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Optimization Models for Seaport Operations and Empty Container Management

By

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Abstract

Managing or scheduling the daily operations and functions of a seaport or container terminal is a complex process. One of the main challenges concerns the management and sequencing of concurrent operations and as well as the subsequent ones.

The main function of a typical container terminal is to deal with the flow of containers (empty and loaded) between its seaside and landsides of the terminal. There are numerous logistical functions, each one serving a specific area and purpose such as the handling of containers (loading/unloading), transporting them between terminal areas (e.g quay area, container yard, container inspection area, gate area), as well as the stacking, lifting, inspecting, repairing of containers while also ensuring that they are kept in a good state of maintenance. The rapid growth of global trade has resulted in the constant movement of cargo from regions of production to regions of consumption. As such, the empty container logistics cycle is a challenging and complex process that is of great importance to the shipping industry that seeks to minimize or avoid congestion in container depots and seaports.

Experience has taught them that the movement of empty containers must not be random as it leads to congestion and can have the effect of clogging the entire shipping service network. It also leads to an increase in the accumulation level of empty containers in the surplus seaports and to the shortage of empty containers in the deficit seaports. Seaports can, therefore, gain a competitive edge if they can create efficiencies in their logistical management and in the control of their containers. The ability to increase the throughput, or to minimize the completion dwell time of containers within their terminals is vital to their overall efficiency and profitability. They also must demonstrate their ability to limit the accumulation of large numbers of containers (empty and fully loaded), and to avoid the congestion of containers inside the container yard (CY). Empty Containers Management (ECM) has, therefore, become a significant area of interest in maritime transportation and the container-shipping industry, especially because the largest shipping companies keep expanding their vessel fleet deployment across the oceans due to the rapid growth in global trade and maritime industry revolution.

There are usually various conflicting objectives in the container shipping market as there are in the usage of container assets. On one hand, a major objective of container shipping companies is to minimize the cost related to the movement of empty/laden container movements between several locations (depots, seaports, container freight stations, supply/demand regions, consigners and consignees), while simultaneously aiming to maximize revenue. On the other hand, container leasing companies aim to extend the container leasing term (duration of lease) as long as possible in order to increase their income. Conversely, container terminals aim to minimize the dwell time of containers (duration of stay) within container yard in order to avoid problems associated with the accumulation of large numbers of containers (empty and fully loaded), and to avoid the congestion of containers inside the container yard. By contrast, their customers aim to reduce the total time of container journey as much as possible among voyage routes in order to increase the possibility of timeous demand fulfilment and to reduce their expenses. Therefore, the main challenges that are faced by stakeholders is how to manage and control their container movements

to increase throughput, reduce expenditure, minimize unnecessary operations, and satisfy customer demand amidst different levels of cyclic fluctuation in demand and market requirements.

The efficient management of container terminals is therefore an important part of a successful implementation of seaport management, and it plays a significant role in logistics and supply chain management. This thesis aims to study and discover the main daily functional operations and sub-operations at typical container terminals, the terminal equipment deployed, container vessels and containerships, types of terminals, seaport logistics, seaport management, seaport performance and efficiency, and to present most of the problems that arise in the seaside and landside of terminals. It focuses on how reverse logistics can improve the management of returnable containers, and how to determine the optimum number of returnable containers. It also focuses on how to address empty container repositioning problems in maritime transportation, and how to optimize empty container movements among seaports and depots. Also, it focuses on how to optimize voyage routes for the containerships and vessels to transfer empty containers on shipping service networks. It aims to find the optimal service level, with optimal efficiency and service conditions, for the container stacking process in a seaport container terminal under the impact of synchronization and the sequence of daily operations and activities between the seaside and landside of terminals. It also investigates the problem of assignment of suitable berths to incoming vessels under different scenarios of berthing policy and priorities to discharge vessel.

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Chapter 1

Introduction

1.1 Background: Container terminal operations management has become a significant area of interest in the maritime industry especially given that conventional general cargo terminals have been greatly enlarged and developed into the current multi-purpose terminals through which most commercial goods flow. The need for greater efficiency and more productivity at seaport terminals is the driving force behind this phenomenon. As such, managing and scheduling the daily operations and activities of a seaport container terminal is a complex but highly essential operational and logistical process. The sheer number and magnitude of tasks that have to be accomplished with exact timing and seamless synchronicity are as daunting as they are unavoidable if a container terminal is to be run smoothly. They involve numerous types of equipment, cranes, trucks and vehicles to handle the flow of containers, whether empty or loaded. Any delay or error in the sequencing or planning of events and activities at a seaport container terminal can have a knock-on effect on the scheduling and management of the terminal's operations. Such operational delays could result in increased dwell time of containers (empty and fully loaded) at container yards and, thus, to increased costs as a consequence of the waiting time of containerships and equipment. The staying time of containers in the yard area as well as the resultant congestion that would occur are constantly in focus. Such delays lead to the reduced productivity (throughput) of seaports and to a reduction in the possibility of timeous demand fulfilment.

The efficient management of container terminals is an essential element to ensuring the optimal scheduling of Berth, Quay, Yard, and Gate operations. Every step in the sequencing of operations and activities that occur on a daily basis between the seaside and landside of a terminal must be properly aligned as far as human and financial resources can afford. Each of them plays a significant role in seaport performance criteria. The key motivator for seaport operators is to maintain their competitive edge. This underlying motive requires them to efficiently manage and control the containers that flow through their terminals, and it also requires them to solve three related issues: to increase productivity, to rationalize every component of their operations, and to minimize costs. Striking the right balance among all these three areas while monitoring the inevitable cyclic fluctuations in demand and supply forces, not to mention the constantly evolving technological and market requirements, is the driving force behind this study. The availability of empty containers in the seaport terminals depends on several factors such as fluctuation level of supply/demand, capacity limitations in seaports and depots, accumulation/shortage level in the surplus and deficit seaports, and the randomness level of empty container movement. One of the day to day concerns of seaports is to minimize the completion dwell time of containers within the terminals and to avoid the accumulation problem of large numbers of containers (empty and fully loaded). It is also to avoid the congestion of containers inside the container yard (CY). Furthermore, seaports authorities aim to minimize the total cost related to the sequence of operations and activities during the flow of containers between seaside and landside of terminals.

1.2 **Research aims and objectives**

This research aims to address the empty containers (ECs) distribution and repositioning problems in maritime transportation. It focuses on how to optimize the movement of ECs among seaports and depots, in alignment with varying demand conditions, and taking into account the logical sequence of operations and schedules on voyage routes. It also aims to provide a precise understanding of the concept of Empty Container Repositioning (ECR). It focuses on the impact of different leasing and purchasing policies to optimize the empty containers repositioning among several seaports and depots. The research further focuses on how to optimize voyage routes of containerships and vessels operated by shipping service networks. This is in order to minimize the total expected cost associated with ocean transportation, including handling costs (on/off), storage costs, and leasing and purchasing costs. The research aims to find solutions for alleviating or eliminating non-essential movement of ECs by optimizing a shipping service network's ability to reduce the total voyage route time. Associated objectives are to manage the sequencing of vessels' movement and, ultimately, to decongest seaports.

Further, the research aims to study the impact of synchronization on seaport container terminal operations as well as the underlying problems and challenges of the container stacking process. It examines how to evaluate the performance of operations and activities inside container terminal areas, such as the application of a queuing system, in order to establish and achieve optimal efficiency and service conditions that could be utilized by terminal operators. This involves, *inter alia,* solving berth allocation problems that are a predominant issue in a seaport container terminal, and how to assign suitable berths to vessels while balancing often conflicting berthing priorities.

A related aim is to study the reverse logistics problem and how to manage the returnable containers from the hinterland to the seaport. The ability to determine the optimum number of returnable containers, as well as the optimum number of new containers that should be ordered from a vendor - as a replacement and replenishment mechanism, while balancing the optimal cycle time of such replenishments – is a further goal of this study.

This research also aims to establish and examine the rationalization of the main daily functional operations and sub-operations at a typical container terminal. It will outline these functions and activities by questioning their continued use or non-use in the day to day containers management cycle.

Finally, the research aims to establish new models, or to modify and develop existing models, in order to solve the problems that are prevalent at seaport container terminals.

1.3 Research Questions

- How best can container terminals distribute or redistribute the containers (empty and fully loaded) from the supply seaports to the demand seaports
- How best can container terminals reposition empty containers from the surplus seaports to the deficit seaports
- How can seaport authorities be aided in determining whether and when to lease or purchase the required quantity of empty containers

- How can seaport authorities reduce the accumulation level of empty containers at surplus seaports, while simultaneously ensuring that there will be no shortage of empty containers at the deficit seaports
- How can seaport authorities select the most suitable voyage routes for the containerships sailing across shipping service networks? This is of particular importance to them due to the inherent imbalance that exists between the surplus and deficit seaports, the limitations of containership capacities, and the sequence of containerships scheduled to carry a specified number of containers between various seaports
- How can seaport authorities re-optimize shipping service networks? This procedure reduces total voyage times and provides for shorter distances between supply and demand seaports, especially if the required shipment is ordered from a supply seaport and distributed to a series of demand seaports on the shipping service network
- How best can seaports authorities reduce or minimize the dwell time of containers (empty and fully loaded) at container terminals
- How best can seaports authorities manage or schedule the daily operations and activities of a seaport container terminal
- How best can seaports authorities schedule the sequence of operations and activities between seaside and landside of terminals
- How best can seaport authorities determine the most efficient container stacking strategy while managing various conflicting objectives (minimize the reshuffles and number of future relocations of containers in a storage yard, or maximize the yard density and stacking area capacity utilization
- How can seaports authorities and container terminal operators determine how many berths and quay cranes are assigned to the vessels while adhering to berth allocation policy and service priorities
- How can reverse logistics improve the management of returnable containers

The research contributes to finding the answers to all these questions and offers a number of solutions to address existing problems faced by seaside and landside container terminals operators.

1.4 Outline of the thesis

The outline of this thesis is organized as follows:

Chapter 1, Introduction: briefly describes the scope of the study, its objectives and potential contributions while introducing some of the seaport terminology, as well as the inherent rationale or problems occasioned by containerization, container types and sizes, container vessels and containerships, types of terminals, seaport container terminal operations, seaport container terminal equipment, seaport logistics, seaport management, as well as seaport performance and efficiency.

Chapter 2, Literature review: presents the sources from existing literature on the identified problems and questions raised; it classifies the studies according to the types of problems and the critical issues inherent at container terminals. Different approaches have been proposed and particular focus is placed on the many solutions offered by various authorities in order to address the problems.

Chapter 3 Consists of two sections: Section one presents an economic return quantity model for a multi-type empty container management system with storage constraint. Section two presents an integrated lot sizing model for a multi-type container return system, with shared repair facility and possible storage constraint.

Chapter 4 also consists of two sections: Section one presents the empty container repositioning problem at South Africa's seaports. This is drawn from a paper that was published in the international conference on industrial engineering and operations management (IEOM), Bali, Indonesia, January 7 – 9, 2014. The paper addresses the empty container repositioning problems faced by South Africa seaports (Cape Town, Port Elizabeth, East London, Durban, and Richards Bay), by optimizing the repositioning process, with the aim of minimizing the total cost of empty container movements between supply ports and demand ports. Section two presents the optimal routes for the vessels to transport empty containers under various shipping service network designs. It draws from a paper published at the international conference on industrial engineering and operations management (IEOM), Dubai, United Arab Emirates, 3-5 March 2015. The paper seeks to optimise the movement of empty containers among shipping routes at South Africa seaports, subject to the optimisation of cost of port transfer, considering port operations (handling on/off, inventory-holding, leasing and purchasing new empty containers).

Chapter 5 Consists of two sections: Section one presents ideas on the optimization of container stacking processes while being mindful of the impact of synchronization on seaport container terminal operations. It draws from a paper that was published for the International Conference on Industrial Engineering and Operations Management (IEOM), Pretoria/Johannesburg, South Africa, October 29 – November 1, 2018. The paper aims to find the optimal service level, with optimal efficiency and service conditions for the container stacking process in a seaport container terminal. Section two presents the assignment of suitable berths to the vessels given the variety of conflicting berthing priorities. The paper aims to offer suitable berthing solutions for the discharge of vessels operating under different scenarios of berthing policy or priorities and vessel serving.

Chapter 6 is a presentation of the findings, conclusions and recommendations of this research study and will provide answers to the research questions in addition to highlighting future research possibilities.

1.5 Development of Containerization

Historically, the first container was made by Malcolm Mclean, who was a president of a trucking company in the United States. The beginning of the era of containerization was in 1956, when the first containership (Ideal-X) set sail from New York to Houston, carrying 58 specially designed containers (truck-trailer vans) above deck. Following that first voyage, another containership with capacity was able to carry 226 containers (35 foot length) in 1957 and was serviced between Newark and Puerto Rico, also between Newark and Houston [Rodrigue, Comtois and Slack 2006 (pa 24), Transportation Research Board-Washington, D.C. 1992 (pa 17, pa 26), Song and Panayides 2012 (pp 49-52, pp 218-220)]. To control the development of different container systems, in 1961, the United States proposed an international standard container size (8 ft width × 8 ft height × 10 ft, 20 ft, 30ft, 40 ft length), and that size was approved in 1964 as the international standard for intercontinental transport [Song and Panayides 2012 (pp 49-52)].

Between 1969 and 1971, Sea-Land Services Inc. was provided vessels (higher-capacity cellular container liners) to carry (1000-1200 containers)., With the use of a gantry crane the completion time of loading and unloading cellular container vessel was vastly reduced from about one week, in a traditional cargo vessel, to about one day, w, thus greatly enhancing efficiency and productivity. as. Many containerships during the period between 1972-1974 were designed with twin-screw steam turbines, and some containerships with diesel engines. Cellular containerships became a dominant feature of international and regional transport systems in the early 1980s, and the containerships of this generation generally ranged in capacity from 1500 to 3000 TEUs (Twenty-Foot Equivalent Units which can be used to measure a ship's cargo carrying capacity) with drafts of up to 35 feet, and a service speed of between 20 to 24 Knots. [Transportation Research Board-Washington, D.C. 1992 (pp 26-30)].

During the period between 1984 and 1987, most of the containerships were built with diesel engines and could carry large capacities. However, they were characterized by low service speeds, a drawback which was counter balanced by their higher capacities (2500-4000 TEUs) with drafts of 38 to 40 feet, and with typical service speeds from (18 to 23) Knot [Transportation Research Board-Washington, D.C. 1992 (pp 28-29)]

At the beginning of 1990, the American containerships fleet consisted of 93 vessels, and most of which carried 56% TEU containers (20 × 8 × 8.5 feet), and 37% FEU (Forty-foot Equivalent Unit) 40 × 8 × 8.5 feet containers). Furthermore, the number of TEU containers in the USA 2388000 and the majority of marine containers (89%) were dry vans and specialized containers constructed with steel. Some containers are made of aluminium (almost all refrigerated containers) [Song and Panayides 2012 (pp 49-52, pp 218-220)].

1.6 Container types and sizes

Due to the high growth in the international trade that has enabled rapid distribution of goods to every corner of the globe container types and sizes tend to expand annually. This has been the case since containers were first used in the early 1960s until today. The one major development since then is that containers are now built according to International Standards Organization (ISO) specifications. While there are many types of containers that are used in both the land and maritime transportation industry they are usually classified according to the purpose and usage, or to the type of goods and products being transported. In general, the containers can be tagged as either as ISO or Non-ISO containers as explained below (Branch 2007 (pp 361-372), Ligteringen and Velsink 2012 (pp128-129), Tack and Huat 2000 (pp 32-35)]:

a) The most common standard is the **TEU (Twenty-foot Equivalent Unit)** or (dry freight container). It is designed for all types of general merchandise and products, and is also used, with suitable modification, for the carriage of bulk cargoes, be they solid or liquid. The dimensions of most 20ft containers are 20 ft (6.1 m) length, 8 ft (2.44 m) width and 8 ft or 8 ft 6 inches (2.6 m) height. The internal volume of the container is approximately 32 m^3 and the maximum gross weight they can carry is 30480 Kg.

b) **The 40 ft container,** or FEU (Forty-foot Equivalent Unit), is most widely used for general cargo, and it has the same width and height as the 20 ft container, but the length of a FEU is a twice that of a TEU. The internal volume for the container is approximately 65 m^3.

c) **Refrigerated containers:** this type of container is used for shipment of perishable and frozen cargoes (meat, dairy products and fruit). The containers are designed and fitted with the refrigeration units, and therefore require an electrical power supply for operation on the ship and on the container terminal. They are available in 20 ft, 40 ft and 40 ft hi-cube (40 × 8 × 9.6) ft sizes.

d) **Insulated containers:** These are used to transport food stuffs and perishable cargo requiring to be carried under temperature control. This is in order to protect them against heat loss or gain and is achieved by installing a blow-air refrigeration system to allow free air circulation around the perishable cargo The internal volume for the container is approximately 29 m^3, and the maximum gross weight reaches 24000 Kg. .

e) **Bulk containers:** These containers are designed to carry products such as dry powders, seeds and granular substances in bulk. Usually, many circular hatches are fixed in the roof structure of containers for loading and unloading cargo. Container dimensions according to ISO are: 20 ft × 8 ft × 8 ft 6 inches, and the internal volume is 33.1 m^3; maximum gross weight is 24000 Kg.

f) **Ventilated containers:** These are ideal for conveying products such as coffee and cocoa of which condensation damage is a major consideration. They are built with a special ventilation system (ventilation galleries) positioned along the top and bottom side rails of the container so as to allow the passive ventilation of cargo. In this way they are similar to the dry freight container. The dimensions of ventilated containers are 20 ft × 8 ft × 8 ft 6 inches, with an internal volume equal to 32.3 m^3, and can carry a maximum gross weight equal to 24000 Kg.

g) **Flat rack containers and platform flats:** They are designed to facilitate the carriage of oversize or 'awkward' cargoes, such as vehicles and lumber which are large or indivisible loads. Other examples are large items of machinery, building materials, construction equipment and many more.. Some of these containers have collapsible ends or spring-assisted foldable end walls to allow for moving the large or indivisible item on the container during loading and unloading. Usually, a combination of the two or more flat rack containers can be used to move uncontainerable cargo between ports. The total weight of the cargo must not exceed the static capabilities of the flat rack containers. Most flat rack containers are 40 ft long and a maximum gross weight equal to 45000 Kg, although some are made in the 20 ft category and a maximum gross weight equal to 30480 Kg.

h) **Tank containers:** These are ideal for the transport and storage of all types of bulk liquids (toxic, hazardous and non- hazardous and gases). They are a safe method to carry these and other liquids as they are protected by a box frame (20 ft × 8 ft × 8 ft 6 inches) as well as stainless steel construction. This type of container is classified for many particular applications (the IMO type, light weight tanks, food grade tanks, insulated tanks and special tanks). Tank container can be shipped by rail, road and sea, and have a capacity ranging from 12000 litres to 35000 litres.

i) **Military containers:** These are used for carrying military equipment to overseas military forces and peace-keeping missions and can be fitted on., land, sea and air vessels. They are designed in two categories (Quadcon and Tricon), which are mini containers designed to interlock in order to create one standard consisting of 4 Quadcon units or three Tricon units to make up 20 ft ISO container. The created container) is delivered as a one module but can be separated into its individual units. Both these types are loaded and unloaded by using smaller mechanical handling devices, and are conveyed by vehicles.

j) **Sea cell containers:** These date back to the beginning of the era of containerization between 1969 and 1971. Sea cell container took the container revolution to new and improved levels of productivity and efficiency, given that they can be lifted by all types of container handling equipment. They offer an increased volume of 3.5% and a heavier payload of 34 tons (compared to 30 tons in a traditional 40 ft container).

k) **Open top containers:** These are ideal for carrying sheets of glass, timber and machinery as well as large, awkward items, indivisible loads and oversize cargoes, which cannot be stowed in the conventional container. This container is described as an open sided or open top container because cargoes can be loaded from the top or through its doors and are, typically covered with tarpaulin tilts to protect the cargo.

l) **Hanger containers**: These are very popular in the Far East and North American markets, because they are used for the shipment of a wide variety of consumer products such as garments on hangers. The hanger container is equipped with removable beams in the upper part of the container, and it is classified into two types (the first: 12.2m long, 2.4m wide, 3m high; and the second: 6.1m long, 2.4m wide, 3m high).

m) **Swap bodies:** These are used to carry palletized cargo, and can be easily transferred from a rail wagon to a truck, or from a truck to a barge to complete an overland journey. Usually, the Swap Bodies enable pallets to be carried more economically than in standard marine containers, and can be stacked (as laden units) in the terminals and container yard as three-high (for class C, 7.15m or 7.45m long) and two-high (for class A, 13.6m long)., Further, they can be utilized in lift on/off short sea and barge operations. Figures 1.1 and 1.2 show the major components of a container (full assembled and exploded view. Figures 1.3 and 1.4 show container types, and the table no.1.1 represents container sizes.

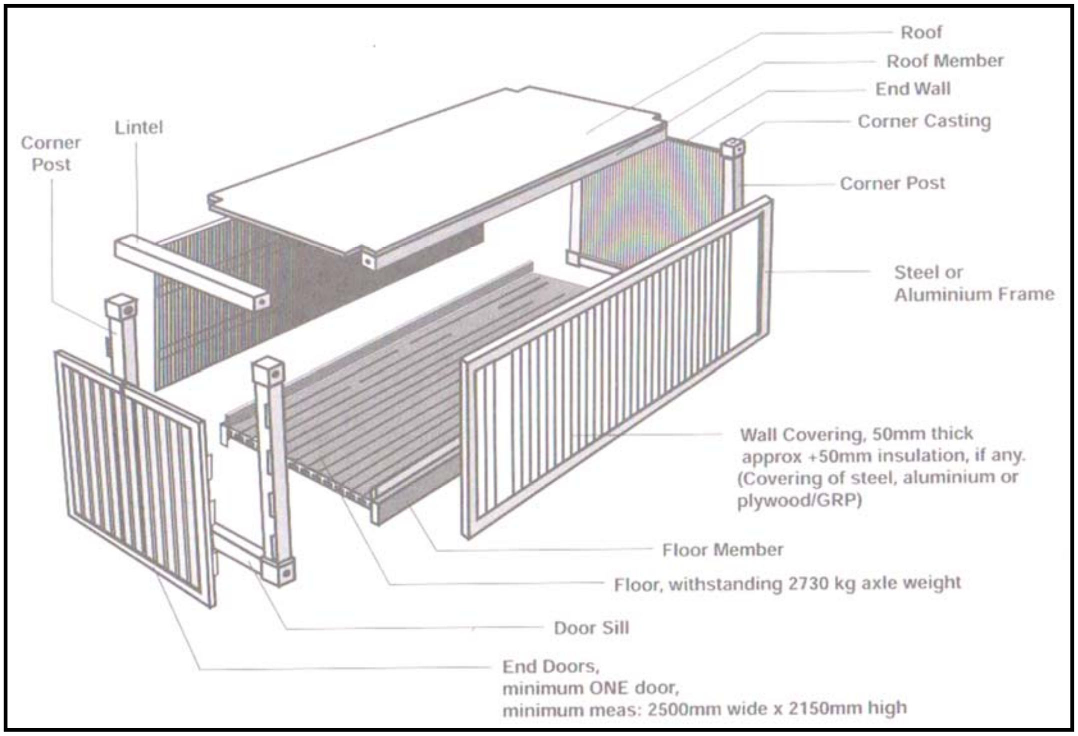


Figure 1.1: Major components of a container (full assembled) [Tack and Huat 2000 (pa 11)]

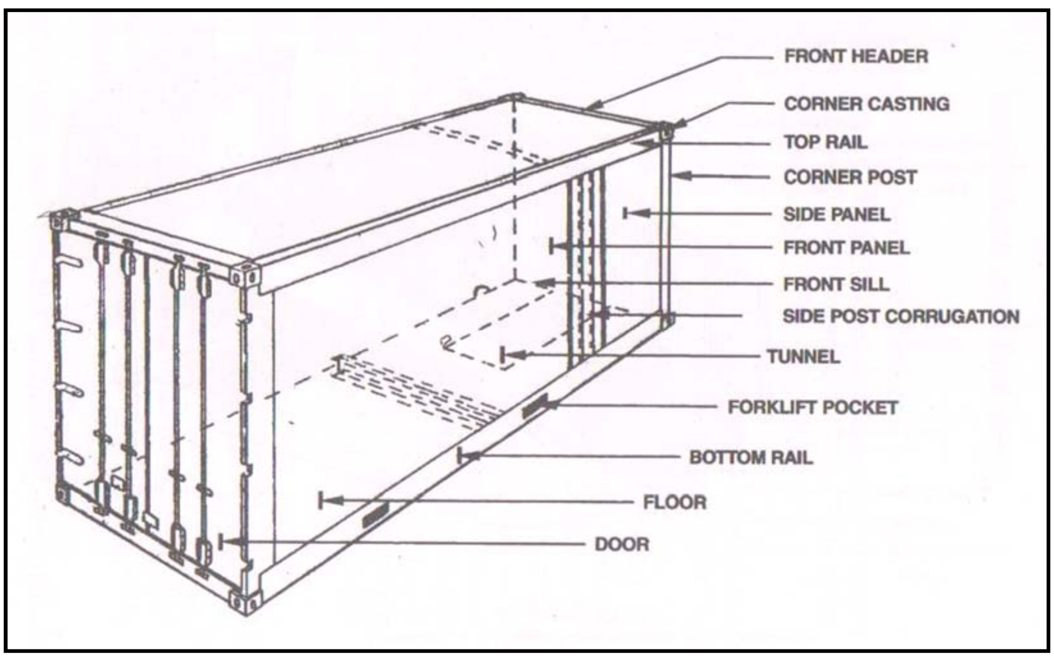


Figure 1.2: Major components of a container (exploded view) [Tack and Huat 2000 (pa 12)]

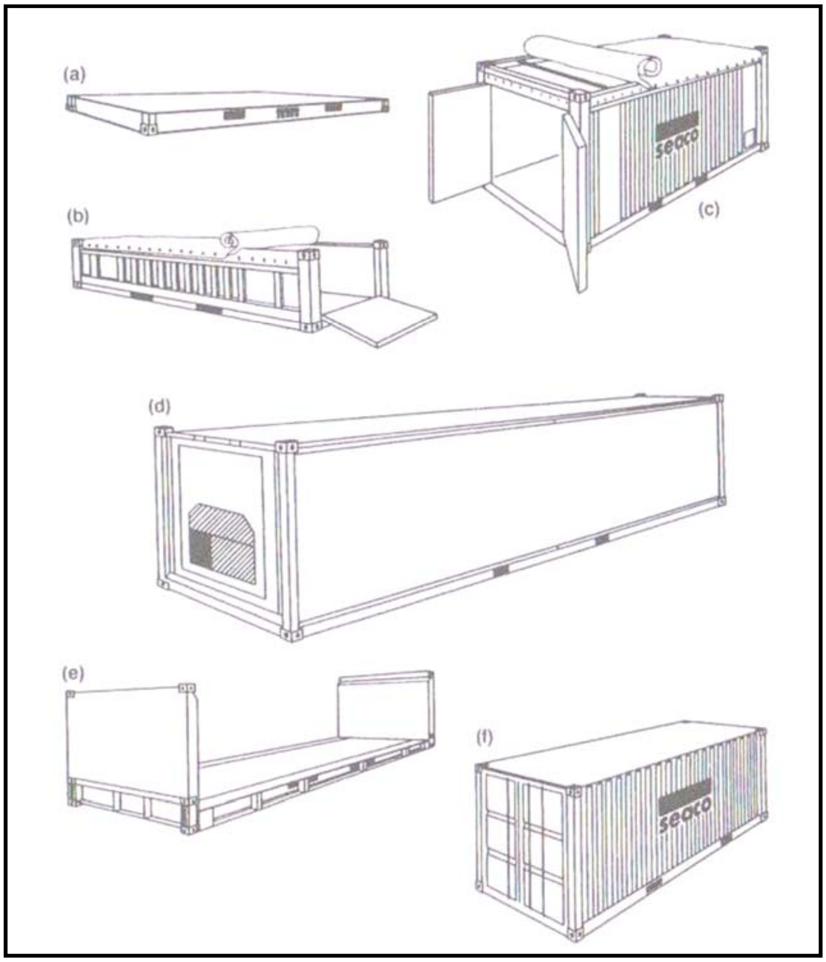


Figure 1.3: Container types [BRANCH 2007 (pp 362-363)]

a- 20 ft platform flat.

b- 20 ft half-height with ramp end door and tarpaulin roof.

c- 20 ft open top for large awkward items.

d- 40 ft refrigerated container.

e- 20 ft spring-assisted folding end flat-rack.

f- 20 ft covered container.

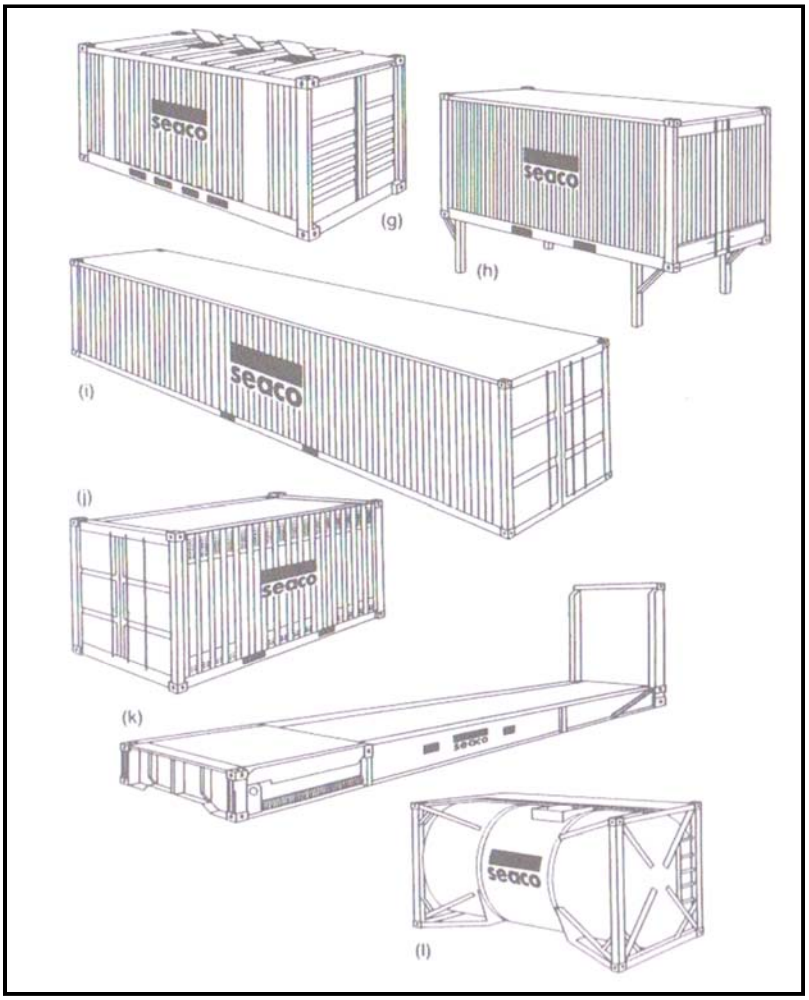


Figure 1.4: Container types [BRANCH 2007 (pp 362-363)]

g- 20 ft bulk container for grain.

h- 7.15 m swap body with demountable legs, 2.5 m width for two-pallet-wide European operation.

i- 40 ft high cube 9 ft 6 in high for cargoes that cube out.

j- 20 ft ventilated container for cargoes such as coffee and cocoa.

k- 40 ft sea deck-style combined flat-rack and platform flat.

l- 20 ft tank container for bulk hazardous and non-hazardous liquids.

ISO Type	TEU	External Dimensions (m)	Maximum Lifting Capacity (tons)	Cubic Capacity (m^3)
IC (20 ft)	**1**	**6.05 × 2.435 × 2.435**	**20**	**29**
IA (40 ft)	**2**	**12.190 × 2.435 × 2.435**	**30**	**60.5**
IB (30 ft)	**1 ½**	**9.125 × 2.435 × 2.435**	**25**	**45**
ID (10 ft)	**½**	**2.990 × 2.435 × 2.435**	**10**	**14.1**

Table 1.1: Container sizes [Tsinker 2004 (pa 39)]

1.7 Container Vessels and Containerships

The evolution of containerships started after World War II, when Malcolm Mclean launched the first containership, (Ideal-X), in 1956. which initially a general cargo ship or tanker, and was then converted to carry containers.

Their development is classified according to the containership's generation, each of which is characterized by large and more efficient ships or vessels than the previous one, the distinctive features being distinguished by a particular shape and size and built with ever increasing dimensions and capacities.

Each generation is determined by the relative size of a containership that can be measured by the total number of loaded containers. The generational classification of containerships as well as associated characteristics are shown in the table down below. [Ligteringen and Velsink 2012 (pp 15-19)]

Class	Capacity TEU	Deadweight (average) ton	Length of containership (m)	Draught (m)	Beam (m)
First generation	**750-1100**	**14000**	**180-200**	**9**	**27**
Second generation	**1500-1800**	**30000**	**225-240**	**11.5**	**30**
Third generation	**2400-3000**	**45000**	**275-300**	**12.5**	**32**
Fourth generation	**4000-4500**	**57000**	**290-310**	**12.5**	**32.3**
Post-Panamax	**4300-5000**	**54000**	**270-300**	**12**	**38-40**
Super Post-Panamax (or Jumbo Post-Panamax	**6000-9000**	**90000**	**310-350**	**14**	**43**
Ultra Large Container Ship (ULCS)	**14000**	**157000**	**400**	**15.5**	**56**

Table 1.2: Classification of containerships generations [Ligteringen and Velsink 2012 (pa 17)]

The first generation of containerships covers the period between 1956 and 1969., All containerships during that period were originally general cargo ships or tankers which were converted. The converted containership was used after fitting holds with cell guides to secure the containers on the decks both horizontally and vertically. The capacities of containerships for this generation ranged from 750 TEU to 1100 TEU, and most were built with steam turbines to carry specific capacities with low service speeds (from 18 to 21 Knots), and drafts (draughts) of less than 9 m. The second and subsequent generation of these vessels were known as cellular containerships and were custom built to only carry containers During the period of the second generation, between 1969 and 1971, the containership's capacities ranged from 1000 TEU to 1800 TEU, and the containers were secured by lashing systems and were arranged on the deck in rows parallel to the containership's axis., . These, too, were powered by steam turbines which typically gave them service speeds ranging from 20 to 23 Knots, and drafts of up to 11.5 m. [Transportation Research Board-Washington, D.C. 1992 (pp 26-28)]

The capacities of containerships in the third generation - from 1972 to 1974 - were increased rapidly and ranged between 2400 TEU and 3000 TEU, and were mainly powered by twin-screw steam turbines, while some were powered by diesel engines that could achieve ranging between 22 Knots and 26 Knots, and drafts of up to 12.5 m. The fourth generation of containerships (1978-1983), were designed with large capacities ranging from 4000 TEU to 4500 TEU, and drafts up to 12.5 m, but the service speeds fell to 20-24 Knots. Due to the rise in oil prices in 1973 caused by the oil crisis of the time, most containerships of that generation were built with single-screw steam turbines, or with low-speed diesel engines to reduce the amount of fuel consumed. A distinguishing feature of fifth generation containerships was they were built according to the most Panamax size (capable of passing through the Panama Canal, or similar width elsewhere), and powered with diesel engines to carry up to 4400 TEU. During this period (1984 to 1987), the low fuel consumption trend was continued, With the typical service speeds ranging from 18 to 23 Knots, and with drafts from 11.5-12 m. [Transportation Research Board-Washington, D.C. 1992 (pp 28-29)]

The sixth generation of containerships is known as the Post-Panamax generation which featured, a beam size that was wider than that permitted by the Panama Canal, and the design of the hull was made wider and shorter than that of Panamax design. Their carriage capacities ranged from 4300 TEU to 5000 TEU, with drafts reaching up to 12 m but they could not be used in the Panama Canal or similar width maritime passageways. [Transportation Research Board-Washington, D.C. 1992 (pa 29)]. The large containerships or container vessels required deep draughts to ease the loading/unloading process at seaports, while the smaller vessels could do the same in shallow draughts to carry the cargo and to moor at shallow-water ports.

In 1996, the capacities of container vessels were increased from Post-Panamax capacities to Super Post-Panamax (or Jumbo Post-Panamax) capacities, where the capacity ranged between 6000 TEU and 9000 TEU, and the draft was increased up to 14 m. Furthermore, the maximum service speed was increased to 24.5 Knots. Emma Maersk shipping company added had an Ultra Large Container Ship (ULCS) to its fleet in 2006., The capacity of a ULCS ranged from 12500 TEU to 14000 TEU, and the draft reached up to 15.5 m. At the beginning of 2011, Emma Maersk shipping company ordered 50 new containerships with a capacity of 18000 TEU, and with draft up to 15 m. [Ligteringen and Velsink 2012 (pa 17)].

During the period (2013-2014), the containerships were designed with large capacities up to 18000 TEU, and drafts up to 16 m.

Figure 1.5 shows the major components of a containership.

