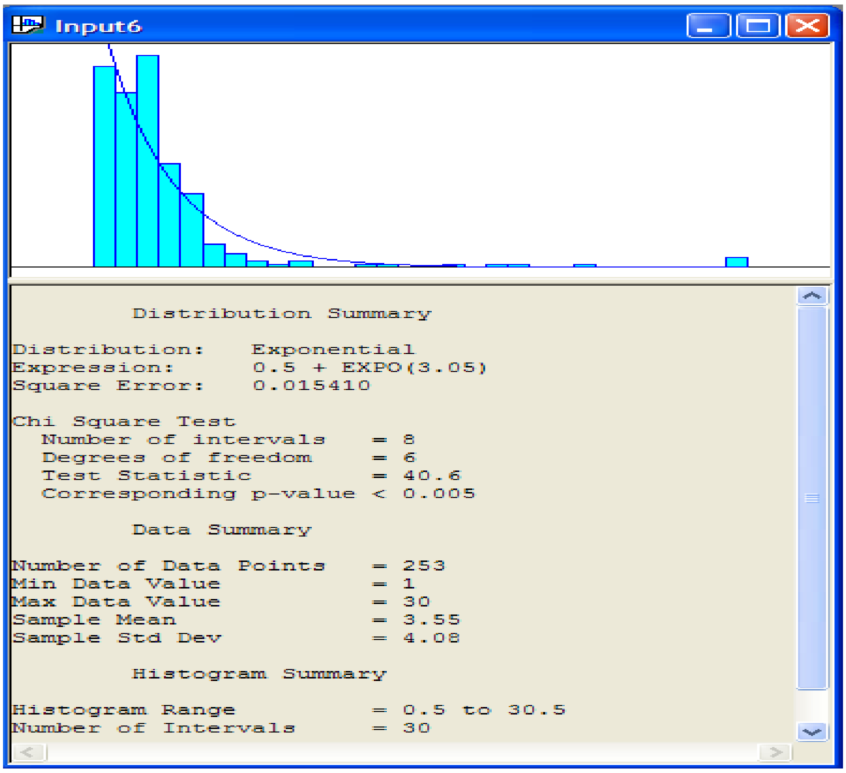

6.2.2.1 *Inter-arrival Time of Ships*

The inter-arrival time distribution is a basic input parameter that has to be assumed or inferred from observed data (Kelton et al., 2007). The most commonly assumed distributions in literature are the exponential distribution (Demirci, 2003; Dragovic, Park, Radmilovic, & Maras, 2005; Pachakis & Kiremidjian, 2003); the negative exponential distribution (Shabayek & Yeung, 2002) or the Wiebull Distribution (Dragovic et al., 2005). Figure 6.4 shows the distribution summary of inter arrival time of ship at MCH.

Figure 6.4: Distribution Summary of Inter Arrival Time

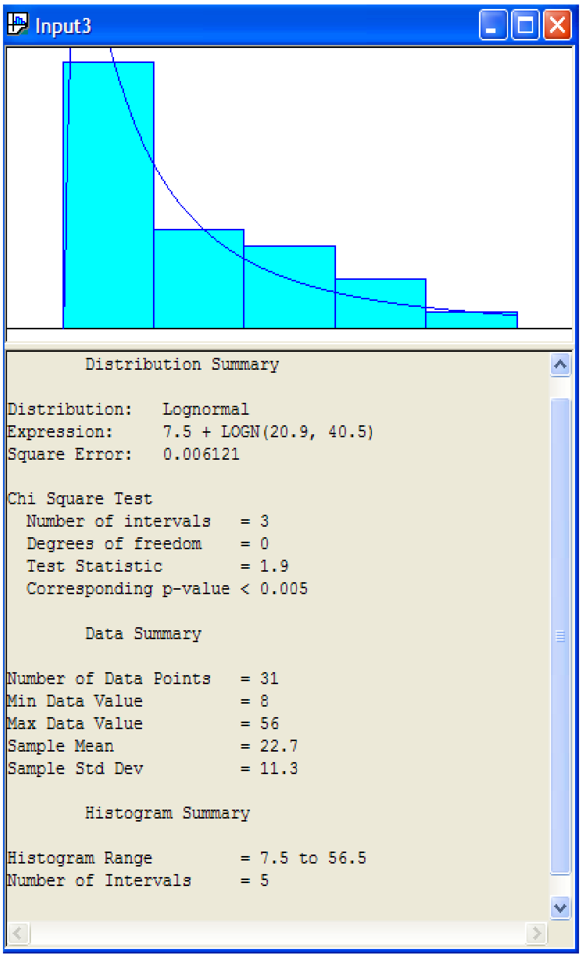


```
           Distribution Summary

Distribution:    Exponential
Expression:      0.5 + EXPO(3.05)
Square Error:    0.015410

Chi Square Test
   Number of intervals    = 8
   Degrees of freedom     = 6
   Test Statistic         = 40.6
   Corresponding p-value  < 0.005

           Data Summary

Number of Data Points     = 253
Min Data Value            = 1
Max Data Value            = 30
Sample Mean               = 3.55
Sample Std Dev            = 4.08

           Histogram Summary

Histogram Range           = 0.5 to 30.5
Number of Intervals       = 30
```

6.2.2.2 *Loading and Unloading of Ships*

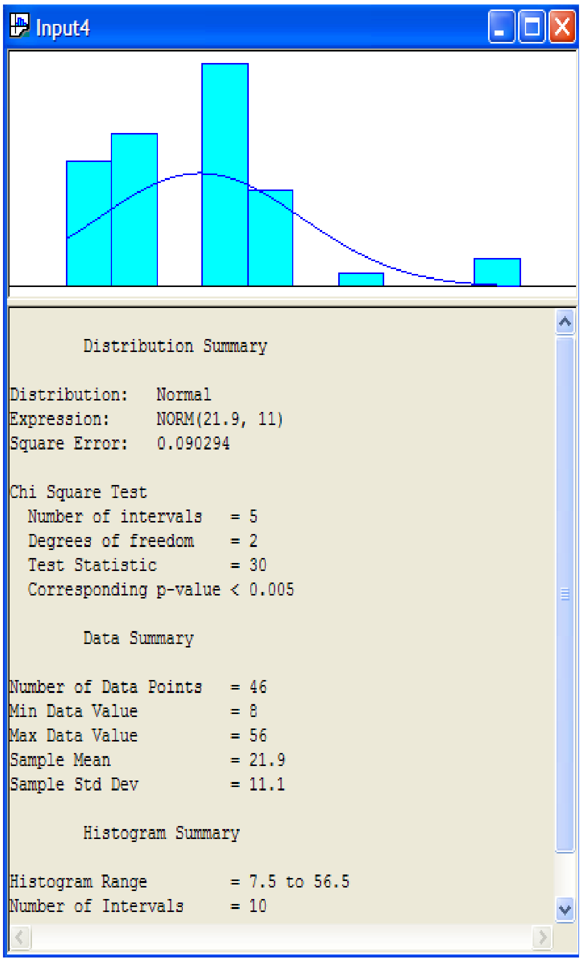
Accurate representation of number of lifts per ship call is one of the basic tasks of ship-berth link modelling procedures (Dragovic et al., 2005). Empirical distributions of the number of lifts per ship are often found to fit the lognormal distribution (Dragovic et al., 2005; Park, Dragovic, & Mestrovic, 2008) and normal distribution (Dragovic et al., 2005). Figure 6.5 and Figure 6.6 shows distribution summary of loading and unloading of ship respectively.

Figure 6.5: Distribution Summary of Loading of Ship



```
        Distribution Summary

Distribution:   Lognormal
Expression:     7.5 + LOGN(20.9, 40.5)
Square Error:   0.006121

Chi Square Test
  Number of intervals    = 3
  Degrees of freedom     = 0
  Test Statistic         = 1.9
  Corresponding p-value < 0.005

        Data Summary

Number of Data Points    = 31
Min Data Value           = 8
Max Data Value           = 56
Sample Mean              = 22.7
Sample Std Dev           = 11.3

        Histogram Summary

Histogram Range          = 7.5 to 56.5
Number of Intervals      = 5
```

Figure 6.6: Distribution Summary of Unloading of Ship

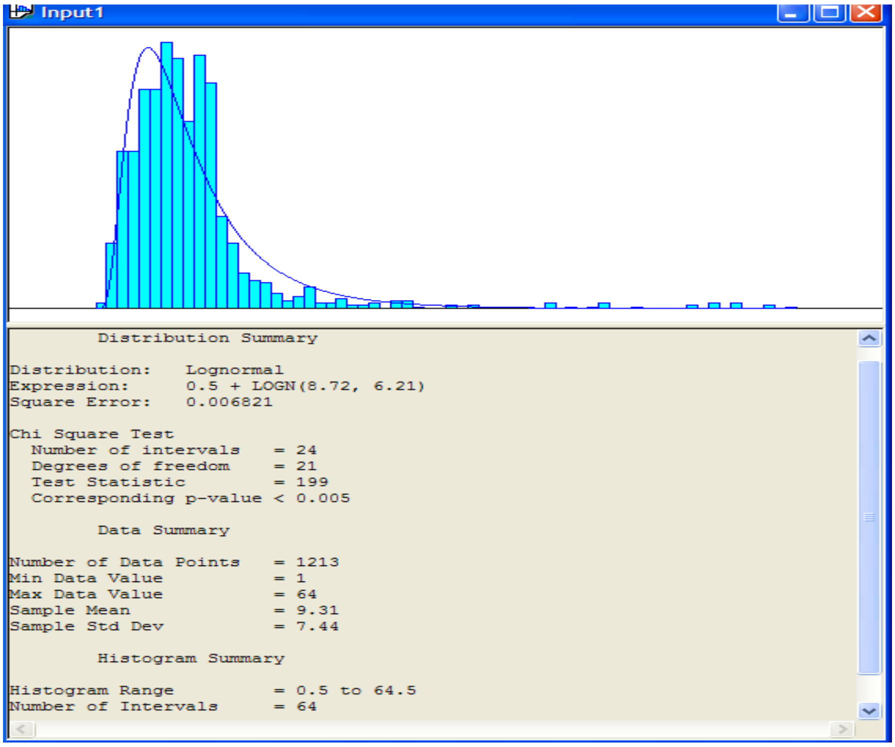


```
        Distribution Summary

Distribution:   Normal
Expression:     NORM(21.9, 11)
Square Error:   0.090294

Chi Square Test
  Number of intervals    = 5
  Degrees of freedom     = 2
  Test Statistic         = 30
  Corresponding p-value < 0.005

        Data Summary

Number of Data Points    = 46
Min Data Value           = 8
Max Data Value           = 56
Sample Mean              = 21.9
Sample Std Dev           = 11.1

        Histogram Summary

Histogram Range          = 7.5 to 56.5
Number of Intervals      = 10
```

6.2.2.3 Un-stuffing Container

As mentioned earlier, it is a unique characteristic of Male’ Port that all containers get stripped open in port. Importers take unstuffed cargo leaving empty containers. To obtain an accurate representation of un-stuffing time of containers, about 1200 container data are obtained from MPL and are analysed using Input Analyser. Figure 6.7 shows the probability distribution of un-stuffing time of containers.

Figure 6.7: Distribution Summary of Un-stuffing Container



```
        Distribution Summary

Distribution:   Lognormal
Expression:     0.5 + LOGN(8.72, 6.21)
Square Error:   0.006821

Chi Square Test
  Number of intervals   = 24
  Degrees of freedom    = 21
  Test Statistic        = 199
  Corresponding p-value < 0.005

        Data Summary

Number of Data Points   = 1213
Min Data Value          = 1
Max Data Value          = 64
Sample Mean             = 9.31
Sample Std Dev          = 7.44

        Histogram Summary

Histogram Range         = 0.5 to 64.5
Number of Intervals     = 64
```

6.2.2.4 Summary of Distribution Estimation

Table 6.1 shows summary of all input parameters used in the model.

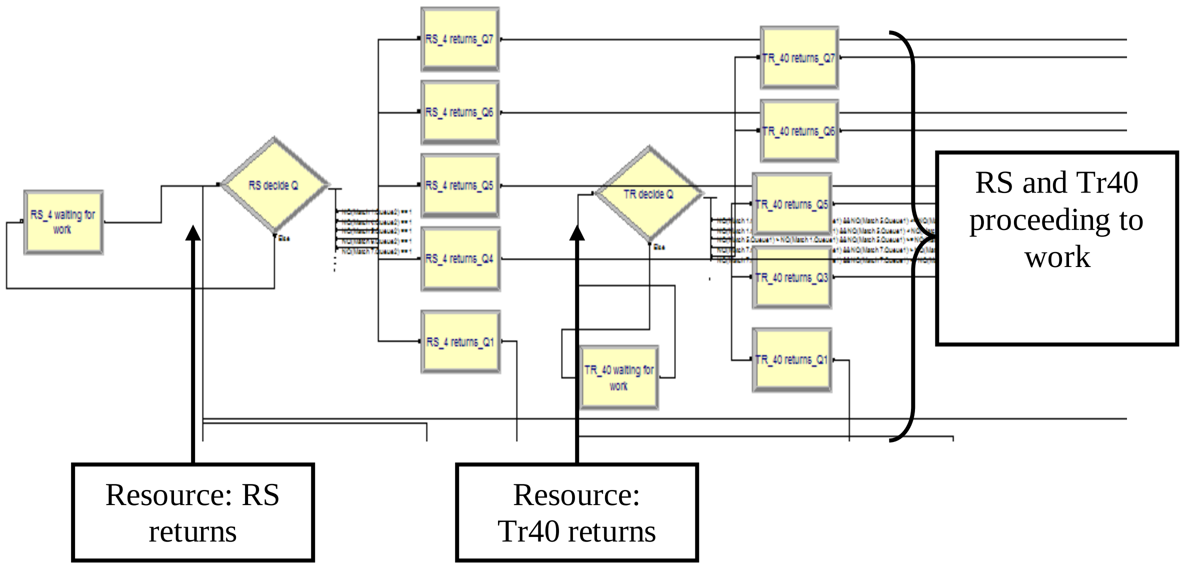
Table 6.1: Summary of Simulation Model Parameters

Type of data	Distributions	Parameters
Number of	Constant	
Ship cranes		2 (per ship)
Trailer (20’)		1
Trailer (40’)		1
Forklifts (20’)		2
Reach-stacker		3
RTG		1
Processing time		
Inter arrival of ship (days)	Exponential	0.5+Expo(3.05)
Loading time of ship (hours)	Lognormal	7.5+LOGN(20.9,40.5)
Unloading time of ship (hours)	Normal	NORM(21.9,11)
Un-stuffing time (days)	Lognormal	5+LOGN(8.72,6.21)
Ship crane (minutes)	Uniform	UNIF(2, 4)
Forklift (minutes)	Triangular	TRIA(2, 2.5, 3)
Reach-stacker (minutes)	Triangular	TRIA(2, 2.5, 3)
RTG (minutes)	Triangular	TRIA(3, 4, 5)
Speed Limits		
Trailer (20’)	Constant	15km/h maximum
Trailer (40’)	Constant	10km/h maximum
Transportation speed (m/s)		
from a berth to yards	Triangular	
with a container		TRIA (6, 8, 10)
without a container		TRIA (10, 12, 14)

6.2.3 Resource Unit Simulation Models

Most simulations involve “players” called entities that move around, change status, affect and are affected by other entities and the state of the system, and affect the output performance measures (Kelton et al., 2007). These entities often compete with each other for service from resources that represent things like personnel, equipment, or space in a storage area of limited size. An entity seizes a resource when available and releases it when finished (Kelton et al., 2007). In this study containers (20 foot and 40 foot) are the entities and resource unit are represented by either Ship Crane (SC), Trailer (Tr), Forklift (FL), RTG, and reach-stacker (RS). Resource units like RS, TR, FL, and RTG are also considered as entities for the controlling purposes. Port resources have to be controllable rather than programmed for specific operation cycles (Solomenikov, 2006). There are two different sets of resources for two different types of entities (20 foot and 40 foot containers). Figure 6.8 shows how these resources are controlled in the model.