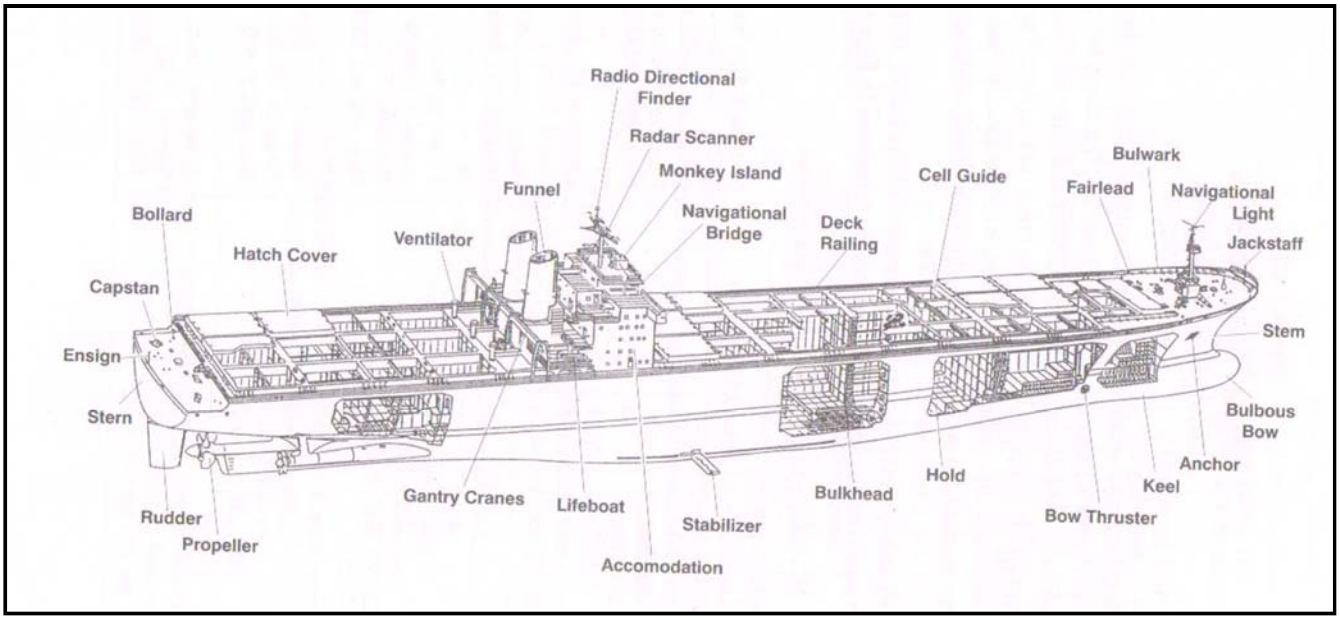


Figure 1.5: Major components of containership [Tack and Huat 2000 (pa 65)

1.8 Types of Terminals

1- **Conventional general cargo terminal:** This type of terminal is the first of its kind, and it was designed for the handling of break-bulk cargo and goods varying in shapes, dimensions and weights, such as machinery and parts. The conventional general cargo terminal is not of great importance in the modern era but they are still needed. This is because some seaports cannot simply construct special terminals to deal with each sort of commodities or goods, because space constraints (due to lack of land availability) and the capital expenditure as well as the labour that would be required. Furthermore, the specialized terminals are established to deal with certain cargoes that adhere to specific requirements and considerations. Sometimes a modern general cargo terminal can be able to deal with variety of requirement to suit including containers that are carried by multi-purpose vessels, and sometimes the special terminals are required especially for oil and liquid gas in terms not only for economic reasons, but also for safety reasons. [Ligteringen and Velsink 2012 (pp 114-115)]
2- **Multi-purpose terminal:** These are used to deal with break-bulk cargo, containers and Ro/Ro cargo. There is very little difference between a multi-purpose terminal and a modern

general cargo terminal, except the former is a little more developed than the latter in terms of terminal layout and type of equipment used. Furthermore, converting from a traditional general cargo terminal to a multi-purpose terminal is a complex process, requiring not only additional land space (quay side and yard side), but adequate pavements to install modern container cranes and special arrangements for the ramps of Ro/Ro ships. [Ligteringen and Velsink 2012 (pa 115)]

3- **Ro/Ro terminal (Roll On/Roll off):** This is ideal for mooring Ro/Ro ships (usually has a ramp at the stern of the ship, thus enabling trailers and trucks to roll on or off the ship itself for purposes of loading or offloading cargo depending on berth location, and the quay layout of the terminal. (Quarter ramp or Stern ramp), where the quarter ramp of ship enables the ship to moor at any plane area of quay side, while the stern ramp of ship requires a special place on the quay side or even requiring special berth construction at the seaport. [Ligteringen and Velsink 2012 (pp 115-116)]
4- **Container terminal:** These terminals have a substantial surface area for storage and stacking containers for several days or weeks. There are many functions and activities that are associated with containers management such as handling, transportation, stacking. They feature a set of cranes, straddles, carriers, trucks, and vehicles that serve at many areas of the terminal such as between seaside and landside.. To achieve an efficient loading/unloading process the container storage area is located as near as possible to the berths. . [Ligteringen and Velsink 2012 (pp 117)]
5- **Liquid bulk terminal:** These are generally used for receiving and storing bulk crude oil, petroleum products, chemicals and liquid gas headed for refining facilities or marketing facilities (for further transfer or shipped directly to the destination). The loading/unloading process of the liquid bulk carriers (crude oil tanker, product tanker, parcel tanker and liquid gas tanker) is performed via a central manifold in midship or via cargo capable of pumping the liquids by means of transfer hoses and cargo pipelines. as well as floating or submarine pipelines. As a safety measure, given the flammability or toxicity of liquid bulk (hazardous liquids or toxic chemicals), the storage tanks are surrounded by levees or dikes to prevent fires and as environmental protection systems. Furthermore, the storage tanks are placed in locations close to the refinery or chemical factory. [Ligteringen and Velsink 2012 (pp 117-118)]
6- **Dry bulk terminal:** These are primarily built to deal with specific type of cargo or products (large quantities that are unpackaged and are available in uniform dimensions), such as iron ore, coal, raw materials and cereals. There is a difference between the loading and unloading process for the same commodity in the import dry bulk terminal and the export dry bulk terminal, whereby the unloading of dry bulk carriers at the import terminal is done with quay cranes and specialized grabs, while the loading process for the same cargo at the export terminal is done with the use of a conveyer belts system. The cargoes are stacked in long piles in the open air or in closed silos, depending on the type of cargo. The storage area for both terminals (import and export) is neared the seaside of the terminal or at both sides of water. [Ligteringen and Velsink 2012 (pp 118)]
7- **Floating terminal:** These are used to overcome existing problems with inadequate or limited port infrastructure, and are a suitable alternative in terms of dredging and maintenance of the channel or berth to the required depth. They are a flexible alternative

for dealing with environmental and parking problems at seaports as well as crowded cities which have a waterfront. Floating terminals have the capacity to store raw commodities such as coal, iron ore and bauxite. To reduce transportation costs, floating terminals are established closest mining sites. Finally, the project implementation time for a floating facility is between 12-24 months and much shorter than a shore-based facility. [BRANCH 2007 (pp 390-393)]

8- **Fruit terminal:** This type of terminal is designed with refrigerated warehouses to store and keep fruit from going bad. In most cases the refrigerated warehouses in modern fruit terminals are located near the waterfront, and the cargoes are transferred directly from the ships into the warehouses by conveyer belts or by luffing cranes at the quay. Different forms of packaging fruit (palletised boxes or containerised) are handled by luffing cranes, and these cranes are much lighter and less complex than those used in container terminals or dry bulk terminals. [Ligteringen and Velsink 2012 (pp 118-119)]

1.9 Seaport container terminal operations

The logistical function of a container terminal consists of several operations, each one serving a specific area and purpose in the terminal [TACK and HUAT 2000 (pa 10)]. The flow of containers through the terminals is a complex system with highly dynamic interactions between the various terminal areas (units) and incomplete knowledge about future events [Voß et al 2009 (pa 417)].

With the rapid growth in global trade and the revolution in the maritime industry, , the development of terminals in terms of size, function, and geometrical layout, resulted in additional activities and operations, especially as the terminals grew in size and developed from the conventional general cargo terminals to the multi-purpose terminals [Tsinker 2014 (pp 130-134)].

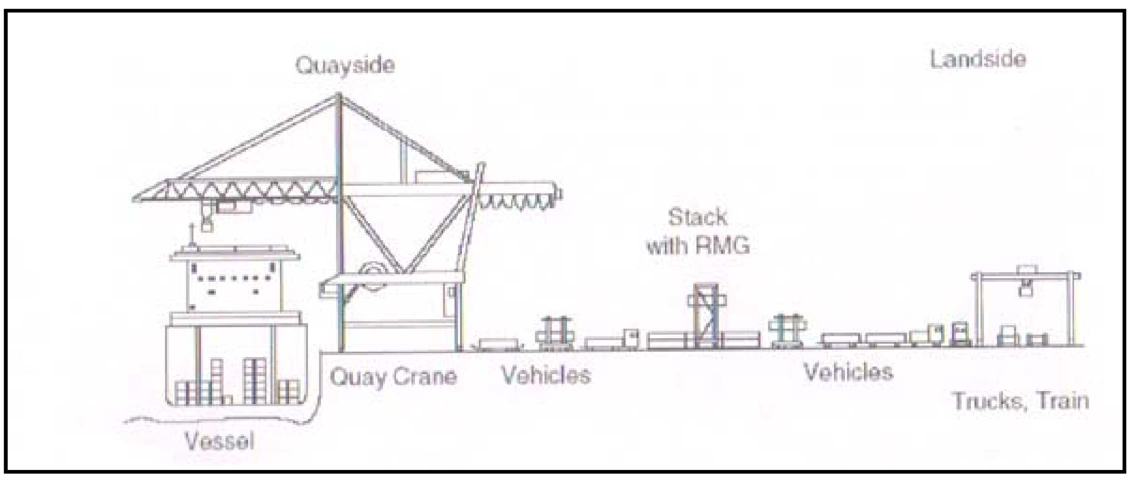


Figure 1.6: Layout of the typical seaport container terminal operations [Kim and Günther 2010 (pa 6)]

They are many functions and operations between the seaside and landside of container terminals, even though the primary operations of a typical container terminal are to deal with loading/unloading of containers from/to containerships moored at the berth, as well as handling on/off containers by cranes at the quay area, transfer containers from seaside to landside (or vice versa) by various forms of means of transport stacking of containers in the container yard, temporary storage of containers in blocks, and finally transfer containers from container yard to the gate area [Meisel 2010 (pp 10-11), Kim and Günther 2010 (pp 5-7)]. When the containerships (vessels) arrive at seaport, the quay cranes unload (discharge) the containers from the vessels and put them on Yard Trucks (YTs) or Automated Guided Vehicles (AGVs) or Multi Trailer System (MTS)., These containers are then transferred from the quay area to container yard (ship-to-yard transportation) for stacking and temporary storage. The quay area (berthing area) is equipped with quay cranes for the loading and unloading of vessels although some containerships are self-equipped with cranes in order to enable transhipment operations independent of the equipment offered at a terminal. However, vessel operators usually abstain from this option because a sufficient standard of equipment is offered at most terminals. A loading or unloading operation of a container is referred to as a move, and the productivity of quay crane is measured by the number of moves per hour. The loading of containers on to containerships is carried out by the same quay crane operations in the reverse order. Vessels may be served by up to six quay cranes, depending on their size and type [Meisel 2010 (pp 10-15), Kim and Günther 2010 (pp 5-7)].

In reality, the container yard consists of many blocks, and the blocks are used for the stacking and temporary storage of containers. At a container yard, the yard cranes are used for stacking the containers one on top of another into the blocks. Various types of yard cranes are allocated a set of yard blocks, and these cranes can be Rubber Tyred Gantry cranes (RTG), Rail Mounted Gantry cranes (RMG), or Automated Stacking Cranes (ASCs). The yard cranes pick up the containers from yard trucks and put them in stacking areas (blocks) by rows, columns and tiers, and the containers are stored for a certain period in the blocks. Storage capacity is a key performance indicator for terminals, where storage space is scarce. After temporary storage, the containers are transported by yard trucks (which are deployed between quay side and yard side) from a stacking area to the gate area or external trucks and trains areas to send the containers to the customers. Import containers are stored at container yards until the process of sending the containers to their destinations begins. Export containers are stored at container yard until they are loaded onto the dedicated vessels [Meisel 2010 (pp 10-15), Ligteringen and Velsink 2012 (pp 45-46)].

There are numerous additional operations inside a seaport terminal such as containers inspection, containers repairing and maintenance, and cleaning containers. These operations reflect the outcomes of the continuous development of container terminals, and they are used as a performance measurement (in addition to the general functions or operations) to evaluate the seaport's efficiency and the development level of the seaport infrastructure, particularly in terms of technologies, equipment, terminal areas, and production resources.

1.10 Seaport container terminal equipment

Within the seaport container terminal areas, there are many types of equipment used to carry out or deal with the tasks and functions between the seaside and landside of terminal. Most marine terminals use Quay Cranes (QCs) [see Figure 1.7] at the quay area for loading and unloading of containers from/to the vessels. The quay cranes are generally rail mounted or rubber-tyred, and they move along the length of the quay or the berth. Normally, the quay cranes are rope-hoisting or rope-traversing, and they are provided with a trolley and a cabin. They are equipped with spreader beams which attach to the corner casting of the container to enable it to be lifted [Ligteringen and Velsink 2012 (pp 129-131), Meisel 2010 (pp 11-12), TACK and HUAT 2000 (pp 97-98)].

One of the most cost-effective methods for enhancing the capacity and capability of container terminals is to increase the number of quay cranes per berth. As a guide, the quay crane can be installed every 60-80 m along the berth. Hence, the capacity of a standard berth of 350 meters in length can be maximized by installing 4-5 quay cranes. The productivity per berth can vary from 80000 to 1000000 TEUs per berth per year. Generally, the quay crane productivity at peak is 40-50 moves/hr, but the average is 20-30 moves/hr [TACK and HUAT 2000 (pa 98), Ligteringen and Velsink 2012 (pp 130-131)].

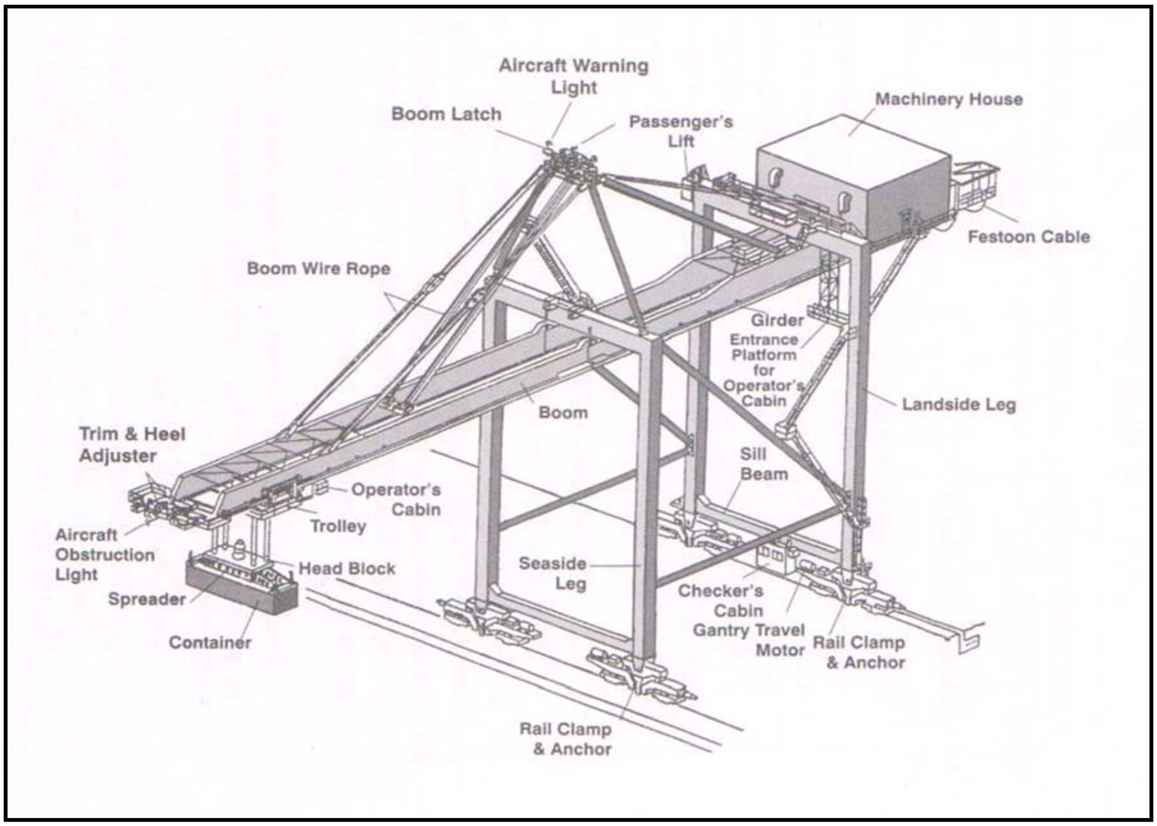


Figure 1.7: Major components of a single trolley quay crane [TACK and HUAT 2000 (pa 113)]

They are six types of equipment used to deal with the transport process between the quay and the storage yard of containers, namely, Forklift truck (FLT), Reach stacker, Chassis or Yard Trucks, Straddle Carrier (SC), Multi Trailer System (MTS), and Automated Guide Vehicle (AGV). The forklift truck is used most often for the handling of 20 ft empty containers only, and the modern forklift trucks [see Figure 1.8A] are equipped with spreaders to pick up a container from above. On multipurpose terminals with limited container throughput and much space, this type of equipment may offer an economic solution. Reach stacker [see Figure 1.8B] is more developed than (FLT), but the difference with the forklift truck is that this equipment handles the container by means of a boom with a spreader, and it can reach the second row of containers in a stack., Additionally, it handles only loaded 20 ft containers [BRANCH 2007 (pp 131-132)]. Chassis Yard Trucks [see Figure 1.8C] represent the technologically modest way of container transport, as they are moved by tractor units that pull chassis carrying the containers. They are single trailers for use in the container yard only., They are considered to be economically attractive because of low purchase and maintenance costs as well as high flexibility regarding the workload of a terminal. Nevertheless, labour costs for drivers lead to high operational costs. If the yard trucks are used at the container terminal, the containers can be stored on the transport chassis in the yard [Ligteringen and Velsink 2012 (pa 132), Meisel 2010 (pp 12-14)].

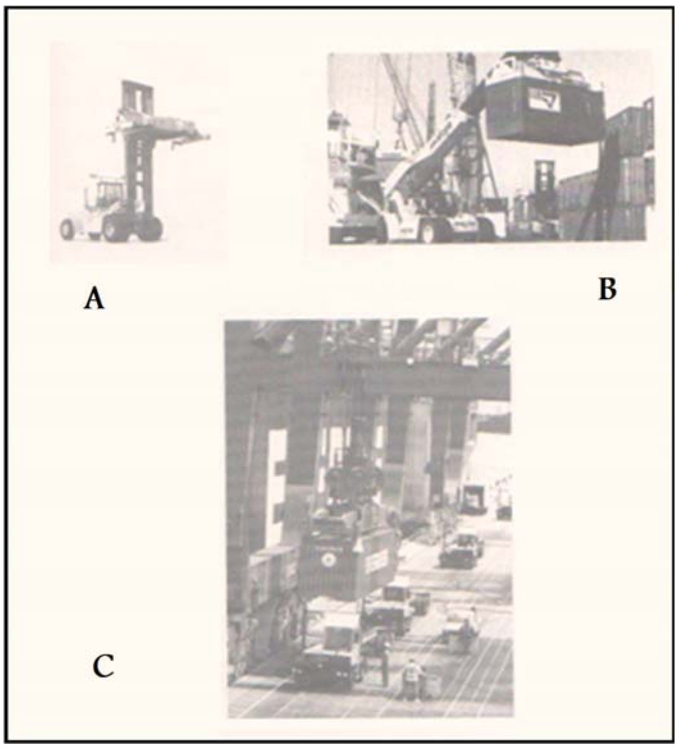


Figure 1.8: Forklift truck (A), Reach stacker (B), Chassis or Yard Trucks (C) [Ligteringen and Velsink 2012 (pa 133)]

Straddle Carriers (SCs) [see Figure 1.9A] are quite popular in container terminals because they are highly flexible and versatile machines due to easy mobility. They are multi-purpose transports as they not used only for moving containers, but also to lift and stack containers. When the quay cranes put the unloaded containers on the quay ground, the straddle carriers pick up them up and they can be moved away without a crane waiting for the next service process. This process avoids crane redundancy and leads to increased crane productivity in terms of moves per hour. Compared to Chassis (Yard Trucks) hire or purchase, high yard and equipment maintenance costs, and operational costs along with the employment of straddle carriers, poor visibility resulting in accidents, causing damage to containers and human injury, and (SCs) emit high noise levels which are generated during operation. The Multi Trailer System (MTS) [see Figure 1.9B] is used at a high throughput capacity container terminal. This equipment is a series of up to 5 trailers interconnected and pulled by one-yard tractor. This system is developed and manufactured in the Netherlands and has a special device to keep all trailers in line when making a turn [Ligteringen and Velsink 2012 (pa 132), Meisel 2010 (pp 12-15), Tack and Huat 2000 (pp 138-139)].

Automated Guide Vehicles (AGVs) [see Figure no.9C] are able to carry one 40 ft container or two 20 ft containers. The movement of (AGVs) is guided by induction coils installed in the pavement, and the vehicles move along the quay in one direction and along the yard in the other direction. Automated Guide Vehicles are remote-controlled from a central station and therefore facilitate a further drastic reduction of manpower, and the reliable execution of work plans resulting from the elimination of human failure. They are used in high throughput capacity container terminals, but it should be noted that they are complicated and sensitive equipment [Ligteringen and Velsink 2012 (pa 132), Meisel 2010 (pp 13-15)].

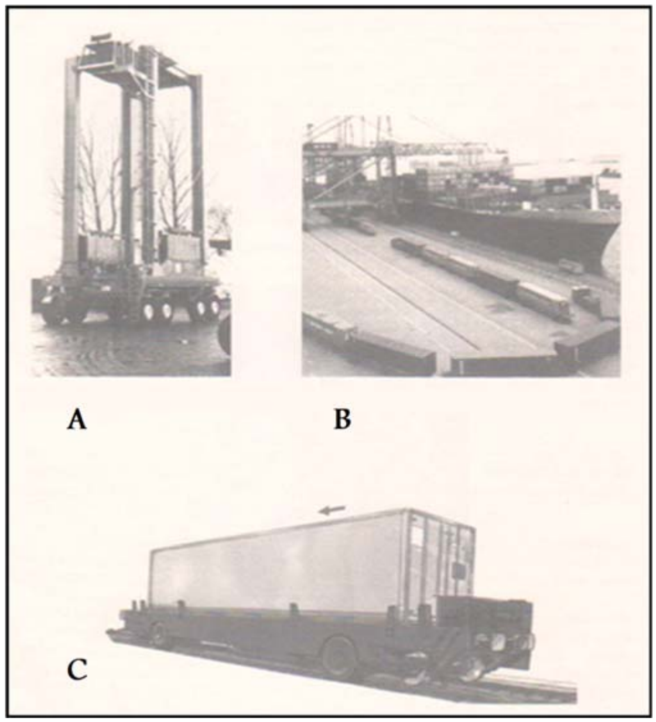


Figure 1.9: Straddle Carrier (A), Multi Trailer System (B), and Automated Guide Vehicle (C) [Ligteringen and Velsink 2012 (pa 134)]

Various types of equipment (yard cranes) are used in the yard area, an area that is divided into a set of blocks, separated by traffic lanes. It is used for intermediate storage of import containers. The yard cranes can be Rubber Tyred Gantry cranes (RTG), or Rail Mounted Gantry cranes (RMG) or Automated Stacking Cranes (ASCs). Generally, the yard cranes pick up the containers from yard trucks and put them in stacking areas (blocks) where they are organized by rows, columns and tiers. Both cranes, RTG and RMG, stack the containers up to six tiers high, but the uppermost tier of each stack remains empty in order to allow a crane passing over it with a container. Usually, a Rubber Tyred Gantry crane [see figure no.10] spans up to eight container rows, and a Rail Mounted Gantry crane [see figure no.11A] spans up to 13 container rows. One of the rows may be reserved for the service of transport vehicles. RTG cranes are flexible (can be moved from one stack to another) but require good subsoil conditions in view of the relatively high wheel loads on the pavement., They, therefore, require high civil engineering costs for the maintenance of gantry paths. However, there are several advantages of deploying RTG cranes: high crane reliability with low maintenance cost, low accident rates and causing less damage to containers. Comparatively, RMG cranes are inflexible and have poor mobility. (Further, they offer poor selectivity due to high stacking of containers, and they cause obstruction to operations in the event of a major crane breakdown., They also incur high energy costs. Nonetheless, they do have some advantages: very high crane reliability with low maintenance cost, minimal manpower to operate, low yard maintenance costs, low noise level generated during operation, and easier to automate crane operation as they are on rails [Ligteringen and Velsink 2012 (pa 132), Meisel 2010 (pp 14-15), TACK and HUAT 2000 (pp 134-137)]. Automated Stacking Cranes (ASCs) [see figure no.11B] reach across 5 containers and operate 1 over 4 high, in the most recent terminal extension. Although they require high maintenance costs, associated labour costs are minimal, and they are used in high throughput capacity container terminal [Ligteringen and Velsink 2012 (pa 132)].

Figure 1.10: Rubber Tyred Gantry crane (RTG) [Ligteringen and Velsink 2012 (pa 136)]

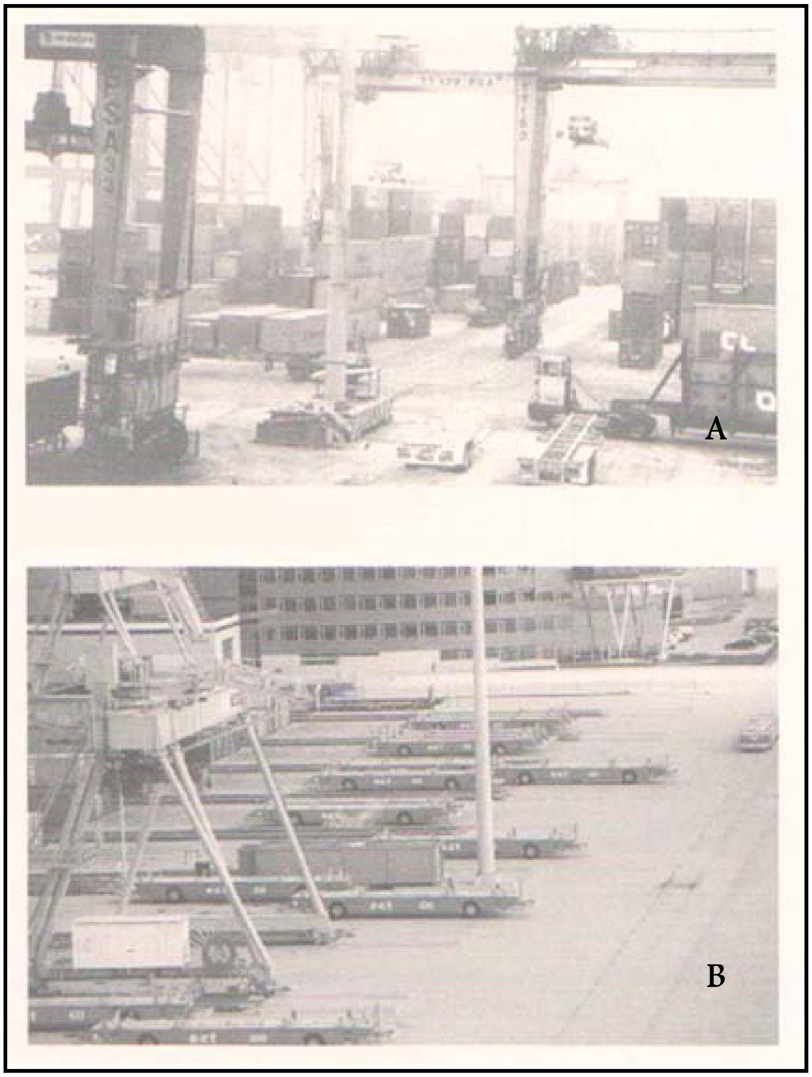


Figure 1.11: Rail Mounted Gantry crane (A) and Automated Stacking Crane (B) [Ligteringen and Velsink 2012 (pa 137)]

The transport of containers between the stacking area and the trucks stations or trains area (and vice versa) is done mostly by Straddle Carriers (SCs), because they can move above the trucks. Usually, self-service of trucks is possible if containers are stored on chassis in the yard area, and the containers are transported by yard trucks from the stacking area to the gate area. The particular equipment selection that is implemented in a terminal constitutes a set of requirements for the management of terminal operations. [Ligteringen and Velsink 2012 (pp 132-136), Meisel 2010 (pa 15)].

1.11 Seaport Logistics

The term Port Logistics refers to the process of planning, implementing, managing and controlling the physical flow of moving cargoes and all the relevant information through port terminals. The physical flow consists of the port entry, stevedore, transit, storage, and linkage system. [Song and Lee 2015 (pa 41-42), Liu 2012 (pa 402)] In modern logistics systems, port/terminal operations involve not only loading/unloading cargoes to/from a vessel, but also various value-adding services including warehousing, storage and parking and arranging inland transportation modes. [Song and Panayides 2012 (pa 12)]

Container terminals represent highly dynamic and highly stochastic logistics systems. They represent a complex system with highly dynamic interactions between the various handling, transportation and storage units, with all of them communicating amidst incomplete knowledge about future events. [Kim and Günther 2010 (pa 7-9)] The ports, as logistics systems, integrate both transport and cargo handling functions with other logistics components such as distribution centres. Therefore, they do not only optimize the movement of goods and service within the entire transport and logistics chain, but also provide complementary services and add value, to the larger logistics and supply chain network, as well as to the ultimate customers and users. [Bichou 2013 (pa 23, pa 25)]. The evaluation of the performance of a logistics system is determined by how well it performs in creating value-added benefits to the customer in a cost-effective way. The objective of logistics is to minimize the total cost of a series of continuous and inter-related activities that are associated with the application of planning, organization, operation and management functions, rather than the cost of individual activities. In maritime logistics, the shipper wants to minimize the total logistical costs associated with transportation, warehousing, inventory, lot quantity, order processing and information costs. Relatedly, the shipping lines aim to minimize the total door-to-door transport costs, including cargo handling and port costs. [Bichou 2013 (pa 23, pa 24)]

More recently, port operators began offering a range of logistics services beyond the traditional package of services to ships and cargo. Depending on their logistical status ports are generally classified as network ports, transhipment ports, direct-call ports and/or feeder ports. The conflicting goals in this classification stem from how to provide value-added services to both ships and cargo by ports. For instance, the network ports provide high value-added services to both ships and cargo, but they also generate traffic from/to the port and its hinterland and foreland. on the other hand, the transhipment ports provide high value-added services to ships, but low value-added services to cargo. These ports provide fast turnaround times for ships and are suitable for cargo concentration and distribution. Conversely, the while direct-call ports provide low value-added services to ships, they provide high value-added services to cargo. Finally, the feeder ports provide low value-added services to ships, but that is not necessarily true of cargo. [Bichou 2013 (pa 9,11)] In reality, the value-added services provide a competitive edge to ports, and this addition leads to enhancing their growth and profitability. [Bichou 2013 (pa 24)].

Port or terminal services are classified according to services to ships (pilotage, towage, mooring, bunkering, ship repair), services to cargo (loading/unloading, stacking and storage), nautical services, and value added services (packing and labeling, consolidation and break bulk, repositioning and distribution). These services are carried out in ports (terminals) or in their vicinity. [Bichou 2013 (pa 12)]

In terms of logistics and supply chain management, the value of port services to shippers may be extended to indirect value-adding services such as inventory management, product conversion, market customization, process decoupling, postponed manufacturing, modal shift and regional distribution. The same can be said of shipping lines in terms of turnaround time and operational efficiency. [Bichou 2013 (pa 23)]

1.12 Seaport management

With the continued development of the maritime industry and containerization, the ports are becoming increasingly complex and dynamic entities with various activities. They are much more than a transfer point between sea and land as they also serve as distribution, logistics and production centres. The range of seaports is wide as they can be as small as quays from which vessels can be moored to very large-scale centres with many terminals and clusters of industries and services. They are defined as a gateway to trade and a link in transport chain between sea and land. They are regarded as critical infrastructure resources despite being very dissimilar in their roles, assets, operations, functions, activities, services and institutional organization. According to their scope and service offerings, ports are variously classified as trade-related (traffic type, origin versus destination), network-related and logistics-related (hub versus feeder, direct-call versus transhipment), space-related (local versus national, hinterland versus foreland) and sector-related (direct versus indirect). [Bichou 2013 (pa 1-2, pa 31-33), Branch 2007 (pa 382), Song and Lee 2015 (pa 41-42)] Additional port classifications are shown in table no.3. [Bichou 2013 (pa 11)]

There are many activities, operations and functions that are carried out by different types of equipment, cranes, vehicles and trucks as containers flow through ports/terminals (import, export, and transhipment) or container depots, Nonetheless, the main functions of ports are to facilitate the movement of vessels (containerships) and goods within seaside and landside of seaport, to deal with berth allocation, stowage planning, quay crane scheduling and assignment, yard crane scheduling, container stacking, vehicles and trucks dispatching, ships building and repairing. Furthermore, the ports are used and served as hubs for inland trade and intermodal and multimodal activities. [Bichou 2013 (pa 156-158), Song and Panayides 2012 (pa 275), Burns 2015 (pa 27)]. Given the wide range of activities that are carried out by different actors inside ports at various levels and several types of users of the infrastructure and services, port management can be defined as the process of organizing, monitoring and controlling the activities of a seaport within the global maritime industry challenges to achieve goals that are cantered on improving the performance and achievement of sustainable import/export levels. [Burns 2015 (pa 2)] It should be noted that in the modern era, there are many constraints that may impinge on port management's ability to function fully. These may be as varied as local area authorities, customers (shippers, ship owners), national government, international regulations, regional trade arrangements, trade unions, pressure groups (environmentalists) and competition from neighbouring ports. [Alderton 2005 (pa 105)]

Criterion	Port category
Cargo/commodity type	Dry bulk port, liquid bulk port, general cargo port, etc
Ship type	Ferry port, Ro-Ro port, multipurpose port, LNG port, etc
Trade type	Import port, export port, transhipment port, transit port, etc
Institutional model	Landlord port, tool port, service port, etc
Ownership model	Private port, public port, semi-public port, etc
Management model	Trust port, corporatized port, autonomous port, etc
Organisational model	Centralised port, decentralised port, devolved port, etc
Geographical scope	Gateway port, local port, coastal port, inland port, etc
Logistics status	Feeder port, hub port, transhipment port, network port, etc

Table 1.3: Different classifications of ports [Bichou 2013 (pa 11)]

There are many factors that may influence the selection of shipowners' choice of ports like: location, operating costs, the levels of traffic (import and export cargoes), the level of efficiency, competition and innovation, the level of infrastructure, the degree of technology that is associated with port operations, the projected level of profitability, and the quality of the port management. The latter is an important factoras it is basis upon which policies and strategies are calibrated are applied in the port, as well as to provide the flexibility to deal with emerging problems. [Branch 2007 (pa 394-396)]

There are four fundamental stages of port management and operations to deal with, starting with the arrival vessels at the ports from until departure from port boundaries. The first stage is called Off-Port-Limits (OPL) operations, a term referring to when in-coming vessels are not scheduled to visit the particular port of call for loading/unloading operation but are in transit and need specific port-related services. The services that are provided by ports in this stage are: procurement (food supplies, spare parts, victualing of stores) passenger drop-off, crew changes, embarking and disembarking of vetting inspectors, regulatory auditors, marine surveyors, and repair teams as well as medical and emergency services. The second stage includes vessel navigation and berthing in port, services which are arranged prior to vessel's arrival (berth request for incoming vessels, notice of vessel arrival, special provisions for carrying hazard cargoes in case of an emergency, cargo manifest), services during the vessel's arrival (pilotage services, berthing/unberthing, mooring/unmooring, and anchoring operations). The third stage is related to ship operations at the berth or terminal which include loading/unloading, stowage, bunkering, victualing and so on. The ports in this stage guarantee the safety of vessels until they leave, and the ports provide all operations (loading/unloading, cargo distribution through intermodal and multimodal services) within the supply chain. Finally, the fourth stage is concerned with port and terminal operator's logistics network. In this stage the ports represent as logistics and distribution centres, and they coordinate and arrange all logistics activities including forwarding, collecting, evaluation and distribution. [Burns 2015 (pa 108-116)]

1.13 Seaport performance and efficiency

Ports are traditionally known simply as sites consisting of different transport equipment and infrastructures for berthing (anchoring) vessels (containerships) and to transfer cargoes/goods from one mode of transport to another (vessel to land or vessel to vessel) by the link between maritime and inland transport. They are an isolated set of facilities and infrastructure located along the sea-land interface to serve the vessels and transfer goods. [Liu 2012 (pa 410), Song and Lee 2015 (pa 41)]. Ports play a significant role in the management and coordination of cargoes and information flows. Therefore, they are not only looking for more space on land and/or existing waterways and offshore, but also the ports concerned with deepening their basins and approach channels to accommodate larger vessels. The growth in vessel sizes and the development of new vessel technologies leads to an increase in the water depths in channels and alongside the extended-length berths (up to 15-18 m) to accommodate a new generation of post-Panamax vessels. [Tsinker 2004 (pa 2)]

The resultant competition among ports leads to increased productivity and operational efficiency in order to enhance the competitive edge in the port industry. Generally, the ports aim to achieve high productivity by maximizing output production (loading, unloading, storing, and dispatching) and optimizing the usage of available input resources (equipment, capital and labour). The basic definition of port productivity is the ratio of output per unit to the inputs employed, or the ratio of average output per period to the overall resources utilized or costs incurred during that time. [Burns 2015 (pa 161), Cullinane 2010 (pa 174), Burns 2015 (pa 28)]. This indicates that port productivity is measured by the ability of port to move cargoes through it within a unit of time under actual conditions. There are a combination of factors that determine a given port’s productivity, but the first factors are quantitative ones like: size of terminal, infrastructure, capacity of loading/unloading, warehousing capacity; and the second factors are qualitative like: professional expertise, speed, precision. [Cullinane 2010 (pa 15), Notteboom 2002 (pa 46)]. The reality of the port industry is that the ports (container ports) do not produce containers, but they provide interchange service to the containers, and the productivity of any port is measured in terms of port throughput, i.e. the total tons or containers of cargo that move through it. The productivity measures of storage areas and berths for any port, used to evaluate port productivity include number of containers in unit area of land and number of containers in unit area of berth length. There are five efficiency indicators for the container terminals in the seaports. The first indicator is the standardized quay-wall-handling capacity, representing the annual handling capacity of a container terminal. It is determined by dividing the annual handling capacity by the length of quay wall of container terminal (annual TEU per quay wall meter).