Figure 6.8: Resource Unit Control Structure



Once a resource unit is created upon the simulation program it enters into a decide module. Here, the resource unit looks for work and if there is no work it enters into a *hold module*. The resource unit is held in the module until a signal is received requesting the resource unit. This reduces resource queuing at locations where they are not needed at a given point in time. Furthermore, it helps allocating resources where is it most needed instead of wasting time in less needed queues.

This corresponds well to the real-life working algorithms at MCH where resource units like trailers and forklifts are parked when there is no work and drivers take breaks during free time. Once these resources are needed for a job the supervisor in charge radio calls the driver and the resource unit is sent to the job immediately. Once the resource is at the location of resource job the duration of the job is modelled by a respective *Process module*. The process module uses input parameters, modelled by probability distribution functions based on basic data, which bring random deviation to the working time of resource units.

6.2.4 Modelling Resource Operational Cycle

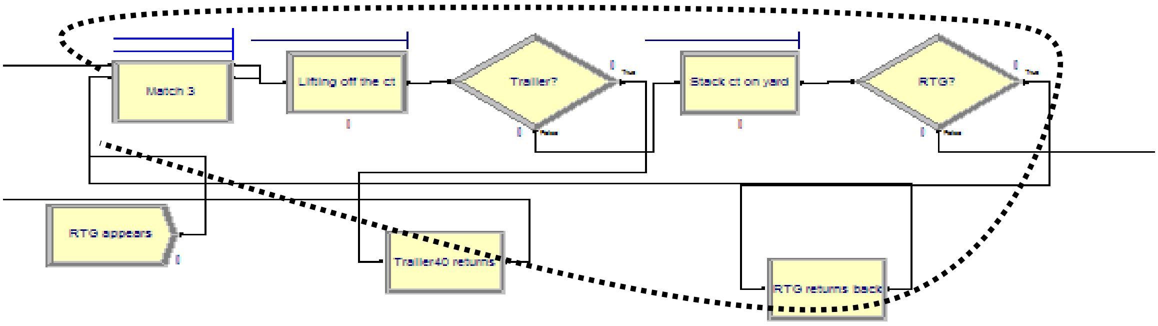
One of the most important and challenging tasks about modelling is to choose a reasonable level of detailed abstraction without making the model too complex for the end user (Kelton et al., 2007). To keep the model logic simple and realistic, resource operational cycles are introduced in the model. Some resource cycles featured in the model are presented in the following paragraphs.

Rubber Tired Gantry Crane operational cycle: - RTG to start work the following events need to occur:

1) current working time should be positive
2) should receive a signal indicating work

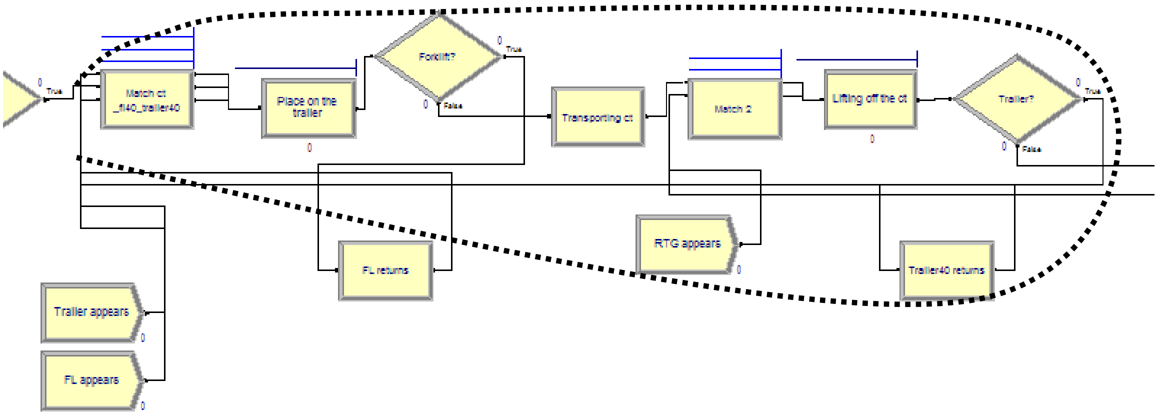
The first provision allows taking into consideration the lunch breaks, shift change breaks, and resource failures. The second condition allows the equipment not to make unnecessary moves when there is no work or wait in a queue when there is no job Figure 6.9 shows RTG's operational cycle.

Figure 6.9: Rubber Tired Gantry Crane (RTG) Operational Cycle



Trailer Operational Cycle: - Figure 6.10 shows trailer operation cycle. Modelling logic of trailer operational cycle is more complicated than that of TRG because it has more queues.

Figure 6.10: Trailer Operational Cycle



6.2.5 Modelling Container Chain

To develop the simulation model, the logic of MCH is divided into three levels. The first level involves general processes, for example ship arrives → unload import containers → load export containers → ship leaves terminal, to more detailed processes such as loading and discharging of each single container, to allocation and monitoring of resources to each of these entities. The general processes are represented by a top-level model and more detailed ones are represented with sub-models. Accordingly, three models structures representing different levels of detailing are developed.

1) **Top–level:** General model of MCH representing the service processes of every single container ship entering the port. This model shows the logistics of servicing of vessels at berth and at anchorage, using lighters.

2) **Loading/unloading containers:** a detailed model of berth and anchorage services showing in detail loading and discharge of every single container move.

3) **Clients take cargo:** a detailed model of import yard and un-stuffing area services.

The latter is modelled separately because of the software limitations. The Academic Version of Arena, used in this study, has a range of limitations; for example, boundaries on number of Modules, Elements, Cinema Objects and the size limitation of 150 entities. The entire chain of MCH is too big to be modelled in the Academic Version, therefore, ‘Clients take cargo model' is developed separately and conjoint results are analysed using Microsoft Excel. Figure 6.11, Figure 6.12, figure 6.13 and figure 6.14 show Top-level model, Unloading of container model, Loading of container model, , and Clients take cargo model respectively.

Figure 6.11: Top–level Model

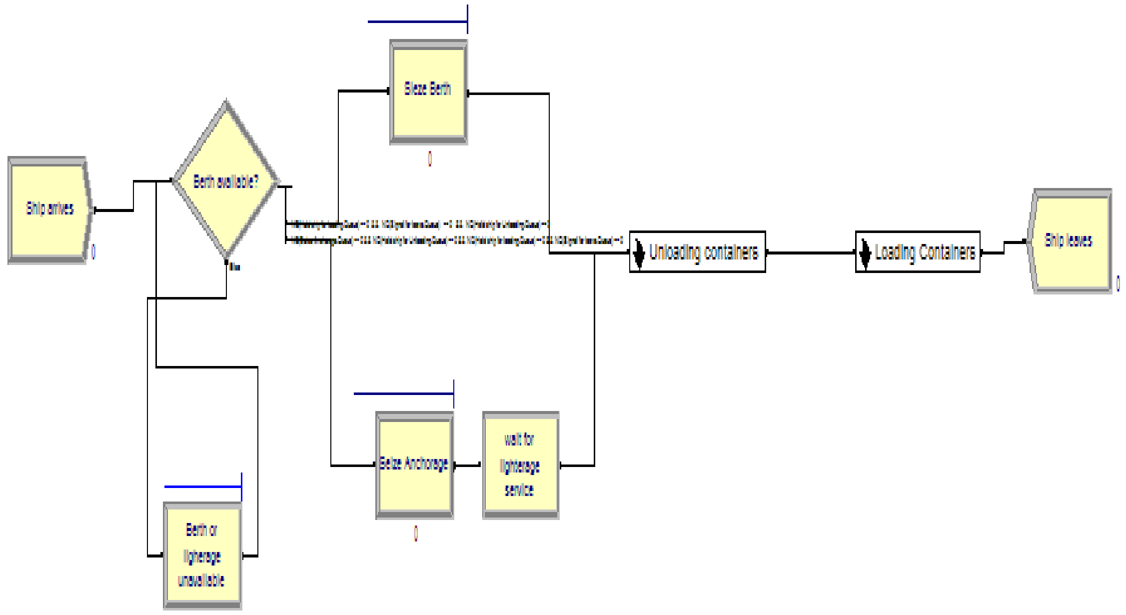


Figure 6.12: Unloading of Container Model (Sub-model)

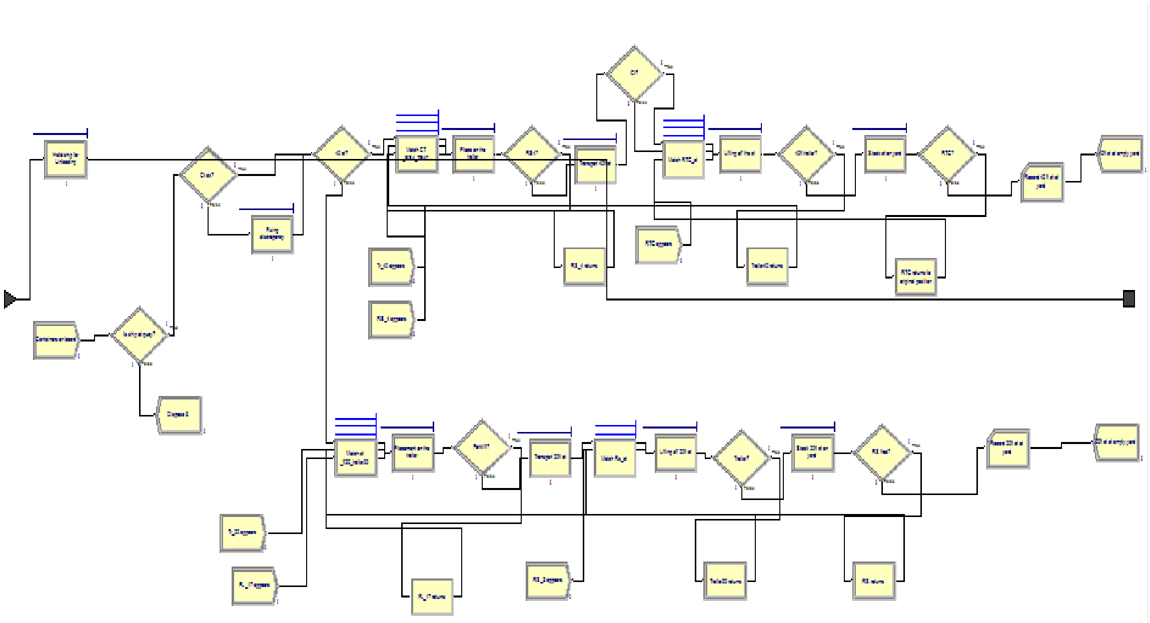


Figure 6.13: Loading Container Model (Sub-model)

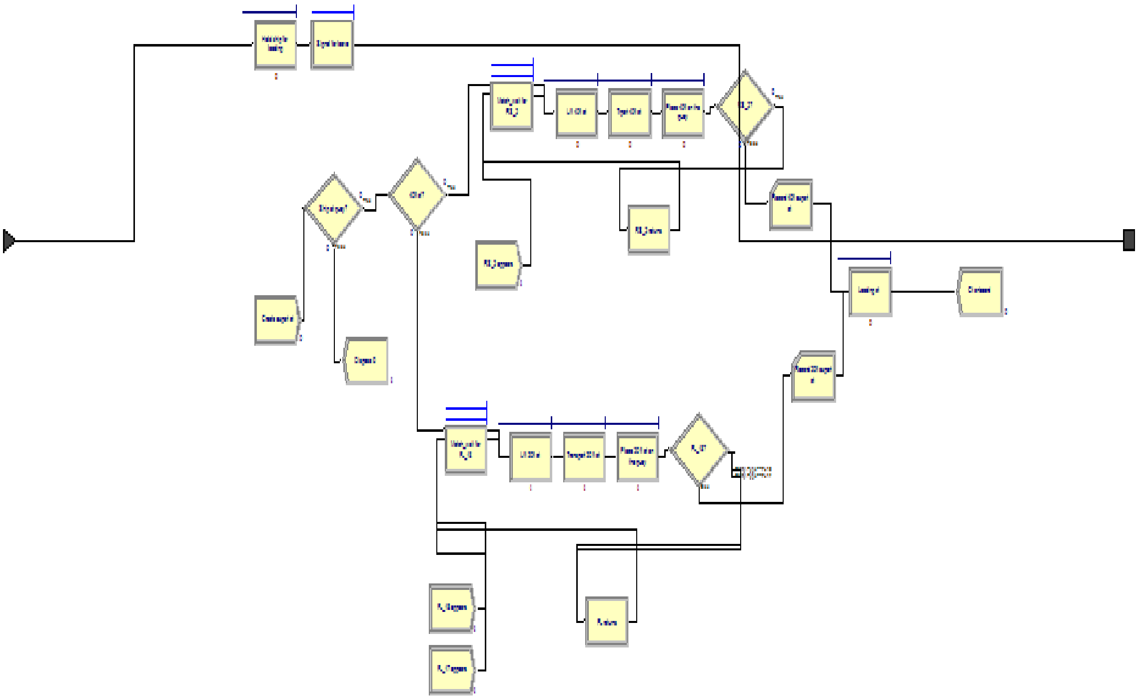
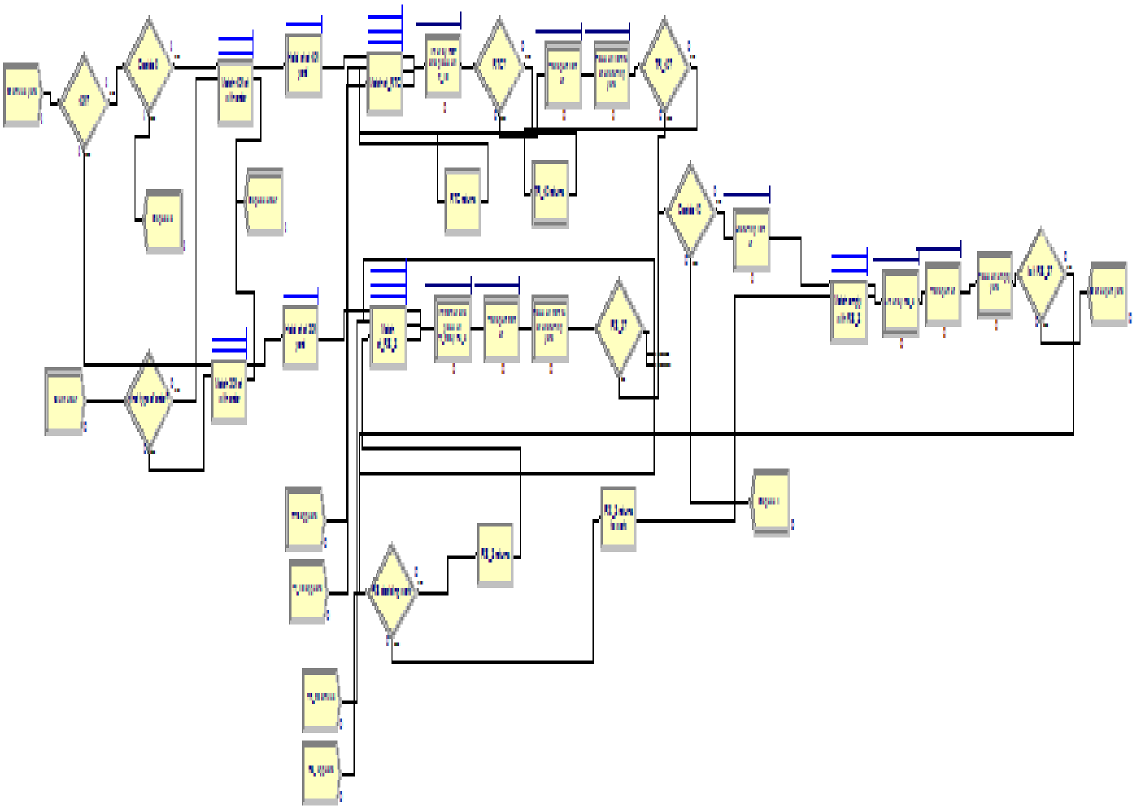


Figure 6.14: Clients Take Cargo Model



6.2.6 Model Assumptions

Modelling of a complete container terminal is extremely complex (C. Chen et al., 2007); and therefore, it is *"difficult to model the reality of a container terminal in a simple model"* (Meier, Lackner, Fischer, & Biethahn, 2006, p. 3). Thus, assumptions are made whilst developing the MCH model, and they are listed below.

- The model takes into account the vessel process from arrival to departure only. The hinterland processes are not considered
- All stowage planning and yard planning are done correctly and corresponding orders are given promptly
- Ship cranes can reach all containers across onboard ship, and are able to lift every container
- Delays arising from problems such as weather and strikes are not considered; however, machine failures and shift break delays are taken into account
- Every container stays at the right place in the yards - import yard, export yard, and un-stuffing yard. No reshuffling of containers occurs during stacking or un-stacking process, and no unnecessary movements of containers take place
- Every importer/distributor is equal, no bribery or politics appear

6.2.7 Model Verification and Validation

Having constructed and run the model, the next activity would be to verify that the "code" (Arena file) is free of bugs and validate that the conceptual model really represents the system being studied (Kelton et al., 2007). Model verification is a process where the modeller ensures that the model behaves as intended (Huynh & Walton, 2005). To verify and debug the model, Arena's Run Controller tool is used. This tool allows the modeller to step through the programme in stages as entity progress from one module to the next. It also allows Break on Module and Highlight Module. In addition, some animations are done to see visually how ships, containers, cranes, and trucks move within the system. This helped in detecting unintended and undesired movements of equipment; thus assisted in verifying the logic implemented. *"....animation is often useful during the verification and validation phases* *because it allows you to view the entire system being modelled as it operates"* (Kelton et al., 2007, P. 132).

Model validation is the task that ensures the model works in the same way as the real system. It also ensures that the results it produces are within an acceptable level of accuracy (Huynh & Walton, 2005). To this end, validation of the MCH model was performed by comparing statistics on terminal operation, obtained through simulation experiments, with real life data, provided by MPL management. For this purpose, the Chi-Square statistical test was applied. To compare real data with simulation output three statistics were used: inbound container, dwell time of container, and quay utilisation. The simulation model was run for 44 statistically independent replications, as Huyunh & Walton (2005) did in their study. The simulation time period is 30 days, 15.5 hours a day, 6 days a week (MCH operates 6 days a week, 15.5 hours a day). The average results of the above three statistics from simulation experiment versus the actual data provided by the management are as follows.

Inbound container:	Actual = 3979 TEUs per month
	Simulation result = 4174.55 TEUs ±10.40 ($\alpha = 0.05$)
Dwell Time of container:	Actual = 12 days (average)
	Simulation result = 14 days ± 1.05 ($\alpha = 0.05$)
Quay utilisation:	Actual = 70%
	Simulation result = 74.45% ± 8 ($\alpha = 0.05$)

Comparison between output and real data show fairly similar values and are in agreement with each others. This conclusion gives validity to the model.

6.3 Chapter Summary

The chapter concentrates on the development of a simulation model using Rockwell Software Arena. The model parameters are analysed using Input Analyser. To develop MCH simulation model, the logic is divided into three levels. The first level involves general processes which are represented by top-level model and more detailed ones are represented with sub-models. To keep the model logic simple and more realistic, resource operational cycles are introduced in the model.

Since complete container terminal modelling is complex, several assumptions were made while developing the model. To validate the model comparison is made between simulation results and real data provided by the management of MPL. Three statistics are selected and the observation shows very similar values. This supports the validity of the model.

CHAPTER 7

Presentation and Discussion of Results

7.1 Introduction

The previous chapter has described the development of a simulation model and how it was run. This chapter discusses the results of the research and the outcomes in detail. As such, the chapter is divided into two sections. The first section deals with presenting and analysing the results. The second section discusses the results and their implications in the light of methodological constraints, leading to conclusions and recommendations.

7.2 Presentation of Results

The outputs of the simulation exercise provide various logistic parameters that are informative for several possible management decisions. However, only the following variables are considered for this assessment as they are the most relevant ones for this study;

- ***Vessel turn around time* -** the time gap between vessels’ berthing and departure. The variable includes the queuing time for a free berth.
- ***Berth capacity* -** the berth usage
- ***Yard capacity* -** the yard land area usage
- ***Container dwell time* -** the elapse of time between a container’s arrival (inbound) and its departure (outbound)
- ***Queue values for berth and lighterage services* -** vessel time in queue for free berth and lighterage service
- ***Utilisation of ship cranes* -** the proportion of available time that ship cranes are operating
- ***Utilisation of container handling equipment***

7.2.1 Simulation Model Output

The model was run for 44 statistically independent replications for a period of 15.5 hours a day for 30 days. The average results were recorded within Arena as reports. Figure 7.1 shows a sample report from Arena. See Appendix G for a full set of reports.

Since the model was run for 44 replications, Arena collected summary results of output performance for each replication and averaged them over all replications. The "Half Widths" shown in the reports are half widths of confidence intervals at 95% confidence interval on the expected value of the performance measures. The formula to compute half width is shown below (Kelton et al., 2007).

$$H = t_{n-1,1-\alpha/2}\frac{s}{\sqrt{n}}$$

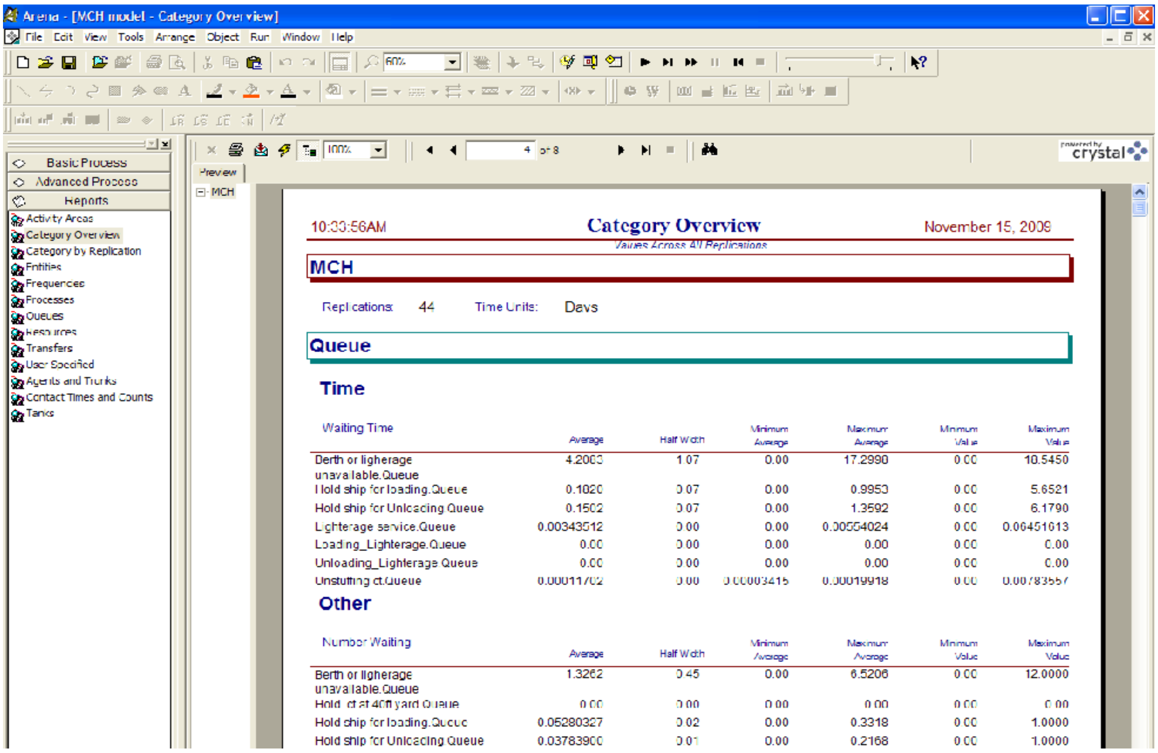
Where:

H = half width of the $(1-\alpha)$ confidence interval, $\alpha = 0.05$

s = sample standard deviation

n = number of replications

Figure 7.1: Simulation Model Output Report



10:33:56AM **Category Overview** November 15, 2009

Values Across All Replications

MCH

Replications: 44 Time Units: Days

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Berth or ligherage unavailable.Queue	4.2003	1.07	0.00	17.2990	0.00	10.5450
Hold ship for loading.Queue	0.1020	0.07	0.00	0.9953	0.00	5.6521
Hold ship for Unloading Queue	0.1502	0.07	0.00	1.3592	0.00	6.1790
Lighterage service.Queue	0.00343512	0.00	0.00	0.00554024	0.00	0.06451013
Loading_Lighterage.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unloading_Lighterage Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unstuffing ct.Queue	0.00011702	0.00	0.00003415	0.00019918	0.00	0.00783557

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Berth or ligherage unavailable.Queue	1.3262	0.45	0.00	6.5206	0.00	12.0000
Hold ct at 40ft yard Queue	0.00	0.00	0.00	0.00	0.00	0.00
Hold ship for loading.Queue	0.05280327	0.02	0.00	0.3318	0.00	1.0000
Hold ship for Unloading Queue	0.03783900	0.01	0.00	0.2168	0.00	1.0000

7.2.1.1 Ship Turnaround Time

7.2.1.1.1 Ship Time at Berth

Simulation results show that a ship occupies a berth on average 5.25 days (± 0.86; $\alpha = 0.05$) for loading and unloading purposes. The maximum time is shown 21.76 days on average, and the minimum is shown 2.34 days on average. This represents only the elapsed time that was accrued by ships at berth or lighterage. Table 7.1 shows a summary of ship time at berth statistics.

Table 7.1: Ship Time at Berth (Value Added Time)

Simulated elements	Value (days)
Ship's time at berth (μ)	5.25
Ship's time at berth (σ)	± 0.86
Minimum average	2.34
Maximum average	21.76

7.2.1.1.2 Ship Waiting Time for Berth Queue

Table 7.2 shows statistics of ships "waiting time for berth queue". On average ships spend 4.20 days (± 1.08; $\alpha = 0.05$) at anchorage waiting for a berth. The maximum waiting time for berth queue is shown as 17.30 days average over 44 replications. The maximum average is calculated by collecting maximum ship waiting time of each replication and averaging them over all replications.

Table 7.2: Ship Wait Time for Berth Queue

Simulated elements	Value (days)
Ship's waiting time for berth (μ)	4.20
Ship's waiting time for berth (σ)	± 1.07
Minimum average	0.00
Maximum average	17.30

7.2.1.1.3 Total Accumulated Time

Table 7.3 shows the total accumulated time of ships at berth (ship turnaround time). This represents the total time that is accrued by ships at berth or queue, associated with loading and unloading activities, as well as non-value added time and waiting time of ship for berth availability. Thus, this represents turnaround time of ships.

The results show the mean ships turnaround time is 7.06 (± 1.00; $\alpha = 0.05$). The maximum turnaround is figured out as 21.76 days and the minimum is shown to be 2.34 days, averaged over 44 replications.

Table 7.3: Ship Turnaround Time

Simulated elements	Value (days)
Ship's turnaround time (μ)	7.06
Ship's turnaround time (σ)	± 1.00
Minimum average	2.34
Maximum average	21.76

7.2.1.2 Container Throughput

Table 7.4 shows simulation results of container throughput (inbound plus outbound). The total container throughput per month is shown as 8347 TEU with a half width of 10.40; $\alpha = 0.05$. The minimum average is 8215 TEUs while the maximum is shown around 8545 TEUs per month. The minimum and maximum averages of container throughput are calculated by collecting minimum and maximum number of containers (inbound plus outbound) of each replication and averaging them over all replications.

Table 7.4: Container Throughput

Simulated Elements	Value (TEUs)
Throughput (μ)	8347
Throughput (σ)	± 10.40
Minimum average	8215
Maximum average	8545

7.2.1.3 Dwell Time of Containers

The mean dwell time of containers (the average length of time that each container spends in the terminal) is shown 14.14 days average (±0.5; $\alpha = 0.05$). The maximum average is shown 22.24 days. Table 7.5 shows simulation outputs of container dwell time statistics.

Table 7.5: Dwell Time of Containers

Simulated Elements	Value (day)
Dwell time of containers (μ)	14.14
Dwell time of containers (σ)	± 0.05
Minimum average	0.44
Maximum average	22.24

7.2.1.4 Utilisation of Equipment

Arena reports two utilisation statistics, called Instantaneous Utilisation and Scheduled Utilisation for each resource used in the model. Instantaneous Utilization is calculated by computing the utilisation at a particular instant in time (that is, [number of resource units busy] / [number of resource unit scheduled] at that point in time) and calculating a time-weighted average of this over the whole run (Kelton et al., 2007). This can be expressed by the following formula (Kelton et al., 2007):

$$\int_0^T U(t)dt / T$$

Where:

U(t): Number of Resource units busy / number of Resource unit Schedule

T: Time period

Schedule Utilisation is the time average number of units of the resource that are busy (taken over the whole run), divided by the time-average number of units of the resource that are scheduled (over the whole run) (Kelton et al., 2007). This can be expressed by the following formula (Kelton et al., 2007):

$$\frac{\int_0^T B(t)dt / T}{\int_0^T M(t)dt / T} = \frac{\int_0^T B(t)dt}{\int_0^T M(t)dt}$$

Where:

B(t): number of units of the resources busy at time t

M(t): number of units of the schedule at time t

7.2.1.4.1 Utilisation of Ship Cranes

Table 7.6 shows instantaneous and schedule utilisation of ship cranes. Instantaneous utilisation figure 0.20 shows that 20% of the time of the entire run the ship cranes were busy. The schedule utilisation figure 0.24 explains that the ship cranes were utilised only 24% of their total available time.