The second indicator is called the standardized storage-handling capacity. It is similar to the previous indicator in terms of the determination of the annual handling capacity of a container terminal but differs as far as the storage area of container terminal. It is determined by dividing the annual handling capacity by the total terminal area (annual TEU per hectare). The next indicator is the storage-yard fraction. All container terminals aim to increase the value of this indicator as far as possible in order to increase their storage capacity. This procedure leads to an increase in the annual terminal throughputs. The fourth indicator is the yard density. This indicator reflects the quality of the stacking operations and storage area utilization and is determined by dividing the average used storage capacity by the number of hectares that are used for storage of containers (number of container/hectares of the container storage yard). Finally, the accessibility of containers in the stacking area/storage yard is an important indicator to evaluate the storage function in the container terminal. It is determined by the stacking height in the storage yard and the knowledge about the sequence of containers that are retrieved from the stacks. This indicator is measured by the average number of reshuffles (unproductive moves) that are required to select a certain container in stacking area to send it to quay side by vehicle for next journey. [Kemme 2013 (pa 34-36)]

1.14 Seaport container terminal problems

As mentioned before, a seaport container terminal represents a complex system with highly dynamic interactions among the various operations and activities, as well as incomplete knowledge about future events. These operations need many types of equipment, cranes, trucks and vehicles to carry out the functions or to deal with the flow of containers between Quay Area (QA) and Container Yard (CY). One of the main challenges concerns the managing or controlling of concurrent daily tasks, functions and sub-operations that determine the flow of inbound and outbound containers between seaside and landside of a container terminal. Due to the rapid growth in global trade and the maritime industry revolution, the development of seaport terminals required additional functions and operations, especially when the container terminals were enlarged and redeveloped from the conventional general cargo terminals to multi-purpose terminals. That level of growth has spawned many problems for terminal operators. These problems relate to managing, controlling, planning, synchronizing and scheduling the sequence of operations, functions, events, and activities of seaport container terminal. These problems can be classified into seaside container terminal problems and landside container terminal problems as shown down below.

1.14.1 Seaside Container Terminal Problems

1.14.1.1 Berth Allocation Problem (BAP)

The berth allocation problem is one of the foremost planning problems in a container terminal., It is, at its base, an assignment and scheduling problem as it relates to incoming vessels arriving at the container terminal, and must be assigned to berthing positions at determined schedules [Kim and Günther 2010 (pa 63), Guldogan 2011 (pa 11)]. Usually, the berthing capacity is limited by the length of quay, and all vessels must moor and serve within its boundaries. To avoid the costly challenge of vessels overlapping in the assigned berths, the terminal operator does not allow them to occupy it at the same time [Meisel 2010 (pp 18-21), Kemme 2013 (pa 46)].

The main function of the berth allocation process is to manage and control the arrival and departure events, and to select the next vessel from the queue (at least one vessel is always waiting in the queue) to moor at which berth will be next at the quay [Böse 2011 (pa 142)]. The quay of consists of many berths (sections), and each single berth can serve one vessel within a period of time. The large vessels need more than one berth along a quay in order to deal with the container handling (loading/unloading) process. In the meantime, a single berth can serve (handle) two small vessels. Actually, there are many spatial constraints that restrict the berthing positions of vessels along a quay. The relation between berths, location of vessels and quay is shown in the figure 12. When the quay divides into a number of sections and a finite set of berths, the layout of berth is called, Discrete Layout. Each vessel in this layout can occupy a suitable berth within a specific time. The locations of berthed vessels along a quay are organized according to the design of container terminal and the construction of the quay (see Figure 1.12 a and b).

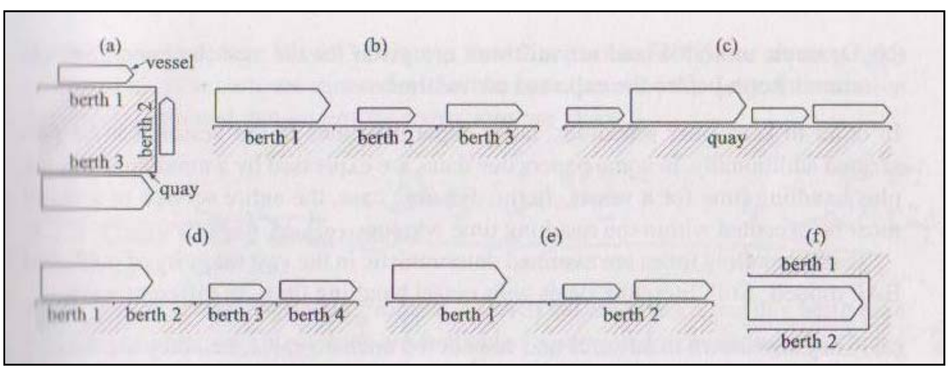


Figure 1.12: The relation between berths, location of vessels and quay [Meisel 2010 (pa 19)]

When the quay is not divisible into a finite set of berths, then the vessels can moor anywhere along a quay or at arbitrary positions within the boundaries of the quay., This kind of layout is called

Continuous Layout (see Figure 12c). The Continuous Layout is more flexible than the Discrete Layout in the terms of the berth allocation and it achieves a higher efficiency in berth usage and productivity, but it is more complicated than the Discrete Layout, especially in berth planning and utilization of the quay space [Meisel 2010 (pa 19), Guldogan 2011 (pa 11)].

Large vessels may occupy more than one berth along a quay, and the small vessels may share one berth. This type of layout is similar to Discrete Layout, and it is called Hybrid Layout (see Figure 12 d and e). Occasionally, there are two opposing berths that can be used to handle a large vessel from both sides, and this kind of berth is called an indented berth (see Figure 12f) [3 (pa 19)]. There are two approaches in the arrival times of vessels: the Static arrival and the Dynamic arrival. In the Static arrival, the vessels can berth immediately after waiting at the port, or the vessels can berth earlier than the expected arrival time. That means, there are no arrival times given for the vessels on the berthing times. In the Dynamic arrival, the vessels cannot berth before the expected arrival time. That means that fixed arrival times are communicated to the vessels prior to arrival at the berth [Meisel 2010 (pp 19-20)].

1.14.1.2 Quay Crane Assignment Problem

Quay cranes are one of the most essential equipment used in a container terminal, and they are supposed to be lined up alongside the quay for the loading and unloading of vessels. The berthing area is equipped with quay cranes to serve various vessels, and these cranes can be moved to every vessel, but they are not able to pass each other. Usually, the quay cranes that are assigned to each vessel, are assigned to different sections or hatches of the vessel [Meisel 2010 (pa 21), Kim and Günther 2010 (pa 5 and pa 8)]. When the vessels arrive at a container terminal, they are assigned to particular berths and a number of quay cranes. In the berthing plan of a container terminal, , the terminal operator must know the volume of containers to be loaded and unloaded, as well as the maximum number of quay cranes that are allocated to serve the vessel [Meisel 2010 (pa 19 and pa 21), S. Tang, Teo and Wei 2008 (pa 69)].

The handling capacity of a container terminal depends on the number and capacity of quay cranes. In general, assigning more quay cranes to the vessel can accelerate the handling time of the vessel in comparison to other vessels that are berthed along the quay. Furthermore, more quay cranes can result in interference at the berthing area. The assignment of quay cranes to the vessel is called QC-to-Vessel assignment, and there are two approaches to this: The time-invariant QC-to-Vessel assignment and variable-in-time QC-to-Vessel assignment. In the time-invariant assignment, the number of quay cranes that are assigned to the vessel is constant during the complete handling time, whilst, in the variable-in-time assignment, the number of quay cranes that are assigned to the vessel can change during the complete handling time [Kim and Günther 2010 (pa 17), Meisel 2010 (pa 22)].

1.14.1.3 Container Stowage Problem

The stowage planning problem deals with assignment of export containers to empty slots within a vessel, each of which is served at a container terminal and has a specific stowage plan for container loading operation, see Figure 1.13 [Meisel 2010 (pp 24-25), Kim and Günther 2010 (pa 134)].

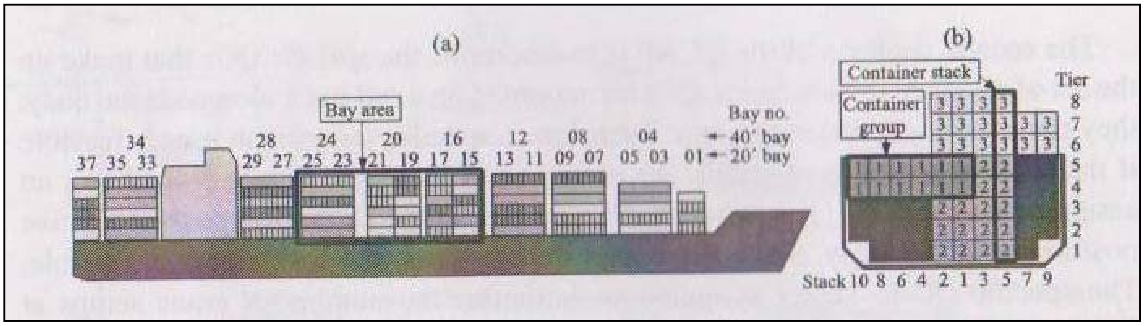


Figure 1.13: The storage location structure of a vessel (a) and a bay (b) [Meisel 2010 (pa 24)]

The objective of the stowage plan is to minimize the reshuffles as much as possible, and to maximize the capacity utilization of the vessels. Usually, the stowage plan specifies which container will be loaded at which slot (a container position in a bay) in the vessel [Kemme 2013 (pa 45), Kim and Günther 2010 (pa 134), Meisel 2010 (pa 25)].

The stowage plan consists of two steps (two levels). The first step is a rough stowage plan, which is generated by assigning container classes to slots. The containers in this step are assigned to positions according to their attributes in terms of type (e.g. reefer, standard dry), size (TEU, FEU), weight and port of destination. The second step is a precise stowage plan, which is generated by assigning individual containers to slots of their container class.

The assignment of container classes to slots can be restricted as, for instance, the refrigerated containers can only be assigned to slots that are provided with electrical supply, Additionally, the containers that carry dangerous goods should preferably be stored preferably below decks. Generally, the heavy containers should be stored below decks as low as possible [Kim and Günther 2010 (pa 134), Meisel 2010 (pa 25)].

1.15 Landside Container Terminal Problems

1.15.1 Container Stacking Problem

In a container yard, the accessibility to the containers in the stacking area, is an important issue to deal with the selection of container storage location within the blocks to minimize the reshuffles or unproductive moves due to inappropriate storage locations and the stacking orders of containers [Kemme 2013 (pa 50), Meisel 2010 (pa 26)]. Actually, within a container stacking area, the containers are arranged and identified separately according to the import, export and empty containers. The arrangement of containers is classified according to their type (size, reefer, and dangerous goods), modality and date/time of departure. The refrigerated containers should be stacked very close to reefer points to avoid heating [UNCTAD 1991 (pa 18), Kim and Günther 2010 (pa 133)]. In general, within a container yard, the containers are stacked and stored according to segregation strategy or scattering strategy. Each strategy utilizes many criterions of container classification such as destination (inbound, outbound, transshipped), status (FCL, LCL, empty), type (reefer, dangerous .. etc) and size (TEU, FEU, non-standards) [Bichou 2009 (pa 142)]. The stacking strategy of any container terminal must be achieved while being guided by the following objectives [Kim and Günther 2010 (pa 133)]:

- Efficient use of storage space.
- Efficient and timely transportation from quay side to stacking area and further destination (and vice versa).
- Avoidance of unproductive moves.

The stacking profile of a container terminal and the movement of containers between stacking area and quay side, and between stacking area and the gate are determined by a container yard configuration and layout [Bichou 2009 (pa 142)]. The stacked containers must be arranged with sufficient leeway and not be squeezed to capacity, otherwise the yard crane productivity will suffer and the number of unproductive moves will increase, see Figure 14 [UNCTAD 1991 (pa 18)]. Therefore, increasing the height of stacking area leads to maximizing the total number of containers that can be accommodated within the yard. Additionally, the number of reshuffles increases sharply with the stacking height [Böse 2011 (pa 249), Kim and Günther 2010 (pa 133)].

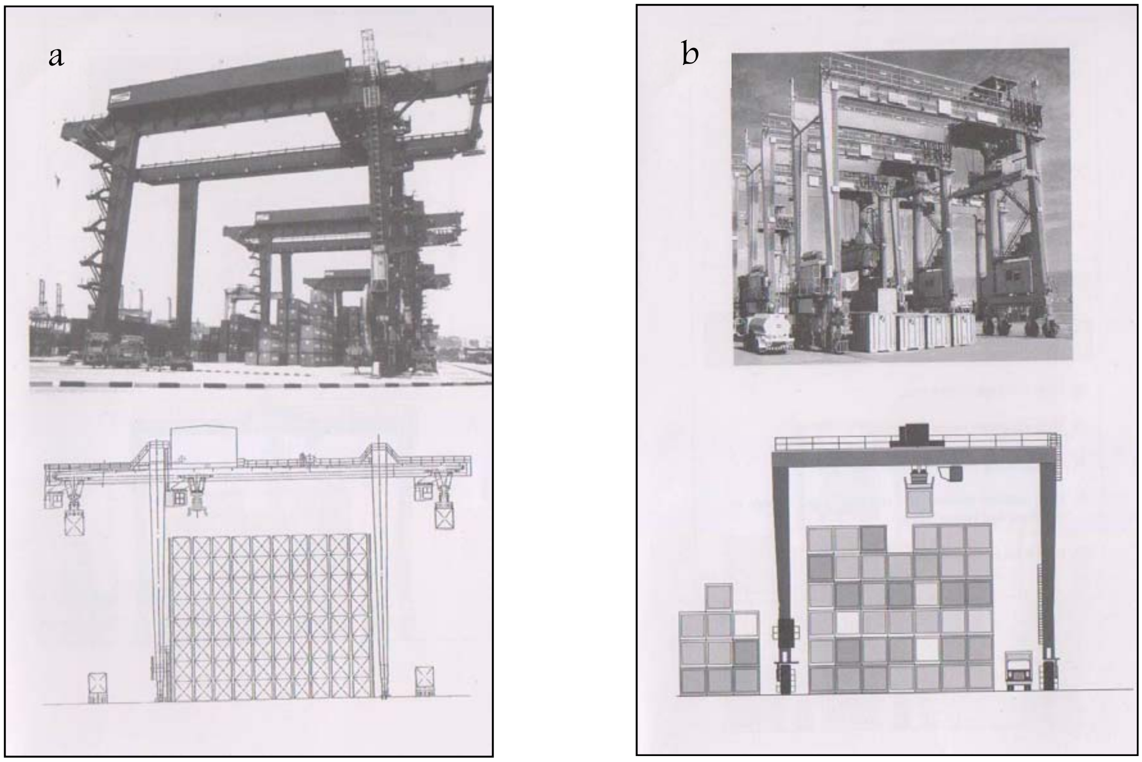


Figure 1.14: The stacking of containers by (a) Rail Mounted Gantry crane (RMG) and (b) Rubber Tyred Gantry crane (RTG) [Tack and Huat 2000 (pa 135 and pa 137)]

There two stacking strategies, namely, Category stacking strategy and Residence time strategy. In the first strategy, one container defines the category of containers, and all the containers of the same category are stacked on top of each other. In the residence time strategy, one container is stacked on top of other containers, as long as its departure time is earlier than that of all containers stacked underneath it, [Kim and Günther 2010 (pa 133)]. The best container stacking strategy must be predetermined by finding the optimal storage slots in the yard for the incoming containers or by choosing the suitable yard blocks, thereby positioning the inbound containers within the chosen yard blocks. By so doing several objectives might be addressed e.g. minimizing the number of future relocations, minimizing the overall crane utilization, or storing containers of equal destination within the same bays [Böse 2011 (pp 252-253), Kemme 2013 (pa 49)].

There are several factors that determine the selection of a suitable container handling system for container yards such as the size of operations, the required stacking density and land available, labour costs and the availability of skilled labour [Bichou 2009 (pa 142)]. The conflicting objectives in the stacking approaches lead in different approaches for organizing the yard area. Maximizing the yard density and minimizing the number of shuffle moves are the major objectives for solving the problem. Therefore, the determination of the stacking capacity is a major design challenge at a container terminal [Kemme 2013 (pa 50), Kim and Günther 2010 (pa 133)].

1.15.1.2 Empty Container Repositioning Problem

Empty container repositioning from the surplus areas (seaports) to the deficit areas is an important issue for the seaport, depots, shippers, container haulage companies and liner shipping companies. According to the trade imbalance and the widespread use of containerization due to the globalization, empty container repositioning has become a challenging issue in the maritime logistics industry. The rapid growth in global trade leads to increase in the trade volume among the major trading regions and causes the movement of cargo to one direction over time from the point (region) of production to the point (region) of consumption. The whole empty container logistics cycle starts when the empty containers return from the consignee, and thereafter, these containers are stored at container depots. The final problem is the repositioning of empty containers from the surplus areas to the deficit areas [Song and M. Panayides 2012 (pp 29-30), Lun, Lai and Cheng 2010 (pa 156)].

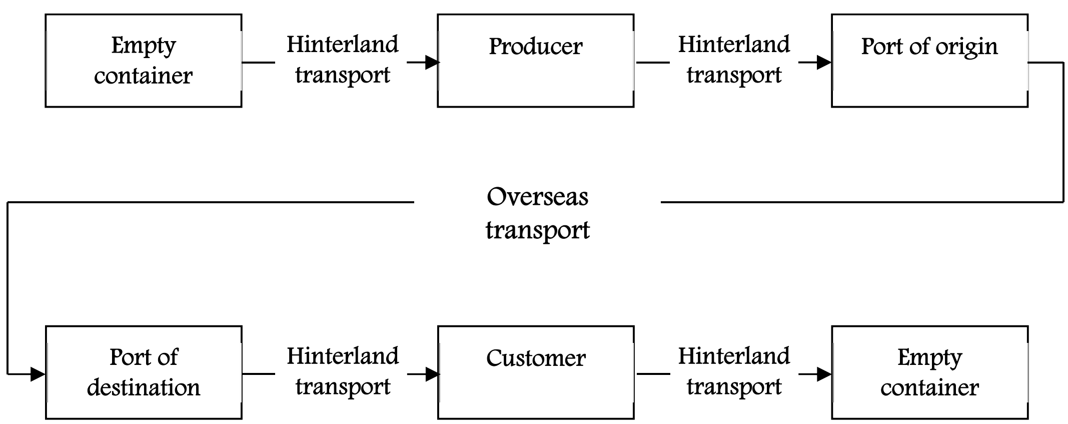


Figure 1.15: Empty container logistics cycle [Kemme 2013 (pa 10)]

The flow of empty containers among ports, container depots, importers and exporters play a major role in the global supply chain. Before the empty containers can be used to fulfil the demand from exporters, they are stacked at a container depot. These containers are repaired maintained and cleaned at the depot before they can carry the goods. From the container depot, the containers are transported by trucks to the exporter premises, where they are stuffed with cargo. The laden containers are transported to an inland container terminal by trucks (the hinterland transport is not necessarily executed by only one mode of transportation), and then these containers are transported by train to the seaport container terminal (port of origin) for export. The laden containers are transported from the port of origin to the port of destination by vessels (oversea transportation), and the containers are then moved from the port of destination to the customer by hinterland modes of transportation, where they are stripped. Finally, the empty containers are transported to the container depotuntil the next journeys, see Figure 1.15 [Song and M. Panayides 2012 (pp 33-34), Kemme 2013 (pp 9-10)].

The strategy of empty container reuse is an effort to reduce the empty container repositioning among seaports. This strategy is used to interchange the empty containers outside the seaports to reduce congestion and to minimize operational costs [Lun, Lai and Cheng 2010 (pa 161), Petros A. Ioannou 2008 (pp 212-213)]. There are two methods for empty container reuse: Depot-direct and Street-turn. In depot-direct method, the empty containers are stored, maintained and interchanged at off-dock depots. This method is used to establish a supply point for reusable empty containers and facilitating empty container drop off and pick up when the terminal gates are congested. In the street-turn method, the empty containers are directly moved from local consignees to local shippers. This method is used to save the driving times to/from container terminal in order to avoid the congested areas around the gates [Lun, Lai and Cheng 2010 (pa 161), Petros A. Ioannou 2008 (pa 213)].

There are different perspectives on empty container management. Container shipping lines are responsible for the full management of empty containers. This responsibility includes the repositioning, repairing and maintenance of empty containers. Meanwhile the leasing companies tend to ignore the issue of empty container repositioning because they can still make a profit even when their containers become empty within the lease period [Song and M. Panayides 2012 (pp 34-35)].

1.15.1.3 Vehicle Dispatching Problem

With the development of maritime cargo transportation, the authorities of the seaport container terminals expanded their terminals in size and improved the horizontal-transport operations between the quay area and the container yard (and vice versa) to increase the efficiency and usage of the transportation and handling equipment inside the container terminals. During the flow of containers between quay side and yard side, the containers are transferred by many types of vehicles (Yard Trucks (YTs), Straddle Carriers (SCs), Automated Guided Vehicles (AGVs) … etc) that are deployed at the seaports. The assignment of vehicles to quay cranes, the selection of travel routes of vehicles, the sequencing of vehicles and transport orders and the coordination between the vehicles, quay cranes and yard cranes are the main issues that are dealt with when examining the vehicle dispatching problem. The objective is to minimize the empty travel of vehicles and to minimize the travel distance [Kim and Günther 2010 (pa 156), Meisel 2010 (pp 27-28), Kemme 2013 (pp 47-48)].

The concurrent operations of quay cranes and yard cranes lead to complex sequence coordination process between the vehicles and the cranes. The quay cranes are used to load/unload the containers to/from the vessels, whilst, the yard cranes are used to lift-on/lift-off the containers at the stacking area (or storage area). There are two approaches in the assignment of vehicles to the quay cranes. In the first approach, the vehicles are assigned exclusively to quay cranes. The reduction of empty travel of vehicles in this approach is limited, and the empty travels from the quay area to the yard area or vice versa are unavoidable, because the quay cranes typically are operated in single cycle mode, i.e. the cranes are used consecutively to perform loading operations or unloading operations. In the second approach, the vehicles are pooled and served by more than one quay crane. This strategy is more efficient than the first strategy in terms of the reduction of empty travels, and it is used to minimize the number of vehicles that are required for the transport operation. In pooling strategy, some quay cranes are used to load (handle-on) containers, while the others are used to unload (handle-off) containers. This process leads to reduction of the empty movement of vehicles by performing loading travels from the quay area to the yard area and vice versa., Additionally, it leads to reduction of the waiting time of quay cranes [Kim and Günther 2010 (pa 180), Meisel 2010 (pa 27)].

1.16 Scope and limitation of work

There are many limitations made to the scope and parameters the study. These mainly include:

- The study does not cover all scopes of seaport operations and container management problems. The main operations covered include empty container return management, shipping route planning, berthing and stowage problems.
- The proposed models that are used to solve the problems of empty container repositioning and the suitable routes for shipping service network design were deterministic models.
- Generally, only deterministic models were developed for almost all problems solved, apart from the queuing models presented.
- For the queuing models developed, the queue discipline in container stacking problem was only First-in First-out (FIFO), and in this queuing system, where the three stage multi-server tandem queue system at a container terminal was considered, the de-lashing containers process was ignored in order to facilitate the solution of the problem.
- In the problem of the assignment of suitable berths to the vessels under different berthing priorities, all the vessels (low or high priority) are not allowed to berth before the expected arrival time to simplify the solution. Only arrival at berthing time was allowed.
- Where actual data was used, the data underpinning the analysis was gathered initially through a historical data of selected South Africa Seaports only, especially for published papers in chapter 4 (section 1 and section 2).

Chapter 2

Literature Review

2.1 Introduction

In this chapter a survey of literature pertinent to seaport container terminal operations problems is presented. Different approaches have been proposed, each proving varied solutions to address the problems that seaport container terminals face. The problems they attempt to solve are very complicated and there are no easy solutions. Terminal operations and containers management problems have received a lot of attention from many scholars in recent years; some scholars have dealt with individual problems like empty containers repositioning, empty containers allocation, container shipping service networks, container stacking, and container stowage. But some scholars have been focused on the optimization of operations in container terminals, their performance and efficiency, reverse logistics, operational management of equipment, berth allocation, berth scheduling, terminal equipment and vehicles scheduling, as well as quay and yard cranes scheduling.

The following literature is categorized and delineated according to the type of problems:

2.2 Empty containers repositioning problem

Choong et al (2002) discussed the planning horizon length on empty container management for multimodal transportation networks (Truck, Rail, Barge) – a case study of potential container-on-barge operations within the Mississippi River, to minimize the total costs of empty container flows between locations. The proposed mathematical model is based on the costs of empty container movements, costs of holding empty containers at container pools (or depots), and empty container leasing, buying or borrowing cost. Jula et al (2006), developed a mathematical model to optimize the empty container reuse in the Los Angeles and Long Beach (LA/LB) port. The proposed model is based on the number of empty containers moved between ports and depots, to minimize the total cost of dynamic empty container movements. The experimental results show that, when the time is critical, empty container reuse is shifted towards Depot-direct methodology (establishing a supply point for reusable empty containers, and adding buffer capacity to the marine terminals), where the waiting time in the ports is minimal., When the travelling cost and traffic congestion are the important factors, Street-turn methodology (the empty containers are moved from local consignees to local shipper) provides the best match between supply and demand of empty containers. Song et al (2007) focused on container allocation on shipping routes to optimize the distribution volume at ports for each voyage. The researchers proposed models to determine the container allocation volume at ports and on vessels. Their models are used as a measure for liner companies to make full use of containers and to minimize operational cost considering the cargo supplies at the ports on the routes. Wang et al (2008, established a liner programming model to reduce the cost of empty container allocation, and transportation among different ports. The researchers presented a systematic description to the process of empty container allocation and transportation. According to them, its characteristics explained the major effect factors and the subjective and objective reasons which cause the empty container allocation. The proposed model is based on the rent containers strategy and container storage fees in the ports to minimize the total costs including load and unload costs, ocean transportation cost, the cost of empty container storage, and the rent empty containers cost. Feng and Chang (2008), addressed empty container reposition problems for intra-Asia liner shipping as a towage problem (case study: shipping service network in intra-Asia Taiwan Liner Shipping Company). Stage one identifies and estimates the empty container stock at each port, and stage two models the empty container reposition planning with shipping service networks as the Transportation Problem. The researchers proposed the models to estimate the quantity of empty container stock at ports and to minimize the total cost of repositioning empty containers between supply ports and demand ports. The results show that the models provide optimization techniques to minimize the cost of empty container reposition and to provide evidence to adjust strategy of restructuring the shipping service network. Belmecheri et al (2009), modified a mathematical model to optimize empty container reuse between several sites (regional consignees, shippers, depots, and port terminal), as well as to minimize the local costs of empty container inland movements. The proposed model is based on summation of total costs of empty container movements between several sites as a function of time. According to the results that were obtained by using the model, the researchers found that the modified model can improve the cost, in a real case study, by 20%, and the model has a large impact on the local economy.

Chandoul et al (2009), focused on the optimization of the returnable container management problem. The researchers proposed a model (linear integer program model) to minimize the total costs, including empty container transportation cost between sites, purchasing cost of new containers, and storage cost. The research aimed to determine the optimal policy for container management and to find the suitable purchased quantity of new containers, at the right period, to meet system requirements, and to find the best movement model of empty containers between several sites and depots. Li and Han (2009), used a stochastic programming model to optimize the repositioning of empty containers under uncertain demand and supply. The proposed mathematical model is used to minimize the total costs, including transportation costs (empty container transportation, loading, unloading), renting cost, and storage cost of empty containers. According to the simulation and results that were obtained by using the proposed model, the researchers found that the changing in the expected total cost depends on many factors like: route changes, unit cost of renting, the number of empty containers in the ports, and the demands. Sun et al (2009), focused on the empty container repositioning problem between seaports, and developed a mathematical model to minimize the total cost of empty container repositioning between two ports (a real case study) in a cycle which includes railway freight, stock change and handling change. The proposed model is based on railway freight rate, railway capacity and the supply meeting demand. The researchers found that the model is efficient in solving the problem, and offers the best distribution route, the optimal volume of empty containers, and the optimal repositioning cost. Dong and Song (2009), focused on container fleet sizing and empty repositioning problem in multi-vessel, multi-port and multi-voyage shipping systems with dynamic, uncertain and imbalanced customer demands. The researchers developed a model based on Genetic Algorithms and Evolutionary Strategy, combined with an adjustment mechanism, to minimize the total costs, including transportation costs, repositioning costs, inventory-holding costs, lifting-on/lifting-off costs, and the lost demand penalty costs. The scholars found that the evolutionary algorithm-based policy (EAP) can achieve more cost savings (as a general insight), if the system has higher inventory costs, lower lifting costs, or higher lost-sale penalties. According to the simulation experiments and results, the scholars found that fleet sizing is closely related to empty repositioning as the optimal fleet sizes vary when different repositioning policies are used. Xiaolong (2010), analyzed the inland empty container reposition (ECR) problem under certain and uncertain conditions, and established a model based on the random parameters of inland repositioning systems. The proposed model is used to minimize the total costs, including the empty container movement cost, the cost due to satisfy the certain empty container demand, and the cost due to satisfy the random empty container demand. According to the analysis and results that were obtained, by using the objective function with random demand conditions comparing with results under a certain condition, the researcher found that the total cost of the former one is a bit higher than the total cost, with certain conditions. The solution of the model is efficient, reasonable and effective. Bean and Joubert (2010), proposed a stochastic model to deal with empty container relocations under supply and demand uncertainty. The proposed model (based on CPLEX solver 9 to solve the problem) is used to minimize the total cost of relocating empty containers, and consists of transportation cost, holding cost and shortage penalty cost due to unmet customers demand. The researchers found that the stochastic model provides more reliable solutions than the expected value model. Lee et al (2011), developed an inventory-based control policy to reposition empty containers in a multi-port system with uncertain customer demand. They formulated a model to optimize the movement of ECs from surplus ports to deficit ports, and to minimize the expected total cost, including transportation cost, inventory holding of unused EC cost, and leasing EC cost. They proposed two approaches to solve the problem under balanced and unbalanced scenarios.

The first approach is Non-Linear Programming NLP (solved by Matlab, version 7.0.1) and the second approach is Infinitesimal Perturbing Analysis (IPA-based gradient technique-algorithm coded in Visual C++ 5.0). The numerical results show that the proposed approaches provide a potential methodology contribution in reduction to the total operation cost. Huang (2011), presented a dynamic model based on time expanded to minimize the expected total cost of multi-class empty container repositioning. According to the results obtained by using the proposed model to solve empty shipping container reposition problems among different ports, the model is reasonable and useful for solving these problems, as it offers the best way to save money and the lowest cost for allocation of empty containers among different ports. GUO et al (2011), proposed a model to minimize the total costs, including operating costs and capital costs during the containers transportation in the container shipping network (10-ports static empty container shipping system). The scholars applied two strategies for empty container allocation in maritime container shipping networks: allocation by minimum cost (AMC) and allocation by shortest distance (ASD). The proposed model is based on the cargo volume, flow direction, carrying ship, and the transhipment of empty and loaded containers. According to the results that were obtained by using the computational experiments, it can be seen that 24.7% of the total shipping cost is attributable to empty container allocation, and the results show that the empty container allocation strategy AMC is much more economical than ASD strategy.

Song and Dong (2011), addressed the empty container repositioning problem between two sets of ports (export ports and import ports), and used two policies (The flexible destination port policy (FDP) and determined destination port policy (DDP)) to evaluate the effectiveness of empty container management for three major shipping routes (Europe-Asia, Trans-Pacific, and Trans-Atlantic). The researchers formulated a model to minimize the total costs, including inventory holding costs, lost-sale penalty costs, lift-on costs, lift-off costs, and laden/empty containers transportation costs. According to the results that were obtained by using the numerical experiments, the researchers found that the DDP is slightly better than FDP, within 2%, in scenarios where the trades are fairly balanced across the longest ocean leg, while FDP outperforms DDP significantly (by up to 22%) for scenarios with imbalanced trade patterns. Furthermore, the system encompasses the middle range of fleet sizes. In particular, FDP achieves the largest cost reduction in comparison with DDP in terms of the optimal fleet sizes. YI (2012), established a simulation model and proposed a gradient-driven algorithm to optimize the maritime empty container repositioning problem in a multi-port system with inventory-based control policies. The purpose of the study was to optimize the fleet size and to minimize the repositioning cost, holding unused empty containers cost, and leasing empty container cost. He applied two inventory-based control policies (two-level threshold policy and single-level threshold policy) to manage empty containers and to make ECR decisions involving whether to reposition empty containers, to or from which ports, and in what quantity. The numerical experiments show that the proposed simulation and algorithm demonstrate the effectiveness of the proposed policies and provide some insights for liner shipping operators in managing empty containers. Also, the two-level threshold policy outperforms the single-level threshold policy, especially in the systems with high uncertainty.

Quang-Vinh Dang et al (2012), developed a simulation model and genetic algorithm-based heuristics to optimize the positioning of empty containers in the inland multi-depot system, as well as to minimize the expected total costs including inland positioning/ re-positioning cost, overseas cost, holding cost and leasing cost. They applied four heuristic methods of inland positioning policy (alternative approach for replenishing empty containers with shorter lead-times) to find the best strategy of empty container replenishment. The numerical results show that the total cost goes up, i.e. the overseas positioning cost and holding cost have no change, while the inland positioning cost increases, because of the upward trend of its unit cost. Altena (2013), formulated a mathematical model for empty container positioning (and repositioning) problem in hinterland transport. The proposed model is set up to study the effects of different scenarios in multimodal transport (truck, rail and barge) at Maersk Line (container shipping company), and it is used to minimize the total costs, including handling cost, storage cost and transportation cost. According to the results and analyses that were obtained by using the proposed model based on four approaches (effects of order deadline, effects of change in stock level, effects of container reuse and the amount of transports in different scenarios), the model contributes to cost savings in the hinterland transport operations of Maersk Line, and it improves empty container repositioning and shift truck transport towards rail/barge at Maersk Line. Thomas Hjortnaes (2014), focused on repositioning of empty containers in the port of Rotterdam and its hinterland and developed a mathematical model (Mixed Integer Linear Program) to minimize the total cost of network flow problem between inland and ocean terminals. The proposed model consists of repositioning cost of damage and non-damage containers, repairing cost of damage containers, and evacuation cost of non-damage containers. The proposed model is implemented in a Decision Support System (DSS) tool in (Matlab 2014 a) to investigate the outcome of the pre-established scenarios according to data from Maersk Line. According to the results, the scholar found that the travel distance between inland and ocean terminals (short or large distance) can have an effect on handling costs. Also, depending on the distance travelled a different focal point exists with respect to reduction of operations costs. The proposed approach supports decision makers and it assists in tactical/operational decision making. Moreover, the results serve as proof of performance towards higher management.

Moon and Hong (2016), formulated a Mixed Integer Programming model (MIP) for repositioning both standard and foldable empty containers to minimize the total costs for transportation, inventory, handling, folding and unfolding processes, container leasing, and installation of facilities for folding and unfolding processes. They also suggested linear programming-based Genetic Algorithm and Hybrid Genetic Algorithm to obtain satisfactory solutions for complex problems within reasonable computation times. The results show that the LP- based GA offers near-optimal solutions in a suitable time and both LP- based GA and Hybrid GA can solve large problems within a reasonable time in contrast with MIP model which requires impractical computation time.

Jeong et al (2018), focused on direct shipping service routes with an empty container management strategy and developed an optimization model for two-way four-echelon container supply chain to determine the number of empty containers to be repositioned among selected ports, the number of leased containers and route selection to satisfy the demands for empty and laden containers for exporters and importers in two regions. The proposed model shows optimized routes according to the total relevant cost minimization.

Gençer and Demir (2019), reviewed the extant literature on Empty Container Repositioning (ECR) problem. They classified the studies into six categories: management of empty container repositioning, actors in empty container repositioning, optimization models in empty container repositioning (deterministic and stochastic models), cost estimation in empty container repositioning, strategies in reducing empty container repositioning and the importance of information technologies in empty container repositioning. The purpose of the study is to reveal underlying studies on ECR in the literature and put forward research and real-life application opportunities in the field of ECR.

2.3 Empty container distribution problem

Zenzerović and Bešlić (2003), addressed the problem of Cargo Transport by container ship on the selected route. The proposed model (linear fractional programming) is based on the cost of transportation, the cost of container ship staying in port, and the cost of container ship during the voyage (Fixed and Capital costs). It is used to show how to estimate operational efficiency by taking into account maximum profitability as a criterion function which has to be optimized. The researchers found that the model can be used in operative planning when making respective business decisions referring to the structure of cargo and by other transport means, aiming for maximum profitability. Choong et al (2003), analysed how planning horizon affects empty container flows in multimodal transportation (truck, rail and river barge) networks, and explained the major factors that are affected by choosing a planning horizon (Concentration of the activities in the network, Transit time of the container movements, and End-of-horizon effects). The researchers developed an integer programming model to minimize the total cost of empty container management over a given planning horizon, and the model is based on the cost of empty container movements between locations, cost of holding empty containers at containers pools, and leasing or purchasing cost. The results show that the longer planning horizon can give better empty container distribution plans for the earlier periods, and that the longer horizon allows better management of container outsourcing as well as encouraging use of slower and cheaper transportation modes.

Rensburg et al (2005), developed a computer simulation model (SimSea) to increase the performance of the operational activities in the ocean transportation industry. The paper focused on how to design the services that determine the sailing schedules of the vessels, and how to route the containers from their origins to their destinations when the carrier or vessel can choose between various paths for a particular shipment. The researchers simulated the transport of containers by container vessels to optimize the scheduling policies of the terminal, port, depot, and container yard in order to reduce the waiting times and to improve the overall performance. Sun and Zan Yang (2006), addressed the imbalance of demand and supply for empty containers between ports, container freight stations (CFS) and containers yards (CY) by establishing a model to determine the optimal cost of empty container distribution and leasing. The researchers compared the results of many conditions of empty container distribution strategy, empty container leasing strategy and empty container distribution and leasing strategy depending on the volume of demand and supply. The proposed model is based on the loading and unloading costs of containers, and transportation cost of the return containers, in addition to empty container storage cost and leasing cost. Sibbesen (2008), studied container positioning problems (CPPs) in port terminals and suggested mathematical models (Mixed Integer Linear Programming MILP and Binary Integer Linear Programming BILP) and a heuristic algorithm to determine the optimal sequences of positions and moves for containers in a single storage block of a terminal yard. According to the computational experiments of the thesis, the results from the models indicate the difficulty in obtaining optimal solutions. The results from the heuristic achieved the optimal solutions, and the solution procedure provided high-quality outputs in very short run times. Furió et al (2009), developed a mathematical model to optimize land empty container movements among shippers, consignees, terminals and depots, as a case study in the port of Valencia. The aim of the paper is to support maritime agent decisions around container movements to achieve costs reduction of container fleet management. The proposed model is based on the cost of empty container movements between locations and the cost of empty container storage at terminals and depots. According to the experimental results that were obtained by using the proposed model, the researchers found that the model gives the optimal solution to the problem rapidly. Moon et al (March 2010), proposed a plan for transporting or positioning empty containers between container ports with respect to leasing and purchasing considerations in order to reduce the imbalance. The researchers developed a mathematical model (based on mixed integer programming genetic algorithms (GA), and hybrid genetic algorithms) to minimize the total costs, including transportation cost, handling cost, inventory holding cost, leasing cost, and purchasing cost. The results show that the LP-based GA and the hybrid GA are capable of solving problems of larger size, and that the hybrid GA is more efficient than the LP-based GA in terms of computation time. Furthermore, the experiments pointed out the limitation of the hybrid GA when the number of ports becomes too large.