Table 7.6: Utilisation of Ship Cranes

Simulated Elements	Instantaneous Utilization	Scheduled Utilisation
Utilisation of ship cranes (µ)	0.20	0.24
Utilisation of ship cranes (σ)	± 0.02	± 0.02
Minimum average	0.05	0.06
Maximum average	0.30	0.35

7.2.1.4.2 Utilisation of Quay

The instantaneous and schedule utilisation of quay shows similar figures because the capacity of the resource (quay) was considered fixed and there is no inactive or failed state with regard to quay. The simulation result shows that 74% of the time the quay is utilised. Table 7.7 shows statistics of quay utilisation.

Table 7.7: Utilisation of Quay

Simulated Elements	Instantaneous Utilization	Scheduled Utilisation
Utilisation of quay (µ)	0.74	0.74
Utilisation of quay (σ)	± 0.08	±0.08
Minimum average	0.22	0.22
Maximum average	1.00	1.00

7.2.1.4.3 Utilisation of Other Equipment

The results shows that for 6% of the entire run the RTG was busy, and only 7% of RTG's available times were utilised. The instantaneous utilisation of reach-stackers, 20 foot trailer, 40 foot trailer, and forklifts show 14%, 26%, 7%, and 8% respectively. The schedule utilisation of reach-stacker is 16%, 20 foot trailer is 30%, 40 foot trailer is 8%, and forklifts 9%. Table 7.8, Table 7.9, Table 7.10, and Table 7.11 show instantaneous and schedule utilisation statistics of RTG, reach-stacker, trailers, and forklifts respectively.

Table 7.8: Utilisation of RTG

Simulated Elements	Instantaneous Utilization	Scheduled Utilisation
Utilisation of RTG (µ)	0.06	0.07
Utilisation of RTG (σ)	± 0.01	±0.01
Minimum average	0.01	0.01
Maximum average	0.10	0.11

Table 7.9: Utilisation of Reach-stackers

Simulated Elements	**Instantaneous Utilization**	**Scheduled Utilisation**
Utilisation of reach-stackers (µ)	0.14	0.16
Utilisation of reach-stackers (σ)	± 0.02	±0.02
Minimum average	0.02	0.02
Maximum average	0.23	0.26

Table 7.10: Utilisation of Trailers

Simulated Elements	**Instantaneous Utilization**	**Scheduled Utilisation**
Trailer 20 foot (Tr_20)		
Utilisation of Tr_20 (µ)	0.26	0.30
Utilisation of Tr_20 (σ)	± 0.03	±0.03
Minimum average	0.03	0.03
Maximum average	0.41	0.47
Trailer 40 foot (Tr_40)		
Utilisation of Tr_40 (µ)	0.07	0.08
Utilisation of Tr_40 (σ)	± 0.01	±0.01
Minimum average	0.01	0.01
Maximum average	0.11	0.13

Table 7.11: Utilisation of Forklifts

Simulated Elements	**Instantaneous Utilization**	**Scheduled Utilisation**
Utilisation of forklifts (µ)	0.08	0.09
Utilisation of forklifts (σ)	± 0.01	±0.01
Minimum average	0.02	0.02
Maximum average	0.13	0.14

7.2.1.5 Capacity Evaluation

7.2.1.5.1 Yard Capacity

The existing container yard of MCH has an area of about 1.6 ha that consists of 1487 TEU ground slots. In the yard, containers are stacked three high on average. The ratio of working slot to stacking slot is 0.33: 0.67 ("Maldives Ports Limited," 2009). Simulation results show that dwell time of containers is 14 days. The peak factor is assumed as 1.2 (Cronje, 2006). MCH operates 356 days a year. Based on these data the annual yard capacity (the number of TEUs that can be accommodated in the container yard for a period of one year) can be calculated using the following formula proposed by Watanabe (2002).

$$AnualYardCapacity = (L \times H \times W \times K) \div (D \times F)$$

Where:

L = number of container ground slots (in TEU)

H = mean stacking height of containers

W = number of working slots (in TEU) in container yard expressed as a proportion ($0 < W < 1$)

K = total number of working days per year

D = mean container dwell time in the container yard

F = peaking factor $F > 1$)

$\therefore$ Annual Yard Capacity of MCH = (1487 x 3 x 0.33 x 356) ÷ (10 x 1.2)

= 43673 TEUs

7.2.1.5.2 Berth Capacity

MCH has a single container berth of 101m in length with an alongside depth of 9.5 m. The containers are loaded/unloaded using ships' own gear. Each ship has two cranes and the handling rate is 5 TEUs per hour. MCH operates 15.5 hours a day, 6 days a week, 356 days a year. The berth utilisation is considered to be 70%, although the actual berth utilisation of MCH shows over 74%. Seventy is the upper limit; no prudent terminal operators allow their berth occupancy to exceed 70% (Cronje, 2006). Using these statistics annual berth capacity of MCH can be calculated using the following formula proposed by Cronje (2006).

$$AnnualBerthCapacity = B \times H \times C \times W$$

Where:

B = Berth Utilisation

H = Per-crane Handling Rate

C = Number of Cranes

W = Working Hours per Day

$\therefore$ Annual Berth Capacity of MCH = 356 x 70% x 5 x 2 x 15.5

= 38626 TEUs

7.3 Discussion of Results

7.3.1 Revisiting the Research Objectives

In order to focus on the main analysis and to direct the discussion, the research objectives are reiterated here. In general, the main objective of this research was to analyse the current situation of MCH and identify logistic bottlenecks that exist within the port terminal. The more specific objectives include but are not limited to:[3]

- analyse the ship working rate of the port terminal
- analyse the utilisation of port terminal equipment
- analyse berth capacity of the port terminal
- analyse the yard capacity of the port terminal
- analyse dwell time of container in the port terminal
- analyse and propose measures that can be taken by MCH to maximise the capacity
- provide a cost benefit analysis for implementation of the proposed measures

7.3.2 Ship Working Rate

Simulation result shows that meantime of ship at berth is 7 days (± 1.00; $\alpha = 0.05$) out of which about 4 days are spent on waiting for berth queue, and about one and half day each on loading and unloading containers. This means about 57% of the total time of a ship at MCH is spent waiting for berth queue. Figure 7.2 shows column chart for ship waiting time for major queues.

7.3.3 Utilisation of Resources

Figure 7.3 shows a histogram of schedule utilisation of main resources of MCH. It is obvious that quay or berth utilisation is highest compared with other resources. Simulation results show that berth utilisation is over 74%. According to (Cronje, 2006) prudent terminal

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[3] see chapter 1, section 1.2

operators never allow their berth occupancy to exceed 70%, and according to him even this figure is considered to be an upper limit rather than a working limit.

The utilisations of other equipment currently show fairly low percentages. However, this seems to be only a short-term problem, and it is unlikely to be the case in the long-term because of the increasing trend in cargo traffic in the future.

Figure 7.2: Ship Waiting Time for Queue

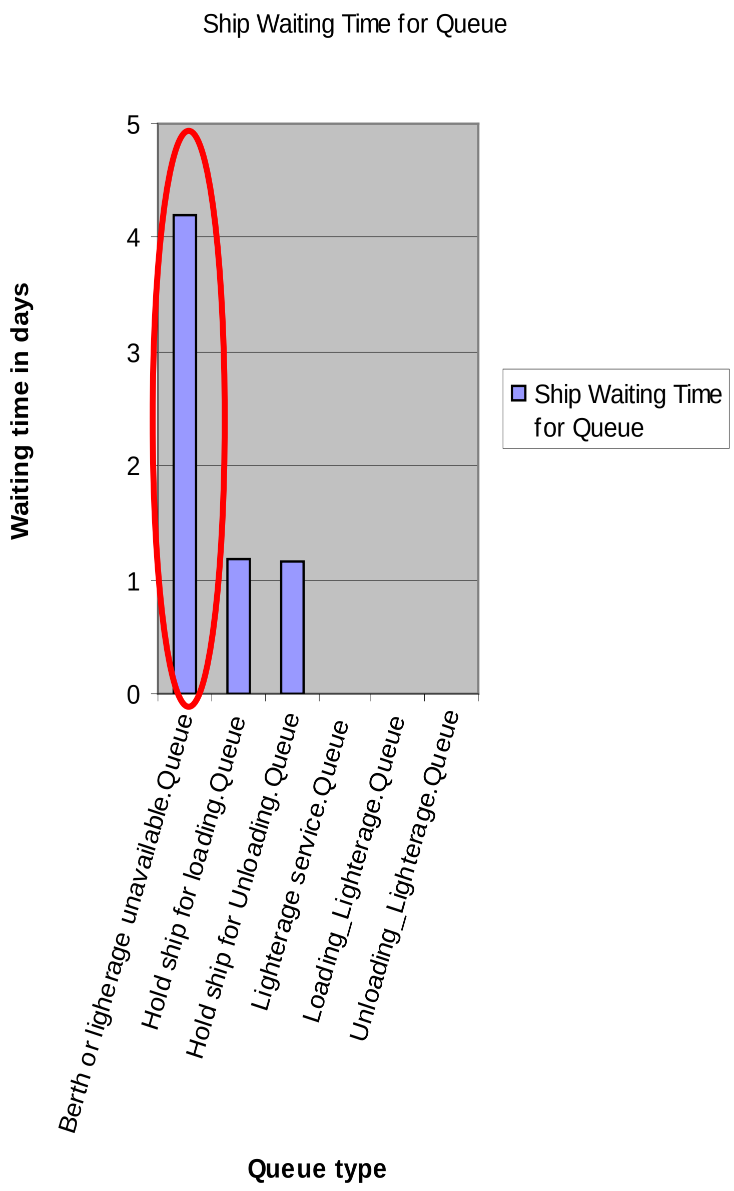
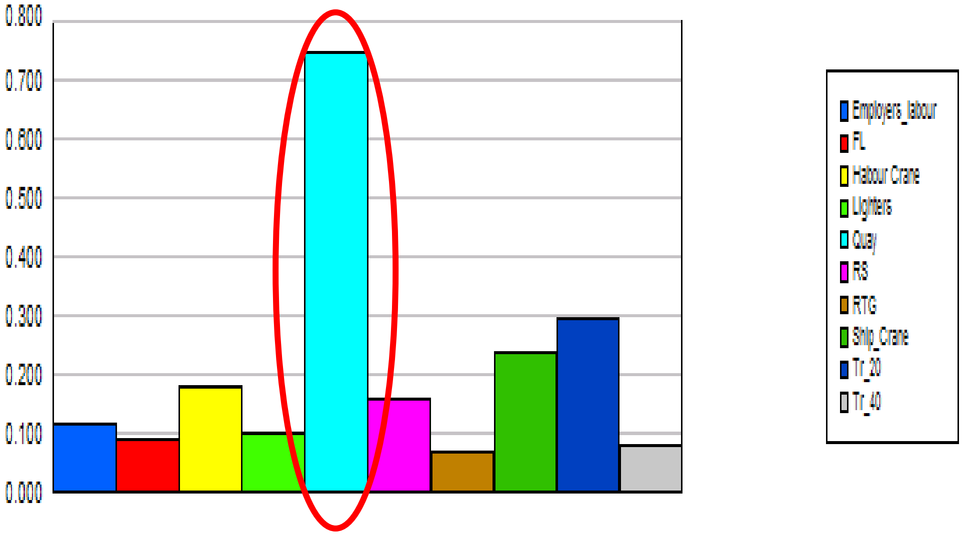


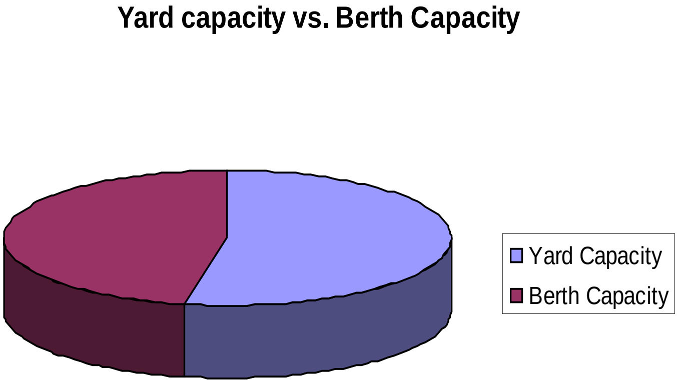
Figure 7.3: Schedule Utilisation of Resources



7.3.4 Yard Capacity vs. Berth Capacity

The annual berth capacity of MCH under the assumed conditions of analysis shows that annual yard capacity is 43676 TEUs and berth capacity is 38626 TEUs per year. These indices suggest that yard capacity is significantly greater than berth capacity. Figure 7.4 shows a pie chart representing yard capacity and berth capacity.

Figure 7.4: Representation of Yard Capacity and Berth Capacity



7.3.5 Identification of Main Constraints

It is evident from the forgoing discussions that the major limitation or bottleneck is the berth or quay. The berth capacity constraint is the main reason for longer queues and ship delays at

MCH. This capacity constraint may arise due to the limited number of quays (MCH has a single quay) or slower processing time of equipment such as ship cranes and other equipment related to container handling and transport. However, the simulation results confirm that container handling equipment are performing well with regard to queues and utilisations – no container handling equipment is used more than 30% of its available time.

Therefore, the berth capacity constraints arise either due to MCH having a single quay, higher processing time of ship cranes, or container handling rate at berth. Currently, container handling rate at alongside berth is 70 TEUs/berth/day and handling rate at lighterage is 42 TEUs/berth/day.

7.3.6 Scenario Testing

Scenario testing is performed using Arena to compare three scenarios against the base case to see which scenario has the maximum effect on ship waiting time for berth. The base case represents the present working algorithm of MCH and each scenario represents a hypothesis. In the first scenario, an additional yard (area equivalent to half of the current import yard) was introduced. In the second scenario, a new berth or quay having the same length as the current berth was introduced. In the third scenario, ship cranes (which are currently used to load and unload containers) were replaced with two quay cranes with assumed processing time of Uniform (2, 3) (Merkuryev, Merkuryev, & Tolujev, 2000). For each scenario, 44 statistically independent replications were performed.

Figure 7.5 shows computer generated outcomes for each scenario showing the best possible scenarios. In the chart the vertical box plot indicate 95% confidence intervals on expected values for each alternative scenario, and those coloured red are determined to be significantly better (less ship waiting time for berth) than those coloured blue. Figure 7.6 shows a numerical value of each scenario, such as minimum and maximum across the replications, the half width of 95% confidence intervals, and low and high values that are the bounds of the confidence intervals.

Figure 7.5: Berth Waiting Time by Scenario

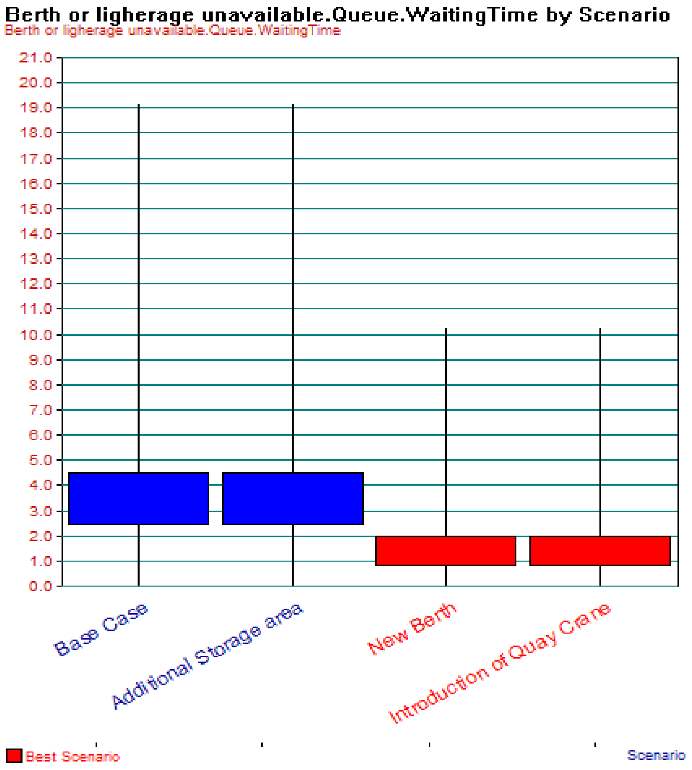
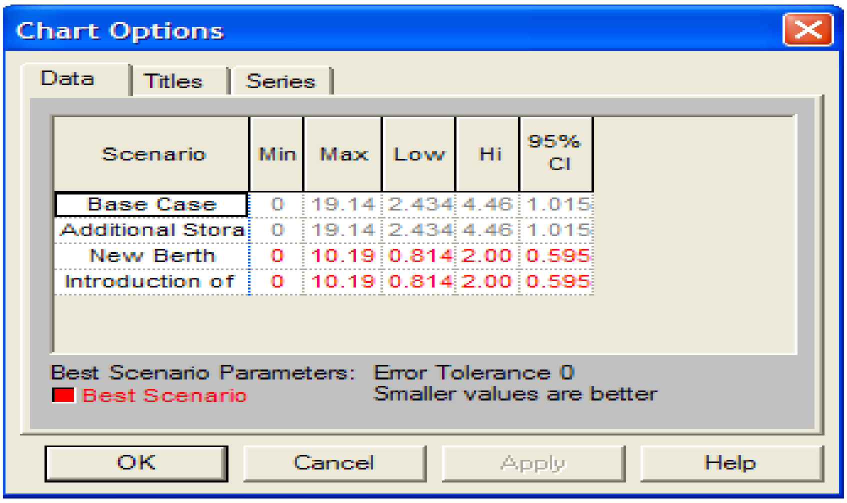


Figure 7.6: Numerical Values of Each Scenario



Scenario	Min	Max	Low	Hi	95% CI
Base Case	0	19.14	2.434	4.46	1.015
Additional Stora	0	19.14	2.434	4.46	1.015
New Berth	0	10.19	0.814	2.00	0.595
Introduction of	0	10.19	0.814	2.00	0.595

Best Scenario Parameters: Error Tolerance 0

🟥 Best Scenario

Smaller values are better

Scenario 1 shows no effect on ship waiting time for berth compared to the Base Case. However, Scenarios 2 and 3 show significant improvements on ship waiting time for berth.

7.3.7 Measures to be Taken to Maximise Capacity

Berth waiting time by scenarios verify that MCH requires either an additional berth or 2 quay cranes (QCs) for lowering the current ship waiting time for berth. Generally, international container harbours have several QCs. However, a QC is ineffective if it does not contribute to progress more than a minimum value which is estimated as 80,000 TEU/year/berth take into account its procurement cost and running cost (Imai, Chen et al., 2007). In the case of MCH, forecasted container throughput traffic (Low Case) will reach 80,000TEUs in 2016. Thus, the QC is difficult to justify for insertion into the harbour base on economical grounds before 2016.

The second scenario is to design a new alongside berth. MPL can extend the existing berth to another 101m, at the same time providing a structural base for QCs for future use. At present, MCH has one large mobile crane having a 150 ton capacity. This could be used to handle containers at berth in conjunction with ship gear until QCs are introduced in the future. Currently, the crane is only being used to load and unload containers from lighterage, as the existing alongside berth was not designed to load on the deck for these types of cranes. The new berth will help in releasing the pressure on vessel congestion at MCH and will reduce ship waiting time at berth significantly. However, such a huge project can only be undertaken if it is financially feasible. Therefore, the next section analyses the costs and benefits of a project based on this second scenario.

7.3.7.1 Cost Benefit Analysis of Extended Alongside Berth

7.3.7.1.1 Estimation of Costs

The construction cost for a quay wall with a retaining height of 17m is approximately 38360 EURO per metre of quay (Vandamme, Beraers, & Aerts, 2007), which is equivalent to NZ$80,487 (28 November, 2009). The cost breakdown is shown in table 7.12.

Table 7.12 Construction cost breakdown

Cost component	Cost per metre of quay wall in EURO
Lowering of groundwater and protection measures	4,570
Earth Works	4,760
Concrete	15,040
Steel reinforcement	5,145
Sheet piling	2,115
Mooring equipment	625
Fendering	2,200
Erosion protection	935
Other(*)	2,970
Total	38,360

Source: (Vandamme et al., 2007)

In addition, the dredging and reclamation would cost approximately US$70 (97.56 NZ$) per m^3 (Simth, 2005). It is assumed that the new berth will require dredging of about 3300 m^3 and will cost NZ$323,400 in total. The new quay will have equal length and depth as the existing berth. Therefore, it is estimated that the quay will cost approximately NZ$8,129,187 (NZ$80,487 x 101m). The whole berth (quay plus dredging) therefore, will cost NZ$8,452,587.

7.3.7.1.2 Estimation of Financial Benefits

The financial benefits of the project are assumed to derive from the revenue charges paid by the users of the port services by comparison between the case of “without the project” and that of “with the project”. The charges are calculated on the basis of the Tariff on MPL for container vessels ("MPL tariff," 2009). The financial benefits of the project are calculated from the difference between the revenues from charges in the case of with-the-project and those in the case of without-the-project. The financial benefits with-the-project and without-the-project are summarised in Table 7.13 and Table 7.14 respectively. The detailed revenue from charges is shown in Appendix F.

In the case of without-the-project, the limit on the capacity of the existing container berth will be attained by the year 2011 (ie Annual Berth Capacity 38626 TEUs). Therefore, revenue will be constant throughout the period from 2011 to 2020 for the case without-the-project. In the case of with-the-project, the limit of capacity of the new container berths will be attained at the year of 2018, and thereafter revenues and charges are assumed to remain constant.

Table 7.13: Financial Benefits With-the-project in NZD

Year	Number of estimated containers (Medium Case)	Container Vessel call	Charges for Marine Service	Charges for Container Operations	Total
2011	34,145	85	21,879	24,068,913	24,090,792
2012	37,647	94	24,123	26,537,131	26,561,253
2013	41,411	104	26,534	29,190,738	29,217,272
2014	45,458	114	29,127	32,043,128	32,072,255
2015	49,808	125	31,915	35,109,456	35,141,371
2016	54,484	136	34,911	38,405,582	38,440,493
2017	59,511	149	38,132	41,949,130	41,987,262
2018	64,915	162	41,595	45,758,426	45,800,020
2019	70,724	177	45,317	49,853,207	49,898,524
2020	76,969	192	49,318	54,255,326	54,304,644

Table 7.14: Financial Benefits Without-the-project in NZD

Year	Number of estimated containers (Medium Case)	Container Vessel call	Charges for Marine Service	Charges for Container Operations	Total
2011	34,145	85	21,879	24,068,913	24,090,792
2012	37,647	94	24,123	26,537,483	26,561,606
2013	38,626	97	24,750	27,227,583	27,252,333
2014	38,626	97	24,750	27,227,583	27,252,333
2015	38,626	97	24,750	27,227,583	27,252,333
2016	38,626	97	24,750	27,227,583	27,252,333
2017	38,626	97	24,750	27,227,583	27,252,333
2018	38,626	97	24,750	27,227,583	27,252,333
2019	38,626	97	24,750	27,227,583	27,252,333
2020	38,626	97	24,750	27,227,583	27,252,333

Table 7.15 shows the additional cash flow resulting from the project.

Table 7.15: Additional Cash Flow in NZD

Year	Number of estimated containers (Medium Case)	Container Vessel call	Charges for Marine Service	Charges for Container Operations	Total
2011	0	0	0	0	0
2012	0	0	0	0	0
2013	2,785	5	1,298	1,963,155	1,964,453
2014	6,832	12	3,184	4,815,545	4,818,728
2015	11,182	20	5,211	7,881,873	7,887,084
2016	15,858	29	7,390	11,177,999	11,185,389
2017	20,885	38	9,732	14,721,547	14,731,279
2018	26,289	48	12,251	18,530,842	18,543,093
2019	26,289	48	12,251	18,531,195	18,543,446
2020	26,289	48	12,251	18,531,195	18,543,446

7.3.7.2 Financial Evaluation

7.3.7.2.1 Project Life and Project Evaluation Period

The project evaluation period is 10 years from 2011 to 2020. It is assumed to take a year for construction work.

7.3.7.2.2 Indicators for Financial Evaluation

Based on the financial benefits and the cost as mentioned above, the financial evaluation is undertaken using the indicators of the Internal Rate of Return (IRR) the net present values (NPV) which is the difference of the financial benefits and the financial cost, payback period, and financial benefit cost ratio (B/C).

7.3.7.2.3 Result of Evaluation

The indicators for the financial evaluation are figured out from the cash flow of the financial cost and benefits during the project evaluation period from 2011 to 2020 as shown in the Table 7.16.

Table 7.16: Project Cash Flow

No.	Year	Cash Flow (NZ$)
1	2012	(8,452,587)
2	2013	0
3	2014	0
4	2015	1,964,453
5	2016	4,818,728
6	2017	7,887,084
7	2018	11,185,389
8	2019	14,731,279
9	2020	18,543,093

IRR = 37%
NPV = NZ$ 23,735,675
B/C = 1.8
Discounted Rate = 10%
Payback period = 6 years

The IRR is figured out to be 37% showing a high financial return and the NPV and the B/C discounted by 10% indicate NZ$23,735,675 and 1.8 respectively. The payback period is just six years, meaning the investment will be recovered within six years. The NPV of NZ$ 23,735,675 is the difference between the financial benefits and the financial cost resulting in high amounts of surplus benefits. The B/C of 1.8 indicates that the rate of the economic benefits to the economic cost is 1.8 times. Therefore, it could be judged that this project is highly feasible from the financial viewpoint.

7.3.7.3 Dwell Time of Container

The necessary storage area on land for laden and empty containers depends on the number of containers entering the port and the dwell time of the containers. With respect to the dwell time, it is the special characteristic of the port that containers, neither laden nor empty are supposed to leave the port through the land gates for city. Entire import containers un-stuffed and goods sent to storage or directly to trucks at the port area, then empty containers are left at the port yard. Hence, the dwell time of the container is decided by the elapse of time between two consecutive visits to Male, by the shipping line being the owner of the containers. The simulation results shows that mean container dwell time is 14.14 days (±0.5; $\alpha = 0.05$) with maximum dwell time of 23 days.

As a general rule, import containers should not remain in the terminal for more than 3 to 5 five days (Cronje, 2006); and many container terminals in fact deliberately apply disciplinary tariffs as a disincentive against longer terminal dwell times (L. H. Lee et al., 2006).

The current policy of MPL allows storing of containers for the first 10 days free of charge. This allows owners to store their containers free of charge in the terminal for quite a long time. These stored containers inevitably result in the terminal becoming congested, which results in the time increasing to access containers for landside delivery, or more importantly for ship loading.

In order to avoid the inefficiencies mentioned above the ‘free storage’ days could be brought down, to maybe 3 to 5 days, so that owners consider exporting empty containers earlier to avoid incurring demurrage charges.

A special facility could also be designed for location, situated as close as possible to the container yard, where containers can be accumulated and made ready for export. This empty container depot can be owned and operated by a private party, entirely independently of the ownership structure of MCH for the purpose of profit making.

7.4 Research Limitations

All research projects have limitations, and all results must be interpreted in the light of these limitations. As such, while much useful information has been derived from this study, there are some practical limitations that must be mentioned.

Firstly, this research used the Academic Version of Arena for the simulation exercise. The Academic Version of Arena has a series of limitations including boundaries on number of Modules, Elements, Cinema Objects and a size limitation of 150 entities. The whole logistic chain of MCH is far too big to be modelled in the Academic Version. Therefore, two separate models were developed to cover the entire chain of MCH, and conjoint results were analysed using Microsoft Excel. Consequently, some minor errors may have occurred that would not have occurred if the whole chain was modelled together.

Secondly, the observations in this thesis are restricted to the operational side of the berth and yard area. It does not investigate the hinterland connections, pre-marshalling, and stowage planning, although the management of MPL firmly believes that better hinterland connection and pre-marshalling could increase the existing capacity considerably. Hinterland, pre-marshalling and stowage planning are, unfortunately, beyond the scope of this thesis.

Thirdly, the thesis does not investigate the effects of regional ports which were developed a few years ago for the purpose of sharing some functions of MCH for container traffic demand. The MPL believes that these ports will assist in easing congestion at MCH in the future. However, until now there is no progress as shippers favour MCH over regional ports because of incompatible infrastructure and demand patterns. This study assumed that for the next ten years, all international cargo will flow through MCH.

Finally, the time horizon for the proposed project is assumed to be only until 2020 with the assumption that the terminal will be completely moved to a new island (Hulhumale' most likely) in 2020 in accordance with the 7th National Development Plan. Upon development of the new port the existing port will most probably be converted to a local harbour. Thus, the project evaluations and the container traffic estimations were performed only for a 10 years horizon.

7.5 Future Research

The management of MPL believes that proper hinterland connection may create more capacity at MCH in the future, and believe pre-marshalling can also assist in achieving extra capacity. It would be very useful if an investigation was performed to examine how much capacity could be achieved with regard to hinterland connections and pre-marshalling through improvements in planning.

An investigation could also be carried out to examine the practicability of separation of existing container storage yard from the berth. The existing storage yard can be shifted to the southern side of the island near South Harbour, which is half a kilometre in distance. These two facilities could be linked using a dedicated railway line.

7.6 Summary and Conclusions

The port industry has been evolving constantly over time. The fast growing international seaborne trades have contributed to the development of the port industry over the years. Terminal performance has become a crucial issue for port authorities as the container turnaround grew. Port bottlenecks and congestion are the two major factors that affect port performance. Several methods of modelling and simulation are used for analysing port bottlenecks and congestion. The most modern methods concentrate on using computer simulations for the complete terminal rather than sub parts of port operations.

By using computer simulation techniques, this research has investigated the situation of MCH and identified logistic bottlenecks that exist at the port. To set up the simulation model, field research was conducted at MCH. The observation technique was considered as the most appropriate data collection method for the study. Both, qualitative and quantitative data were collected using a focus group, interviews, on-site observations, and time and motion measures.

For modelling purpose, the logic of MCH was divided into three levels. The first level involved the general processes (the top-level model) and more detailed processes were represented with sub-models. The model was run for 44 statistically independent replications for a period of one month.