Chou et al (2010), addressed the empty container allocation problem among six major container ports on the trans-Pacific route. The researchers formulated a two-stage model to determine the optimal volume of empty containers at a port and to reposition empty containers between ports to meet exporters' demand over time. The proposed model is based on the costs of loading and unloading containers, leasing cost of empty containers, storage cost, supplies, demands and ship capacities for empty containers. According to the results that were obtained by using the proposed mixed fuzzy decision making and optimization programming model, the researchers found that the model can be used to solve the empty container allocation problem well. Mhonyai et al (2011), presented the review of facts, problems, and solution to the container management in maritime transportation, and discussed the geographical diversification of the maritime routes and supply chain of container management. The researchers focused on many literature reviews, according to the classification of problems that are associated with container supply chain, and to the classification of the objective functions and constraints that are used in solving container management problems. The aim of the paper is to solve the problems by optimization techniques with objective function of minimizing cost of operations (transportation, holding, lifting on/off, etc). Hajeeh and Behbehani (2011), to address the empty container distribution problem among ports, and to do so by using two approaches: Transportation Problem (TP and Capacitated Plant Location (CPL)) to find the optimal sequence of ship movements between ports. The proposed model is based on the number of empty containers that are carried by ships and the number of stoppages that are made by ships at ports, in order to minimize the total cost including transportation cost and stoppage cost that is imposed on the ships at ports.

Özdemir et al (2015) focused on empty container management and studied empty container flow balance in major Turkish ports to address empty container accumulation problem in some Turkish ports. They analyzed the statistical data that are gathered and the interviews that have been made with port authorities and governing departments, and found that only two Turkish container ports (Haydarpasa and Kumport) suffer from empty container accumulation problem.

Xie et al (2017), focused on empty container management in intermodal transport system (railway transport at a dry port and shipping liner at a seaport), and formulated two models (centralized and decentralized) to optimize empty container delivery policy between the dry port and the seaport to improve the coordination between railway and shipping liner firms with sharing of the resulting profit. The numerical results show how the coordination improves the performance of the system, the profit of each firm due to shearing of the resources of empty containers between the firms and the satisfaction level of container demands.

Gusah et al (2019), studied empty container logistics in port of Melbourne in Australia, and proposed a conceptual model (simulation model) to support decision makers for developing and improving the system of empty container movements in the port of Melbourne. The outputs of the conceptual model are: summary tables of the stakeholders of the freight system, logistics process maps and a stakeholder interaction diagram (the relationship between stakeholders and the operational and financial arrangements). The proposed model was a proof-of-concept which provided an opportunity to graphically imitate the logistics process and interactions of the system in a natural environment.

2.4 Empty containers shipping voyage route problem

Notteboom (2004), presented a review of challenges faced by ports and container shipping companies in terms of activities, operations, facilities, and opportunities to improve the services through cooperation., It also discussed the impact of changes in liner service network design on the major international trade routes. Furthermore, it discussed the integration along the supply chain, and the gradual shifting from pure shipping operations to integrated logistics solutions. Hus and Hsieh (2005), developed a two-objective model to minimize the total shipping and inventory costs, to decide whether to route a shipment (ECs) through a hub or directly to its destination. The proposed model applied for two types of shipping routes between two continents, and based on capital and operating cost, fuel cost, and port charge as (shipping costs), as well as waiting time cost and shipping time cost as inventory costs. The results show that the optimal routing decision tends to be direct shipping as container flow between origin and destination ports. The model also provides flexibility for carriers en-route in decision-making, and a tool to analyse the trade-off between shipping cost and inventory cost. Shintani et al (2007), addressed the container shipping service networks design problem and containership routing problem, by taking into account empty container repositioning. The proposed model, based on the shipping costs (operating and capital costs), and the penalty cost due to unmet customer demand, was used to determine the optimal voyage route that ensures the maximum profit for a liner shipping company. According to the numerical experiments that were obtained by using the proposed model (based on a genetic algorithm), the researchers found that the problem with the consideration of ECR provides a more insightful solution than the one without. Imai et al (2009), modified a mathematical model to optimize the liner shipping network design, taking into account ECR problem, as well as to minimize the total cost associated with capital costs, ECR cost, storage cost, and leasing ECs cost. Many experiments applied on two typical service networks with different ship sizes to address container management and the containers distribution problems in the Asia-Europe and Asia-North America trade lanes. The results show that in most scenarios the Multi-Port Calling (MPC) is superior in terms of total cost, while the Hub-and-Spoke (HandS) is more advantageous in European trade for a costly shipping company.

Song and Carter (2009), applied four strategies to reduce the total cost of empty container repositioning, based on container flow balancing across different shipping service routes (Trans-Pacific, Trans-Atlantic, Europe-Asia), and container fleet sharing among different ocean carriers or shipping lines. The researchers found that the route-coordination strategy is much more beneficial than container-sharing strategy in reducing ECR costs. The route-coordination and container-sharing strategies can also alleviate the degree of EC movements, but it cannot eliminate the ECR problem. Braekers et al (2010), designed a service network for barge transportation with empty container repositioning, and determined the optimal shipping route to transport loaded and empty containers along the Albert Canal which has four hinterland ports connecting to the port of

Antwerp Belgium. The proposed model is based on three different empty container management scenarios between ports in order to maximize profitability and to determine the best location of empty containers in the hinterland ports. Yang and Chen (2010), analysed the network structure of inter-continental container shipping lines and established a model based on Genetic Algorithm to minimize the total transportation cost including the fixed cost of one voyage, fuel cost, port tariff and loading/unloading fees of containers. The proposed model is applied to optimize the container shipping network between ports surrounding Bohai Bay in China and two ports in the west of the USA. According to the results, the researchers found the model helpful and useful to shipping companies and to the ports authorities due to the method that may offer them a tool to design a shipping network that may generate a win-win situation. Reinhardt et al (2010), focused on the shipping network design and routing problems, and formulated a new model (mixed integer linear programming model) to minimize the total cost including transportation cost, transhipping cost, and cost of vessel sailing. The proposed model was based on the routes depending on capacities, heterogeneous vessel fleet, cost of transhipment, and butterfly routes. The researchers used Branch-and-Cut method for solving the problems. The computational results in general show that the Branch-and-Cut method is promising for the liner shipping network design problem and gives a good result on problems with complicating constraints such as non-liner constraints or problems with an exponential number of constraints.

Meng and Wang (2011), developed a mixed-integer linear programming model to deal with the liner shipping service network design problem combined with hub-and-spoke (H and S) and multi-port-calling (MPC) operations and empty container repositioning (case study on Asia–Europe–Oceania shipping operations). The proposed model is used to minimize the total operating cost, and based on fixed operating cost (bunker consumption cost, canal dues, and the fixed cost of calling at the ports), variable operating cost (berth occupancy charge and containers handing cost at each port), and empty container repositioning cost. The results show that the proposed model can be solved efficiently by using the optimization solver CPLEX for all the tested instances and that large cost-savings are achieved by combining the H & S and MPC operations, and by incorporating the empty container repositioning issue in the network design. Shi and Xu (February 2011), addressed the empty container repositioning problem in a fixed route that covers two ports, as two cases, and analysed the structures of optimal policies of empty repositioning decisions. The first case is the offline case, where the demand information is assumed as a random variable with known distribution, and the second case is an online case, where the demand information is partially known. The researchers proposed a model (Stochastic dynamic programming model) to minimize the total costs, including transportation cost (empty and laden containers), holding cost and penalty cost due to unmet customers demand. According to the analysis and results that were obtained by using the proposed model, the researchers found that the offline policy (where the partially available demand information is ignored) is easy to implement and state independent. On the other hand, the online policy (where the partially available demand information is explicitly considered) is relatively difficult to implement and state dependent. Wang and Meng (2012), focused on Liner Ship Fleet Deployment (LSFD) problem with container transhipment operations. The researchers formulated a mixed-integer linear programming model to optimize shipping service route on the Asia-Europe-Oceania shipping network. The proposed model was used to minimize the total cost associated with operating ships and voyages, berth occupancy charge, containers transhipment cost, loading and discharge cost, and cost of chartering in ships. The results show that the model provides optimization techniques and how ship utilization in the optimal solution can be used to redesign liner shipping service route.

2.5 Empty containers repositioning problem with leasing and purchasing strategies

Lopez (2003), analysed how ocean carriers organize or manage the empty container reposition activity in the USA, and focused on many factors and constraints that influence the ocean carriers' decisions in terms of repositioning activities, coordination mechanisms (between suppliers, inland repositioning providers and ocean carriers) and the characteristics of the service (distance and volume). Kim (2004), addressed the scheduling problem for the leasing and purchasing of empty containers in the shipping liners to satisfy the future demand into the long-term planning and short-term scheduling. The proposed mathematical models (deterministic models) are used to minimize the total cost, including leasing cost, purchasing cost, inventory-holding cost and lost demand penalty cost. The models provide the optimal lease and purchase determination, and also provide the basic principles for decision-making. Hsu and Hsieh (2005), analysed the shipping economics of ultra large ships, and formulated a two-objective model to determine the optimal ship size and sailings frequency with respect to different shipping and inventory costs. The proposed model is used to minimize the total shipping and inventory costs, and based on capital and operating cost, the fuel cost and port charge on serving the route.; It also includes costs due to freight waiting to be shipped in a loading port, and on a ship along the shipping route. According to the numerical results that were obtained by using the proposed model, the researchers found that the model can assist container carriers in decision-making by considering all key factors comprehensively and further to find the optimal timing of using ultra large ships.

Olivo et al (2005), proposed a mathematical model (an integer programming model) based on the cost of empty containers transportation and storage cost in depots to minimize the overall cost of managing empty containers between several ports and depots (case study in the Mediterranean basin). The proposed model is used to support the decision-makers to evaluate the transportation systems (truck, rail, ship, barges and mixed modes) over time and to select which available transportation services should be used to reposition empty containers on a given day. Furthermore, the model allows for correcting the system promptly and provides a more detailed representation of transportation systems. Cordeau et al (2007), studied the Service Allocation Problem (SAP) in the Gioia Tauro port in Italy and focused on the containers yard management to minimize the container re-handling operations inside the yard. The scholars formulated two mixed integer linear programming models, and developed a memetic heuristic to solve the problem, and they found that the computational results confirm that the heuristic can be used to handle real-life (SAP) instances, and that the heuristic always yields optimal solutions. Li et al (2007), focused on allocation of the empty container problem between multi-ports (inland line and global line with three ports), and formulated a model (based on a heuristic algorithm) to optimize the allocation policies and to minimize the total cost, including costs of importing and exporting empty containers, holding empty containers cost, and leasing cost. The researchers found that the heuristic algorithm can compute the feasible allocation method for any system state, and that it may be preferable, because the repositioning of empty containers is very simple. Francesco et al

(2008), addressed the Empty Containers Repositioning problem in the Mediterranean region with Multi-Scenario Policies under uncertainty and data shortage. The formulated model (a time extended Multi-Scenario optimization model) is used to minimize the total cost, including inventory cost, handling cost (loading and unloading of ECs), and transportation cost for (ECR). The experimental tests (using solver CPLEX 10.1) show that the Multi-Scenario Policies are better than the deterministic Scenario Policies for shipping companies' needs because Multi-Scenario Policies can allocate more ECs compared to Deterministic Scenario Policies, and, therefore, satisfy large demand fulfilment percentages and yield slightly higher repositioning costs. Song and Zhang (2009), applied many Empty Containers Repositioning policies under different dynamic information of customer demands and shipments, and presented the major important factors that affect the relative performance between the policies. The scholars formulated a model to minimize the total expected costs, including empty containers repositioning cost, inventory cost and leasing cost. The proposed model is used to evaluate the optimal policies under conditions of uncertainty in export and import demands. The results (by using iteration algorithm and Discrete-time dynamic programming) show that the observations from the policies give specific scenarios in which the dynamic information of demand and supply has minimum impact or maximum impact on the Empty Container Repositioning decisions. Theofanis and Boile (2009), studied the factors that affect the empty container logistics management and strategies implemented by ocean carriers to optimize the empty containers management. The paper focuses on the relationship between two major players (ocean carriers and container leasing companies) and the essentially different and conflicting goals, in terms of containers fleet management (repositioning, maintenance and repair) and containers leasing arrangements during the term lease and after off hire.

Chew et al (2011), focused on the Empty Containers Repositioning problem and formulated a two-stage stochastic programming model with random demand, supply, ship weight capacity and ship space capacity. The proposed model is used to minimize the total operational cost in the planning horizon, including transportation cost, handling cost (loading and unloading), holding cost, and the penalty cost. Based on the results that were obtained by using The Sample Average Approximation method (SAA) to solve the problem with multiple scenarios, the researchers found the performance of the proposed model with (SAA) to be promising. Ngoc and Moon (2011), focused on the storage capacity expansion and space leasing problem for container depots, and developed mathematical models to minimize the total cost associated with capacity expansion cost, storage space leasing cost, inventory holding cost, empty containers leasing cost, and empty containers positioning cost. The proposed models were based on number of leased empty containers, number of positioned empty containers, depot capacity, and inventory level of empty containers. The results (by using the heuristic algorithm that is based on Lagrangian relaxation) show that the models contribute effectively to solving the problems and can be used to support decision making between short-term and long-term planning horizons. Jiang (2012), addressed the Empty Containers Allocation problem in the ports, and proposed an uncertain empty containers allocation model based on random variables (demand, supply and ship capacity) to minimize the total cost, including transportation cost, storage cost and leasing cost of empty containers, to optimize the distribution of empty containers demands between ports for each ship voyage across shipping service networks. Moon et al (2012), developed three mathematical models to deal with empty container repositioning problem for foldable and standard containers among multiple ports and across multiple periods. The proposed models are used to minimize the total costs, including repositioning cost, inventory storage cost, purchasing cost, and folding/unfolding costs. The scholars used heuristic algorithms to solve the models, and they found that standard containers have higher priority than foldable containers to satisfy the demand and that the usage of foldable containers can be an effective strategy to reduce the repositioning and inventory costs, as well as to save more than 75% of storage space. However, the experiments show that the high purchasing price of foldable containers prevents them from being widely used, and also because of high production cost, high maintenance cost, and vulnerability to damage.

2.6 Berth allocation problem

Kim and Moon (2003), suggested a simulated annealing algorithm, and formulated a mixed integer linear programming model to minimize the total costs including the cost due to the non-optimal berthing location of vessels in a container terminal, and penalty cost due to delays in the departures of vessels. According to the experimental results that were obtained by using a simulated annealing algorithm and LINDO package for the formulated model, the researchers found that the simulated annealing algorithm renders solutions that are similar to the mixed integer linear programming model, and that the results of the algorithm were near-optimal solutions given that the computational time was within the limits of practical usage. Dai et al (2004), focused on berth allocation planning optimization in a container terminal. Many scenarios and policies are applied to design a berthing system that allocates berthing space to vessels in real time close to their preferred locations within the terminal. The researchers used a simulation model to evaluate the performance of the proposed approach, and they found that the simulation results show that the performance varies according to the various policy parameters adopted by the terminal operator. Furthermore, according to the moderate load scenario, the proposed approach is able to allocate space to over 90% of vessels upon arrival, with more than 80% of them being assigned to the preferred berthing location.

Imai et al (2005), addressed the berth allocation problem in multi-user container terminals (the busy container ports with heavy container traffic), by establishing a heuristic algorithm to minimize the total service times for all ships (the time from arrival to departure and waiting time). The proposed heuristic algorithm is used to solve the problem in two stages; the first stage of algorithm identifies a solution given the number of partitioned berths, and the second stage relocates the ships that may overlap or be located sparsely in a scheduling space. The scholars found that the algorithm can improve the terminal operation and that it yields a feasible solution to the Berth Allocation Problem (BAP). Boile et al (2006), formulated a mixed integer programming model based on a heuristic algorithm to optimize the berth allocation problem with service priorities in a multi-user terminal. The formulated model is used to minimize the weighted total service time (berthing time and handling time), and to find the optimal berth schedule for the assignment of ships to the berthing areas along a quay. The numerical experiments show that the heuristic algorithm is useful for obtaining a new berth allocation scheme to deal with the changes in ship arrival times.

Moorthy and Teo (2006), studied the berth allocation problem, and analysed the impact of the berth template design problem on container terminal operations. The researchers proposed a robust model and used two methods to evaluate the robustness of the berth template (service level-waiting time and operational cost connectivity). They compared the results that were obtained by using two models (robust and deterministic), and the researchers found that the average delays in the deterministic model is 1.65 h with a variance of 2.75, whereas the average delay in the robust model is 0.75 h with a variance of 1.13. Furthermore, 27 vessels in the robust model's template had an expected delay of 0 h, as opposed to 13 vessels in the deterministic mode. The results indicate that the robust model is the better choice to solve the problem, and that it is able to find new templates with slightly better waiting time performance, and to keep the number of overlaps between vessels with a minimum number during actual operations in container terminal. Krcum et al (2007), developed a multi-objective genetic algorithm (based on the Matlab software package) to deal with berth and quay cranes assignment problems, and to minimize the total costs due to the berthing and quay crane operation (handling operation). The proposed algorithm is a useful technique for finding near-optimal solutions for the problems, and it is used to determine the berthing time and position of each vessel, as well as the number of cranes to be allocated to the vessel. Theofanis et al (2007), suggested a genetic algorithm heuristic to optimize the Berth Allocation Problem, and formulated a linear mixed integer programming model to minimize the total weighted service time of all vessels. The scholars studied the Discrete BAP and Dynamic BAP that deal with calling vessels with various service priorities. The experimental results show that the Optimization Based Genetic Algorithm (OBGA) heuristic is more efficient than the Genetic Algorithm heuristic without the optimization component in terms of the variance and minimum values of objective function. Imai et al (2008), proposed a genetic algorithm-based heuristic to address the simultaneous berth and quay allocation problem. The formulated model is used to minimize the total service time (waiting and handling times), and to find the efficient scheduling process of simultaneous berth and crane allocation at a container terminal. The computational experiments show that the proposed algorithm is applicable to solving the problem and to determinning the berth scheduling and quay crane scheduling at the same time. Colias et al (2009), studied the berth allocation problem, and formulated a mixed integer programming model to optimize the vessel arrival time. The proposed model is used to minimize the total waiting and delayed departure time for all vessels. The scholars compared between the numerical results of a Genetic Algorithm (GA-based heuristic) and CPLEX to investigate the performance of the GA heuristic and they found that the developed algorithm can be more beneficial for both the carrier and the terminal operator under the proposed berth scheduling policy. Javanshir et al (2010), modified a mixed integer nonlinear programming model to address the Continuous Berth Allocation Problem (CBAP), and to achieve the best service time in a container terminal. The modified model is used to minimize the service times of the ships (the time spent from arrival to departure including the waiting time). Many numerical experiments are carried out to find the optimal berthing time and berthing location of each ship, as well as the expected ship delay. According to the outputs and results, the researchers found that the modified model can provided better analysis of the berth allocation problem in a more acceptable computational time. Zeng et al (2011), studied the disruption management problem of berth allocation in a container terminal, and developed a mixed integer programming model and a simulation optimization algorithm to optimize the simultaneous berth allocation (berthing position and berthing order of each vessel) and quay crane scheduling problems. The objective of the paper is to decrease the influence of unforeseen disruptions to operation system and decrease the additional cost resulting from disruptions. The scholars applied a simulation optimization approach to assess the influence of disruptions and optimize the new berth schedule coping with disruptions. The numerical experiments indicate that the algorithm based on local rescheduling and a Tabu search can improve the computation efficiency.

Shan (2012), applied a genetic algorithm (coded in LINGO 11.0) to optimize the dynamic berth allocation problem with discrete layout. The optimization model is used to minimize the total service time (waiting time and handling time) of all ships with the consideration of ships service priority. The proposed algorithm is useful to improve the container terminal management as it can find a better solution to the problem. Ma et al (2012), focused on berth allocation planning and proposed an integrated model of combining berth allocation and quay cranes assignments, to improve the container terminal performances. The proposed model is used to minimize the total service time (vessel waiting time and handling time) and vessel transfer rate. It is based on a Two-Level Genetic Algorithm (TLGA) to optimize the problems, and to maximize the performance of the terminal in terms of service quality, the numerical experiments show that the proposed (TLGA) can achieve better solutions for BAP and QCA in serving more important customers, and that it is capable of solving the two problems simultaneously. Hendriks et al (2013), formulated a Mixed Integer Quadratic Program (MIQP) to deal with both the Berth Allocation Problem (BAP) and Yard Planning Problem (YPP) or Yard Allocation Problem (YAP) simultaneously (case study in PSA Antwerp Terminal). An alternating BAP-YAP heuristic is used to solve the formulated model and is used to minimize the overall straddle carrier travel distance between quay and yard, and between yard and hinterland. According to the results that were obtained by using CPLEX 11 to solve the problems, the researchers found that the alternating procedure yields significant reductions in the total straddle carrier driving distance compared with the initial condition. Sheikholeslami et al (2013), proposed a simulation model (based on ARENA package software) to address the problem of Integrating Berth Allocation and Quay Crane Assignment. The proposed simulation is applied on Rajaee Port in Iran, and it is used to evaluate the berth allocation planning and the problems in this domain. Three different policies of berth allocation (randomized allocation, length-based allocation, draft-based allocation) are examined by simulation model to test the performance of berth allocation plans. According to the results that were obtained by using the simulation model, the researchers found that the strategies of length-based allocation and draft-based allocation are dominated by random allocation scenario according to wait time and average anchorage queue length.

2.7 Container stacking problem

Chen and Chao (2004), formulated a mathematical model with time-space network to deal with the storage space allocation problem for export containers in a container yard. The proposed model was applied at the Port of Kaohsiung in Taiwan to evaluate the yard planning with the sort and store strategy. It was used to minimize the total assignment cost, and applied to many adjustment strategies (adjustments in assignment cost, arrival dates of containers and demands of ground-slot sets) to optimize the usage of ground-slot sets in terms of time and space. According to the results obtained by using the model using CPLEC, the researchers found that an optimal solution is easily obtained through application of the network framework. Ng and Mak (2005), developed a mixed integer programming model to address the yard crane scheduling problem in performing a given set of handling jobs (loading/unloading) with different ready times. The proposed model seeks to minimize the sum of job waiting times (completion time, ready time and handling time). A branch and bound algorithm was proposed to solve the scheduling problem and it found the optimal sequence for most problems of realistic sizes. Froyland et al (2008), studied the problem of managing a container exchange facility with multiple semi-automated Rail Mounted Gantry cranes (RMGs) in the landside area at the Port Botany Terminal in Sydney. The scholars proposed an integer programming model (based on heuristic), consisting of three stages (the scheduling of cranes, the control of associated short-term container stacking, and the allocation of delivery locations for trucks and other container transporters). The results show that the model can find effective solutions for the planning problem, and the solution framework helped to minimize the size of the required straddle carrier fleet. The proposed approach indicated that the heuristic is applicable to obtaining an optimal solution to the problem, which includes scheduling the RMGs, assigning the short-term positions of containers, and determining truck bays to be used. Salido et al (2009), focused on the container stacking problem and developed a domain-dependent planning tool based on a heuristic to minimize the number of reshuffles of containers. The proposed planning tool was used to organize all the containers in the yard-bay according to their departure time. The researchers found that the proposed heuristic algorithm can find the optimal solution to minimize the relocations of containers in a container yard and it finds the best configuration of containers in a bay to avoid further reshuffles.

Kefi et al (2010), suggested and developed two models to optimize the container stacking activity within maritime or fluvial ports. The basic model is based on an uninformed search algorithm and it allows for simulating and solving the container stacking process while the extended model is based on an informed search algorithm that allows optimizing this process. The researchers compared between the results that were obtained by using the two proposed models and found that the latter performs much better than the former, and that the heuristics are a better choice to solve the combinatorial optimization problem such as the container stacking problem. Asperen et al (2010), developed a discrete-event simulation model based on Java programming language to evaluate the performance of stacking strategies and stacking rules in a container terminal. The proposed simulation consists of two major components: the generator program and the simulator program. The generator program creates arrival and departure times of the containers, and the output of the generator is a file that contains the ship arrivals, details of the containers to be discharged and loaded, and the specification of the destination of each container. The simulator program reads the output of the generator and performs the stacking algorithms. According to the outputs, the researchers found that the simulation model can capture the amount of detail required and that it is flexible enough to support the evaluation of the stacking rules.

Lee et al (2011), addressed the integrated problem for bay allocation and yard crane scheduling in transhipment container terminals. The scholars developed a mixed integer programming model to minimize the total costs, including yard crane cost (setup and travel costs of yard crane) and task delay cost. According to the complexity of the problem, the scholars proposed a simulated annealing (SA) heuristic to find near optimal solutions. The numerical experiments show that the SA heuristic shows promise of handling the integrated problem. Luo et al (2011), reviewed the literature that are focused on storage and stacking logistics problems in container terminal. They classified the articles and studies into three categories: container storage space allocation problem, design of optimal yard layout and container stacking logistics. The purpose of the study is to provide a new perspective for both managers and researchers on the issue of yard operations management, and to support decision makers to find the optimal solutions to achieve the optimal solutions to optimal service level inside container terminal. Li and Li (2011), focused on a yard template design problem in land-scarce container terminals (high density stacking of containers) for storing export containers with periodical vessel arrival schedules. They proposed a two-phase solution method (determining the size of cluster and then determining the exact shape and position of clusters) and a heuristic algorithm to address the problem. The experimental results (by using ILOG CPLEX) indicate that the solution method is very efficient for generating a solution for the problem, i.e. minimize the number of slots used in yard block and maximize the sharing of slots among the clusters.

Sharif et al (2012), focused on the Inter-Block Yard Crane Scheduling or Deployment Problems in a marine container terminal, and provided an agent-based approach to assign and relocate yard cranes among yard blocks based on the forecasted work volumes. The proposed approach is used to find the effective schedules for yard cranes and to minimize the percentage of incomplete work volume. The scholars applied many strategies to assign the cranes among blocks at the beginning of a planning period based on the work volume forecast. The results show that the proposed approach or model can find an excellent solution in a short time for a range of work volume conditions with high variation. In medium conditions, all work can be finished within planning period. In heavy and above capacity conditions, the percentage remaining incomplete is less than or equal to 1% and within 3% of the optimal respectively. Gharehgozli (2012), applied new methods and developed an integer programming model and heuristic algorithms to increase the efficiency of container stacking operations in a container terminal. The proposed methods can find the optimal and near-optimal solutions for the yard crane scheduling problem and for minimizing container reshuffling. The proposed methods are scheduling a single yard crane with given storage locations and with flexible storage locations, scheduling two non-passing yard crane and minimizing the expected number of reshuffles. Sriphabu et al (2013), developed a simulation model based on the Arena program to determine the time of yard crane that is spent to lift a container and to transfer it to the containership. They applied and developed a genetic algorithm (GA) to minimize the total lifting time and to increase the service efficiency of the container terminal. According to the experimental results that were obtained from the model by using the proposed GA, and First-in, First-Storage (FIFS) rule or strategy, they found that the simulation model based on GA is more efficient than the simulation model based on FIFS rule, and that the efficiency difference increased to 34.78% and the average was 25.47% for all experiments. Borjian et al (2013), studied the Dynamic Container Relocation Problem (DCRP), and proposed a two-stage stochastic optimization model to minimize the number of container relocation moves in a container yard with continual arrivals and departures. The computational results indicate that the stochastic optimization model can achieve the optimal solution of the problem and that it provides solutions closer to the reality of port operations. Jovanovic and Voß (2014), presented a new chain heuristic approach to optimize the Blocks Relocation Problem (BRP), and to minimize the total number of moves. The proposed heuristic was used to decide where to relocate a single block while taking into account the properties of the block that would be moved next. They compared between the results that were obtained by using the proposed heuristic and the several existing methods of this type on test data of a wide range of sizes and found that the chain heuristic achieved the best results in almost all of the tested cases.

2.8 Container stowage problem

Ambrosion et al (2004), proposed a 0-1 linear programming model to optimize the stowage of containerships (case study in the maritime terminal in Genow, Italy) and to finding the optimal plans for stowing containers. The proposed model is based on a heuristic algorithm and it is used to minimize the total stowage time, and the solution approach consists of three phases (pre-processing, pre-stowing procedure and the solution to the problem). The computational experiments show that the proposed approach provides a very good performance in terms of both solution precision and computational time. Moura and Oliveira (2005), studied the Container Loading Problem (CLP) and applied GRASP (Greedy Randomised Adaptative Search Procedure) meta-heuristic to maximize the efficiency of the loading space utilization and to improve the loading stability. The proposed approach is applied to both weakly and strongly heterogeneous types of cargo problems and is compared with three approaches (three different meta-heuristics). These meta-heuristics are Simulated Annealing, Tabu Search and Iterated Local Search. The results show that in terms of volume utilization and cargo stability, the proposed approach provides an efficient method to apply to both weakly and strongly heterogeneous problems, and that some approaches provide better solutions for weakly heterogeneous problems while others provide better solutions for strongly heterogeneous problems. Gümüs et al (2008), developed a multi-stage decomposition heuristic to deal with container stowage problem, and to optimize the loading\unloading process. The proposed heuristic consists of a four- stage decomposition approach (first stage: address the crane efficiency which minimizes the number of overstow, second stage: the number of overstows is further reduced, the third and fourth stages: the final stowage plan is generated). The solution approach by multi-stage Decomposition Heuristic is performing well in testing on real life problems, and it provides a suitable plan that minimizes container over-stowage. Delgado et al (2009), suggested a Constraint Programming (CP) model to optimize the container vessel stowage planning, and to find the optimal allocation plan for a set of containers in an under-deck storage area of a container vessel bay. The objectives were minimizing the over stows, keep stacks empty if possible, and avoid loading non reefer container into reefer cells. They compared between the results that were obtained by using the proposed approach CP and the results that were obtained by using the integer programming IP and Column Generation (CG) approach, they found that the CP approach outperforms an integer programming and Column Generation approach in most instances from different real-life vessels of different size, with different configurations of containers and discharge ports. Martins et al (2009), proposed a Genetic Algorithm (GA) to solve a container stowage problem (CSP) for small containerships that are used in short sea shipping. The purpose of study is to validate and to compare the ability of different approaches to solve the CSP. They compared between the results and outputs that were obtained by using the proposed Genetic Algorithm and Microsoft Excel Solver, taking into account the transverse and longitudinal stability constraints and intact stability criteria. The results show that the GA presents a good solution more easily than the solution using ME Solver, and it can be applied to the problem with large value of constraints.

Min et al (2010), developed a heuristic algorithm to improve the ship stability in automated stowage planning for large containerships. The proposed algorithm is used to adjust stack weight, trim (cross balance, or the moment of balance between bow and stern) and heel angle (horizontal balance, or the moment of balance between the left side and right side). Also, it used to search for alternative feasible locations for containers that affect ship stability. According to the outputs and results, this approach is useful in practice to distribute the weight of containers in effective ways for large containerships, and that it is capable of solving the stability problems. Fan et al (2010), developed a fully automatic stowage plan generation system and proposed two heuristic algorithms to optimize the stowage planning of large containership. The algorithm aims to minimize the number of re-handles, maximize the utilization of cranes and improve the ship stability. According to the outputs, the proposed approach is useful to improve the quality of stowage planning as it provides very good performance in terms of plan quality and computational efficiency.

Zeng Min et al (2010), developed a fully automated system for the planning of large containerships and focused on the weight distribution problem of stowing containers. They applied a stability adjustment model (based on heuristic algorithm) to improve the stability of a stowage plan automatically by using container weights and ballast. The adjustment algorithm is useful and helpful in practice to large containerships in terms of improving safety and stability issues for stowage plans comparing to those generated by experienced planners. Jensen et al (2011), used a symbolic configuration technique based on Binary Decision Diagrams (BDDs) to optimize the container stowage planning. The proposed technique is used as an approach for interactive decision support for modifying stowage plans (re-arrange containers) without breaking overall stability, stress moment, and crane activity requirements. It also provides a guide to help the stowage coordinators to offer them a tool to solve the problem efficiently and a more insightful solution.

Dario and Jensen (2012), developed an accurate slot planning model and used the Constraint Based Local Search (CBLS) algorithm to find near optimal solutions heuristically. The proposed algorithm is implemented in C++, and it is used as a heuristic fallback of an exact constraint programming model. The experimental results show that the percentage of solutions solved within a specific optimality gap, and that the algorithm can actually reach the optimal solution of 86% of the industrial instances. Wenbin HU et al (2012), proposed two mathematical models to deal with ship stowage and loading schedule problems. The proposed models were based on a greedy algorithm with heuristic genetic algorithm to solve the problems. The purpose of the paper is to minimize the container reshuffle rate on board, minimize the yard reshuffle times during the whole ship loading process, minimize the total moving distance of quay crane, minimize the average centre of gravity of the ship, holding appropriate trim and ensuring that the heavy container stacking is in the middle of the ship. They found that the models and algorithms were efficient and effective as the approach to solve the problems and that they have a good container over-stowage performance from the analysis of the experiment's result. Pacino (2012), studied the container stowage planning problem and used 2-phase hierarchical decomposition approach to optimize master planning and slot planning. The first phase distributes the containers into stowage area along the vessel, and the second phase assigns the specific positions to containers within each of the stowage areas. Based on the experimental results, the researcher found that the proposed approach is able to solve large scale container stowage problems, and that it improves the master planning and vessel stability. Zhao et al (2013), studied the vessel slot planning problem in stowage process of outbound containers, and formulated a mathematical programming model to optimize the efficiency and stowage quality of slot planning for outbound containers in container terminals. The examination of the problem consists of three steps (step one: select a target area in a vessel bay, step two: search and choose a container group to obtain the number of blocks and container distribution in each block and yard bays, and step three: stow the selected containers in the slots of a vessel bay selection). The proposed model is used to minimize the yard bay number of a vessel slot. According to the numerical results that were obtained by using CPLEX 10.0, they found that the proposed model is certified and can be helpful to motivate future researches in terms of related vessel stowage problems.

Legato and Mazza (2013), focused on vessel loading sequence and proposed a simulation model (developed in Microsoft Visual Basic 6.0) to estimate the number of reshuffles required with respect to a given loading sequence plan and a given yard configuration. The simulation model is used to support the terminal planners in their daily job, and to evaluate the alternative loading sequences with different loading operations and equipment. The numerical experiments that are applied on a real-life container terminal in Gioia Tauro, Italy, show that the proposed simulation model provides accurate estimates of reshuffles for large size loading plans. Kroer et al (2014), proposed a general model and developed tow algorithms to optimize container stowage problem. They applied two different interactive configuration techniques [(Reduced Ordered Binary Decision Diagrams (BDDs) and fast Boolean Satisfiability (SAT)] to support user-driven modifications of stowage plans. They focused on re-arranging the containers in a single bay section and show two approaches for providing complete and backtrack-free decision support using symbolic configuration techniques. The results show that the (BDDs) can be used to solve real-world sized instances of a single bay, and SAT solutions can be used to solve simplified instance by going beyond a single bay.

Ambrosion et al (2015), focused on Multi Port Master Bay Plan Problem (MP-MBPP) and proposed a Mixed Integer Programming model based on a heuristic to determine the stowage plans in circular routes of containerships and to minimize the time spent by containerships at the ports for loading/unloading operations. According to the outputs of the proposed approach, they found that the model provides an appropriate tool that can find a good stowage solution. Also, it is helpful and useful to the liner planners in terms of getting very good feasible solutions for large containerships (up to 18000 TEU) in a very short computational time. Zhao et al (2016), studied the vessel stowage planning problem and proposed a multi-objective mixed integer programming model to minimize the unavoidable reshuffles of yard cranes, number of over-stowing containers, unnecessary movement of yard cranes, quay crane idleness and unavoidable yard crane remarshalling. They suggested a Genetic Algorithm (GA) to solve the proposed model, and to improve the loading efficiency and stowage quality. The numerical experiments show that the GA can generate a good solution within a time period that satisfies the practical demand, and that it provides a practical significance to improve loading efficiency and stowage quality.

2.9 Seaport container terminal operations costs problem

Vis and Koster (2003), presented a review of various decision problems that arise at container terminals, and described the planning and control levels (strategic, tactical and operational) in making decisions to obtain an efficient container terminal. The scholars described all processes at a manned or automated container terminal, and also examined numerous research documents as part of the literature review to analyse and classify the various decision problems with analytical or simulation models and solution approaches that are used to solve the problems. Murty et al (2004), developed a computerized decision support system (DDS) to optimize the daily operations of container terminals in Hong Kong, and compared between many strategies under different conditions varying with time. The researchers described the daily operations of container terminals in detail, and proposed mathematical models to optimize the daily operations at a container terminal, and to minimize the berthing time of vessels, the resources needed for handling the workload, the waiting time of customer trucks, and the congestion on the roads and at the storage blocks and docks inside the terminal. Furthermore, to make the best use of the storage space in the container yard. Hartmann (2004), established an approach for generating scenarios to optimize the seaport container terminal logistics (case study in HHLA container terminal Altenwerder in Hamburg, Germany), and to address the problems relevant to berth planning and quay crane scheduling. The generated scenarios depend on several parameters such as the horizon, sizes of the modes of transport, parameters dealing with arrival frequencies, and parameters reflecting container properties like size and weight distribution. The application of scenarios can be employed as a test data for algorithms to solve optimization problems in container terminal logistics. Soriguera et al (2006), used a simulation model to optimize the internal transport cycle in a marine container terminal managed by straddle carriers in (Barcelona Container Terminal). The researchers compared between different dispatching and allocating strategies for straddle carriers, to evaluate the service levels within quay side, land side and storage yard, and to minimize the transhipment costs. According to the outputs, the researchers found that the simulation model can assist container terminals in decision-making to optimize the terminal operations and transhipment process with reduce costs.