The results show that containers dwell in the terminal for 14 days on average. The ship turnaround time is 7 days on average. The schedule utilisation of resources demonstrates that the berth is the single most utilised resource of the terminal. The berth utilisation is over 74%. The annual berth capacity of MCH shows 38,626 TEUs and yard capacity is 43,676 TEUs per year. This indicates that yard capacity is significantly greater than berth capacity. Berth Capacity seems to be the major bottleneck that creates longer queues and ship delays at MCH.

Therefore, it was suggested that MPL should design an alongside berth extension to accommodate additional berth capacity. The financial evaluation shows that the proposed project would be highly feasible from the financial point of view.

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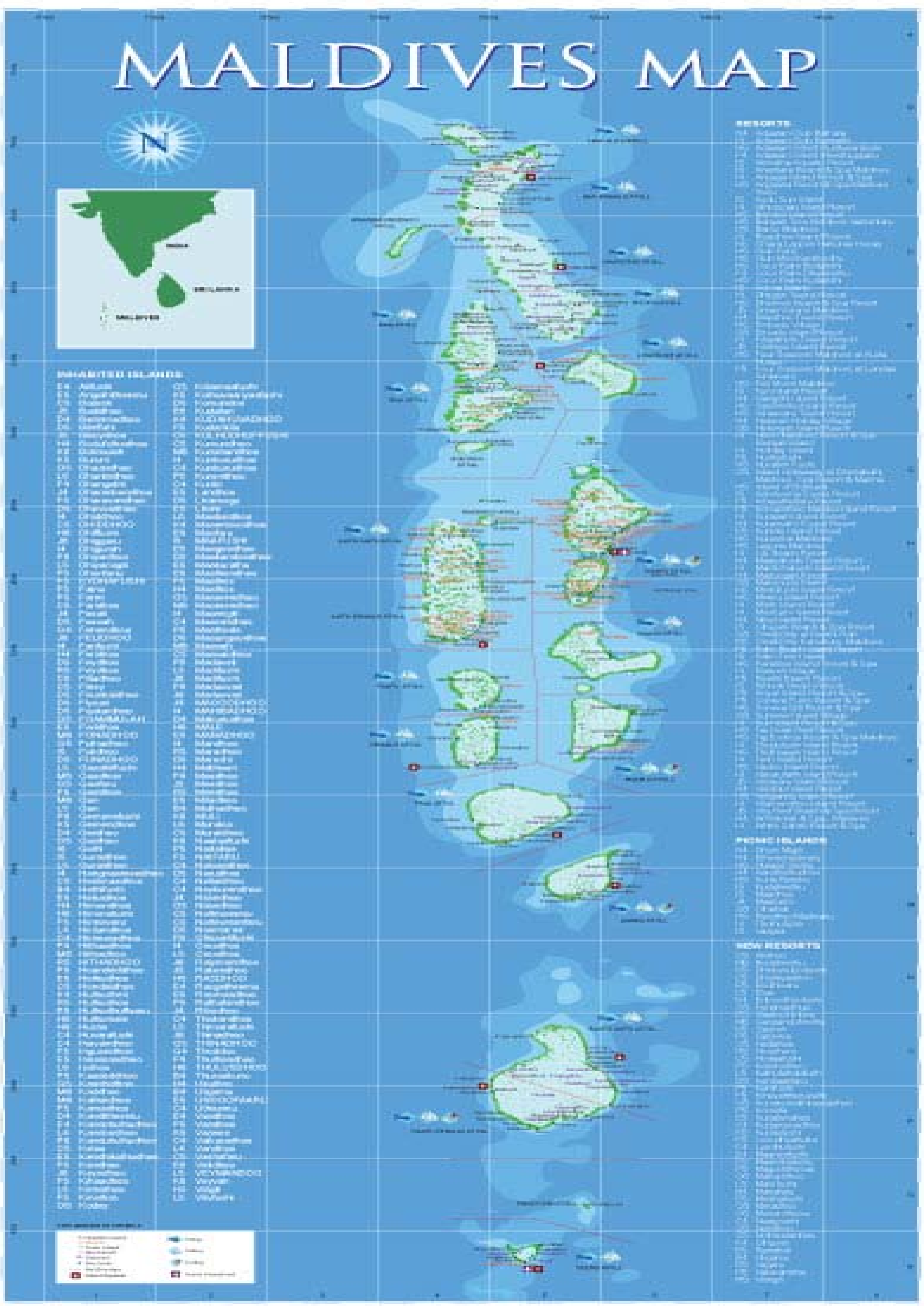
Appendix A

Map of the Maldives



Source: ://www.maldivestourism.net/travel/map/

Appendix B

Cargo Handling Equipment

B.1 Tugs /Service Boats

- 01 Tug Bollard Pull 12 tons
  * 01 Tug Bollard Pull 8 tons
  * 01 Tug Bollard Pull 4
  * 01 Service Boat
  * 01 Pilot Boat
  * 01 Service Launch

B.2 Barges

* 06 Hatch Barges 150 tons
* 02 Hatch Barges 200 tons
* 03 Flat Top Barges 300 tons

B.3 Cranes

* 01 Mobile Crane 110 tons (Max. 10 meter radius 35 tons)
* 01 Mobile Crane 60 tons (Max. 10 meter radius 25 tons)
* 01 Mobile Crane 40 tons
* 06 Mobile Cranes 25 tons

B.4 Container Handling Facilities

* 01 Reach-stacker 45 tons 4 high, 5th high 27 tons
* 01 Terminal trailer 20'
* 01 Terminal trailer 40'
* 01 Tug master (Terminal Tractor)

B.4.1 Forklift

- 03 Forklifts 2 tons
  * 06 Forklifts 2.5 tons (Electric)
  * 08 Forklifts 3 tons
  * 02 Forklifts 4 tons
  * 01 Forklifts 10 tons
  * 02 Forklifts 25 tons (Container Handling)

Source: ://www.maldport.com.mv/port_info_terminals.html

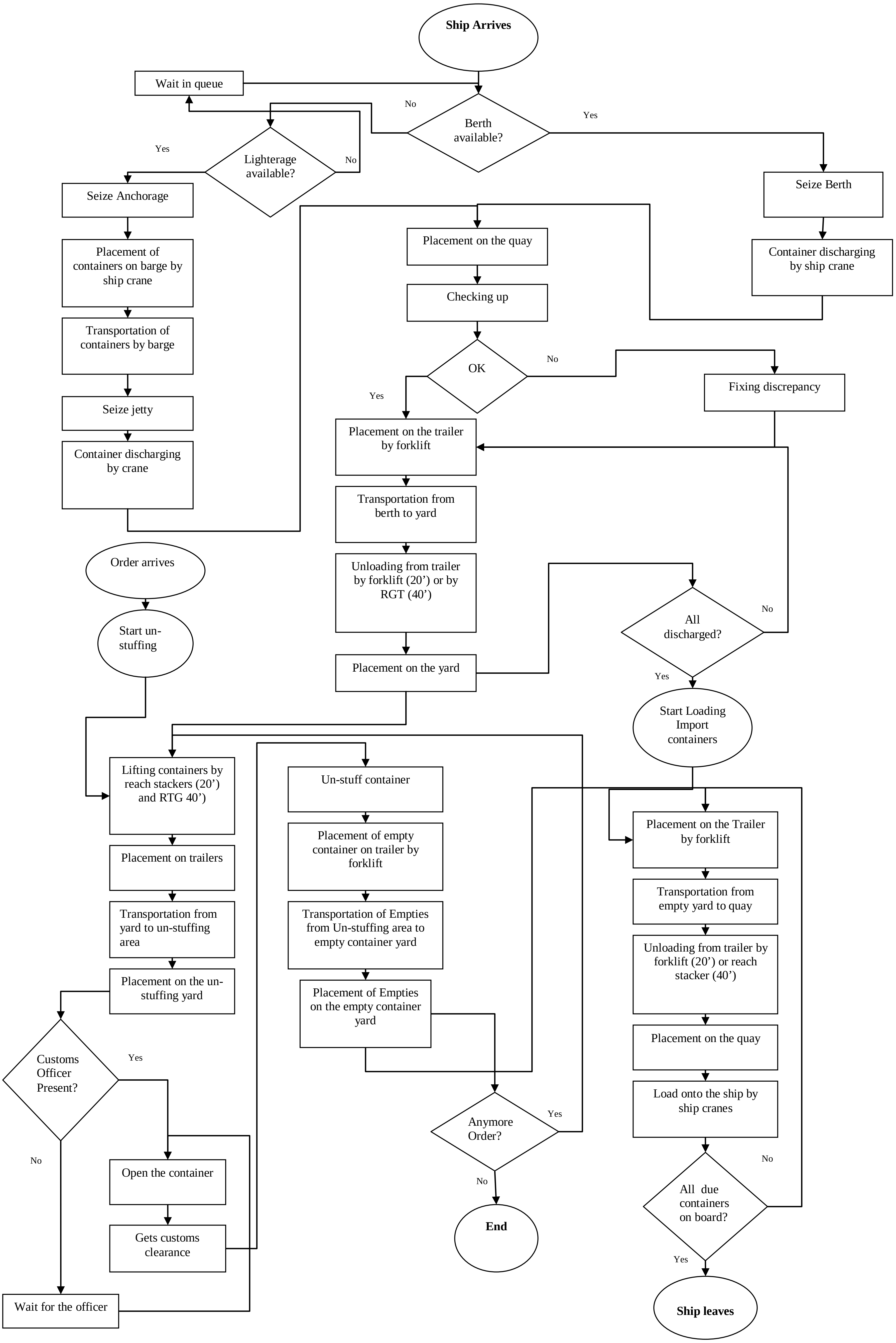
Appendix C

Focus Group Participants

Name	Position	Organisation
Hussain Naeem	Assistant Managing Director	Maldives Ports Limited
Ali Ahmed	Director	Maldives Ports Limited
Ahmed Wajeeh	Executive Director	Transport Authority
Ibrahim Yasir	Assistant Director	Transport Authority
Mohamed Zubair	Manager	Goodfaith Limited (importer)
Ahmed Adil	Manager	Pink Orchid (3pl)
Ibrahim Hassan	Shareholder/Manager	Happy Corner (importer)

Appendix D

Terminal Logic Flowchart


Ship Arrives
Wait in queue
No
Berth available?
Yes
Yes
Lighterage available?
No
Seize Anchorage
Seize Berth
Placement of containers on barge by ship crane
Placement on the quay
Container discharging by ship crane
Checking up
Transportation of containers by barge
OK
No
Yes
Fixing discrepancy
Seize jetty
Placement on the trailer by forklift
Container discharging by crane
Transportation from berth to yard
Order arrives
Unloading from trailer by forklift (20') or by RGT (40')
All discharged?
No
Start un-stuffing
Placement on the yard
Yes
Start Loading Import containers
Lifting containers by reach stackers (20') and RTG 40')
Un-stuff container
Placement on the Trailer by forklift
Placement on trailers
Placement of empty container on trailer by forklift
Transportation from empty yard to quay
Transportation from yard to un-stuffing area
Transportation of Empties from Un-stuffing area to empty container yard
Unloading from trailer by forklift (20') or reach stacker (40')
Placement on the un-stuffing yard
Placement of Empties on the empty container yard
Placement on the quay
Customs Officer Present?
Yes
Load onto the ship by ship cranes
Anymore Order?
Yes
No
No
No
Open the container
All due containers on board?
End
Gets customs clearance
Yes
Ship leaves
Wait for the officer

Appendix E

Information Checklist

Geographic and Demographic Information

- ❖ The current Population
- ❖ GDP growth trend
- ❖ Tourism sector growth
- ❖ Fisheries sector growth
- ❖ Major commodities
- ❖ Commodities imported (figures

Demand Drivers for Imports

Major demand drivers that influence import growth: GDP growth, Tourism growth, Population growth

Cargo Traffic Information

Cargo Traffic Growth

- ▪ Inbound 20 foot TEUs
- ▪ Inbound 40 foot TEUs

- ▪ Outbound 20 foot TEUs
- ▪ Outbound 40 foot TEUs

Vessel Traffic

- ❖ Existing Shipping services
- ❖ Shipping Lines
- ❖ Number of vessels
- ❖ Type of vessels
- ❖ Vessel sizes and capacity in TEUs
- ❖ Average cargo discharge per trip in TEUs
- ❖ Frequency of Calls

Distribution and Logistics

- ❖ International distribution network
- ❖ Domestic distribution network
- ❖ How long traders/distributers hold goods
- ❖ Current lead-time

Trade Facilitations

- Do customs procedures hinder efficient trade logistics?
- Understand customs procedures; work schedule, policies on clearance, etc
- How much work customs has done in implementing the Revised Kyoto Convention?

Port Facility Layout

Find a layout of the port and specific measurements

Current Maritime and Port Administration

- Port Management and administration structure
- Identify all public and private parties involved in terminal management and operations
- Port reforms if any…. When?

Legislations

Understand the legal basis of port sector

Economic Cost and Benefit

For Simulation

- Inter arrival time of ships
- Ship waiting time for dock
- Barging time of a ship
- Loading time of a container
- Unloading time of a container
- Time it takes to transport a container to yard once offloaded from a ship
- Time it takes to place a container at the yard
- Times it takes to un-stuff a container

- Distance Between:
    - Wharf and the container yard
    - Yard and un-stuffing area
    - Un-stuffing area and Gate
    - Wharf and break-bulk cargo
    - Break-bulk cargo shed and Gate

Area measurement

- Container Yard
- Break-bulk cargo storage shed
- Un-stuffing Area
- Quay
- Basin

- Number of trucks
- Number of Quay Cranes
- Number of Yard Cranes
- Number of Forklifts
- Speed of trucks and forklifts

Other information

- How high the containers are stacked
- Documentation process time
- Working schedule

Appendix F

Cash Flow of the Proposed Project

F.1 Cash Flow With-the-project (MRF)

Year	Number of estimated Imported containers (High Case)	Container Vessel call (see Note 1)	Charges for Marine service			Charges for container operations								Total
			Entry charge (see Note 2)	Anchorage charges (see Note 3)	Professional Pilot-age fees (see Note 4)	Stevedoring charges for containers (see Note 5)		Handling charges of containers (see Note 6)		Other Marine services (see Note 7)		Storage charges for laden containers (see Note 8)		
						20 foot	**40foot**	**20 foot**	**40 foot**	**20 foot**	**40 foot**	**20 foot**	**40 foot**	
2011	34,145	85	25,609	213	174,993	30,954,747	129,040,272	19,838,245	8,126,510	13,461,666	5,514,418	9,919,123	4,063,255	221,119,051
2012	37,647	94	28,235	235	192,938	34,129,093	142,273,088	21,872,617	8,959,867	14,842,133	6,079,910	10,936,308	4,479,934	243,794,358
2013	41,411	104	31,058	259	212,231	37,541,867	156,499,830	24,059,791	9,855,818	16,326,287	6,687,877	12,029,896	4,927,909	268,172,822
2014	45,458	114	34,093	284	232,970	41,210,292	171,792,302	26,410,808	10,818,885	17,921,619	7,341,386	13,205,404	5,409,443	294,377,486
2015	49,808	125	37,356	311	255,263	45,153,861	188,231,757	28,938,158	11,854,185	19,636,607	8,043,911	14,469,079	5,927,093	322,547,580
2016	54,484	136	40,863	341	279,228	49,392,970	205,903,226	31,654,914	12,967,073	21,480,120	8,799,085	15,827,457	6,483,537	352,828,812
2017	59,511	149	44,633	372	304,991	53,950,285	224,901,189	34,575,601	14,163,499	23,462,015	9,610,946	17,287,800	7,081,750	385,383,080
2018	64,915	162	48,686	406	332,687	58,849,376	245,323,905	37,715,325	15,449,651	25,592,542	10,483,692	18,857,662	7,724,826	420,378,756
2019	70,724	177	53,043	442	362,458	64,115,627	267,277,190	41,090,354	16,832,193	27,882,740	11,421,845	20,545,177	8,416,097	457,997,164
2020	76,969	192	57,726	481	394,464	69,777,141	290,878,201	44,718,699	18,318,503	30,344,831	12,430,413	22,359,349	9,159,252	498,439,058