Vacca et al (2007), discussed and analyzed the critical issues which arise in the management of container terminals such as berth allocation, quay crane scheduling, storage policies and strategies, transfer operations, and ship stowage planning. Furthermore, the researchers used operations research methods and techniques to optimize terminal operations, and to addresses the congestion and traffic problems in the terminals of Antwerp (Belgium) and Gioia Tauro (Italy) as a case study. These techniques used to increase and improve the efficiency and productivity in port operations within the quay side and the yard side. Esmer (2008), presented the performance measurements of container terminal operations, and focused on productivity indicators, efficiency and effectiveness of activities/services to handle and control container flows from vessels to container yard and from container yard to the terminal gate, or vice versa. The paper classified the performance measurements of container port/terminal into four categories: production, productivity, utilization, and services to evaluate the distinction between the current and previous port efficiency and effectiveness.

Froyland et al (2008), studied the problem of managing container exchange by multiple semi-automated Rail Mounted Gantry cranes (RMGs) in the landside area at the Port Botany Terminal in Sydney. The scholars proposed an integer programming model (based on heuristics), consisting of three stages (the scheduling of cranes, the control of associated short-term container stacking, and the allocation of delivery locations for trucks and other container transporters). The results show that the model can find effective solutions for the planning problem, and the solution framework contributes to minimizing the size of the required straddle carrier fleet. Seyed Hosseini and Damghani (2009), developed a fuzzy mathematical programming model to solve the container allocation problems in maritime terminals. The proposed model (based on LINGO 8.0 to solve the problem) is used to optimize the distance between berths and container terminals areas, and to minimize the total distance to transfer the containers from the ship to the terminal area. The results show that the proposed model is robust and addresses the imprecision regarding the distance berth and terminals area. Vacca et al (2010), focused on the optimization of operations in container terminals, and the integrated optimization of interdependent decision problems that deal with berth allocation and quay crane assignment. The scholars also analyzed the issues related to traffic congestion in container yard and the tactical planning of operations. According to the optimization approaches that were used in terminal management (Hierarchical and Integrated approaches), the scholars found that the integrated approach always finds the optimal solution to the problem in a reasonable time and provides a more efficient use of terminal resources. Wong and Kozan (2010), developed a model to optimize the seaport terminal operations, and to increase the efficiency of container management in a multi-berth and multi-ship environment. The proposed model is based on Tabu search algorithms to solve the problem, and to improve the operations efficiency in terms of loading/unloading, handling, containers transfer operations and container yard layout. The model is used to support the seaport authorities for analysing the relationship between various factors for increasing port throughput, including the layout of the container yard. Dragovic et al (2010), focused on the operational management of the dynamic transfer equipment (yard trucks) deployed between the quay and the container yard, during the container loading/unloading process at Korea container terminal. The scholars developed a Real-Time Location System (RTLS) and modified simulation models based on dynamic transfer operations to improve the productivity of the container terminal, and to increase the terminal efficiency. Moghadam and Noori (2011), developed a generic model to deal with container yard operating systems, and analyzed the concept of different cost functions that are used in modern container terminals. The proposed model is used to evaluate the economic efficiency and effectiveness of container yard equipment such as semi-automated Straddle Carrier (SC), Rubber Tyred Gantry crane (RTG) and automated Rail Mounted Gantry crane (RMG). Furthermore, it is used to determine the total container yard operations cost and consists of container yard land development and maintenance costs, crane investment, manning and maintenance costs and container transfer cost. Clausen et al (2012), used a simulation method (ContSim) to optimize container terminal operations by determining the best mix of operating strategies for crane control, stacking area, handling area and resource management. The simulation method (ContSim) enables port authorities to manage and optimize the container terminal with every operation into the seaside and landside areas and provides a daily control panel to plan the deployment and the operating strategy mix for the upcoming day.

2.10 The time interference between seaport container terminal operations problem

Chu and Huang (2005), compared among three different handling systems in seaport container terminals [Straddle Carriers (SC), Rubber-Tired Gantry crane (RTG), and Rail-Mounted Gantry crane (RMG)] to determine the container terminal capacity. The researchers discussed and analyzed the critical factors which have an effect on the procedure of determining terminal capacity such as yard size, the adopted yard handling system, yard crane dimensions, container transshipment ratio and the average container dwell times in the container yard. According to the outputs and results, the researchers found that the general equation (model) can be very useful and helpful for container terminal planning with regards to the selection of handling technology, site location or proposed service expansions. Bish et al (2005), studied the impact of vehicle deployment on the container terminal throughput, and suggested a model based on heuristic algorithms to deal with the vehicle dispatching problem in a mega container terminal, and to optimize different vehicle dispatching policies (discharging and job sequences, uploading job sequences, and combined job sequences). The proposed model is used to minimize the total time for the vehicles to discharge all containers from the ship and upload new containers onto the ship. The researchers compared between different instances (single ship with a single quay crane, and single ship with multiple quay cranes) to find the effective dispatching policy that assigns vehicles to jobs so as to minimize the time span. The numerical experiments reveal that the model provides near-optimal results for the vehicles dispatching problem. Schmidt et al (2005), developed a computer modeling (Data Gathering Model) to improve the efficiency of operations and activities of small and medium sized ports or container terminals, and to resolve the operational problems. The proposed model (electronic Terminal Planning Board-TPB) enables seaport authorities to re-engineer terminal layout, selection of cargo handling equipment and working methods to reduce manpower, minimize travelling distance and time by using different routes, equipment and arrangements of slot spaces to increase terminal capacity, terminal throughput and terminal efficiency. Furthermore, the model affords potential planning opportunities and operationally feasible results, in addition to improving the efficiency of the container terminals by increasing the cargo throughput, reduces the turn-a-round time of vessels and other vehicles as well as the unproductive times on the terminal. Le-Griffin and Murphy (2006), investigated the critical factors that are effected on the container terminal productivity (case study in the ports of Los Angeles and Long Beach). The scholars presented a brief survey of port facilities and cargo handling characteristics at both ports and described the common productivity measures of container terminals such as crane utilization and productivity, berth utilization and service time, land utilization and storage productivity, gate throughput and truck turnaround time and labor productivity. The scholars found that the productivity of a container terminal is influenced by a range of factors (internal and external), and that terminal operators can control some of these factors, while others are beyond their control. Leong and Lau (2007), focused on the job schedule problem for handling, transportation and stacking equipment [Quay Crane (QC), Prim-Mover (PM), Yard Crane (YC)] in a container terminal, and formulated a mathematical model based on a heuristic algorithm to minimize the completion time of the QC sequence, traveling time of PM, and cycle time of YC. According to the computational experimental results that were obtained by using the proposed model to test the efficiency of the algorithm, the researchers found that the algorithm provides the optimal solution for the problem, and gives a better relationship between the Gross Crane Rate (GCR) and the available equipment (PM and YC). Mak and Sun (2009), proposed a new hybrid optimization algorithm to address the problem of scheduling multiple yard cranes in a container yard, and to minimize the sum of the completion times of the yard cranes. The proposed algorithm consists of combining the techniques of genetic algorithms and Tabu search method (GA-TS). The researchers formulated a mixed integer program mathematical model to minimize the summation of container ready time, the handling time, the yard crane travelling time and the waiting time of yard cranes due to inter-crane interference. The computational results show that the new algorithm (GA-TS) is an effective and efficient means to solve the problem and provides a reasonable solution within limited time, as well as providing cost-effective solutions on average 20% better than those found by genetic algorithm (GA).

Vidal and Huynh (2010), built a multiagent-based simulation model to simulate and analyze the behavior of the yard cranes, and to evaluate the collective performance of the system. The proposed model is used to minimize the distance between the cranes and trucks, or to minimize the total waiting time (including the time it takes a crane to arrive at a bay where the truck is parked and the time it takes the crane to perform both re-handling and delivery moves). The scholars found that the proposed model can provide a powerful tool to assess the performance of yard cranes in the seaport container terminals. Asperen et al (2010), developed a simulation model (based on Java programming language) to optimize container stacking strategies, and to evaluate the container stacking rules in the marine container terminals. The scholars compared between each strategy in terms of the efficient use of storage space, the limiting transportation time from quay area to stacking area (and vice versa), and the avoidance of reshuffles, to evaluate the performance of container stacking in a yard, and to minimize the total travel time of the stacking crane when the container enters and exits the stacking area. Furthermore, to balance the travel and hoisting time of the stacking crane and the time taken by reshuffle moves. Wang and Kim (2011), suggested a heuristic algorithm to address the Quay Crane scheduling problem, and proposed a mathematical model to estimate the impact of a QC schedule on the workload of yard cranes in each block of container terminal. The model is used to minimize the total completion time, the total expected delay time due to the interference of QCs, traveling time of QC, the excessive allocation of blocks to each QC, in addition to the make-spam of QCs. The numerical experiments are carried out to test the performance of the heuristic algorithm, and they showed a reasonable performance for the application to practices. Guo et al (2012**)**, formulated a mixed integer programming model to address the problem of Gantry Crane Scheduling (GCS) in the railway container terminals. The proposed model is based on Particle Swarm Optimization (PSO) algorithm to optimize the scheduling problem, and to minimize the completion time of all tasks of gantry cranes. The researchers compared between the results of a traditional genetic algorithm (GA) and CPLEX to the results of the proposed algorithm, to evaluate the effectiveness of the (PSO) algorithm. Experimental results show that the (PSO) algorithm is more suitable than (GA) for solving the (GCS) problem, and that it outperformed both (GA) and CPLEX in terms of solution quality and run time. Sterzik and Kopfer (2012), used a Tabu search heuristic algorithm to address the problem of inland container transportation among multiple terminals, depots and several customers in a hinterland region. The proposed holistic mathematical model is used to minimize the total operating and waiting time of the trucks, and it is used to handle the vehicle routing and scheduling as well as empty container repositioning at the same time. The computational experiments show that the Tabu search heuristic algorithm performs well with respect to effectiveness. Wang et al (2013), focused on the problem of quay crane allocation in the container terminal, and proposed a fuzzy c-means cluster algorithm to improve the production efficiency of container terminal, and to reduce the time and cost of the container vessels mooring in the seaport. The researchers used the method of cluster analysis of data mining to analysis the container terminal quay crane allocation with historical data. The data mining consists of the basic information of the ship, of the amount of ship loading and unloading, of ship docked operations and of quay crane allocation. The results show that the data mining mode (based on fuzzy c-means algorithm) is useful and effective.

Shen and Ko (2013), formulated a mixed integer programming model to deal with the Berth Allocation Problem (BAP) and Quay Crane Assignment Problem (QCAP). The proposed model is used to determine the best berthing positions and berthing times for several ships at berths or at arbitrary positions along the quay length. Furthermore, it is used to determine the sequence of tasks (individual container, container group, ship-bay) to be operated for each quay crane assigned to a ship. The scholars found that the model is helpful and useful to minimize the total turnaround time for serving all containerships, but it cannot provide the optimal solution for large size problems.

2.11 Reverse logistics problem

Fleischmann et al (1997), focused on the reverse logistics and the management of return flows of products and materials in industrial production processes. They presented a review of various perspectives in the numerous researches to provide an overview of major issues in the reverse logistics field. They classified the issues into three main areas (reverse distribution planning, inventory control in systems with return flows, and production planning with reuse of parts and materials) to analyse and classify the various decision problems. They accomplished this with analytical models (deterministic and stochastic) and solution approaches that are used to solve the problems and to provide a better understanding of the issues in reverse logistics. Imre (2002), focused on reverse logistics and analysed Economic Order Quantities (EOQ) inventory model for reparable items that was offered by Schrady. The scholar reformulated and solved the model of Schrady by modification based on more than one procurement batch and two or more repair batches. According to the outputs the scholar found that the modified model can obtain a more effective solution for a higher return rate and that the inventory holding strategy and policy provide better results comparing with that suggested by Schrady. Brito and Konings (2006), studied the reverse logistics of empty maritime containers and analyzed three strategies of empty container management (1st strategy: Balancing out trade with recycling flows, 2nd strategy: the use of foldable containers and 3rd strategy: information and communication technology) with respect to benefits, requirements and further opportunities. They show a clear perception of reverse logistics and the main issues for the efficient management of the fleet of empty containers in supply chains as well as the major actors that are involved in the maritime container flows and the challenges faced by these actors in terms of container capacity, location and movements. Chandoul et al (2008), proposed a model to optimize the reusable containers transportation between several customer sites, depots and supplier sites. The optimization model is used to minimize the total cost of network flow. The proposed model and modelling the problem as a network flow within reverse logistic context are useful to improve the container management systems, and to find a better solution to the problem with different decisions variables as well as to understand the system behaviour. Finally, the researchers found that an optimal solution is easily obtained through application of the network framework under some simplifying assumptions. Garrasco-Gallego and Ponce-Cueto (2009), reviewed the academic literature on the returns forecasting models and techniques that are used for the reusable containers. They classified the articles and studies into two categories: dynamic regression models for returns forecasting and the value of individual containers track information in returns forecasts. The purpose of study is to apply these techniques and models to a real case study in the Liquefied Petroleum Gases (LPG) in Repsol group in Spain to characterize their logistical practices, and to find the optimal replacement control policy for the reusable containers. They proposed a forecasting model to estimate the return rate and the return delay distribution.

The outputs indicate that the monthly forecast of returns (reusable containers) is not very different from the monthly forecast of sales, when the LPG company dealing with high value reusable containers. That means the proposed forecasting model for the returns adds minimal additional value to the planning and control processes. Thoroe et al (2009), proposed a RFID (Radio-Frequency Identification) technology as a possible solution to manage returnable containers. They used a deterministic inventory model (based on setup and holding costs) to analyse the impact of implementation of a RFID on container tracking systems. The implementation of RFID was analysed according to costs of returnable containers and benefits, inventory control policy, optimum refurbishment lot size, profitability and alternatives (replenishment of tagged containers and supplementary tagging of returned containers). According to the outputs and results, the researchers found that the proposed RFID technology can increase container rate and that it is a profitable usage in reverse logistics systems. Additionally, the research provides one of the first insights into theoretical effects of the application of RFID in container management. Maleki and Reimche (2011), analysed the physical flow and the information flow of returnable containers within the logistics chain to address the problems that are associated with management of returnable containers at MAAN company (Midwest Assembly and Manufacturing). The proposed approach deals with several of the automatic identification technologies that have the potential to improve the management of returnable containers. The proposed recommendations to address the problems were divided into three strategies (improve the communication and information flow by adding additional capabilities to the computerized supplier network, ensure supplier liability through the incorporation of a legal statement in the bill of loading and implement a tracking technology). The outputs show that the proposed recommendations can improve the management of returnable containers in MAAN Company; also, the recommendations would enable the company to track and locate the container in the logistics chain, maintain an accurate container inventory and reduce the number of containers that the company is losing. Dobos (2011), focused on reverse logistics inventory systems and proposed an Economic Order Quantities model to deal with products recovery management. The scholar re-examined the existing model to investigate the efficiency and the ability of the model to determine the optimal decision variables (batch numbers and batch sized (lot sizes) of manufacturing and re manufacturing). The model seeks to minimize the relevant costs for manufacturing and remanufacturing (setup cost, holding cost, linear production and manufacturing costs, linear disposal cost and holding cost for non-serviceable items). It is used in the managerial praxis in case of relatively constant demand and return rates.

Kumar and Kumar (2013), reviewed and summarised the literature that are focused on the Closed Loop Supply Chain Management (CLSCM) and Reverse Logistics (RL). They classified the articles and studies into five categories or themes: Green Operations (Reverse Logistics), Green Design (designing a product or a service that encourages environmental awareness), Green Manufacturing (product development and /or system operation to minimize environment impact), Waste Management, and Product Life Cycle Assessment. The purpose of the study is to provide a new perspective for improving performance of the processes and products according to the requirements of the environmental regulations through the effective implementation of CLSCM. Kim and Glock (2014), suggested and developed a mathematical model for a closed-loop supply chain with reusable containers under a stochastic return rate. The proposed model is used to determine the total cost of operating system, and it consists of fixed and variable costs (inspecting, repairing and ordering containers) and holding cost of containers in inventory. The purpose of the paper is to study the impact of Radio-Frequency Identification RFID-tagged containers on the supply chain, and to propose a method for managing and evaluating the use of RFID in the tracking of reusable containers. The numerical analyses indicate that the use of a developed model can be very useful and helpful for supply chain systems and that it can serve as a decision support tool. Cobb (2016), focused on Close-Loop Supply Chain (CLSC) and proposed an inventory control model to determine the total cost of returnable transport items, and it consists of fixed and variable costs (inspection and repairing containers), purchasing cost, and inventory holding cost. The outputs and the analysis show that the optimal solution (minimum total cost) is obtained when the total expected holding costs are equal to the total expected fixed costs, and that when the inspection and repairing runs begin simultaneously. Katephap and Limnararat (2017), focused on a returnable packaging under various reverse logistics arrangements and proposed a mathematical model to determine the total effective packaging cost, including disposable packaging, importer inland cost, ocean freight cost, exporter inland cost and packaging cleaning and repairing cost. They applied three reverse logistics arrangements (single-trip, round-trip and multi-trip) to evaluate the proposed model and to investigate the operational, economic and environmental advantages of the returnable packaging under these arrangements. The outputs of the study and the results of numerical calculations show that the multi-trip arrangement was most operationally and environmentally viable, and that it reduced the total packaging cost by up to 61% while packaging waste cost up to 68%. Furthermore, the single-trip arrangement achieved the shortest payback period of 0.33 year when compared with the other arrangements. Suuhal and Mangal (2017), formulated an Economic Order Quantities model to deal with supply chain management and to optimize inventory control as a case study in B Brown Medical India Pvt. Ltd. They compared between the results obtained by using the proposed model to those obtained by using current inventory model for company., They found that the proposed model achieved the best results in reduction of total annual cost, ordering cost, carrying cost, number of orders, order size and average inventory. Fan et al (2018), established two inventory models to minimize the total cost for returnable container management in a supply chain system for a single-vendor and multi-buyer. They applied two cases that the buyers can invest to reduce the loss fraction of returnable containers or the buyers do not invest. They compared between the results and the optimal solutions that were obtained by using the two proposed models for case 1 and case 2 and found that the optimal total cost of case 1 is lower than that of case 2. Additionally, the replenishment frequency of new returnable containers in case 1 is lower than that in case 2.

Shah et al (2018), proposed Economic Production Quantity (EPQ) models and applied three scenarios to deal with the returned/reworked defective products during imperfect production proceses and after the sale of products (defective products may be either reworked or refunded or completely scrapped). They formulated two EPQ models (based on price-sensitive stock-dependent demand) to maximize the profit. The purpose of the study was to facilitate appropriate decisions for managers. Fan et al (2019), studied a close-loop supply chain of the Returnable Transport Items (RTI) and developed two inventory models to minimize the total cost of the system (case study of a single manufacturer and a single retailer). They proposed two inventory models based on two sceneries (is the retailer investing in reducing RTI loss or not?) and they are used to optimize the total cost of the RTI supply chain system. They consist of the fixed and variable costs of inspecting and ordering RTI, the holding cost of RTI and the investment cost of the retailer to reduce RTI loss. The results and numerical examples show that the supply chain system will be more efficient if the retailer invests to reduce RTI loss, and that the total cost of a supply chain system will be reduced. Furthermore, when the manufacturer provides side payment proportion of compensation to the retailer, the system can be coordinated, and the optimal total cost of both manufacturer and the retailer are reduced.

2.12 Other problems types

Lawrence Edward Henesey (2006), studied Multi-Agent Systems (MAS) for container terminal (CT) management and proposed a simulation approach "SimPort" to evaluate container terminal management policies. The proposed approach is used to improve the performance and the efficient usage of available resources by applying novel methods and technologies through computer-based support for management decision making as well as automation. The results of the research indicate that the performance of a container terminal can be improved by using agent-based technologies and that this technique is a viable approach to several areas of CT management. Moreover, a multi-agent-based simulation seems to offer container terminal management a suitable tool to control, coordinate, design, evaluate and improve productivity. Hoshino and Ota (2007), designed an automated transportation system in a seaport container terminal for the reliability of operating Automated Guided Vehicles (AGVs) and Automated Transfer Cranes (ATCs), taking into account the maintenance activities of operating vehicles and cranes or robots (AGVs and ATCs). They developed an operation model in which the AGVs and ATCs enter a maintenance mode while operating on the basis of their reliability. They proposed an optimization technique to determine the optimal number of AGVs and ATCs with their mean time between failures (MTBFs) as a combinatorial design solution for a given demand. The scholars found that the proposed methodology is effective for the design of a highly efficient transportation system by considering the reliability of the operating vehicles and cranes (AGVs and ATCs) or robots, and designing their MTBFs with the given demands.

Gujjula and Günther (2008), studied the impact of storage block assignment for import containers on the Automated Guided Vehicles being dispatched in highly automated seaport container terminal. They applied three storage block assignment strategies (two of them with an intent on a low AGV travel time and one random strategy), varying from each other in terms of overall AGV travel time, 'starving' and blocking time of the quay cranes, and overall waiting time of the AGVs at the storage blocks before being served by an Rail Mounted Gantry (RMG) crane. They evaluated the strategies by means of simulation, and they found that the random strategy, despite causing, the highest AGV travel time, outperformed the other strategies for several scenarios in terms of starving and blocking times of quay cranes, and that the random strategy provides low AGV waiting time at storage blocks and low congestion rate when compared with other strategies. Petering and Murty (2008), studied the effect of storage block length and yard crane deployment systems on the overall performance of a seaport container terminal. The researchers constructed a simulation model (based on Visual C++ 6.0.) to increase the productivity and to improve the performance. They used the Gross Crane Rate (GCR, i.e. average quay crane work rate) as a performance measure of a container terminal. The proposed simulation model applied for four scenarios, varying from each other in terms of number of Yard Trucks (YTs), number of Yard Cranes (YCs), length of blocks, and yard crane deployment systems. The experiments are applied for two different container terminals [small terminal with seven different yard layouts (block lengths of 168, 84, 56, 42, 28, 24, and 14 slots), and large terminal with twelve different yard layouts (block lengths of 360, 180, 120, 90, 72, 60, 40, 36, 24, 20, and 18 slots) with two different yard fleet size scenarios (less equipment for 20 YCs, 40 YTs and more equipment for 25 YCs, 72 YTs) in each terminal. Experimental results show that a block length between 56 and 72 slots (20 ft container size) yields the higher GCR, and that the yard crane deployment system that restricts yard crane movement yields a higher GCR than a system that allows greater yard crane mobility.

Park et al (2009), focused on the operational management of the dynamic transfer operations based on real-time positioning, and developed simulation models (based on ARENA and Visual Basic) to address the Yard Trucks (YTs) deployment problem in Hanjin Gamman Container Terminal (HGCT) in Korea. The researchers compared between two types of strategies for assigning delivery tasks to yard trucks: the first is a dedicated strategy (-current strategy- the group of YTs is assigned to a quay crane, and deliver containers only for that quay crane), and the second is a pooled strategy (-improved strategy- all the YTs are shared among different quay cranes, and thus any YT can deliver containers for any quay crane). According to the results that were obtained by using the simulation models, the researchers found that the pooled strategy can raise productivity by more than 25% over the dedicated strategy. Tian et al (2009), studied the impact of port infrastructure on port handling capacity in China, and analyzed the panel data of 14 ports for the period between 1997 and 2006. They focused on the empirical research of the relationship between port infrastructure (quay length, number of berths) and port handling capacity (the area of shed and storage yard of port, comprehensive throughput capacity) to establish what the factors are and how they affect the port handling capacity. Generally; they found the development of port infrastructures has a long-run impact on the port handling capacity. In China, the longer quay lengths significantly increase port handling capacity, and the large number of berths for 10000 ton-class or larger ships has a positive impact on port handling capacity. Finally, the effect of comprehensive throughput capacity on port handling capacity is positive and significant. Guan (2009), studied the gate system congestion behaviour and developed an optimization model (a multi-server queuing model) to minimize gate system operating cost and truck waiting cost. The objectives of the thesis are to analyse the gate capacity system utilization and compare it to the congestion level, also, to provide alternatives to optimize gate operation, and investigate gate congestion mitigation alternatives port of New York/New Jersey. The outputs show that the alternatives provided an increase in capacity and reduced congestion costs (operating costs) for Marine Container Terminal (MCT) operator and truckers. Also, the optimization results provided possible solutions to mitigate gate congestion and improve gate system efficiency. Sha and Huang **(2010)**, studied the internal structure and operation mechanism of Port Operation System (POS), and proposed a generic system dynamic model (SDM) to simulate the operational process at the port (Lianyungang port in China as a case study) in order to provide a useful tool to achieve three management goals (guarantying service time, improving quality and lowering cost and increasing profit). According to the outputs, the researchers found the SDM helpful and useful to decision makers to analyze the POS in order to achieve the management goals and to support decision making for port strategy and port policies.

Sinha and Ganesan (2011), applied a simulation optimization technique (discrete-event simulation technique) to address the issues of managing container business operations with varied degree of demand priority and segmented demand. The scholars analyzed several opportunities to improve overall system performance under uncertain and complex business environments, and they analyzed the system behavior over the planning horizon and determined the optimal control parameters. The proposed simulation is used to minimize the cost and maximize the revenue. According to the simulation experiments and results, the scholars found that the simulation can be very helpful in taking various strategic decisions such as fleet size and service level agreements under diverse business environments. Furthermore, the simulation is applied to decide the optimal order/service lead time for the high priority customers to maximize profit. Tavasszy et al (2011), developed a strategic model (worldwide freight model) to forecast the yearly container flows over the world's shipping route. The proposed model is based on trade information from 437 container ports and more than 800 maritime container liner services around the world. It is used to analyze possible shifts in future container transport demand, and to understand the impact of future, uncertain developments in container flows on port throughput. The scholars applied many scenarios to evaluate the impacts of changes in the transport system, and they formulated a model (based on the costs of route) to calibrate the scenarios and policies. The proposed model consists of total cost of transhipment at port (all relevant, measurable and hidden service characteristics of ports such as handling cost, fuel costs, and congestion costs. The total cost of transportation over the links that are used by the route, and the costs due to times that are spent during transhipment at port and transportation over link were also analyzed. The scholars found that the model is able to reproduce port throughput statistics rather accurately.

Vacca (2011), focused his thesis on container terminal management and proposed models and algorithms to solve large scale optimization problems (telecommunication, transportation and logistics) and to support the decision making process. He proposed a heuristic and an exact solution algorithm to deal with a class of split delivery vehicle routing problem. Also, models (Mixed Integer Quadratic Programming MIQP and Mixed Integer Linear Programming MILP) to deal with the integrated planning of berth allocation and quay crane assignment. The results and outputs that were obtained by using the models and algorithms are promising and yield significant improvements in terms of efficiency, productivity and cost reduction. Ghanbari et al (2012), proposed a simulation model to evaluate the performance of Marshalling Yard Storage Policy in Shahid Rajaee Container Port (SRCP) in Iran. The researchers compared between two storage strategies for storing containers in the yard. The first strategy is the current storage system of containers in the yard, and the second strategy is the proposed strategy for storing the containers in a buffer area near the quay, also known as a marshalling yard. They analyzed the results by considering the loading and unloading norm as a performance indicator, and they found that the marshalling yard strategy can improve the volume of loading and unloading operations up to 7.62% in a year, and that it can increase the loading and unloading norm up by to 14% compared to the current storage strategy.

Jiangang (2012), focused on storage yard management for container transhipment terminals (single-terminal system and multi-terminal system), and developed new optimization models (based on heuristic code in C++, commercial solver CPLEX 12.1) and solution approaches to obtain an integrated berth, feeder schedule and storage template which supports the tactical planning for two terminal systems, and to enhance yard crane efficiency and storage effectiveness in the storage yard. The thesis supports storage yard allocation decisions and other interdependent decisions for terminal operators with various planning areas (single yard block, single and multi-terminal systems). It also considered various planning levels (strategic design, tactical planning and operational scheduling). Xinjia (2012), applied two container storage strategies (partial space-sharing and flexible space-sharing) to improve the space utilization in storage yard of a transhipment hub port. In the first strategy, the port of storage space is allowed to be shared between two adjacent storage locations, and in the second strategy, the container space can be shared by two different vessels as long as their containers do not occupy the space at the same time. Two approaches are proposed to deal with the first strategy to decide the size of sharing and non-sharing space in each storage location. The second strategy is formulated as a mixed integer program (MIP) and then the researcher developed a search algorithm which combines MIP and heuristics to find the solution. The numerical experiments show that the performance under the second strategy is better than first strategy when the space is light. Also, the short-term planning methods perform better than the long-term planning under both storage strategies when the space is sufficient.

Hakam and Solvang (2013), summarized the articles and papers that are focused on the sustainability of seaports logistical operations and supply chain activities. They classified the relevant articles into groups according to the publication per time period in terms of port performance, port sustainability, port supply chain management, port multimodal or intermodal, port cluster and Environmental Management System (EMS). The aim of the paper is to identify the main research areas, the main authors and paper sources in order to make sense of data and describe existing research efforts and identify future trends. Nieuwkoop et al (2013), proposed a mathematical model to determine the optimal vehicle configuration for an Inter Terminal Transport (ITT) system at Massvlakte areas in the port of Rotterdam. They applied various scenarios with different terminal layouts varying from each other in terms of total annual TEU throughput, demand fluctuations, vehicles (type, number and loading rate). The purpose of the research was to provide a decision support mechanism in planning layout configuration and vehicle requirements of an (ITT) system and to build a reliable tool able to determine an optimal vehicle configuration matching a determined performance level for an (ITT) system.

Tierney et al (2014), studied the Liner Shipping Fleet Repositioning Problem (LSFRP) with cargo flows, and proposed a novel mathematical model (based on the fixed costs for inflexible arcs and port fees, the cost of sailing on flexible arcs, and the profit from delivering cargo and equipment) and a Simulated Annealing (SA) algorithm to solve the problem. The objective was to maximize the container carrying profit (the profit from delivering cargo and equipment). They compared between the performance and the outputs that were obtained by using the proposed approach. They found that the proposed approach is capable and able to find the optimal solution, or that it is very close to the optimal solution, and quickly finds solutions; for instance, that they are too large for CPLEX to solve. Huang et al (2014), reviewed and summarised the literature that are focused on the resource allocation problems in seaport container terminals. They studied the problems that are associated with port operations such as berth allocation, quay crane scheduling, vehicle dispatching, storage yard allocation, and human resources management. They also classified the relevant researches and papers into three groups according to prospects for the development in the theory and application: optimization for single resources allocation, integrated optimization for multiple resources, and online optimization for resource allocation. The aim of the study is to provide a support in suggesting recent research trends on port operations. Ndiaye et al (2014), proposed a Hybrid Ant Colony algorithm and Genetic Algorithm (HAC/GA) to address the container storage problem at a seaport container terminal and to determine the optimal storage plan. The purpose of HAC/GA is to minimize the total distance travelled by straddle carriers between the quays and the container yard. They compared between the results that were obtained by using HAC/GA and the results that were arrived at by CPLEX. According to the outputs, they found that the algorithms are very suitable to solving the problem and that they provide very good and more efficient results. Akyvz and Lee (2014), applied a Column Generation (CG) algorithm to deal with Service Level Assignment and the Container Routing Problem (SACRP). The proposed algorithm is used to optimize the ships fleet deployment and sailing speed over cyclic routes (case study of OOCL's ship fleet with ships capacities 4000, 5000, 8000, 1000 and 12000 TEUs, covering 33 different ports in Europe, Asia and Australia across 7 service routes), as well as to minimize the total costs including the bunker cost at each voyage, loading/unloading cost, and transhipment cost. According to the computational experiments, they found that the Column Generation algorithm yields heuristic solutions very fast, and that it provides a better solution than the one without in terms of ship capacity reduction. Lee (2014), focused on Empty Container Logistic optimization, and proposed a 3-stage framework: the first stage studies the forecasting of laden shipment demand, the second stage optimizes the carrier's fleet size by using an inventory model, and the third stage is used to optimize repositioning costs as a Decision Support System to assist the empty container logistics team in daily operations. The proposed framework is used as standardized systematic processes for ocean carriers to handle empty container logistics across different locations (ports and depots). The outputs and results show that the proposed framework offers opportunities for carriers to reduce their fleet size and minimize the total cost due to empty container logistics. M. RAMPHUL et al (2017), studied the impact of foldable/collapsible containers as a technological innovation on empty container management in Port Louis in Mauritius. The paper focuses on the usage of foldable containers (as alternative) comparing with the standard containers. To enhance the cost effectiveness in the logistical chain and to improve the efficiency of space allocation and storage area in the ports. The scholars found that there are many advantages of using foldable/collapsible containers instead of standard containers., These advantages are: the foldable/collapsible empty containers can be folded/collapsed as five or six empty containers (compared with one standard empty container), reduce the movements of containers or the inland transfer within the port areas, reduce on/off handling of empty containers in the repositioning process, reduce the repositioning storage and capital costs for port. Finally, they reduce the congestion and unproductive movements of containers on the board.

Chapter 3

LOT SIZING MODELS OF ECM

Section One: Economic Return Quantity Model for a Multi-Type Empty Container Management System with Storage Constraint and Shared Cost of Shipping.

A modified version of this section has been submitted to the American Journal of Mathematical and management Science

3.1.1 INTRODUCTION

Empty Container Management (EMC) is a phenomenon that arises as a result of the imbalance between the container demands for the imported and exported goods in a country. In instances where a port tends to import more than it exports, there is usually an oversupply of containers, whereas when it exports more than it imports, there is usually a shortage of containers. All economies tend to have some mix of these two types of ports. There is, therefore, usually the need to move the containers from some areas of surplus to the areas of deficit. This area of surplus could be another port, or some inland consolidation centre like a container depot. Moving such containers around is usually cost intensive and needs to be managed effectively. Other issues could complicate this problem further. One such issue is container attrition. This is because containers are usually lost or damaged or even converted to some other uses during their life cycle such that some of the containers that have been moved to the hinterland may not return to the port or may return in an un-useable state. In addition to this, the shortage may also be dynamic in nature. This means even if there is a relative balance between the import and export demand rate for containers, there could be the challenge of alignment between the time of need for both such that the containers coming from import might not be available to be used for export at the appropriate time. All these imbalances usually necessitate the need to procure new containers to augment those in circulation while also repositioning empty containers in use.

Another complicating issue is guaranteeing the appropriate mix of containers available at the point of use. There are different types of containers: twenty-foot equivalent units (TEU) forty-foot equivalent units (FEU), specialised container types like refrigerated containers, and all possible combinations of these categories. This means it is not sufficient to have enough containers that could meet the aggregate demand, but to also have the appropriate mix to meet the demand for each type of container in appropriate quantities. Empty Container (EC) repositioning is about moving containers around from areas of over-supply to areas of under supply. Such movement may include moving containers from the port to some locations in the hinterland and moving them back there to the port such that the container is being used and re-used. In addition, there may be the need to move the container to some temporary storage points such as container deports or similar maintenance yards. The use of ports may be as a result of the need to consolidate containers for shipment to places of need, but it might also be due to some space constraint at the port, since space in the port is not infinite. This is also important because many ports might have been built long ago, and with economy growth over time, the port has not been expanded at a commensurate rate, and there might have been little or no space available for port expansion since most port areas are usually highly developed, densely populated and near natural expansion barriers- the sea - hence, there is usually scarcity of land for continuous port expansion. This scenario usually creates challenges for the shipping of containers in an economic manner between the usage points and temporary rest points. The port, hence, charges some money for each day a container spends in the port. The charges may also depend on the type of container stored. The mode and contract of shipment of containers are other areas that might make container management and repositioning more difficult. While many private users may simply use trucks to move containers on the road because of the relatively low number of usage and accessibility factors of trucks, it is usually not cheap to use them for mass movement of repositioning containers. Most carriers (especially common carriers) aim for volume when they ship materials, and as a result, tend to give price breaks or use other discounting techniques that can induce volume shipments. As a result, it pays to consolidate container shipment and move *en masse* in order to reduce the cost of shipment. For instance, a rail carrier may provide a train head to transport a given number of containers at a fixed cost. Some additional marginal cost may then be charged for each of the containers moved by the head depending on the type of containers moved. This also implies that when the different container types are shipped individually, the cost of shipment is paid for each type separately as opposed to if they could be consolidated and shipped together. If the number of containers attached to the railhead is less, it does not necessarily reduce the cost of operating the freight train. As a result, the carrier sets a fixed (or at least a minimum) number of containers per shipment. This means the port management authority can decide to fully utilise this shipment quota or decide to carry less and yet pay the full cost. The quantity and mix problem discussed are important for both the repositioned and newly procured containers.

All the issues raised may have significant impact on the annual cost of ports operation. There is, hence, a need to determine the optimum number of containers to reposition and/or purchase per cycle as well as the length of the cycle and the mix of each type of container in each repositioning or replenishment cycle. This is a lot-sizing problem with integrated reverse logistics in which there are multiple types of containers, and in which there are constraints on the storage capacity with economy of scale on the shipping. While there have been models of reverse logistics presented since Schrady (1967), the complexities of the container repositioning as discussed seems not to be well captured, and hence the need for this work.

The sections of this paper are structured as follows. Section 1 is the introduction and background to the problem, and this has just been presented. Section 2 is a presentation of the literature background on Empty Container Management problem, and a brief touch on return logistics lot-sizing problem. Section 3 presents the model formulation, stating the assumptions and Notation and then derivation of the optimal return lot-sizing quantity as well as solution algorithm, especially in cases of infeasibility of solution obtained. Section 4 presents special cases of the model and sensitivity analysis of the solution to some key model parameters. Section 5 is a numerical example, while section 6 is the conclusion and recommendation.