F.2 Cash Flow Without-the-project (MRF)

Year	**Number of estimated Imported containers (High Case)**	**Container Vessel call (see Note 1)**	**Charges for Marine service**			**Charges for container operations**								**Total**
			Entry charge (see Note 2)	**Anchorage charges (see Note 3)**	**Professional Pilot-age fees (see Note 4)**	**Stevedoring charges for containers (see Note 5)**		**Handling charges of containers (see Note 6)**		**Other Marine services (see Note 7)**		**Storage charges for laden containers (see Note 8)**		
						20 foot	**40foot**	**20 foot**	**40 foot**	**20 foot**	**40 foot**	**20 foot**	**40 foot**	
2011	34,145	85	25,609	213	174,993	30,954,747	129,040,272	19,838,245	8,126,510	13,461,666	5,514,418	9,919,123	4,063,255	221,119,051
2012	37,647	94	28,235	235	192,941	34,129,547	142,274,978	21,872,907	8,959,986	14,842,330	6,079,991	10,936,454	4,479,993	243,797,596
2013	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2014	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2015	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2016	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2017	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2018	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2019	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486
2020	38,626	97	28,970	241	197,958	35,017,076	145,974,800	22,441,706	9,192,988	15,228,301	6,238,099	11,220,853	4,596,494	250,137,486

F.3 Cash Flow from the Proposed Project (MRF)

Year	**Number of estimated Imported containers (High Case)**	**Container Vessel call (see Note 1)**	**Charges for Marine service**			**Charges for container operations**								**Total**
			Entry charge (see Note 2)	**Anchorage charges (see Note 3)**	**Professional Pilot-age fees (see Note 4)**	**Stevedoring charges for containers (see Note 5)**		**Handling charges of containers (see Note 6)**		**Other Marine services (see Note 7)**		**Storage charges for laden containers (see Note 8)**		
						20 foot	**40foot**	**20 foot**	**40 foot**	**20 foot**	**40 foot**	**20 foot**	**40 foot**	
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	2,785	5	1,519	13	10,380	2,524,790	10,525,030	1,618,085	662,830	1,097,986	449,778	809,043	331,415	18,030,869
2014	6,832	12	3,726	31	25,463	6,193,216	25,817,502	3,969,102	1,625,897	2,693,319	1,103,287	1,984,551	812,949	44,229,042
2015	11,182	20	6,099	51	41,677	10,136,785	42,256,957	6,496,452	2,661,197	4,408,306	1,805,812	3,248,226	1,330,599	72,392,159
2016	15,858	29	8,650	72	59,105	14,375,894	59,928,426	9,213,208	3,774,085	6,251,819	2,560,986	4,606,604	1,887,043	102,665,891
2017	20,885	38	11,392	95	77,842	18,933,209	78,926,389	12,133,895	4,970,511	8,233,714	3,372,847	6,066,947	2,485,256	135,212,096
2018	26,289	48	14,339	119	97,984	23,832,300	99,349,105	15,273,619	6,256,663	10,364,241	4,245,593	7,636,809	3,128,332	170,199,104
2019	26,289	48	14,339	119	97,986	23,832,753	99,350,994	15,273,909	6,256,782	10,364,438	4,245,674	7,636,955	3,128,391	170,202,341
2020	26,289	48	14,339	119	97,986	23,832,753	99,350,994	15,273,909	6,256,782	10,364,438	4,245,674	7,636,955	3,128,391	170,202,341

Note 1: On average a ship carries 500 TEUs, therefore number of ship calls = total container/500

Note 2: Entry charge =300 MRF per ship

Note 3: Anchorage charges =(MRF 50 per day). It is assumed only 5% ships stay at anchorage

Note 4: Professional Pilotage MRF 2050 per hour. It is assumed that pilotage will take an hour on average

Note 5: Stevedoring charges for containers=MRF2185 per 20 foot container; MRF4369 per 40 foot container

Note 6: Handling charges of containers= MRF1400 for 20 foot container; MRF2800 for 40 foot container

Note 7: Other marine services include ship idle time, Tug service, Salvage operations, and Port state control permit.

Note 8: Storage charges for laden containers = (average chargeable dwell time 5 days; MRF 700 per days for 20 feet, MRF 1400 per days for 40 foot)

Appendix G

Simulation Output Reports

11:24:47PM **Category Overview** November 15, 2009

Values Across All Replications

MCH

Replications: 44 Time Units: Days

Entity

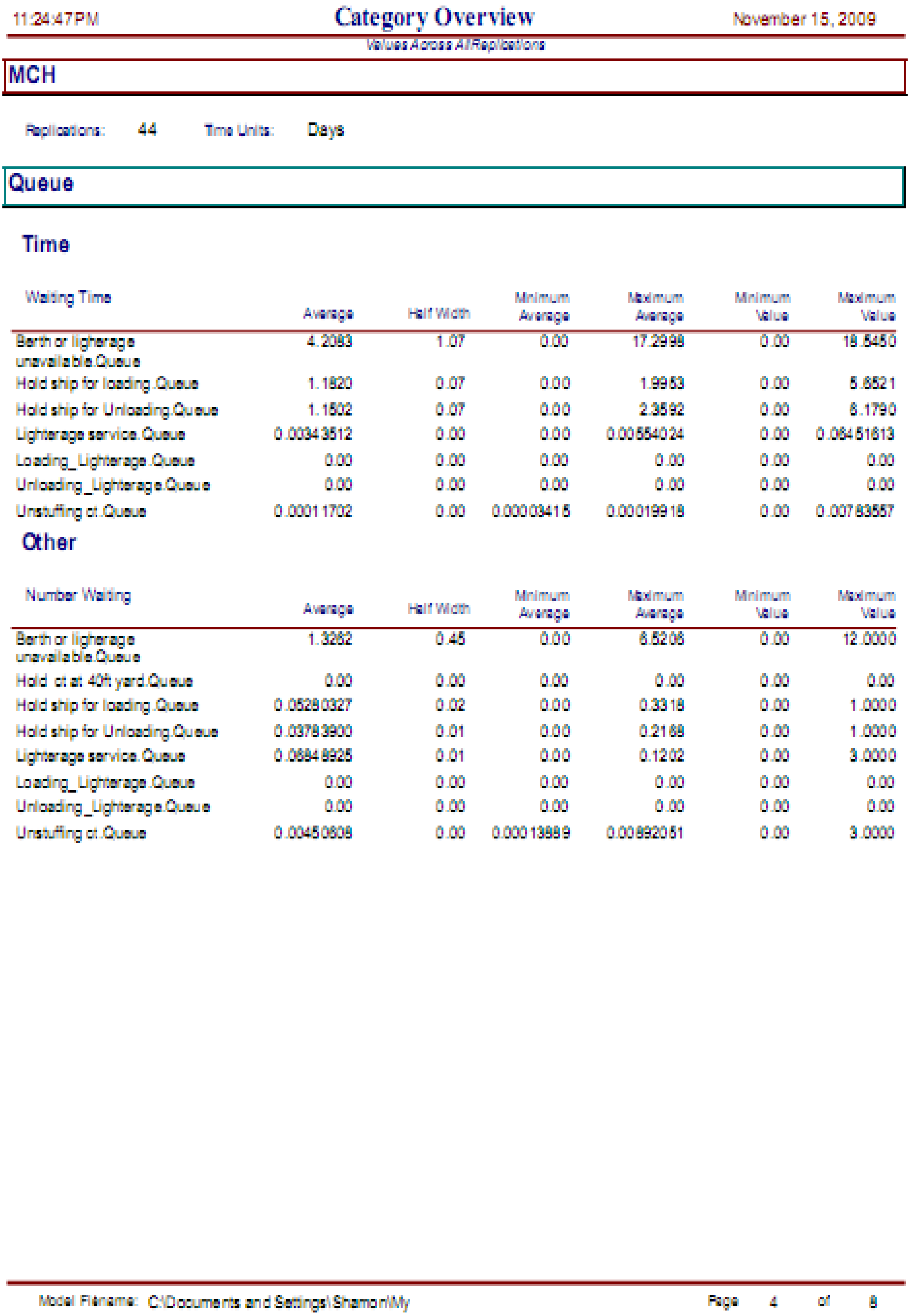
Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Container	4174.55	10.40	4108.00	4272.00
Ship	10.7273	1.44	3.0000	20.0000

Number Out	Average	Half Width	Minimum Average	Maximum Average
Container	4173.34	10.40	4107.00	4269.00
Ship	6.7955	0.81	1.0000	13.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Container	2.4871	0.28	0.3368	4.2434	0.00	22.0000
Ship	2.9230	0.58	0.2403	8.5172	0.00	14.0000

Model Filename: C:\Documents and Settings\Sharon\My Page 3 of 8



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Category Overview

Values Across All Replications

November 15, 2009

MCH

Replications: 44 Time Units: Days

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Berth or ligherage unavailable.Queue	4.2083	1.07	0.00	17.2998	0.00	18.5450
Hold ship for loading.Queue	1.1820	0.07	0.00	1.9953	0.00	5.6521
Hold ship for Unloading.Queue	1.1502	0.07	0.00	2.3592	0.00	6.1790
Lighterage service.Queue	0.00343512	0.00	0.00	0.00554024	0.00	0.06451613
Loading_Lighterage.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unloading_Lighterage.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unstuffing ct.Queue	0.00011702	0.00	0.00003415	0.00019918	0.00	0.00783557

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Berth or ligherage unavailable.Queue	1.3262	0.45	0.00	6.5206	0.00	12.0000
Hold ct at 40ft yard.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Hold ship for loading.Queue	0.05280327	0.02	0.00	0.3318	0.00	1.0000
Hold ship for Unloading.Queue	0.03783900	0.01	0.00	0.2169	0.00	1.0000
Lighterage service.Queue	0.06848925	0.01	0.00	0.1202	0.00	3.0000
Loading_Lighterage.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unloading_Lighterage.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Unstuffing ct.Queue	0.00450608	0.00	0.00013889	0.00892051	0.00	3.0000

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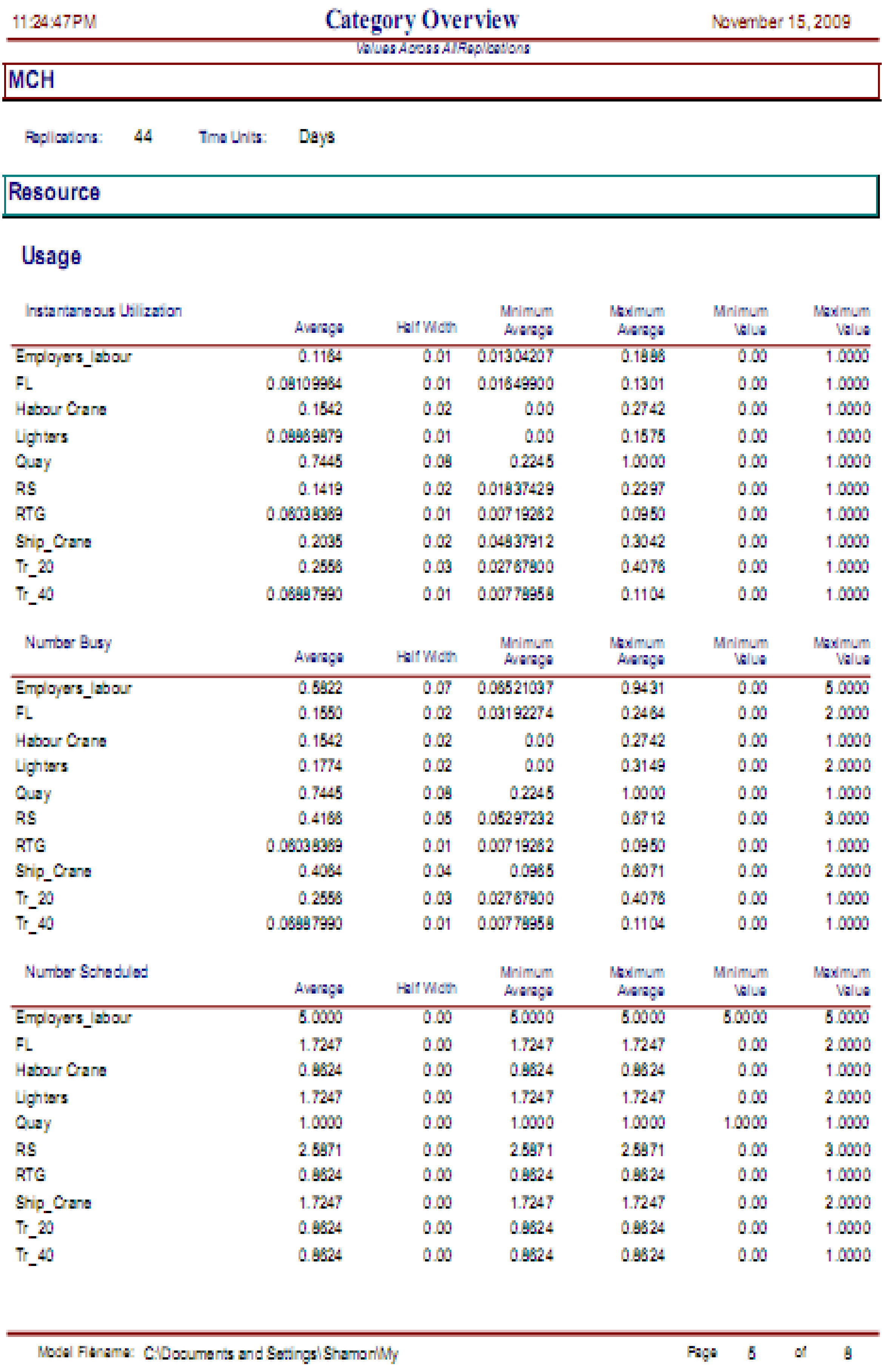