3.1.2 BRIEF LITERATURE REVIEW RECAP

Empty container repositioning seeks to move containers to where they are needed, and a number of authors have written about this problem. Feng and Chang (2008) addressed empty containers repositioning problems for intra-Asia liner shipping as a two-stage problem using a case study. The first stage identifies and estimates the empty container stock at each port while the second stage models empty container reposition planning with shipping service network as the Transportation Problem. They proposed the models to estimate the optimal quantity of empty containers stock at the ports and to minimize the total cost of repositioning empty containers between supply ports and demand ports. The results show evidence of their model's usefulness to minimize the cost of empty container repositioning and to provide evidence to adjust strategy of restructuring the shipping service network. Li and Han (2009) used a stochastic programming model to optimize the repositioning of empty containers under uncertain demand and supply. The proposed model seeks to minimize the total costs including transportation cost (empty containers transportation, loading, unloading), renting cost and storage cost of empty containers. Their results indicated that changes in the expected total cost might be significantly affected by many factors like changing routes, unit cost of renting, the number of empty containers in the ports and the demand. Dong and Song (2009) considered a container fleet sizing and empty repositioning problem in multi-vessel, multi-port and multi-voyage shipping systems with dynamic, uncertain and imbalanced customer demands. They developed a mathematical programming model using the Genetic Algorithm and Evolutionary Strategy combined with an adjustment mechanism, to minimize the total cost which includes transportation costs, repositioning costs, inventory-holding costs, lifting-on/lifting-off costs, and the lost demand penalty costs. Results indicated that fleet sizing is closely related to empty container repositioning cost as the optimal fleet sizes vary when different repositioning policies are used. Lee et al (2011) developed an inventory-based control policy to reposition empty container in a multi-port system with uncertain customer demand. They formulated a model to optimize the movement of ECs from surplus ports to deficit ports and to minimize the expected total cost, which includes transportation cost, holding cost of unused EC, and the cost of leasing ECs. They proposed two approaches to solve the problem under balanced and unbalanced scenarios. The first approach is a Non-Linear Programming (NLP) approach and the second approach is Infinitesimal Perturbing Analysis (IPA-based gradient technique). Numerical results show that the solution potential of both approaches.

Song and Dong (2011) addressed the empty container repositioning problem between two sets of ports (export ports and import ports), and used two polices, the flexible destination port (FDP) policy and the determined destination port (DDP) policy, to evaluate the effectiveness of empty containers management for three major shipping routes (Europe-Asia, Trans-Pacific, and Trans-Atlantic). They formulated a model to minimize the total costs including holding costs, lost-sale penalty costs, lift-on costs, lift-off costs and laden/empty containers transportation costs. Results from the numerical experiments indicated that DDP was slightly better than FDP within 2% in scenarios where the trades are fairly balanced across the longest ocean leg while FDP outperformed DDP significantly (up to 22%) for scenarios with imbalanced trade patterns. Furthermore, the system considered a middle range of fleet sizes and in particular, FDP achieved the largest cost reduction in comparison with DDP in terms of the optimal fleet sizes. Quang-Vinh Dang et al (2012) used a simulation model and a Genetic Algorithm based heuristics to optimize the positioning of empty containers in the inland multi-depot system to minimize the expected total costs including inland positioning and re-positioning cost, overseas cost, holding cost and leasing cost. They applied four heuristics of inland positioning to find the best strategy for empty container replenishment. Numerical results show that an upward trend in EC units has more significant impact on the inland positioning cost increases and the total cost than the overseas positioning cost and holding cost. Moon et al (2012) developed three mathematical models to deal with the empty container repositioning problem for foldable and standard containers among multiple ports and across multiple periods. The proposed models minimize the total cost, including repositioning cost, inventory storage cost, purchasing cost and folding/unfolding costs. They applied heuristics to formulate the models and found that the use of foldable containers can be an effective strategy to reduce the repositioning and inventory costs, as well as to save more than 75% of storage space. As promising as that finding was, experiments showed that the high cost of foldable containers, due to high production and maintenance costs, and their vulnerability to damage, prevents them from being widely used.

While there seems to be a dearth of literature specifically on the management of return container lot sizing, there is ample work reported on general return management. The classic seems to be Schrady's (1967) work from which many others have evolved. Dobos (2002) formulated and solved the Economic Order Quantities (EOQ) inventory model for reparable items based on Schrady's model by changing the one procurement batch and two or more repair batches assumption. He reported that the modified model could obtain a more effective solution for higher return rate and the inventory holding strategy and policy give better results compared to that of Schrady. Dobos (2011) further re-examined the existing models of reverse logistics inventory systems and proposed an EOQ model to deal with products recovery management. He investigated the efficiency and the ability of the model to determine the optimal decision variables (number of batches and batch sizes of manufacturing and re manufacturing components). The model seeks to minimize the relevant costs for manufacturing and remanufacturing (setup cost, holding cost, linear production and manufacturing costs, linear disposal cost and holding cost for non-serviceable items). It is used in the managerial praxis in cases of relatively constant demand and return rates. Thoroe et al (2009) proposed an RFID (Radio-Frequency Identification) technology as a possible solution to manage the returnable containers. They used a deterministic inventory model (based on setup and holding costs) to analyze the impact of implementation of a RFID on container tracking systems. They considered the costs of returnable containers and benefits, inventory control policy, optimum refurbishment lot size, profitability and alternatives (replenishment of tagged containers and supplementary tagging of returned containers) in their analysis. They found that the proposed RFID technology could increase container return rate in reverse logistics systems and lead to more profitability. They provide one of the first insights into theoretical effects of the application of RFID in container management.

Kim and Glock (2014) also developed a mathematical model for a closed-loop supply chain with reusable containers under a stochastic return rate. The total cost of operating system consists of fixed and variable costs (inspecting, repairing and ordering containers) and holding cost of containers in inventory. The purpose is to study the impact of Radio-Frequency Identification RFID-tagged containers on the supply chain, and to propose a method for managing and evaluating the use of RFID in the tracking of reusable containers. Numerical analyses indicate that the usefulness of the model as a decision support tool. Fan et al (2018) established two inventory models for returnable containers management in supply chain system for a single-vendor and multi-buyer. They evaluated the two models using two cases: one where buyers can invest to reduce the loss fraction of returnable containers and the other where buyers do not invest. They found that both the replenishment frequency as well as the optimal total cost of the investment case was lower than that without investment. Fan et al (2019) also presented a case study of a single manufacturer and a single retailer close-loop supply chain of the Returnable Transport Items (RTI) and developed two inventory models to minimize the total cost of the system. They proposed two inventory models based on two scenarios of whether the retailer invests in reducing RTI loss or not. They sought to optimize the total cost of the RTI supply chain system that consists of fixed cost and variable cost of inspecting and ordering RTI, the holding cost of RTI and investment cost of the retailer to reduce RTI loss. Results from numerical examples show that the supply chain system will be generally more efficient if the retailer invests to reduce RTI loss and the total cost of supply chain system will be reduced. Furthermore, when the manufacturer provides side payment proportion of compensation to the retailer, the system can be better coordinated and the optimal total cost of both the manufacturer and the retailer reduced. Cobb (2016) focused on Close-Loop Supply Chain (CLSC) and proposed an inventory control model to determine the total cost of returnable transport items. It consists of fixed and variable costs (inspection and repairing containers), purchasing cost, and holding cost. Results show that the optimal solution occurs when the inspection and repair runs begin simultaneously. Suuhal and Mangal (2017) also formulated an EOQ model based on a case study in an Indian company. They compared the results obtained from their proposed model to those obtained from the current inventory model of the company and found that the proposed model achieved better results in reduction of total annual cost consisting of ordering cost, carrying cost, number of orders, order size and average inventory. Shah et al (2018) proposed an Economic Production Quantity (EPQ) model and considered three scenarios dealing with the return and rework of defective products during imperfect production process and after the sale of products (defective products may be either reworked, refunded or scrapped). They formulated two EPQ models (based on price-sensitive stock-dependent demand) to maximize the profit.

These papers indicate that there can be quantifiable value-add in the general management of empty container return and repositioning as well as in improving the container rate of return. Moreover, there is still opportunity for lot sizing in container management.

3.1.3 MODEL FORMULATION

It should be noted that the shape of the diagrams adopted is different from Schrady's because unlike his model where the NRFI items build up gradually with repair and are withdrawn in batches, the returned containers are transported in batches and continuously withdrawn. In addition, while Schrady's model considers a substitution policy, this study considers such unnecessary. This is because this policy is favoured given that the costs of the Ready for Issue (RFI) significantly outweigh those of the returned Non- Ready for Issue (NRFI) items. The consequence is that the cycle of RFI is followed by that of NRFI because it is better to first issue the expensive RFI stock. For container management and administration, this is not necessary because all the containers are considered good enough when functional, and moreover, it makes no difference whether such is new or used when being withdrawn. The implication of this assumption is that both the new stock and the returned stock can be consumed simultaneously since there is not necessarily any gain by issuing a particular type ahead of the other. For the purpose of generalisation, however, the study derived the model with different holding costs for new and return items and then progressed to a particular case where these are the same. Consider a container management system of a seaport where there are different types of containers used in the port. Each of these types of containers is moved from the port to the hinterland (or another port). After use, the container is to be returned to the port to be re-used as a result of imbalance between inflow and outflow of these containers. Not all the containers sent to the hinterland are returned to the port for re-use because some of the containers become unusable (or lost) and need to be replaced. The lost (or damaged) containers are replaced through procurement.

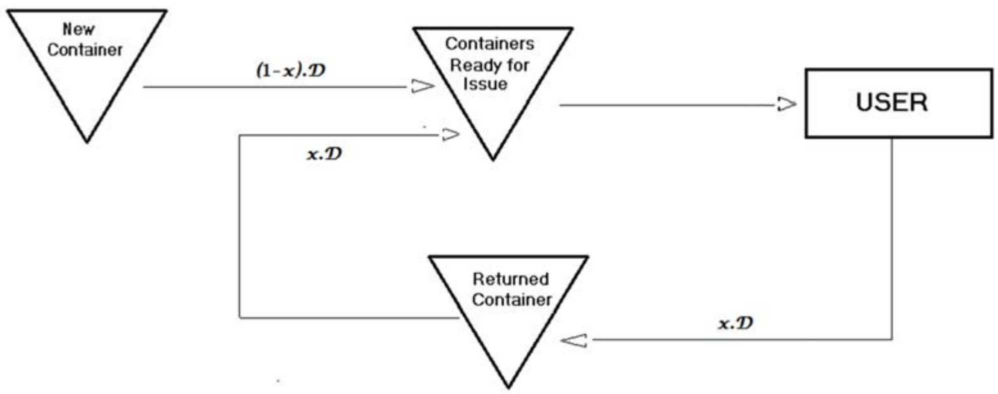


Figure 3.1.1: Schematics of a container return system

The ports authority has an arrangement to ship the containers (new or return) to the port in fixed batches. There is a fixed cost of shipping containers to the port. This cost may be fixed for a batch but could have marginal increase for shipping units of other types together (consider a case of a train head pulling many containers that could also be of different types). The port management can choose to ship different types of containers (return or procured) together or ship each type individually. If they ship in a type of container, there is a fixed cost for such shipment. If they ship different types together, there is a base cost, and then marginal top up for each of the types of containers shipped together. This leads to possible economy of scale and is partly a motivation from the carrier to procure high quantity of shipment. There is also a restriction on the space available for storage of containers at the port. This space must be judiciously allocated among all the different types of containers to ensure that not only are the right aggregate quantities available, but that the right varieties are also available as and when needed.

In this study, a lot sizing model is presented to determine the optimum number of containers to ship back to the port for re-use, as well as the optimum number of new containers to order from vendor as a replacement. In addition, the optimum cycle time for collection and purchase as well as the integrated number of return and procurement cycles for such replenishments is determined. In developing this model, the following assumptions were made:

- There are multiple types of containers that can be shipped together through a common means of conveyance
- The holding cost of the new stock may be different from that of recycled stock (this assumption would be relaxed)
- Demand rate for container is fixed for each container type
- The return rate of each container type is fixed and known
- There is a fixed cost of shipping a container batch, replenishment or return, and there is a possibility of saving some shipping cost by bringing in the different types of containers

together as opposed to bringing each individually. There is also some marginal cost for each different type of container brought together on top of the basic cost of shipping.

- The replenishment cycle for the new container and the recycled container can be synchronised such that the ratio of the consumption of the new stock to the recycled stock is fixed, and is governed by the rate of attrition of the container in use.
- The rate of container attrition is much smaller than the rate of return, and so, it can be assumed that it should be reasonable to have the replenishment cycle being at least as large as the return cycle due to higher usage rate (inference from the classic EOQ model where the optimum lot size is proportional to the demand, all other things being equal)
- The replenishment cycle time can be any integer multiple of return cycle time.

3.1.3.1 Notation

Definitions for the following notations used for the derivation of the model are given below:

We define the following Notation for the derivation of the model:

j is an index for types of containers managed at the port, $j = 1,2, \dots n$

r is a subscript denoting returned containers

p is a subscript denoting purchased containers

D_j is the annual demand rate for container type j

x_j is the proportion of container type j returned to the port from points of use

K_{rj} is the fixed cost of returning a batch of useful container type j from point of use

K_{pj} is the fixed cost of ordering a new batch of container type j to make up for lost or damaged containers

K'_{rj} is the marginal increase in fixed cost of returning a batch of useful container type j from point of use to the port

K'_{pj} is the marginal increase in fixed cost of ordering a new batch of container type j to make up for lost or damaged containers

K_r^f is the fixed portion of the cost of returning a batch of useful container type j from point of use to the port whether single or multiple types of containers are involved

K_p^f is the fixed portion of the cost of ordering a new batch of container type j to make up for lost or damaged containers whether single or multiple types are involved

h_{rj} is the holding cost per unit per year of keeping a returned container type j (this assumption would later be modified during modelling)

h_{pj} is the holding cost per unit per year of keeping a newly purchased container type j (this assumption would later be modified during modelling)

T is a common replenishment cycle time for all containers

T^* is the optimum common replenishment cycle time for all containers

m_j is the number of container return cycles per one cycle of procurement for a container type j (this assumption would later be modified during modelling)

C is the capacity of storage of all types of containers in the port terminal

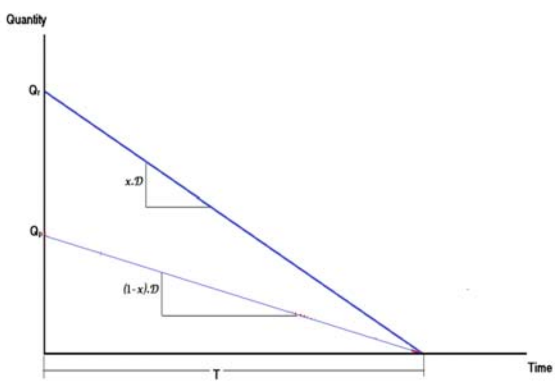
s_j the storage space requirement for a unit of container type j

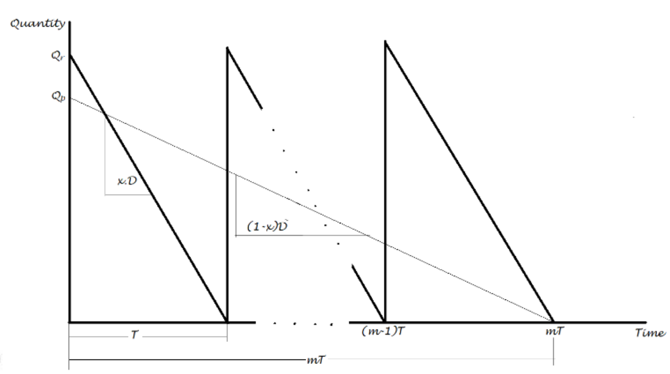
λ is the Lagrange multiplier for a constraint function

Q^*_{rj} is the optimum return quantity for container type j

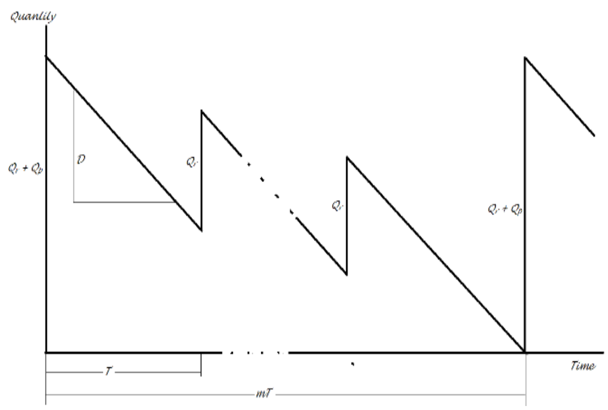
Q^*_{pj} is the optimum replenishment order quantity for container type j

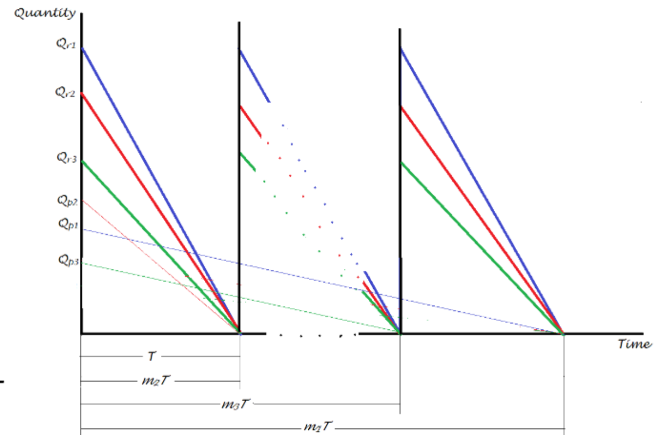
Figure 3.1.2A is the quantity-time graph of the inventory level of containers in a single container inventory management system. The thick line is the graph of the returned containers and the thin line is that of the new container. The norm, as stated in the assumption, is that the return rate of the container is usually close to 1, but this is without any loss of generality for the model development. Also in this example, the consumption of the returned and new container stock ends at the same time given by the cycle time, T, at which time the replenishment is made. This means that m (number of return cycles per replenishment cycle) in this case is 1, but the model would be derived assuming there may be more than one return cycle per replenishment cycle. In general, it would be assumed initially that each container may have a separate number of return cycle, m_j, per single procurement cycle during derivation, but this would be modified to allow all to have a common cycle, m, per return so we can take advantage of economy of scale of purchase in ordering cost.





Figures 3.1.2A and 3.1.2B: Quantity-time graphs of a single container return system





Figures 3.1.3A: Aggregate inventory behaviour for a single return system and 3.1.3B: An integrated cycle multi-item quantity time graph for containers

Figure 3.1.2B shows a more general case in which there are some m return cycles in a single replenishment cycle. One of the objectives of the model to be derived is to seek out the optimum (or at least good) number of returns per replenishment to minimise the total cost of managing the system, and Figure 3.1.2A becomes only an instant of the generalised model in which m is 1.

Figure 3.1.3A shows the aggregate inventory level pattern for a single item with consumption being made simultaneously from both the returned and procured stocks. Figure 3.1.3B is a generalisation of the model of the single type container system to a multi-item model in which there are 3 types of container ($i.e. n = 3$) without any loss of generalisation. In this 3 container type's case, the different colours represent the different container types. The relative levels of container return and replenishment procurement for each of the containers have been arbitrarily chosen.

3.1.3.2 Model presentation

To derive the model, we start by considering the single item case of Figure 2A for the return and replenishment containers. In this diagram, the thick line denotes the graph of the returned containers while the thin line is used to denote that of the new containers purchased to augment the returned containers. We then progress to derive the cost function for the system with n different types of containers in which there is a constraint on the storage space available for all the containers. In deriving the model, a general case in which all items are ordered separately, return cycles per replenishment cycle are different and the holding costs for new and recycled containers are different is first presented, from which particular cases of shared ordering cost and constant holding cost rates are then derived.

Consider a general container management system in which there is a particular container type j whose optimum total inventory management cost (return and procurement) is to be derived. The total cost of this system consists of the costs of managing the returned containers and those of managing the procurement of the new containers.

The cycle cost of managing return containers (excluding purchase cost) can be represented as

$$\frac{x_j D_j K_{rj}}{Q_{rj}} + \frac{Q_{rj} h_{rj}}{2} \tag{1}$$

The cycle cost or managing new containers (excluding purchase cost) is

$$\frac{(1 - x_j) D_j K_{pj}}{Q_{pj}} + \frac{Q_{pj} h_{pj}}{2} \tag{2}$$

In order to be able to integrate the integrated cycle times for the return and procurement sub-systems, we decide to work on cycle times. We would then retrieve the equivalent optimal lot sizes (quantities) for the return system and procurement system from these optimum cycle times since these two are jointly determined. The quantities in the cost functions for the return, the procurement and the total system cost are, therefore, re-written in terms of their cycle time as follows

$$Q_{rj} = x_j D_j T_j \tag{3}$$

$$Q_{pj} = m_j (1 - x_j) D_j T_j \tag{4}$$

$$Q_j = D_j [x_j + m_j (1 - x)] T_j \tag{5}$$

Substituting equations 3 and 4 into 1 and 2 respectively, we have

$$\frac{K_{rj}}{T_j} + \frac{T_j x_j D_j h_{rj}}{2} \tag{6}$$

$$\frac{K_{pj}}{m_j T_j} + \frac{m_j T_j (1 - x_j) D_j h_{pj}}{2} \tag{7}$$

The total cost of managing n-type container system is therefore

$$\sum_{j=1}^{n} \left[\frac{K_{rj}}{T_j} + \frac{T_j x_j D_j h_{rj}}{2} + \frac{K_{pj}}{m_j T_j} + \frac{m_j T_j (1 - x_j) D_j h_{pj}}{2} \right] \tag{8}$$

Considering that there is possible space limitation and it may be impossible to store all types of containers if the combined return quantity and order quantity is too large, the space constraint for all containers managed can be written as

$$\sum_{j=1}^{n} Q_j s_j \leq C \tag{9}$$

Substituting 5 into 9, we have 10

$$\sum_{j=1}^{n} T_j D_j s_j \left[x_j + m_j (1 - x_j)\right] \leq C \tag{10}$$

The problem becomes minimising equation 8 subject to the constraint in equation 10. To solve this problem, we observe that it is either equation 10 is binding or not. If equation 10 is not binding, then we may simply drop it and solve equation 8. This is illustrated in Figure 44 showing the total cost function for a single container case, i.e. $n = 1$, with space constraint. If the constraint is binding, then the capacity limit, C, is to the left of the optimum quantity, Q_j, as shown, rendering the optimum quantity, Q_j, infeasible and hence, making C the best quantity to select since the cost function is convex in Q.

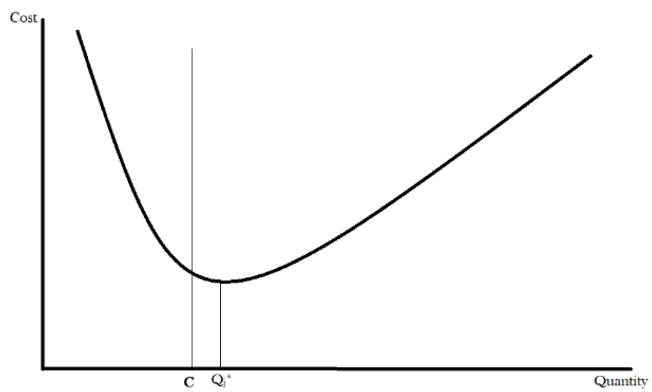


Figure 3.1.4: Behaviour of optimal cost under storage capacity constraint

In a multi-type container system where the constraint is not binding, we partially differentiate with respect to T_j to obtain the optimal cycle time, T_j, for each item, j, as

$$T_j = \sqrt{\frac{2\sum_{j=1}^{n}(K_{rj} + \frac{K_{pj}}{m_j})}{\sum_{j=1}^{n} D_j (x_j h_{rj} + m_j (1 - x_j) h_{pj})}} \tag{11}$$

If the returned container is considered as good as new and their holding cost is the same, then equation 11 becomes

$$T_j = \sqrt{\frac{2\sum_{j=1}^{n}(K_{rj} + \frac{K_{pj}}{m_j})}{\sum_{j=1}^{n} D_j h_j [x_j + m_j (1 - x_j)]}} \tag{12}$$

We may then obtain the optimum lot size of containers to return or purchase from equations 3 and 4 respectively.

Equation 11 (or 12 as appropriate) yields n equations. Since each m_j is also an unknown, each of these n equations of T_j equations can be solved iteratively for the optimum m_j value for each j.

In a case where the constraint is binding, we may transform the inequality in equation 10 into an equation using the Lagrange multiplier, λ, and rewrite equations 8 with 10 as the Lagrangean function

Minimise

$$\sum_{j=1}^{n} \frac{1}{T_j}\left(K_{rj} + \frac{K_{pj}}{m_j}\right) + \left[\sum_{j=1}^{n} \frac{D_j T_j}{2}\left[x_j\left(h_{rj} + 2\lambda s_j\right) + m_j(1 - x_j)(h_{pj} + 2\lambda s_j)\right]\right] - \lambda C \quad (13)$$

Partially optimising 13 with respect to T_j for each j yields

$$T_j = \sqrt{\frac{2\sum_{j=1}^{n}\left(K_{rj} + \frac{K_{pj}}{m_j}\right)}{\sum_{j=1}^{n} D_j\left[x_j\left(h_{rj} + 2\lambda s_j\right) + m_j(1 - x_j)(h_{pj} + 2\lambda s_j)\right]}} \quad (14)$$

Again, if the returned container is considered as good as new and their holding cost taken as the same, equation 14 simplifies to

$$T_j = \sqrt{\frac{2\sum_{j=1}^{n}\left(K_{rj} + \frac{K_{pj}}{m_j}\right)}{\sum_{j=1}^{n} D_j\left[\left(h_j + 2\lambda s_j\right)\left[x_j + m_j(1 - x_j)\right]\right]}} \quad (15)$$

Ordering/Collection cost economy of scale consideration

If there is economy of scale for joint return of different types of container, then we seek to have a common optimal cycle, m, for all containers such that $m_j = m \; \forall \; j$. Let us say each time an order is placed, there is a fixed portion of ordering cost to which some marginal cost of order is incurred for each container type collected (or purchased). There will be cost savings because of shared fixed order cost when multiple containers are moved together (return or purchase cycle). We can write the ordering costs of return and purchase in the form

$$K_{rj} = K_r^f + K'_{rj} \quad (16)$$

And

$$K_{pj} = K_p^f + K'_{pj} \quad (17)$$

If each of the items are returned and purchased independently, the total ordering cost per cycle for all items would be

$$\sum_{1}^{n}\left(K_{rj} + \frac{K_{pj}}{m}\right) = n\left(K_r^f + K_p^f\right) + \sum_{j=1}^{n}\left(K'_{rj} + K'_{pj}\right) \quad (18)$$

If we take advantage of the economy of joint return and purchase, then $n = 1$ for the fixed ordering cost portion and equation 18 becomes

$$\sum_{1}^{n}(K_{rj} + \frac{K_{pj}}{m}) = (K_r^f + K_p^f) + \sum_{j=1}^{n}(K'_{rj} + K'_{pj}) \tag{19}$$

It can be seen that equation 19 would always be less than 18. We would, however, need to check that this saving is not outweighed by the cost of storing the containers, especially because this can be aggravated by the effect of constraint on storage. This is because while the maximum inventory level (I_{max}) of individually collected and procured container management system is always much less than $\sum_{j=1}^{n}(Q_{rj} + Q_{pj})$ if return and procurement are judiciously spaced, and the I_{max} value would gravitate towards a little more than half this sum as the number of items increases, for the system where the cycles are integrated, I_{max} is this entire sum. This makes it quite easy to sub-optimise consequent to cost of holding inventory as the constraint becomes more binding. This means the savings in joint collection and purchase needs to be weighed against this possible additional cost of holding stock.

If the cycle is integrated for collection and procurement, it looks like Figure 3.1.5.

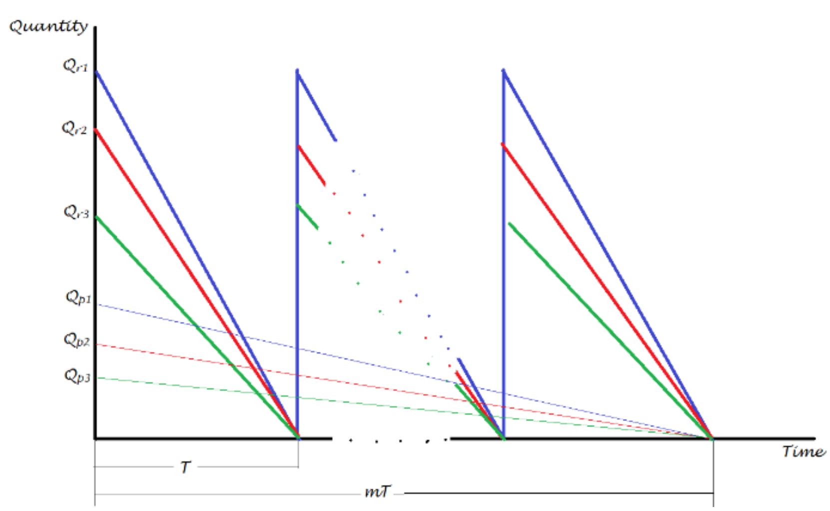


Figure 3.1.5: Lot size diagram for integrated m-collection per single procurement for all items

From equation 11, the optimal common cycle time (common h) becomes

$$T_j = \sqrt{\frac{2[(K_r^f + K_p^f) + \sum_{j=1}^{n}(K'_{rj} + K'_{pj})]}{\sum_{j=1}^{n} D_j h_j [x_j + m_j(1 - x_j)]}} \tag{20}$$

If the constraint is also binding with the economy of scale present, since equation 10 also holds true, and now becomes a hard equality at this point, we may make T the subject as

$$T = \frac{C}{\sum D_j s_j \left[x_j + m_j(1 - x_j)\right]} \tag{21}$$

Solving equation 21 together with 14 yields equations to calculate the value of λ

$$\frac{2}{C^2}\sum_{1}^{n}\left(K_{rj} + \frac{K_{pj}}{m_j}\right) = \frac{\sum_{j=1}^{n} D_j \left[x_j h_{rj} + m_j(1 - x_j)h_{pj} + 2\lambda s_j(x_j + m_j(1 - x_j))\right]}{(\sum D_j s_j \left[x_j + m_j(1 - x_j)\right])^2} \tag{22}$$

When the holding cost is identical, it becomes

$$\frac{2}{C^2}\sum_{1}^{n}\left(K_{rj} + \frac{K_{pj}}{m_j}\right) = \frac{\sum_{j=1}^{n} D_j \left[(h_j + 2\lambda s_j)\left(x_j + m_j(1 - x_j)\right)\right]}{\left(\sum D_j s_j \left[x_j + m_j(1 - x_j)\right]\right)^2} \tag{23}$$

It can be seen in equations 22 and 23 that we cannot factorise λ completely, hence, they have to be solved iteratively for λ. We may also use the optimal value(s) of m (m_j's) obtained from solving the unconstrained problem to find the appropriate value of the λ.

Proof of convexity

To check that equations 11 and 14 actually give the minimum, it suffices to find the second derivative of equation 8 (or 13) with respect to T (or T_j) and confirm that they are positive (semi) definite, which give

$$\frac{2}{T^3 \sum\left(K_{rj} + \frac{K_{pj}}{m}\right)} \tag{16}$$

This function is positive definite since all the input parameters are non-negative and non-zero, and hence the equation 11 and 14 (and their modifications) are minima for the cost functions in 8 and 13 respectively.

3.1.4 SOLUTION PROCEDURE AND ALGORITHM

To determine what the best cost would be, it is pertinent to answer two questions. The first is if there is savings as a result of joint ordering and/or collection of containers. The second is if the capacity constraint is violated or not when the optimal quantities are determined from the optimal cycle times estimated. The process of determining the optimal cost by answering these two questions has been used to formulate an algorithm is presented together with the solution procedure flow chart.

3.1.4.1 Solution algorithm

1. Establish if there is economy of scale in ordering cost in order to choose the path to adopt for the solution. If there is opportunity for saving due to joint procurement ordering cost, follow paths a and b (the left of the flow chart (else, follow path c (the right).
2. Using equation 11 (or 12) iteratively with equation 8, solve for the optimal T_j's for the individual items (containers) and compute the optimal cost
    a. Check feasibility of solution using equation 10
3. Adopting the economy of scale in the ordering cost for joint collection and purchase, using equation 20, solve for T_j's
    a. Check feasibility of solution using equation 10
4. If both are feasible, choose the minimum of steps 1 and 2
    a. Adopting the better feasible cost, using equations 3 and 4, calculate Q_j's,
        i. Stop
    b. Else, proceed to step 5
5. Adopt the m_j values obtained from steps 1 or 2. Using equation 22(or 23), solve for lambda
6. Using equation 14 (or 15), solve for T_j's if individually determined
7. For joint ordering with economy of scale, using equation 21, determine$T$. Adopt equation 19 into equation 14 (or 15) for order cost, solving iteratively with varying m values.
8. Adopting T_j's from steps 5 and 6, and adopting lambda from step 4 or 0 as appropriate, using equation 13, calculate the costs.
9. Choose the minimum of step 7
10. End

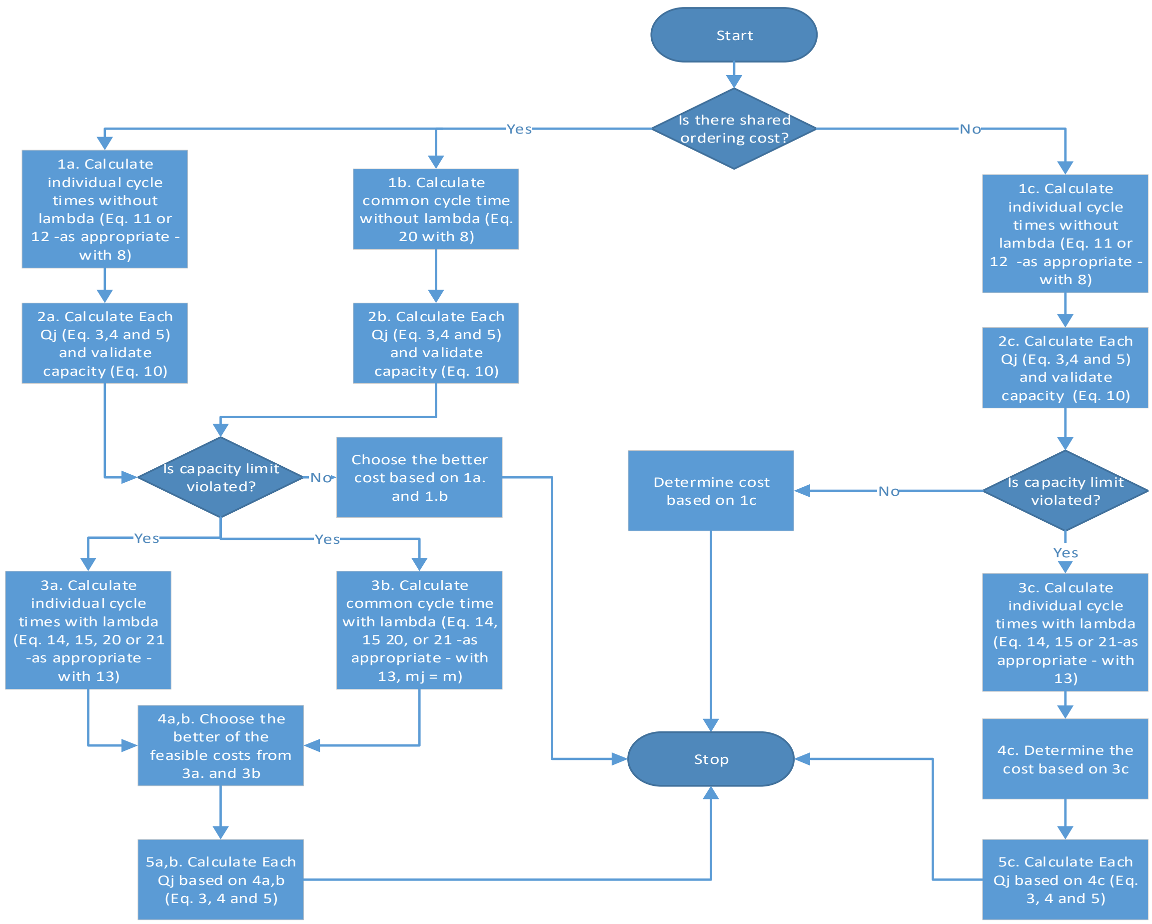


Figure 3.1.6: Solution procedure flow chart

3.1.4.2 NUMERICAL EXAMPLE AND SENSITIVITY ANALYSIS

Two numerical examples were solved using the proposed solution procedure. For the first example (hereinafter Example 1), the storage capacity constraint is not binding and it is binding in the second example (hereinafter Example 2). The following input parameters apply to both examples:

$D_1 = 15\,000\ containers$, $D_2 = 20\,000\ containers$, $D_3 = 25\,000\ containers$, $s_1 = 20\ ft^3/container$, $s_2 = 15\ ft^3/container$, $s_3 = 10\ ft^3/container$, $x_1 = 0.95$, $x_2 = 0.9$, $x_3 = 0.8$, $K_{r1} = \$10\,000$, $K_{r2} = \$8\,000$, $K_{r3} = \$7\,000$, $K_{p1} = \$15\,000$, $K_{p2} = \$12\,000$, $K_{p3} = \$10\,500$, $K_r^f = \$7\,000$, $K_p^f = \$10\,000$, $K'_{r1} = \$3\,000$, $K'_{r2} = \$2\,400$, $K'_{r3} = \$2\,100$, $K'_{p1} = \$6\,000$, $K'_{p2} = \$4\,800$, $K'_{p3} = \$4\,200$, $h_{r1} = \$40/year$, $h_{r2} = \$30/year$, $h_{r3} = \$20/year$, $h_{p1} = \$60/year$, $h_{p2} = \$50/year$, $h_{p3} = \$40/year$.

The storage capacity for all container types in Example 1 is given by $C = 200\,000\ ft^3$, and for Example 2, $C = 100\,000\ ft^3$.

Scenario	Common cycle time (or individual cycle times) ($years$)	Number of return cycles per procurement cycle	Total cost ($\$/year$)	Space requirements (ft^3)
1	$T_1 = 0.1808$ $T_2 = 0.1690$ $T_3 = 0.1750$	$m_1 = 5$ $m_2 = 3$ $m_3 = 2$	$TC_1 = 143\ 770.65$ $TC_2 = 141\ 985.92$ $TC_3 = 140\ 000.00$ $\boldsymbol{TC = 425\ 756.57}$	$C_1 = 65\ 104$ $C_2 = 60\ 851$ $C_3 = 52\ 500$ $\boldsymbol{C = 178\ 455}$
3	$\boldsymbol{T = 0.1895}$	$\boldsymbol{m = 2}$	$\boldsymbol{TC = 357\ 525.56}$	$\boldsymbol{C = 179\ 075}$

Table 3.1.1: Results from Example 1

Four possible scenarios can result depending on the presence of the binding storage capacity constraint and the economies of scales achieved by joint ordering. Tables 3.1.1 and 3.1.2 present the results from the two examples, with the results in the former table corresponding to a case where the constraint is not binding and in the latter table, the constraint is binding. These two cases are further supported by the values of the Lagrange multiplier in the examples, with the positive and negative values corresponding to cases where the constraint is binding and not binding respectively.

An important observation that can be made from the two examples is that joint ordering results in significant cost reductions when compared to equivalent individual ordering policies. In Example 1, the optimal solution is achieved when jointly ordering (for all container types) every $T = 0.1270$ years and having $m = 2$ returns cycles for every single purchase cycle. Under this optimal policy, the total cost is $\$357\ 525.56$ per year. When the storage capacity constraint is binding (as is the case in Example 2), the optimal cycle time and number of returns cycles per purchase cycle remain the same but the total cost increases to $\$362\ 151.68$ per year.

It can also be verified that the value of lambda (the Lagrange multiplier) for the first example is negative $\lambda = -0.8748$ if used in the computation of the optimal cycle time or quantity as indicated in equation 14 of 15 instead of equation 11 or 12 when the constraint is not binding. This is expected because the negative lambda indicates that the capacity was not yet exhausted, and is, therefore, not necessary given the computational effort involved as the simpler equations.

The capacity constraint in the second example justifies the use of equation 14 of 15 instead of equation 11 or 12, and it can be seen that lambda in that case is positive, $\lambda = 0.0816$. This factor is necessary to adjust the optimal cycle time (and hence optimal order quantity) for all items j in order to be within the capacity limit. It can also be seen that with an appropriate choice of lambda, the capacity just got fully utilised as indicated in Figure 3.1.4, but appropriately allocated.

Scenario	Common cycle time (or individual cycle times) $(years)$	Number of return cycles per procurement cycle	Total cost $(\$/year)$	Feasibility	Space requirements (ft^3)
1	$T_1 = 0.1808$ $T_2 = 0.1690$ $T_3 = 0.1750$	$m_1 = 5$ $m_2 = 3$ $m_3 = 2$	$TC_1 = 143\ 770.65$ $TC_2 = 141\ 985.92$ $TC_3 = 140\ 000.00$ $\boldsymbol{TC = 425\ 756.57}$	Storage capacity constraint violated (i.e. Not feasible)	$C_1 = 65\ 104$ $C_2 = 60\ 851$ $C_3 = 52\ 500$ $\boldsymbol{C = 178\ 455}$
2	$T_1 = 0.0926$ $T_2 = 0.0926$ $T_3 = 0.1112$	$m_1 = 5$ $m_2 = 3$ $m_3 = 2$	$TC_1 = 177\ 228.30$ $TC_2 = 168\ 562.77$ $TC_3 = 154\ 626.98$ $\boldsymbol{TC = 500\ 418.05}$	Feasible	$C_1 = 33\ 326$ $C_2 = 33\ 306$ $C_3 = 33\ 368$ $\boldsymbol{C = 100\ 000}$
3	$T = 0.1895$	$m = 2$	357 525.56	Storage capacity constraint violated (i.e. Not feasible)	$\boldsymbol{C = 179\ 075}$
4	$\boldsymbol{T = 0.1058}$	$\boldsymbol{m = 2}$	$\boldsymbol{TC = 383\ 364.92}$	**Feasible**	$\boldsymbol{C = 100\ 000}$

Table 3.1.2: Results from Example 2

Sensitivity Analysis

The sensitivity analysis was done for the case where the constraint is not binding. The following observations were made from the results of the sensitivity analysis as presented in Table 3.1.3 and Figures 3.1.7 and 3.1.8:

- Changes to the storage capacity for all container types (i.e. C) affected the optimal total cost and the cycle time but not the number of return cycle per procurement. For all percentage changes tested, the optimal number return cycles remained two. In general, as the storage capacity decreases the cycle time decreases as well as shown by the 50% decrease in capacity resulting in a 44% decrease in the cycle time. Increasing the capacity also had no effect on the cycle time. This is because the cycle time and quantity are jointly determined and the optimum quantity would not change until when the capacity becomes binding.
- Changes to the cost of holding returned containers (i.e. h_{rj}) were found to have significant impacts on the total cost and the cycle time but not the optimal number of returns per purchase cycle. Case in point, a 50% increase in the holding cost for the returned containers resulted in an 14% decrease in the cycle time and a 16% increase in the total costs. A similar percentage decrease resulted in an increase of 12% in the cycle time and a decrease of 20% in the total cost. Despite these sizable changes, the number of return cycles per procurement cycle remained flat at two for all percentage decreases and increases tested.
- Changes to the holding costs of purchased containers (i.e. h_{pj}) were found to have similar effects on the objective function and decision variables as changes to the holding costs of

returned container. However, the effects on the total cost and cycle time were not as severe as those caused by the holding costs of the returned containers. For example, a 50% decrease in the retuned containers' holding costs resulted in 12% decrease in the total cost while a similar change to the purchased containers' costs resulted in a decrease of 9%. This can be attributed to the assumption that the fraction of returned containers is greater than that of purchased container. This means that the effect of the returned containers on the various cost components is more sizable.

- The cost of returning a batch of useful containers (i.e. K_{rj}) did not affects the optimal solution in three of the four cases tested in the sensitivity analysis. The solution was only affected by a 50% decrease in the return cost. This change was also notable because it is the only case (among those tested in the sensitivity analysis) were an individual ordering policy resulted in lower total costs than a joint ordering policy. When this cost was separated into a fixed portion and a variable portion (i.e. K_{rj}^{f} and $K_{rj}^{'}$), the number of return cycles per procurement cycle were not affected by any of the changes but the cycle time and the total cost showed some movement, with the most notable ones being decreases of 10% to the cycle time and 7% to the total cost as a result of a 50% decrease in the variable cost of returning a batch of useful containers.

- With regards to the ordering cost for purchased containers (i.e. K_{pj}), the assumption that there are more returned containers than purchased containers also affects the impact that changes to this cost have on the total cost and cycle time. The general pattern caused by changes to the returned and purchased containers is the same but the ordering cost of purchased containers has a smaller effect on the objective function due to the assumption as was the case with the holding costs.

- While decreasing the storage space requirement for each container type (i.e. s_j) by 25% and 50% did not affect the optimal solution at all, increasing it by the same amounts resulted in changes to the optimal solution. The storage capacity constraint became binding for both the 25% and 50% increases and consequently the cycle time increased by 11.1% in both cases while resulting increases to the total cost were smaller at 2.5%

Parameters		**Common cycle time (or individual cycle times if optimal)**		**Number of common return cycles per procurement cycle (or individual cycles)**		**Total cost**	
Base example		$\mathbf{0.1895}$		$\mathbf{2}$		$\mathbf{357\ 525.56}$	
C	-50	0.1058	-44.2	2	0	383 364.62	$+7.2$
	-25	0.1585	-16.2	2	0	352 578.17	-1.4
	$+25$	0.1895	0	2	0	357 525.56	0
	$+50$	0.1895	0	2	0	357 525.56	0

K_{rj}	−50	$T_1 = 0.1419$ $T_2 = 0.1380$ $T_3 = 0.1479$	−25.1 −27.2 −22.0	$m_1 = 5$ $m_2 = 3$ $m_3 = 2$	+150 +50 0	347 035.59	−2.9
	−25	0.1895	0	2	0	357 525.56	0
	+25	0.1895	0	2	0	357 525.56	0
	+50	0.1895	0	2	0	357 525.56	+5.9
K_{pj}	−50	0.1895	0	2	0	357 525.56	+5.9
	−25	0.1895	0	2	0	357 525.56	+5.9
	+25	0.1895	0	2	0	357 525.56	+5.9
	+50	0.1895	0	2	0	357 525.56	+5.9
K_{rj}^{f}	−50	0.1809	−4.5	2	0	335 808.26	−6.1
	−25	0.1853	−2.2	2	0	346 825.48	−3.0
	+25	0.1936	+2.2	2	0	367 933.42	+4.8
	+50	0.1977	+4.3	2	0	378 070.95	+5.7
K_{pj}^{f}	−50	0.1771	−6.5	2	0	326 090.98	−8.8
	−25	0.1834	−3.2	2	0	342 144.22	−4.3
	+25	0.1954	+3.1	2	0	372 309.99	+4.1
	+50	0.2011	+6.1	2	0	386 559.84	+8.1
$K_{rj}^{'}$	−50	0.1803	−4.9	2	0	344 607.50	−3.6
	−25	0.1849	−2.4	2	0	351 118.45	−1.8
	+25	0.1934	+2.3	2	0	363 832.34	+1.8
	+50	0.1983	+4.6	2	0	370 042.32	+3.5
$K_{pj}^{'}$	−50	0.1706	−10.0	2	0	331 260.61	−7.3
	−25	0.1803	−4.9	2	0	344 607.50	−3.6
	+25	0.1983	+4.6	2	0	370 042.32	+3.5
	+50	0.2067	+9.1	2	0	382 185.76	+6.9
h_{rj}	−50	0.2116	+11.7	2	0	286 391.30	−19.9
	−25	0.2082	+9.9	2	0	325 408.97	−9.0
	+25	0.1751	−7.6	2	0	386 985.85	+8.2
	+50	0.1635	−13.7	2	0	414 356.82	+15.9
h_{pj}	−50	0.2064	+8.9	2	0	328 297.60	−8.2
	−25	0.1974	+4.2	2	0	343 222.84	−4.0
	+25	0.1825	−3.7	2	0	371 277.70	+3.8
	+50	0.1762	−7.0	2	0	384 538.34	+7.6
s_j	−50	0.1895	0	2	0	357 525.56	0
	−25	0.1895	0	2	0	357 525.56	0
	+25	0.2116	+11.7	2	0	366 285.48	+2.5
	+50	0.2116	+11.7	2	0	366 285.48	+2.5

Table 3.1.3: Results from the sensitivity analysis

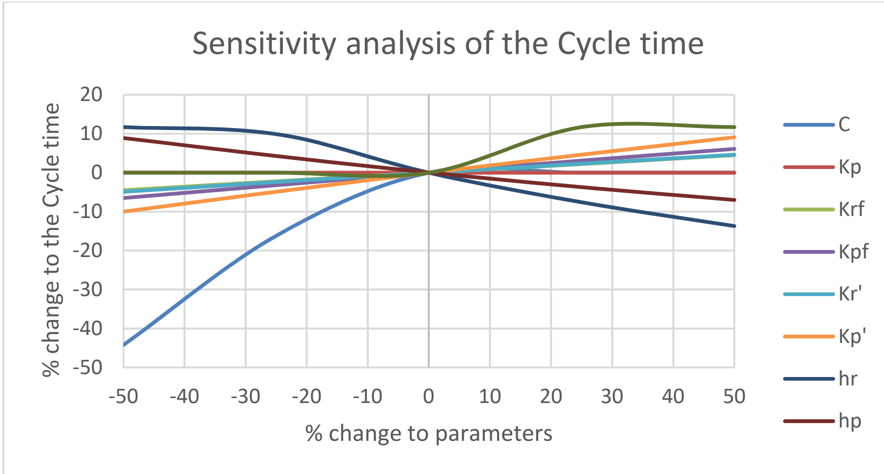


Figure 3.1.7: Sensitivity analysis of the cycle time

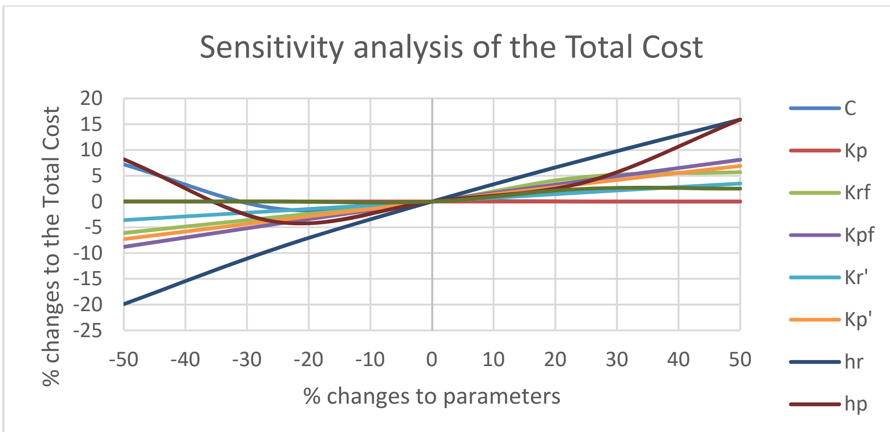


Figure 3.1.8: Sensitivity analysis of the total cost

3.1.5 CONCLUSION

Container return management, including repositioning, is an important part of ports management activities. Repositioning is usually necessary when there is a gap between demand and supply levels for containers in a port, and there is usually the need to move such around. These movements can affect the cost of port operation significantly, and hence, the need to plan them appropriately, not only in terms of meeting the aggregate objectives, but also the types of containers needed, given that shortages could be deemed to have occurred even when there are containers, but not the types needed for the transaction in time. A model that could be used to determine the optimum lot size to move in a multi-item container management system has been presented in an environment where there could be storage capacity constraint and significant savings in moving different types of containers together as a batch. There is also the need to manage the top up containers for lost or damaged ones in an integrated manner. This scenario is common in container return management, and is, therefore, deserving of attention.

Section two: Integrated lot sizing model for a multi-type container return system with shared repair facility and possible storage constraint.

A modified version of this section has been submitted to the Annals of Operations Research

3.2.1 Introduction

The advent of global supply chain management has changed the scale and scope of logistics. Driven by revolution in transportation, information technology and change in the fiscal policies of many countries, many organisations have embraced global supply chain management, and ports have become central in making this a reality. Also central to these port operations is the use of containers as this makes handling of global trade items easier, safer and more secure. An attendant problem that arises due to containerisation is the management of empty containers that have been used to move goods across global and local destinations. There is usually the need to reposition many of these containers due to general imbalance in container demand and supply across most ports of the world. Hardly does a port have a balanced container supply and demand. Most ports are usually either a surplus or shortage end for containers depending on whether they are more import or export biased respectively. This is common in most countries as some ports are closer to the industrial hubs and tend to ship out more items while some are closer to trading areas and bring in more containers. This usually leads to situations where there is always the need to handshake between some surplus and other shortage ports in an economy, which involves container movement and repositioning.

In this section, a problem of container management in a port is considered such that once containers are sent out, not all the containers return. A portion of the containers become lost or damaged to the point of being unusable. Among the returned containers, a portion can be returned to service immediately (maybe after cleaning) while some other returned containers need to be fixed in the repair facility before they can be re-issued for use. The returned containers that are damaged but reparable are fixed and some more containers are bought from vendors to make up for the lost or permanently damaged containers. The cycle is then continuously repeated. In such ports, there are many types of containers to be managed simultaneously. When balancing container demand and supply, it is important to not only meet the aggregate required number of containers, but also the appropriate mix of each of the different types of containers (e.g. different sizes, and special requirements like reefers vs dry containers). The containers share repair facility and storage space. Management needs to decide how much space is allotted to each container in the storage area. This is because storing containers in the port is not free and charges may be dependent on container types. There is the need to provide appropriate storage space for each container type and for all containers altogether. In addition, at the container repair facility, there may be equipment for repairing the containers that need to be set up depending on which type of containers is to be repaired. There is the need to schedule when to repair each container and how much of each to repair in a cycle so as to guarantee the varietal availability of containers. In addition, there is the need to decide when to buy top-up containers and how many to buy. Decisions also need to be made for repositioning of containers from surplus areas to areas of need. All these need to be jointly managed.

This cycle is shown in Figure 3.2.1 where there is a demand at the rate, D, for containers per unit time. Of this demand quantity, only a proportion, x, of the demanded containers comes back for reuse. It is assumed x is close to 1, and this is reasonable for most container management systems.

When the containers return, a proportion of the returned containers needs to be repaired before they can be put back to use. This proportion is y of the returned containers. Hence, the total returned containers is quantity $x.D$, of which $x.y.D$ go into repair while $(1-y).x.D$ return to be reused immediately. There is also the need to buy some more containers, $(1-x).D$, to make up for the quantity that will not return for reuse. The lot size quantity for the containers procured each time such is done is Q_p. When the containers are collected (repositioned), the lot size for each batch transferred is Q_r. When the repair is to be inducted, the lot size for a batch of repair is Q_R. The objective is to find the best quantities, Q_p, Q_r and Q_R to minimise the total cost.

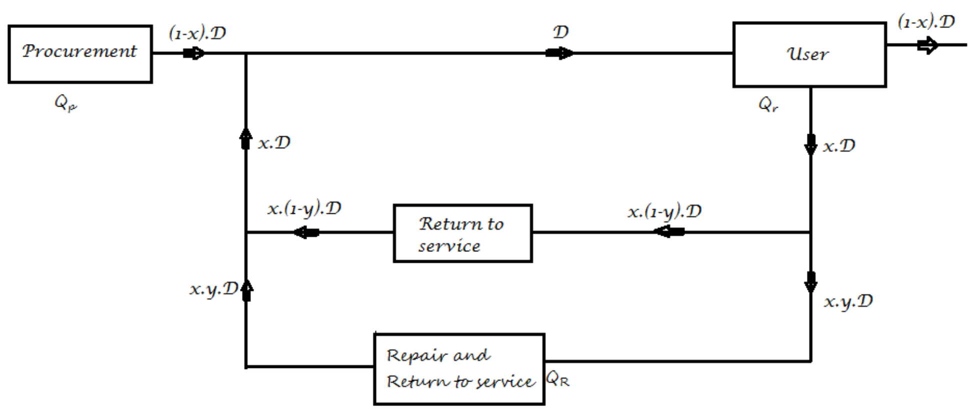


Figure 3.2.1: Container flow cycle with possible repair

While container return system can be classified as some form of the general return logistics problem, different reverse logistics systems exhibit different behaviours, and such need to reflect in the modelling. Not much work has be seen in the area of lot sizing of container return systems. Most reverse logistics models took their general form from those of repairable items, hence, inherited their assumptions as well. Schrady (1967) is a seminal work in these fields. He distinguished between the continuous supplement policy and the substitution policy. While the replenishment triggers differ in the two cases, both however, assumed that the value of the Ready For Issue (RFI) items is higher than that of Non Ready For Issue (NRFI) items, probably up to the order of five to one. The implication is that the RFI items are first utilised before the NRFI are considered in order to minimise the total holding cost. The thought here is, however, more like Koh et al (2002) where consumption occurs simultaneously from both return and new items, and this is discussed next. In the container repair problem presented, the management has to decide on the top-up procurement batch size, the return collection batch size and the in-house repair batch size simultaneously. This presents a three echelon problem as opposed to the two of the traditional repairable inventory system. In addition, the classic repairable inventory system assumes that items are returned continuously but drawn down during each repair batch. The draw down appears as steps in such models. In this problem, it is more realistic in the port's container management case that containers are considered to be returned in batches, and there is a continuous draw down for repair and reuse. This repair process has two phases: the repair and use phase that has a gradual increase (i.e. positive slope), followed by a use-only phase, which is a gradual decrease (negative slope). This is typical of a production-inventory system. All these are shown in Figure 3.2.2 for a single type of container. The topmost graph is that of top up procurement with batch quantity, Q_p, being gradually consumed. There are some $m \geq 1$ integer cycles of return per single cycle of procurement. This is shown in the second graph from top. These returned containers are also brought back in batches Q_r. This graph looks so because the serviceable return containers are available for use immediately, and those that have just been repaired are also available for use immediately. All useable containers of a particular type are stored together where they may be issued, whether purchased, returned in usable form or repaired and ready for use.

The bottom graph is the behaviour of inventory of each inducted batch of repair. It should be noted that the height of this graph is $I_{max,R}$ and not Q_R because of simultaneous repair and use in the first phase of the inventory. There are $n \geq 1$ integer repair cycles for each return cycle. The second graph from bottom (third from the top) maps the inventory position of the returned reparable return containers, a proportion of the returned quantity $Q_{,r}$ that is gradually drawn down for repair in batches of size Q_R, repeated n times until it reaches zero. Hence, there are n cycles of repair in a single cycle of return and $m.n$ cycles of repair in a single cycle of procurement, so, if the cycle time of container repair is T, the cycle time for container collection (repositioning) will be $n.T$, and that for procurement would be $m.n.T$. It can also be seen that also be seen that $Q_r.y = nQ_R$.

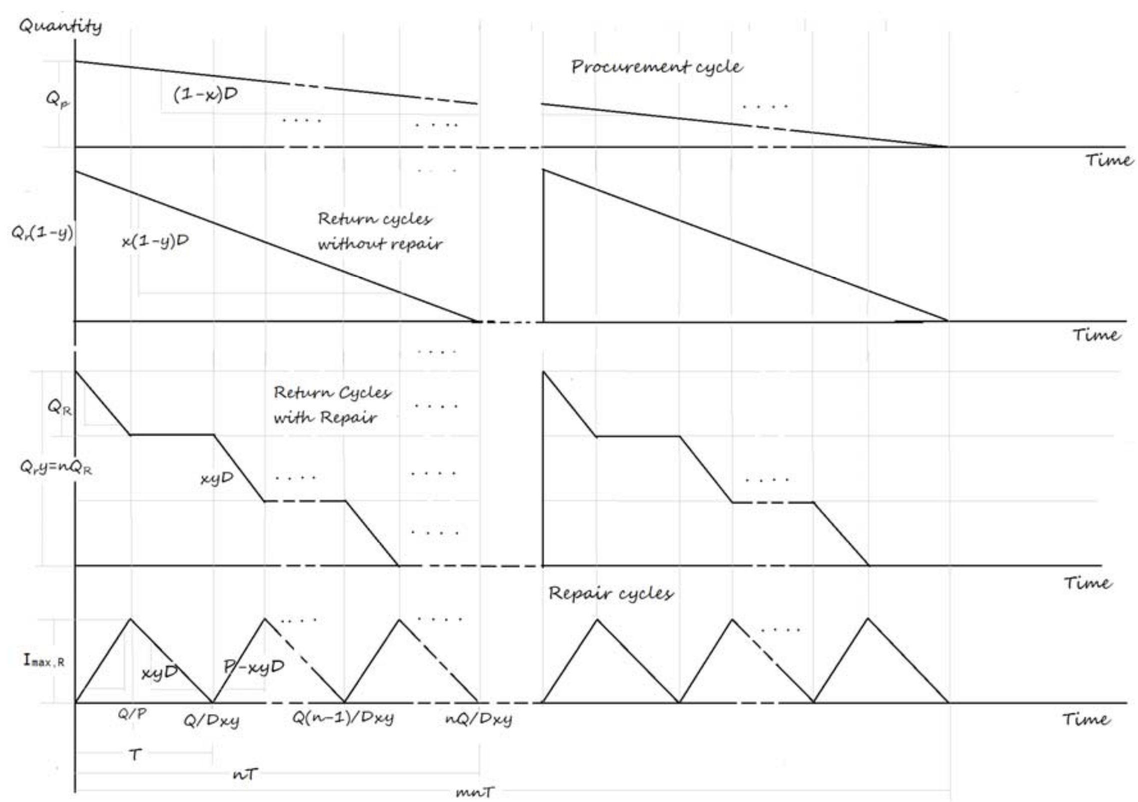


Figure 3.2.2: Inventory-time graphs for procurement, return and repair

While Figure 3.2.2 shows the container stock position for a single type of container, the problem here considers more than one type of containers, so, Figure 3.2.2 would need being overlaid for all types of containers involved. Since the cycle for repair integrates all types of containers because of shared repair and storage capacity, the repair cycle diagram for a three container system with a common repair centre is shown in Figure 3.2.3 (without any loss of generalisation). It indicates the common cycle tim, T, they all maintain in order to sequence the continuous repair cycle to accommodate each container type. This would be further discussed in the model development section.

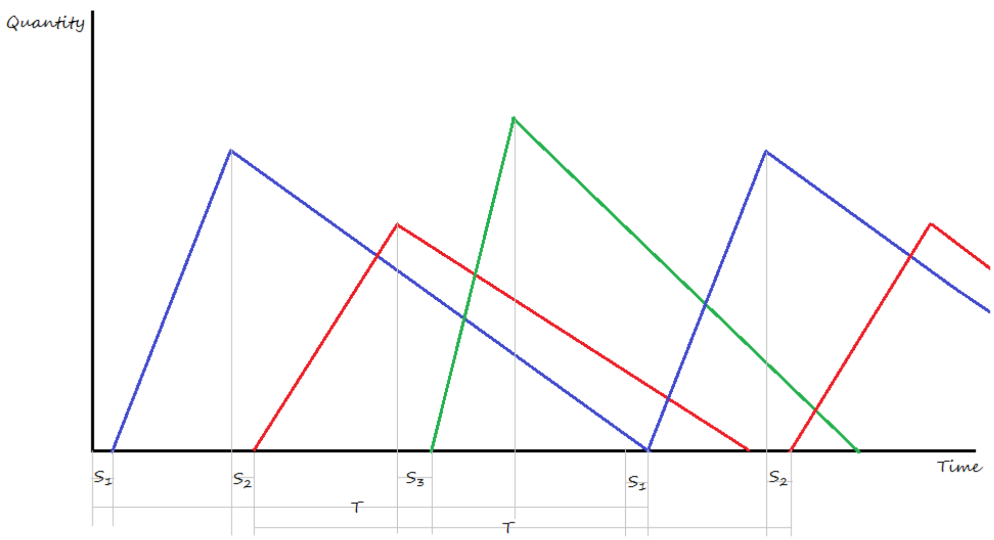


Figure 3.2.3: Integrated common repair cycle for a 3-container repair system

The sections in this paper are now summarised. The first section is the introduction where the problem background is provided and description of the problem is given. The next section is a brief review of the pertinent extant literature in order to identify the context of the solution provided. Following this is the section on model development where the integrated optimal lot sizing formula for this multi-echelon, multi-item problem is developed. This is followed by a section presenting solution algorithm followed by an illustration of this with numerical example. The last section concludes and summarises the objectives and findings of this work.

3.2.2 Literature Review

The age of containerisation has come with its own challenges and the imbalance of shipment of containers is the main one. The demand for and supply of containers in all locations (ports and hinterland) are hardly equal, and this volume difference on one side could more than double the volume at the other side in many instances. Even at a global level, the difference in quantity of containers shipped and received between two destinations could be more than 100 percent of the other side as shown in Gencer (2019). This usually necessitates the need to reposition containers from places of surplus to places of deficit. Kuzmicz & Pesch (2019) stated that 20% of the global container movement and 40 to 50% of landside movement involves Empty Container Repositioning (ECR). About 56% of the 10 to 15-year lifespan of a container is said to usually be spent either being stacked or being repositioned. Shintani et al (2019) reported that the cost of annual global repositioning of empty containers is estimated at about USD 20 billion. This has prompted a lot of research into repositioning, including use of innovations like foldable and combinable containers. The growth of container shipment has also led to growth in fleet and ship sizes for many carriers in the maritime business. Poo and Yip (2019) noted that the carrying capacity of container ships in the world has increased six-fold from 3.17 million in 1990 to 18.9 million in 2014. In addition, the maximum ship size has progressively increased from 4300 Twenty Foot Equivalent Units (TEUs) in 1988 to 18000 TEUs in 2015. Samsung Heavy Industry are currently manufacturing mega ships with capacity to carry 20000 TEUs. While this has aided the shipment of containers globally, it has further aggravated the imbalance between container supply and demand, thereby necessitating further repositioning. Lee and Song (2016) classified research areas in container management into six main categories of strategic, tactical and operational importance with ECR classified mainly as operational but with extensive interface with the other areas. They also stated that current research in ECR seeks to answer two inter-related questions: quantity questions, which seeks to determine the level of containers to maintain in a location or move between two locations; and cost questions, which is about how much it costs to reposition containers for subsequent shipments. Within this scope of work, most research seems to have studied capacity deployment, sizes of shipping vessels, design of shipping networks, routing of vessels and creation of shipping schedules, as stated by Poo and Yip (2019). Researchers have reported a general lack of focus in the landside section of container shipping and repositioning with more work done in the long haul or maritime section.

As part of their findings in a qualitative study, Kolar et al (2018) concluded that there has been general negligence of the study of the dynamics of container movement in the hinterland. They surveyed practitioners in the shipping industry in the Central and Eastern Europe (CEE) region and realised that most models proposed hitherto have focused heavily on the maritime side. Sterzik & Kopfer (2013) noted that while the total volume moved inland is much lower than the maritime movement, the unit cost of movement on land is far much higher than the maritime, hence deserves attention in container repositioning. They classified all land movements as either outbound full, outbound empty, inbound full and inbound empty. They proposed a Mathematical Programming (MP) model for the Inland Container Transportation (ICT) problem considering both resource utilisation and container allocation in the hinterland and solved it using a Tabu search heuristic. Gusah et al (2019) also mentioned the sparseness of work in the landside of container repositioning problem and presented an agent-based simulation model of urban-based goods movement in Melbourne, Australia. Furio et al (2013) is another recent study that has focused mainly on movement of containers considering the implication of street turns as containers are moved inland. Another area that seems not to have had much work generally in ECR is lot sizing of repositioned containers. Lee & Song (2016) discussed inventory management from a container perspective in comparison to that of other products and four main differences were mentioned. Firstly, while for most products the inventory item is consumed, for the container it is more like an equipment used and reused as part of another process. Secondly, while inventory is purchased directly and used for many items, the inventory of containers may be owned, leased, or a combination of both. The third is that container inventory is a 2-way management problem unlike a typical product which is a single way. The fourth difference is consequent to the third, which is that the container system is more like a return logistics system. These characteristics affect how the container inventory system is modelled. The focus is not so much on the price of purchase but the operational cost, and the model is an adaptation of most return logistics inventory models.

The classic model on which most return logistics lot sizing model seems to have been built is the model of Schrady (1967). He presented a model for managing a repairable inventory system in which there are two items: one consisting of items waiting to be repaired, called the Non-Ready for Issue (NRFI) items, and the other containing Ready for Issue (RFI) items. He presented two policies: the continuous supplementing policy and the substitution policy and focussed more on the latter. He considered a case where not all items issued are returned for repair, hence there is a need to procure some new items to supplement the repairable items returned. He developed a closed form solution that can be used to determine the timing and quantity of lot sizes for each of these two items. Many authors have since modified Schrady's work. A notable one for the context of this paper is Mabini et al (1992), which presented a multi-item production-return process in which the reparable items share capacity for repair. He also developed models to lot size the repairable items optimally following the substitution policy of Schrady. Koh et al (2002) is another relevant work in that they considered that both returned items and new items are mixed and simultaneously consumed because they are similar. This represents how containers behave better than Shrady's in that repaired items are not so distinct from procured items and their consumption cycles are, thus, not necessarily separated during consumption. Another similar work in this wise is that of Cohen et al (1980) in that returned items can be returned directly to service. In the work presented here, a container return situation is considered where some of the returned containers are put straight back to reuse while some would need to be repaired before reuse and there is also a need to procure some because a proportion is lost. In addition, there are different types of containers in the system where these different types need to be repaired using a shared facility with finite capacity and planning this repair individually may lead to cycle time overlaps, which is undesirable.

3.2.3 Model development

This section presents the derivation of the total cost and optimal lot size functions. The derivation starts by stating the important assumptions of the model followed by the Notation adopted in the development and then the model development process.

3.2.3.1 Model Assumptions

The following assumptions were made in the derivation of the

- There are multiple types of containers.
- The value of new stock and repaired items can be taken as the same.
- Demand rate for each type of container is fixed and is known.
- The return rate of each container type is fixed and is known.
- The damage rate for each type of container is fixed and is known.
- The rate of container attrition is much smaller than the rate of return, and consequently, the replenishment cycle is reasonable to be at least as large as the return cycle.
- The procurement cycle time can be any integer multiple of return cycle time, and the return cycle time can be any integer multiple of the repair cycle time.
- The demand for RFI is fulfilled proportionately from all types of sources of RFI (procured, return without repair or repaired) since there is no particular selection preference.

3.2.3.2 Notation

The following Notation were adopted:

j is an index for types of containers managed at the port, $j = 1,2, \dots k$

r is a subscript denoting returned containers

p is a subscript denoting purchased containers

R is a subscript denoting repaired containers

D_j is the annual demand rate for container type j

P_j is the annual repair rate (capacity) for container type j

x_j is the proportion of container type j returned to the port from points of use

y_j is the proportion of the returned container type j that needs repair in order to return to serviceable condition after arriving at port

K_{rj} is the fixed cost of returning a batch of useful container type j from point of use

K_{pj} is the fixed cost of ordering a new batch of container type j to make up for lost or irreparably damaged containers

K_{Rj} is the fixed cost of setting up the repair centre for a batch of container type j to be repaired from the batch damaged containers received from return

h_j is the holding cost per unit per year of keeping a container type j. This cost is dependent on the type of container but not on the state of repair of the container

m_j is the number of container return cycles per single cycle of procurement for a container type j, $m_j \geq 1$ and integer

n_j is the number of container repair cycles per single cycle of return for a container type j, $n_j \geq 1$ and integer

C is the capacity of storage of all types of containers in the port terminal

u_j the storage space requirement for a unit of container type j

S_j is the time taken to set up the repair centre for a batch of container type j to be repaired from the batch damaged containers received from return

t is the operational time taken to repair a batch of container type j, (without considering set up)

Q^*_{rj} is the optimum return quantity for container type j

Q^*_{pj} is the optimum replenishment order quantity for container type j

Q^*_{Rj} is the optimum repair quantity for container type j

T is a common replenishment cycle time for all containers

X^* is the optimum value for any given variable X

3.2.3.3 Model development

Consider a multi-item return container management system discussed (see Figure 3.2.1). The first focus is on the dynamics of any one, j, of the k types of containers in circulation. The demand for the container per unit time (say per year) is D_j. The management arranges for the timely return of the containers to continue to service customers. Only a proportion, x_j, of the total number of containers put into circulation is returned to the port where it is needed to be re-used. Of this returned containers, a proportion, y_j, needs to be repaired before it can be put back into use. After repair, the container is as good as new and can go back to use, such that at the steady state, the entire proportion x_j of returned containers can be put back to use again. The portion not returned,(1 - x_j), is procured to make up the demand, D_j, again. At the repair centre, there is a set up time, S_j, necessary to set up the centre for the repair of the container type, j, and the container can be repaired at a rate P_j per unit time (also say per year). The inventory cost of managing this system comprises of the cost of each of the three sub systems. This is presented next for any container type, j.

For the procurement cycle shown in the topmost layer of Figure 2, the total inventory cost rate of the container management is

$$\frac{(1-x_j)D_jK_{pj}}{Q_{pj}} + \frac{Q_{pj}h_j}{2} \tag{1}$$

For the return container subsystem, the total containers returned is split into two: those portion that can go back into recirculation without repair given by quantity $Q_{rj}(1-y)$, and the portion that needs to be repaired in predetermined batches, Q_{Rj}, given by the quantity $Q_{rj}.y$. The fixed cost for this portion is obvious and is the first term of equation 2. The holding cost, however, consists of two parts. The first part is the returned container that can go back into circulation without repair, given by the second layer of the diagram from top, and the layer that needs to be repaired and is gradually drawn down in batches of Q_{Rj}, the third layer from top. There is a relationship between this third layer and the repair (bottom) layer (layer 4 from top). Only the holding cost of the portion not needing repair is represented for now and is given by the second term of equation 2.

$$\frac{x_jD_jK_{rj}}{Q_{rj}} + \frac{Q_{rj}(1-y_j)h_j}{2} \tag{2}$$

The final layer of the Figure is the repair echelon. The fixed repair cost is obvious and would be included later. For the holding cost, the inventory position of the repairable containers in a full return cycle is shown in the two lower levels of Figure 2 (layers 3 and 4 from top). Layer 3 is the position of the reparable containers gradually going into repair drawn in repair batches, and layer 4 is the inventory position of the inducted batches of repair for the container type, j. The holding cost for layer 3 is the time weighted average of this layer, i.e. aggregate inventory divided by total time. The proportion of return quantity needing repair, $Q_{rj}.y$, is gradually drawn down in repair batches of size Q_{Rj}. This forms a pattern in which the first draw is a triangle, followed by a series of trapezia. The height of both the triangle and the trapezia is Q_{Rj}. From this, it can be seen that the total inventory position per return cycle for layer 3 (from top) of Figure 3.2.2 is

$$\frac{n_jQ_{Rj}}{2P_j} + \frac{Q_{Rj}}{D_jxy}\sum_{i=1}^{n-1} i \tag{3}$$

The cycle time for the repair cycle can also be seen to be the number of repair cycles in a return cycle, which is

$$\frac{n_j Q_{Rj}}{D_j x_j y_j} \tag{4}$$

Dividing the total inventory per cycle (equation 3) by the cycle time (equation 4), yields the layer's average inventory per unit time. The layer's average inventory cost for return cycle is thus

$$\frac{Q_{Rj} h_j}{2}\left[\left(n_j - 1\right) + \frac{D_j x_j y_j}{P_j}\right] \tag{5}$$

For the repair layer (layer 4), it can be seen that it is simply an equivalent of a production-inventory system in which there are two periods in a cycle; the first is a joint repair and container withdrawal period and the second is a pure withdrawal period after repair is suspended. The entire cost for the repair subsystem, (layers 3 and 4) can, therefore be written as

$$\frac{x_j y_j D_j K_{Rj}}{Q_{Rj}} + \frac{Q_{Rj} h_j}{2}\left(1 - \frac{D_j x_j y_j}{P_j}\right) + \frac{Q_{Rj} h_j}{2}\left[\left(n_j - 1\right) + \frac{D_j x_j y_j}{P_j}\right] \tag{6}$$

Equation 6 is the form of the cost function for the repair layers (layers 3 and 4 from the top) for the general repairable container system described in the problem. The first term is the set up cost now included; the second term is the holding cost due to the repaired containers (layer 4) and the third term is the holding cost due to the containers waiting to be repaired (layer 3). If the holding cost of the repaired and repairable terms are considered different, this difference is indicated in that the h_j terms in equation 6 are differentiated as say $h_{j,1}$ and $h_{j,2}$ where $h_{j,1}$ may be the holding cost rate for the RFI containers and $h_{j,2}$ the holding cost rate for the NRFI containers. In the current derivation, however, it is assumed there is no need for such differentiation for containers given the constituent of the holding cost of containers and as such, $h_{j,1} = h_{j,2} = h_j$. This makes the cost function simpler by combining the holding cost terms (second and third terms) in equation 6 which leads to

$$\frac{x_j y_j D_j K_{Rj}}{Q_{Rj}} + \frac{n_j Q_{Rj} h_j}{2} \tag{7}$$

One more benefit of the assumption of common holding cost is to be realised later when designing the solution procedure. If the holding cost is the same for repairable and repair containers for a container type and the repair cycle is integrated, the optimum cost is readily found at $n_j = n = 1$.