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Category Overview

November 15, 2009

Values Across All Replications

MCH

Replications: 44 Time Units: Days

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Employers_labour	0.1164	0.01	0.01304207	0.1886	0.00	1.0000
FL	0.08109984	0.01	0.01649900	0.1301	0.00	1.0000
Habour Crane	0.1542	0.02	0.00	0.2742	0.00	1.0000
Lighters	0.08869879	0.01	0.00	0.1575	0.00	1.0000
Quay	0.7445	0.08	0.2245	1.0000	0.00	1.0000
RS	0.1419	0.02	0.01837429	0.2297	0.00	1.0000
RTG	0.06038369	0.01	0.00719262	0.0950	0.00	1.0000
Ship_Crane	0.2035	0.02	0.04837912	0.3042	0.00	1.0000
Tr_20	0.2556	0.03	0.02767800	0.4076	0.00	1.0000
Tr_40	0.06887990	0.01	0.00778958	0.1104	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Employers_labour	0.5822	0.07	0.06521037	0.9431	0.00	5.0000
FL	0.1550	0.02	0.03192274	0.2464	0.00	2.0000
Habour Crane	0.1542	0.02	0.00	0.2742	0.00	1.0000
Lighters	0.1774	0.02	0.00	0.3149	0.00	2.0000
Quay	0.7445	0.08	0.2245	1.0000	0.00	1.0000
RS	0.4166	0.05	0.05297232	0.6712	0.00	3.0000
RTG	0.06038369	0.01	0.00719262	0.0950	0.00	1.0000
Ship_Crane	0.4064	0.04	0.0965	0.6071	0.00	2.0000
Tr_20	0.2556	0.03	0.02767800	0.4076	0.00	1.0000
Tr_40	0.06887990	0.01	0.00778958	0.1104	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Employers_labour	5.0000	0.00	5.0000	5.0000	5.0000	5.0000
FL	1.7247	0.00	1.7247	1.7247	0.00	2.0000
Habour Crane	0.8624	0.00	0.8624	0.8624	0.00	1.0000
Lighters	1.7247	0.00	1.7247	1.7247	0.00	2.0000
Quay	1.0000	0.00	1.0000	1.0000	1.0000	1.0000
RS	2.5871	0.00	2.5871	2.5871	0.00	3.0000
RTG	0.8624	0.00	0.8624	0.8624	0.00	1.0000
Ship_Crane	1.7247	0.00	1.7247	1.7247	0.00	2.0000
Tr_20	0.8624	0.00	0.8624	0.8624	0.00	1.0000
Tr_40	0.8624	0.00	0.8624	0.8624	0.00	1.0000

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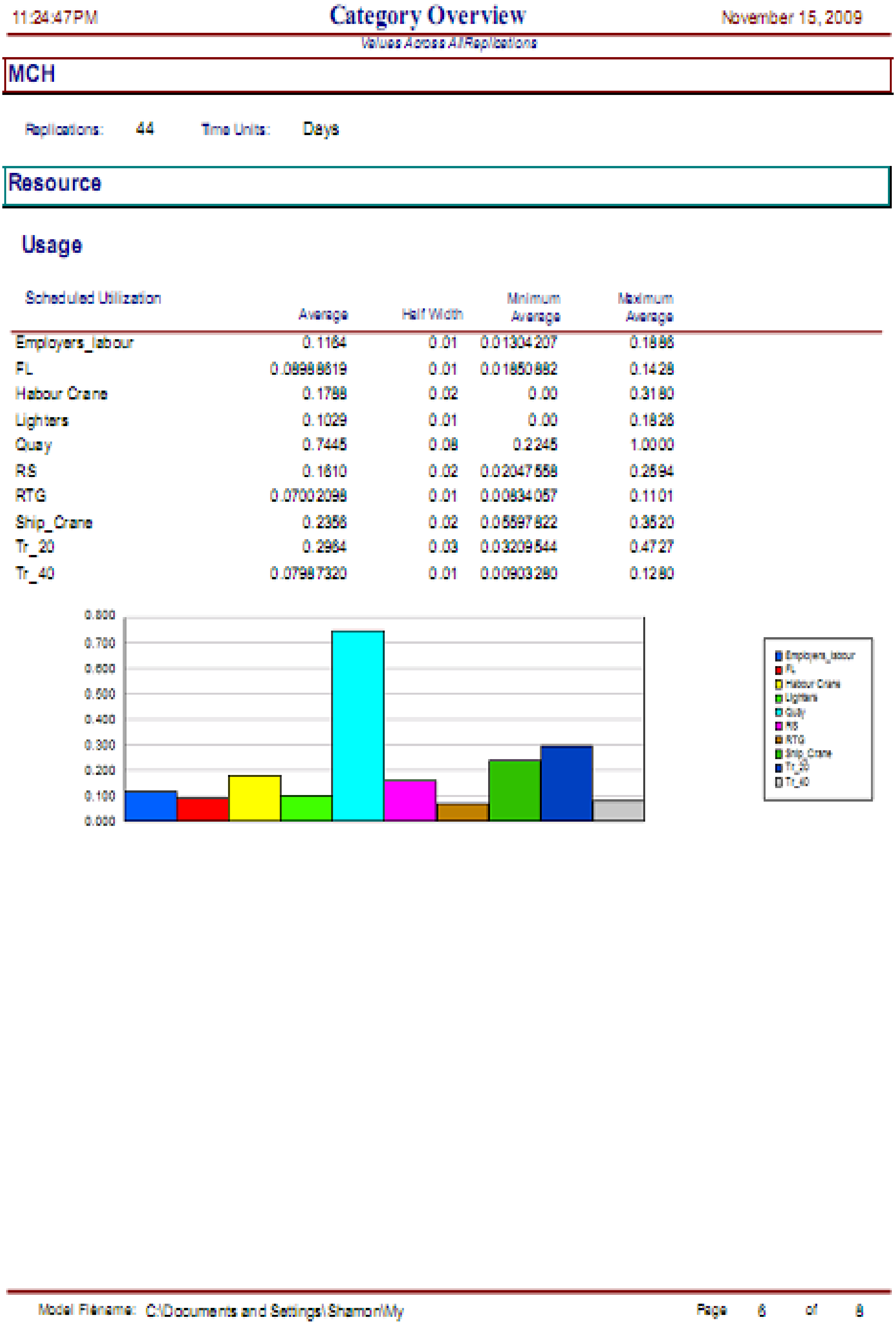

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Category Overview

November 15, 2009

Values Across All Replications

MCH

Replications: 44 Time Units: Days

Resource

Usage

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Employers_labour	0.1164	0.01	0.01304207	0.1886
FL	0.08988619	0.01	0.01850882	0.1428
Habour Crane	0.1788	0.02	0.00	0.3180
Lighters	0.1029	0.01	0.00	0.1828
Quay	0.7445	0.08	0.2245	1.0000
RS	0.1610	0.02	0.02047558	0.2594
RTG	0.07002098	0.01	0.00834057	0.1101
Ship_Crane	0.2356	0.02	0.05597822	0.3520
Tr_20	0.2984	0.03	0.03209544	0.4727
Tr_40	0.07987320	0.01	0.00903280	0.1280

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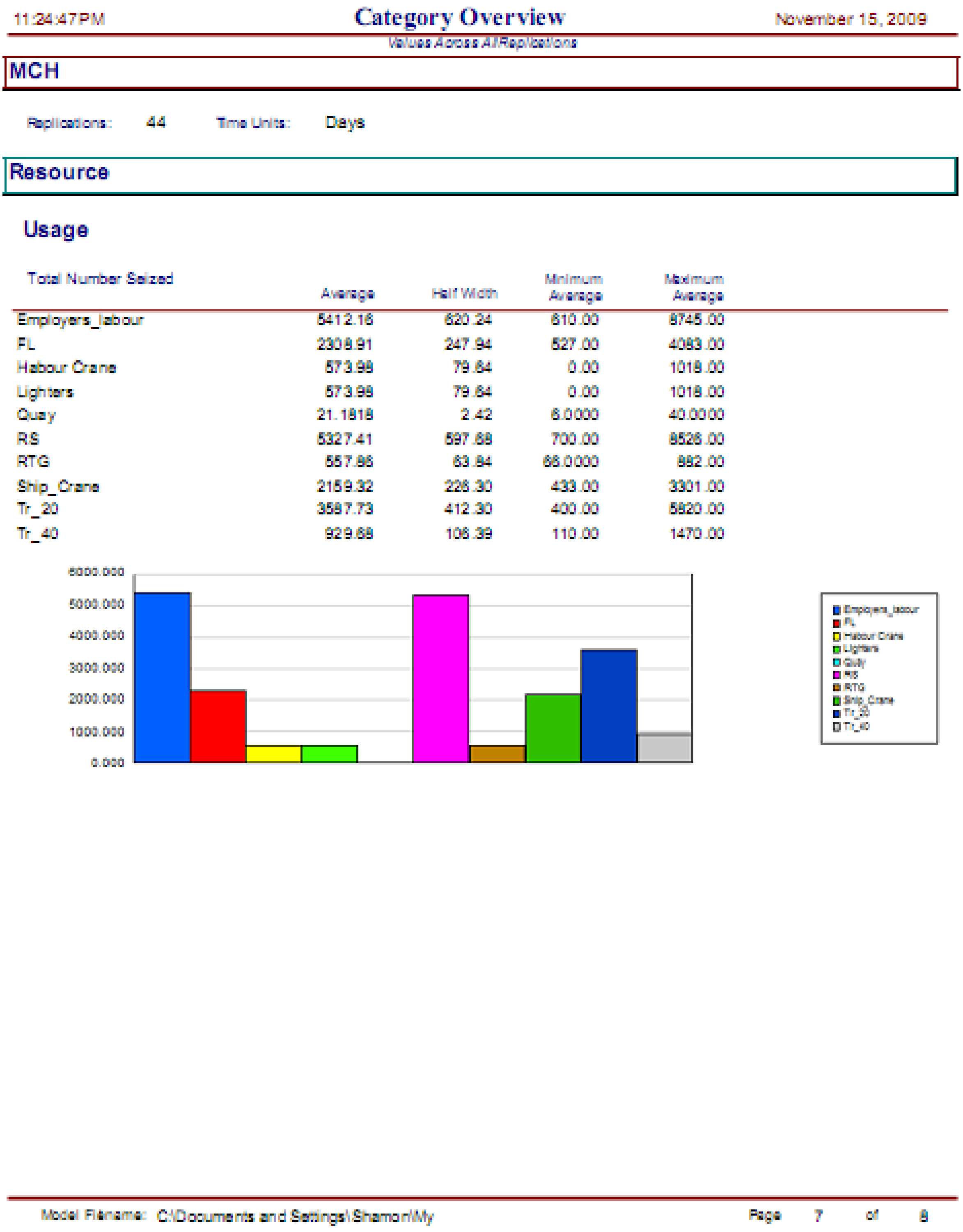

11:24:47PM **Category Overview** November 15, 2009

Values Across All Replications

MCH

Replications: 44 Time Units: Days

Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Employers_labour	5412.16	620.24	610.00	8745.00
FL	2308.91	247.94	527.00	4083.00
Habour Crane	573.98	79.64	0.00	1018.00
Lighters	573.98	79.64	0.00	1018.00
Quay	21.1818	2.42	6.0000	40.0000
RS	5327.41	597.68	700.00	8526.00
RTG	557.86	63.84	66.0000	882.00
Ship_Crane	2159.32	226.30	433.00	3301.00
Tr_20	3587.73	412.30	400.00	5820.00
Tr_40	929.68	106.39	110.00	1470.00

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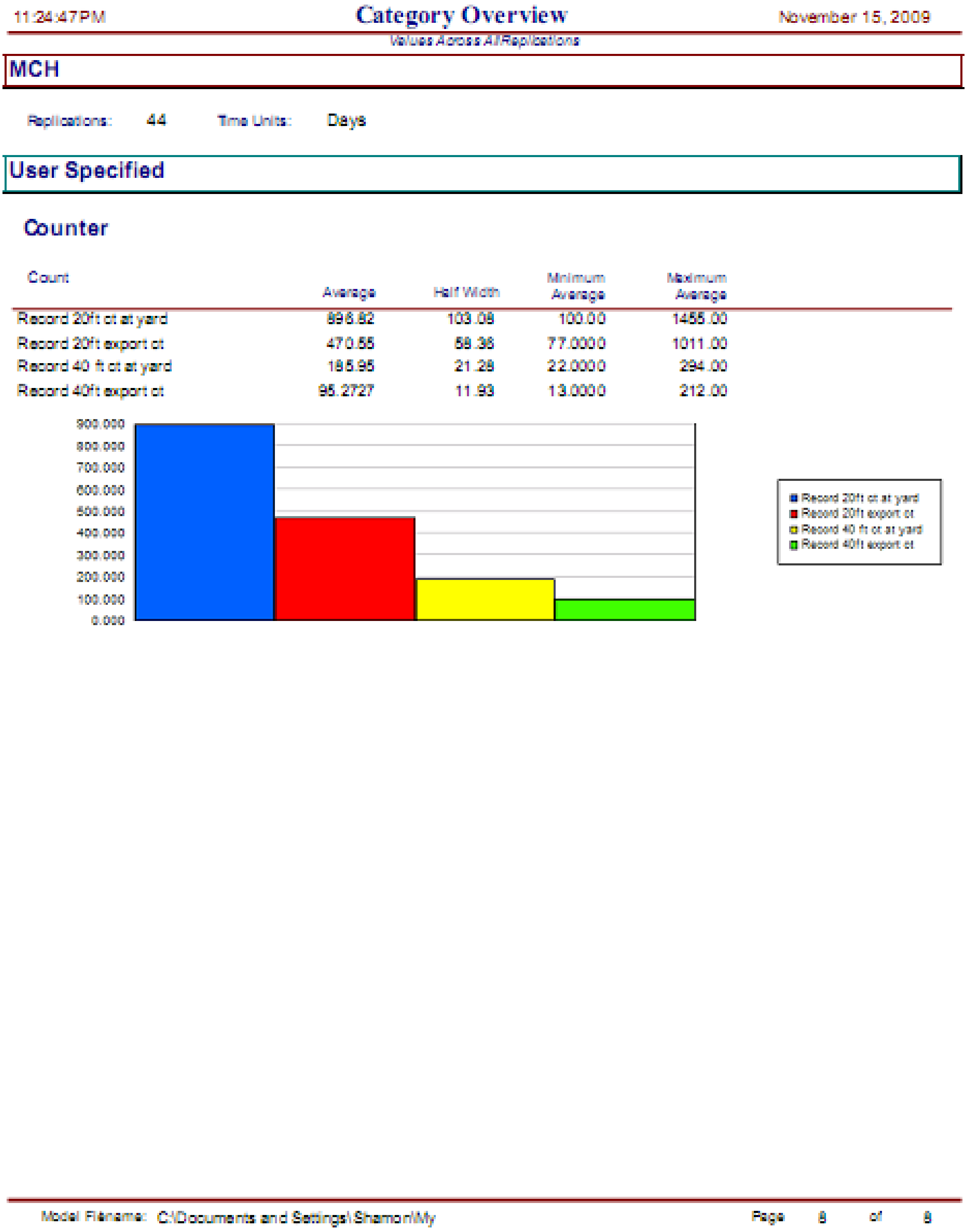

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Category Overview

Values Across All Replications

November 15, 2009

MCH

Replications: 44 Time Units: Days

User Specified

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Record 20ft ct at yard	896.82	103.08	100.00	1455.00
Record 20ft export ct	470.55	58.36	77.0000	1011.00
Record 40 ft ct at yard	185.95	21.28	22.0000	294.00
Record 40ft export ct	95.2727	11.93	13.0000	212.00

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