Adding equations 1, 2 and 7 to derive the total cost rate function for the inventory system yields

$$\frac{(1-x_j)D_jK_{pj}}{Q_{pj}} + \frac{Q_{pj}h_j}{2} + \frac{x_jD_jK_{rj}}{Q_{rj}} + \frac{Q_{rj}(1-y_j)h_j}{2} + \frac{x_jy_jD_jK_{Rj}}{Q_{Rj}} + \frac{n_jQ_{Rj}h_j}{2} \tag{8}$$

It can be assumed that there could be one or more return cycles in a single procurement cycle, $m_j \geq 1$, and one or more repair cycles in a single return cycle, $n_j \geq 1$. With this, the relationship between the quantities per batch of procured, returned and repaired containers relative to the repair cycle time can be written as

$$Q_{pj} = m_jn_j(1-x_j)D_jT_j \tag{9}$$

$$Q_{rj} = x_jn_jD_jT_j \tag{10}$$

$$Q_{Rj} = x_jy_jD_jT_j \tag{11}$$

$$Q_j = D_jT_jn_j\left[x_j + m_j\left(1-x_j\right)\right] \tag{12}$$

Also define, ρ_j, the maximum utilisation level for the repair resource for container j to be

$$\rho_j = \frac{D_j}{P_j} \tag{13}$$

Substituting equations 9 to 11 and 13 into equation 8 and summing over all container types yields

$$\sum_{j=1}^{k}\frac{1}{T_j}\left[\frac{K_{pj}}{m_jn_j} + \frac{K_{rj}}{n_j} + K_{Rj}\right] + \sum_{j=1}^{k}\left[\frac{D_jT_jh_jn_j}{2}\left[m_j\left(1-x_j\right) + x_j\right]\right] \tag{14}$$

Since all containers share a common repair facility that needs to be set up for the repair of each type of container, it is important that the repair of each of these types of containers be completed within a repair cycle. All types of container varieties are catered for in this cycle, and this is a condition for the feasibility of the solution as it prevents cycle overlaps. It then becomes necessary to replace the individual cycle times for each container, T_j, by a common cycle time, T. If the cycle times are integrated this way, it also becomes pertinent that the individual number of repair cycles per return cycle, n_j, be replaced by a common number of repairs, n. Equation 14, therefore, becomes

$$\frac{1}{T}\sum_{j=1}^{k}\left[\frac{K_{pj}}{m_j n}+\frac{K_{rj}}{n}+K_{Rj}\right]+\frac{Tn}{2}\sum_{j=1}^{k}\left[D_j h_j\left[m_j(1-x_j)+x_j\right]\right] \tag{15}$$

The diagram for the common repair cycle for all container types is shown in Figure 3.2.3. For this cycle to be feasible, we have the constraint that all setups and repairs for all containers must be completed within each repair cycle time, T. This is represented as

$$\sum_j S_j + t_j \leq T \tag{16}$$

The repair time for a repair batch of container j excluding set up, t_j, can be expressed as

$$t_j = \frac{Q_{Rj}}{P_j} \tag{17}$$

Using equation 17 with equations 11 and 13, we can rewrite equation 16 as

$$T \geq \frac{\sum_j S_j}{1-\sum_j x_j y_j \rho_j} \tag{18}$$

There is also the possibility of having insufficient space to store the containers at the port. The quantity of return containers that should be repositioned in addition to the quantity purchased and the current containers under repair could be limited by the storage space and not the capacity to repair of the damaged returned containers. This constraint can be expressed as

$$\sum_{j=1}^{k} Q_j u_j \leq C \tag{19}$$

Substituting equation 12 for Q_j in 19 with $T_j = T \; \forall \; j$ yields

$$T \leq \frac{C}{n \sum_{j=1}^{n} D_j \left[\left(x_j + m_j \left(1 - x_j \right) \right] u_j} \tag{20}$$

The general problem becomes that of minimising the cost function, equation 15, subject to the two constraints, equations 18 and 20. In solving this problem, it can be seen that equations 18 and 20 represent the upper and lower limits for any feasible cycle time. This becomes the approach to exploit in solving the problem and would be discussed later.

Optimising equation 15 with respect to T while ignoring the constraint yields

$$T^* = \sqrt{\frac{2 \sum_{j=1}^{k} \left[\frac{K_{pj}}{m_j n} + \frac{K_{rj}}{n} + K_{Rj} \right]}{n \sum_{j=1}^{k} \left[D_j h_j \left[m_j \left(1 - x_j \right) + x_j \right] \right]}} \tag{21}$$

To solve equation 21, it should be observed that m_j and n values are also unknown and the problem would have to be solved iteratively. This can be solved through some numerical approaches or some other search techniques, including random search solution. Once the values of m_js and n that optimise the cycle time have been determined for each of the container types, one needs to check the solution for feasibility using equations 18 and 20. If the constraints are violated, one needs to determine the new cycle time that would be feasible based on either equation 18 or equation 20, depending on which one is violated. Once the cycle time is deemed acceptable, the optimal lot size for each of the containers for the return, purchase and repair lots can be calculated from equations 9 to 11. To consider the impact of the two constraints in the objective function, one can create a Langrangean function including the two constraints and solve. This leads to a series of simultaneous equations involving the differentiation of the Lagrangean with respect to the cycle time and with respect to the first and second lambdas for each j, and with respect to the common number of repairs per return cycle. This may be computationally tedious, and even so, there would still be the need to iterate over m_js. To solve these problems, however, two heuristics that can be used to find good solutions by exploiting the nature of the problem are proposed. The performances of the two heuristics are then compared.

3.2.3.4 Proof of optimality

To check if the cycle time determined in equation 21 minimises the cost functions, it suffices to check the hessian function of equation 15, which is given by equation 22. It can be seen that this function is positive definite since all terms are positive non-zero values. It can, therefore, be concluded that equation 21 provides a minimum for equation 15.

$$\frac{1}{T^3}\sum_{j=1}^{k}\left[\frac{K_{pj}}{m_j n}+\frac{K_{rj}}{m_j}+K_{Rj}\right] \tag{22}$$

3.2.4 Solution Algorithms

A main solution algorithm is proposed to solve this problem. This algorithm sequentially increases n and seeks to find the optimal combination over the varying n values. It starts from $n = 1$ and finds the optimal combination of m_j values that minimises the cost function for each n until either when the total cost no longer decreases or when the solution just becomes infeasible. If infeasibility is attained before this turning point, it seeks a close borderline feasible solution from this infeasible position. This algorithm is called the sequential optimisation heuristic. A second heuristic is proposed which is a random search technique and the result obtained from this search algorithm is compared to that obtained from the sequential optimisation heuristic. The two heuristics are presented next.

3.2.4.1 Solution Heuristic 1

This method iteratively finds the best feasible solution within the search space until a better one could not be found, or find a reasonable infeasible solution as a bound on the cost value and from there seeks out a close feasible solution on the constraint boundary. The solution exploits the fact that all repaired items must have a common cycle time so that every container type is repaired in each repair cycle, hence, only needs to iterate over a single n for all containers and not n_j for each container j as discussed earlier. It starts by fixing the value of n at 1 and uses the solver to search for the best combinations of m_js at $n = 1$. It proceeds to $n = 2$ and iterate. If a better result is obtained, the solution at $n = 2$ is kept as the best. The iteration continues until the solution starts to deteriorate or becomes infeasible. If the best was found before it becomes infeasible, then it keeps the best feasible solution it has found. If it moves to an infeasible region before it to deteriorates, there is the need to check for the better between the last feasible solution found or the boundary solution close to the infeasible region. To find the boundary solution close to the infeasible region, the n and m_j combinations obtained as the last feasible solution is used with the cycle time set to the cycle time T boundary that results in infeasibility (equation 18 or 20). The best cycle time and number of cycle choices are made based on the better of these last two candidate solutions.

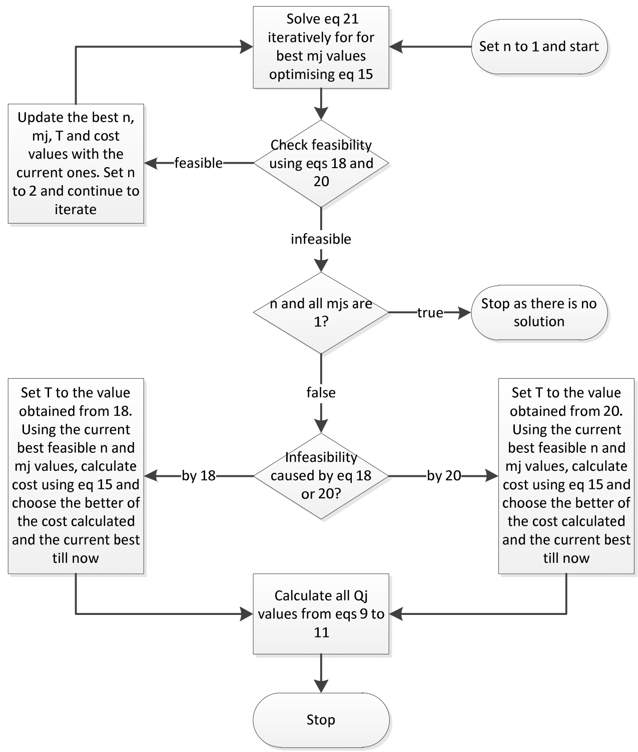


Figure 3.2.4: Heuristic 1 - Sequential optimisation search procedure

3.2.4.2 Solution Heuristic 2

This solution approach makes use of a random search technique. It searches from the feasible search space and finds the best possible solution amongst them. It prevents infeasible combinations of n and m_js from coming into the candidate solutions through some helper functions, which at the same time exploits the nature of the solution to explore the search space. It continues to iterate until the solution converges. The general algorithm is presented in Figure 3.2.5. For the purpose of this research, a Genetic Algorithm procedure was used to implement the solution. A population of feasible candidate chromosomes were generated subject to the two constraints. A chromosome is made up of a vector consisting of values for of n and m_js. A population of feasible candidate chromosomes is generated. The cost function evaluated for each chromosome and the population is ranked. The rank based roulette wheel selection approach was used to cross the chromosomes and then mutation was performed as necessary. New generations were created while the current best chromosome in each generation was preserved as is allowed to progress to the next stage. This iterative procedure is repeated until the terminating condition is reached. The GA procedure is discussed next with the pseudocodes shown in the form of inset figures.

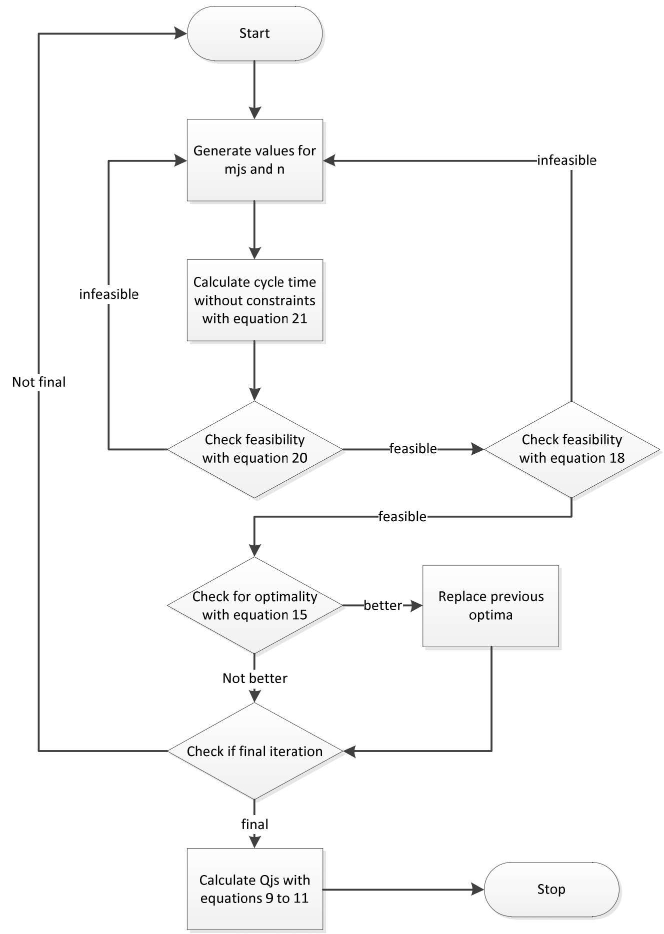


Figure 3.2.5: Heuristic 2 – The GA search procedure

3.2.4.2.1 The Genetic Algorithm

The main function presents the highest level of operational abstraction of the GA algorithm. The important sub-routines and helper functions are presented in Figure 3.2.6. The purpose of the helper functions is to ensure that only feasible set of chromosomes are allowed in the population, and also to help with local search for good solutions for the GA algorithm. One helper each function encodes the upper limit and another the lower limit functions. The third helper function explores the search space using the nature of the problem. It should noted that the lower cycle time limit is not dependent on n and m_j values (equation 18). This gives the advantage that the lower limit is computed only once before the first iteration. The value is henceforth passed as a parameter whenever it is needed. The upper limit and cycle time are, however, dependent on n and m_j values and are recomputed each time new combinations are generated.

The main GA algorithm and its main functions

```
Initialise variables and parameters
Set the lower cycle time limit
Generate initial population
While not yet terminating condition
        Score and rank chromosomes
        Select next generation parents
        Create new generation:
                Preserve the best chromosome
                Crossbreed selected parents to create new offsprings
                Mutate genes of retained parents
EndWhile
Extract global best chromosome and calculate best system parameters
```

Helper functions

```
Set Lower Cycle Time Limit
Set Upper Cycle Time Limit
Ensure cycle time is between the Cycle Time Limits
```

Figure 3.2.6: The main GA algorithm with the helper functions

Initialisation

With this function, the parameter values are set for the number of chromosomes per population, **numPop**, number of iterations, **numIter**, gene mutation rate for chromosomes, **mutRate**, retention rate for chromosomes per population, **retRate**, and number of container types, **numCont**. All cost rates and other known parameters (holding costs, ordering and setup costs, return rates as a proportion of demands, repair rates as a proportion of return containers, demands, space utilisation per container and repair centre's capacity for each container type are entered. The other variables to stipulate the maximum number of return cycles per procurement, **retLim**, and maximum number of repair cycles per return, **repLim** are also set. These two values (retLim and repLim) were judiciously chosen, as discussed later.

Generate the initial population

With this function, the initial chromosomes to start the iterative GA process is created. A chromosome is made up of the number of repairs per return cycle, n, and the number of returns per procurement cycle, m_js. This is stored as a matrix of dimension numPop by numCont + 1. When each chromosome is being generated, the helper functions are used to ensure that only feasible chromosomes are created and that the solution space around a feasible choice of n is logically explored. The first question is choosing limiting values (retLim and repLim) to use for n and m_j values during the initialisation. For the purpose of this work, since the problem had been solved using the first algorithm, it was decided to use three times the maximum value found for the n and m_j values from heuristics 1 and set these as both repLim and retLim. The initialisation algorithm is presented in Figure 3.2.7.

For each counter position (from 1 until numIter)
Set n to any number between 1 and repLim
Set each m_j to any number between 1 and retLim
Use helper functions to ensure feasibility of chromosome
EndFor

Figure 3.2.7: Initialisation procedure

Score and rank chromosomes

This algorithm is used to evaluate the performance of each chromosome in the population and rank them in a non-decreasing order based on the cost. The cost of each chromosome is computed using equation 15. The algorithm is presented in Figure 3.2.8.

For each chromosome
Calculate the cost of chromosome in position
Rank the chromosome based on cost in non-decreasing order
Return the rank vector for chromosome ranking
EndFor

Figure 3.2.8: Scoring and ranking algorithm

Create new generation

This algorithm creates a new generation of chromosome population. It selects a specified number (retention point – **retPoint**) of topmost chromosomes as those allowed to produce the next generation of chromosomes. It defines the retPoint as the product of the chromosome retention rate (retRate) and the population size (numPop). To allocate weights, it uses the ranking of the chromosomes, which was done in the previous step. The chromosome with the cheapest cost is given the highest chance of mating to produce the next generation. The sum of all weights are normalised to unity. This algorithm is shown in Figure 3.2.9.

Mutation and crossover

The next stage in generating the new population involves ensuring that the best gene remains unchanged. For the topmost chromosomes copied up until retPoint, it is desirable to keep most of their features, but mutate some of their genes to explore the possibility of finding some better solutions near them. Some genes of the chromosomes copied into positions 2 up until retPoint are, therefore, mutated. After these genes have been mutated, there is the possibility of generating chromosomes that may produce infeasible solution. The helper functions are called to ensure feasibility and also search for good solutions locally.

For the positions from retPoint+1 till the end, the goal is to create new children as a cross from two good (positions 1 to retpoint) parents. The pairs of good parents for crossing are randomly are selected using the weight generated in Figure 3.2.9 as the parent's probability. After this, the helper functions are called for feasibility and possible improvement of chromosome. The new population that would be fed into the cost function is then complete, and the next iteration can begin again until the number of designated iterations is reached. The algorithm is shown in Figure 3.2.10.

```
Select Topmost Chromosomes
For the topmost ranked retPoint = roundUp (retRate * numPop) chromosomes
        Copy chromosome to new population in the same position
        Create parent selection probability for selected parents (roulette wheel selection)
EndFor
Rank based Roulette wheel selection
Set normaliser to retPoint*(retPoint + 1)/2
Create selection weights
        Set cumulativeWeight for position 1 to retPoint/normaliser
        For positions 2 to retPoint, do
                weightCurrentPosition = (retPoint – position + 1)/normaliser
                cumulativeWeightCurrentPosition = cumulativeWeightPreviousPosition +
                WeightCurrentPosition
        EndFor
Generate a random number
For each parent, do
        Start from position 1,
                While random number is less than cumulativeWeightOfPosition, do
                        Move to next position
                EndWhile
                Select parent in current position for crossover
EndFor
```

Figure 3.2.9: Algorithm to generate new populations for iteration

```
Retain the best chromosome in position 1 unchanged
Mutate given number of genes in Chromosomes
Set numMut to roundUp (mutRate*numCont)
For positions 2 to retPoint chromosomes
        For 1 to numMut
                Randomly select a gene to mutate in chromosome
                Randomly reset the gene value between 1 and retLim
                Use helper functions to ensure feasibility of chromosome
        EndFor
EndFor
Perform Crossover after retPoint
For positions retPoint+1 to numPop
        Select two parents using roulette wheel algorithm
        Perform Crossover
        Use helper functions to ensure feasibility of offspring chromosomes
EndFor
Cross Over
Generate a random crossoverPoint between 2 and numCont
For offspring 1
        Copy genes of parent 1 until before crossoverPoint
        Copy genes of parent 2 from crossoverPoint until numCont
For offspring 2
        Copy genes of parent 2 till before crossoverPoint
        Copy genes of parent 1 from crossoverPoint until numCont
```

Figure 3.2.10: Mutation and crossover functions

Helper functions

Helper 1: Set Lower Cycle Time Limit

This function sets the lower limit for cycle time to ensure feasibility of values from chromosome. Equation 18 was implemented in this function. It should be noted that this function is independent of the number of return cycles and repair cycles.

Helper 2: Set Upper Cycle Time Limit

This function is an implementation of equation 20 and sets the upper cycle time limit that would determine the feasibility of the randomly generated chromosome values. It is dependent on the number of return cycles and repair cycles.

Helper 3: Ensure cycle time is between the two Cycle Time Limits

This function ensures that the cycle time derivable from the values assigned to the number of return cycles per purchase cycle and repair cycles per return cycle yield feasible cycle time. It implements equation 21 and checks the value against the upper cycle time limit and the lower cycle time limit.

It has two sub functions that are implemented depending on the level of changes desired. Equation 21 is first reviewed before discussing the algorithm.

There are two variables that can be used to change the value of cycle time. The number of repair cycles, n, and the number of return cycles, m_js. If the cycle time is greater than the upper limit, the equation suggests increasing n or m_js. If the cycle time is below the minimum level, there is a need to decrease n or m_js. It is can be seen that changing n would change the cycle time much more quickly than changing the m_j values. This is apparent because m_j values are affected by the container loss rate, $1 - x_j$, which is small for most practical cases. This fact is exploited this to drive the rate of convergence of the algorithm. When it is desirable to speed up the search, the value of n is changed, and when a more thorough search is preferred, the change m_js are changed. Combining these two helps to manage how the search procedure would behave, hence, the last helper function is able developed as shown in the algorithm in Figure 3.2.11. In addition, n must not be lower than 1, else the vector of number of cycles will become infeasible. Once the minimum of $n = 1$ is reached, only m_j values are used to drive convergence. In addition, it can be observed that decreasing n and m_j increases both the cycle time and the upper limit of cycle time (equations 20 and 21). So, once n can no longer be used to drive the convergence the goal becomes to ensure that the cycle time is higher than the lower cycle time limit, and that suffices.

```
Set changeRate between 1 and 2
While upper cycle time limit is less than or equal to the lower cycle time limit
        If number of repair cycle per return (n) is greater than 1
                Decrease number of repair cycle per return by 1
EndWhile

While cycle time is greater than the upper cycle time limit
        Select a random container (location j)
        Multiply m_j by changeRate and roundup
EndWhile

While cycle time is less than the lower cycle time limit
        Select a random container (location j)
        Divide m_j by changeRate and roundup
EndWhile
```

Figure 3.2.11: The helper function to control convergence rate

3.2.5 Numerical Examples

Two numerical examples were proposed to test the performance of the two heuristics. The first problem (numerical example) is a 3-container problem and the second is a 6-container problem. The storage capacity are $C = 350\ 000\ ft^3$ and $C = 2\ 000\ 000\ ft^3$ respectively for the 3- and 6-container problems while the other problem parameters are also presented in Tables 3.2.1 and 3.2.2 respectively. The optimal solutions based on heuristic 1 for these two problems are presented in Table 3.2.3 with $n = 1$ as part of the solution. This n value is understandable since the holding cost, repair cycle time and the number of repair cycle per return cycles have been standardised. Sensitivity analysis was done for the result obtained for the 6-container problem only as shown in Table 3.2.4. This is without any loss of generality, but only to avoid unnecessary repetition.

j	1	2	3
$u_j\ (ft^3/container)$	20	15	10
$D_j\ (containers/year)$	15 0000	20 000	25 000
$P_j\ (containers/year)$	18 000	24 000	30 000
x_j	0.9	0.8	0.8
y_j	0.2	0.3	0.25
K_{rj} (\$)	10 000	8 000	7 000
K_{pj} (\$)	15 000	12 000	10 500
K_{Rj} (\$)	20 000	16 000	14 000
h_j (\$/year)	50	40	30
$S_j\ (years)$	0.02	0.018	0.016

Table 3.2.1: Input parameters for the 3-container problem

j	1	2	3	4	5	6
$u_j\ (ft^3/container)$	50	35	25	20	15	10
$D_j\ (containers/year)$	1 000	5 000	10 000	100 000	25 000	50 000
$P_j\ (containers/year)$	1 250	6 250	12 500	120 000	30 000	60 000
x_j	0.9	0.8	0.75	0.75	0.7	0.85
y_j	0.15	0.16	0.18	0.15	0.17	0.2
K_{rj} (\$)	10 000	7 000	5 000	4 000	3 000	2 000
K_{pj} (\$)	15 000	12 000	11 250	10 500	9 750	9 000
K_{Rj} (\$)	20 000	15 000	13 000	8 000	7 000	5 000
$h_j\ (\$/year)$	50	40	30	20	10	5
$S_j\ (years)$	0.015	0.0135	0.012	0.0105	0.009	0.0075

Table 3.2.2: Input parameters for the 6-container problem

3.2.5.1 Solution with Heuristic 2 – Genetic Algorithm

The common repair cycle time was 0.27937 years, n was 1 and the m_js were 2,1,1 or 8,3,1,1,1,1 respectively for the 3- and 6-container problems. To determine the optimal purchase, return and repair quantities for each container type, these values can be substituted into equations 9 to 11 respectively.

	Total cost (TC)	**Common cycle time (T)**	**Number of return cycles per procurement cycle (m_j)**
Example 1 (3 containers)	706 222.34	0.2973	2; 1; 1
Example 2 (6 containers)	951 619.67	0.2937	8; 3; 2; 1; 1; 1

Table 3.2.3: Solution to the 3- and 6-container problems

Parameters	% change	Total cost (TC)	% change	Common cycle time (T)	% change	Number of return cycles per procurement cycle (m_j)
K_{rj}	−50	897 234.87	−5.71	0.2765	−5.86	9; 3; 2; 1; 1; 1
	−25	924 839.40	−2.81	0.2850	−2.96	9; 3; 2; 1; 1; 1
	+25	977 650.24	+2.74	0.3017	+2.74	8; 3; 2; 1; 1; 1
	+50	1 003 005.48	+5.40	0.3096	+5.40	8; 3; 2; 1; 1; 1
K_{pj}	−50	877 157.34	−7.82	0.2816	−4.13	6; 3; 2; 1; 1; 1
	−25	915 845.55	−3.76	0.2866	−2.40	7; 3; 2; 1; 1; 1
	+25	985 598.43	+3.57	0.3037	+3.41	9; 3; 2; 1; 1; 1
	+50	1 018 408.69	+7.02	0.3134	+6.69	10; 3; 2; 1; 1; 1
K_{Rj}	−50	827 609.51	−13.03	0.2547	−13.30	10; 3; 2; 1; 1; 1
	−25	891 793.37	−6.29	0.2748	−6.43	9; 3; 2; 1; 1; 1
	+25	1 007 839.27	+5.29	0.3111	+5.91	8; 3; 2; 1; 1; 1
	+50	1 060 544.25	+11.47	0.3319	+13.02	7; 3; 2; 1; 1; 1
h_j	−50	672 896.72	−29.29	0.4153	+41.42	8; 3; 2; 1; 1; 1
	−25	824 126.81	−13.40	0.3391	+15.47	8; 3; 2; 1; 1; 1
	+25	1 063 943.14	+11.80	0.2627	−10.56	8; 3; 2; 1; 1; 1
	+50	1 165 491.31	+22.47	0.2398	−18.57	8; 3; 2; 1; 1; 1
S_j	−50	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	−25	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	+25	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	+50	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
u_j	−50	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	−25	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	+25	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	+50	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1

C	-50	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	-25	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	$+25$	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1
	$+50$	951 619.67	0	0.2937	0	8; 3; 2; 1; 1; 1

Table 3.2.4: Sensitivity analysis for the 6-container problem

The following observations from the sensitivity analysis are noteworthy:

- For all the different parameter settings tested, the number of repair cycles per return cycle (n) remained constant at 1 as expected.
- None of the changes tested with respect to the storage capacity for all container types (C) had any effects on the total inventory management cost (TC), the number of return cycles per procurement cycle (m_j) and the common cycle time (T). This is because in the example tested, the storage capacity constraint, given in equation (20), was not violated by any of the percentage changes yet. Consequently, the solution remained intact because C has no direct effect on TC and T when the storage capacity constraint is not violated since the optimal values are determined using equations (15) and (21) respectively.
- Changing the holding costs (h_j) had significant effects on both TC and T but not on m_j. As expected, TC increased with increasing holding costs and T decreased with increasing holding costs. The m_j values are not significantly affected by changes to the holding cost is likely because $(1 - x_j)$ is small rand nuances the effects of such changes on m_j except such changes are very significant.
- Changes to both storage space requirement for a single container type (u_j) and the duration of time required to set up a repair centre (S_j) did not have any effects on m_j and T. Similar to C, both parameters (i.e. u_j and S_j) have no direct effect on the expressions for TC and T, as given in equations (15) and (21), when the storage capacity constraint (in the case of u_j) and the repair time constraint (in the case of S_j) are not violated. They only start affecting the optimal solution when those constraints are violated and for this particular example, none of the percentage changes tested resulted in a violation of the two constraints.
- Changes to all three fixed costs (i.e. K_{rj}, K_{pj} and K_{Rj}) resulted in significant effects on TC , m_j and T. The resulting effects followed the same general pattern, the total cost and the cycle time increase with increasing fixed costs. This result is not surprising because the objective of the solution is to minimise costs and if the fixed costs are increased, the solution responds by reducing the number of setups (or orders placed) and this is achieved by increasing the order quantity (which means fewer setups) and thus the cycle time is increased as well. While all three fixed costs showed the same general response pattern, the degree of sensitivity differed among them, with K_{Rj} being the most sensitive and K_{rj} being the least sensitive parameter among the three. K_{rj} is expected to be the most sensitive because it is neither divided by n nor m_j, while K_{pj} should have been the least sensitive if

n is greater than 1. The effect of n dividing K_{pj} is however not really seen on K_{pj} because $n = 1$.

3.2.5.2 Solution with Heuristic 2 – Genetic Algorithm

The GA procedure was used to solve the same sets of problems. The algorithms were coded in Matlab version 2007 and run of a laptop with Intel I7 core and 4GB RAM. Observation about quality of solution and speed of convergence was made as two simulation parameters, numPop and numIter, are varied. Both numPop and numIter were initially set between 20 and 500 and different scenarios and investigated for the 3-container and 6-container problems. Each scenario was run three times and the average values computed. Four of these scenarios are reported in Table 3.2.5. In this table, computation time means the time lapse between start and end of a simulation run as indicated by Matlab's time function calls. Iteration to convergence means the number of iterations at which the minimum cost was first reported in the sample run. It should be noted that the cost has been written in millions of dollars as shown on the cost axis (i.e. 1.02 means 1.02M). The computation time is measured in seconds and reported to three decimal places.

For the 3-container problem, the GA solution found the same answers as the sequential optimisation heuristics (heuristics 1) in all cases except scenario 1 where numPop = numIter = 20. In this case, only one of the three runs converged at the same minimum cost obtained by the heuristics 1 (706,200). The other two were higher. For the 6-container problem, none of the scenarios was able to achieve the minimum cost value obtained by heuristics 1 in any instance of the run. The minimum cost for each run was at least 10 percent more than the cost achieved by heuristics 1. Considering the time taken to solve each scenario of 3-container problem compared to its equivalent 6-container problem and the time of convergence, it balloons. It can also be seen that as either the number of population or iteration increases, the computational effort increases more disproportionately to the gain observed in cost. If the result for numPop=20 by numIter=500 is compared to that of numPop=500 by numIter=20, it can be seen, on the average, that increasing population size seems to produce better result than increasing the number of iterations. It can also be seen, however, that the computational burden of increasing the number of Population is heavier than increasing the number of iterations. These behaviours may be attributable to the series of while loops used in the implementation of the GA model. These are, however, necessary to prevent infeasible solutions, hence, a smarter approach to prevent infeasibility may be necessary.

	3-Container	6-Container
Number of Population	20	20
Number of Iteration	20	20
Computation time	0.035	0.378
Iteration to convergence	7.667	4.667
Minimum Cost achieved	0.71062	1.095
Number of Population	20	20
Number of Iteration	500	500
Computation time	0.59	23.944
Iteration to convergence	78.333	245.667
Minimum Cost achieved	0.70662	1.0765
Number of Population	500	500
Number of Iteration	20	20
Computation time	0.571	9.614
Iteration to convergence	4.667	7.667
Minimum Cost achieved	0.70622	1.0855
Number of Population	500	500
Number of Iteration	500	500
Computation time	13.624	241.898
Iteration to convergence	5.333	160
Minimum Cost achieved	0.70622	1.075

Table 3.2.5: Solution from GA scenarios

Running the model with numPop=2000 and numIter=2000 for the 6-container problem still could not attain the value produced by the first heuristic. Three instances of this were run, and they all converged before 1000 iterations. The average cost found was 1.0735 and the minimum was 1.0726. The average computational time changed from 241.9 seconds (about 4 minutes) to 3862.85 seconds (1.073 hours). In all these instances, by plotting the average cost per population of chromosomes, it was observed that the population average was mean reverting each time a drop occurs as shown in Figure 3.2.12, indicating the steadiness of the variance.

Since all instances with numPop=2000 were observed to have converged before 1000 iterations, an instance with numPop=5000 was run with numIter=1000. The minimum cost in this instance converged at 1.0738 after the 800th iteration as shown in Figure 3.2.13, higher than the result found by one of the instances of runs with numPop=2000. This run of 5000 was achieved at a computational time of 5156.023 seconds (1.4322 hours). It was therefore concluded that it may be computationally difficult to attain the value obtained from heuristic 1.

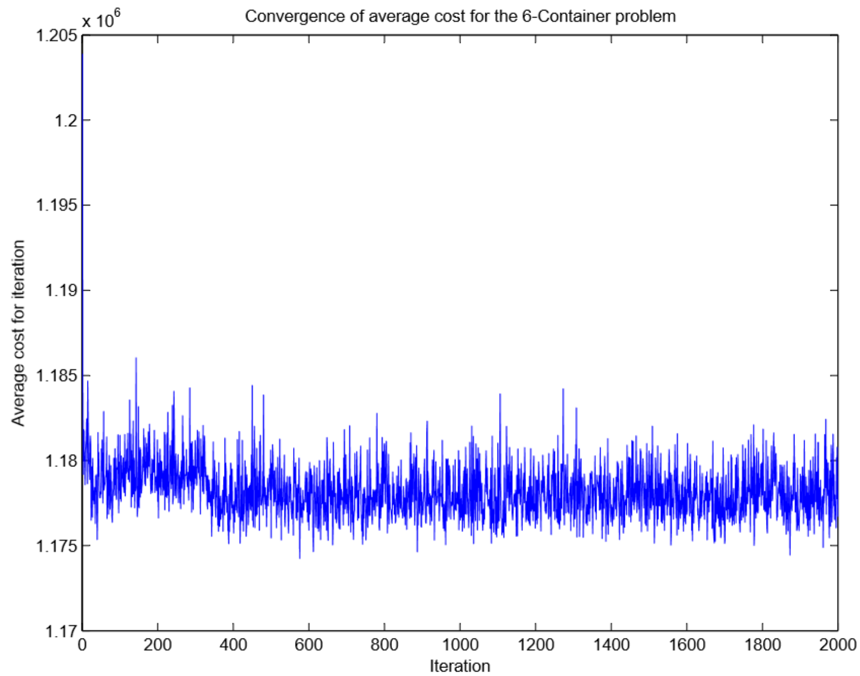


Figure 3.2.12: The average population value reverting to the current mean

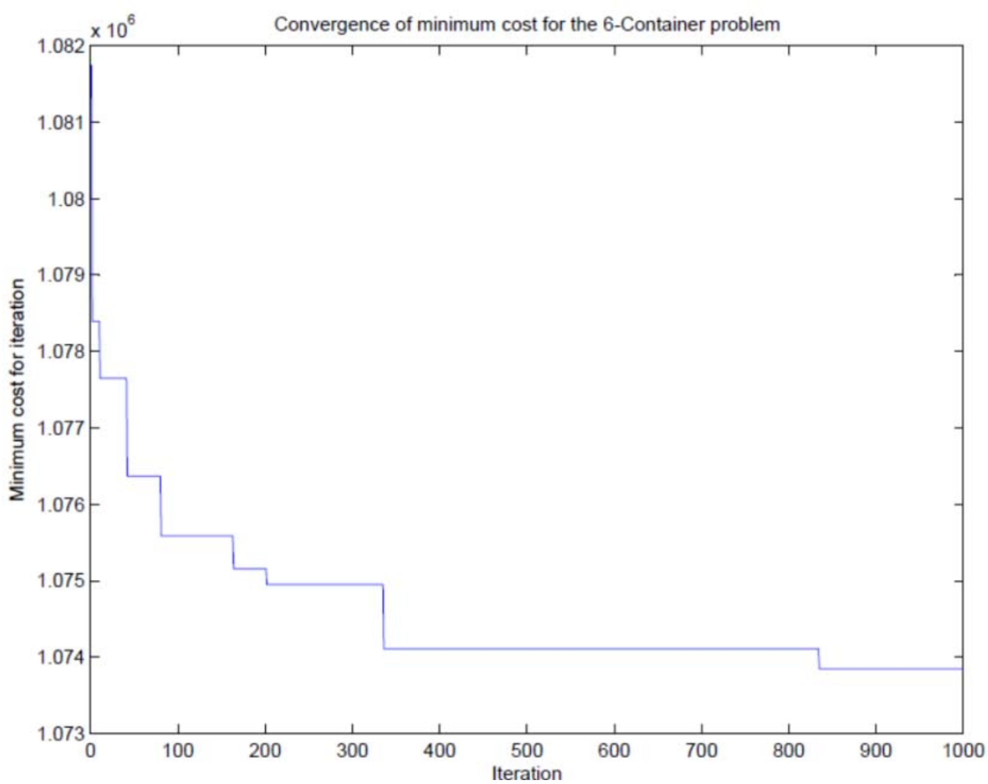


Figure 3.2.13: Convergence of minimum cost for numPop=5000, numIter=1000

3.2.6 Conclusion

A multi-type container return management model in which some of the containers are repaired in a facility with shared repair capacity and limited storage capacity was presented. The functional form for the economic quantities to purchase, collect and repair were derived for the joint return system and the constraining equations for the cycle times (upper and lower bounds) based on repair and storage capacities were derived. The lot sizing functions cannot be solved in closed form, hence heuristic solutions were proposed. The first heuristic is a sequential optimisation algorithm that iteratively seeks the optimal combination of return numbers for a given number of repairs until a turning point the first infeasibility is obtained. From this, either the latest feasible solution observed or the boundary region solution near the infeasible solution is selected as the optimal. The second heuristic solution customises a general random search meta-heuristic. The Genetic Algorithm (GA) model is adapted for this purpose. The sequential optimisation solution seems to produce the better result and also gets it more quickly than the GA model. This is probably because it is particular to the problem of interest.

Chapter 4

Section one: Empty containers repositioning in South Africa seaports

4.1.1 Introduction

Empty containers repositioning plays a very important role in both inland and sea transportation system. This is particularly due to the rapid growth in global trade, for which containerisation is becoming more and more popular. The repositioning system for empty containers in the inland transportation is different from that in sea transportation. The differences are in the management, capacities, routes, timetables, flexibility and constraints. The availability of empty containers in seaports depends on the efficiency of its management. If the empty containers movements between seaports and depots are not managed carefully, it may lead to an increase in the risk of unmet customer demands due to unavailability of the right quantity of empty containers at the right period to meet customer's requirements at the right destination. And for this reason the repositioning system in the sea transportation is more complex than that in inland transportation.

Empty containers repositioning problem is a global problem which seems unavoidable because of the trade imbalance between exports and imports of empty containerised items in the different seaports. The main reason for the difficulty in the repositioning process is that it is not easy to know the suitable quantity of empty containers required in the different ports in the future.

4.1.2 Background

Empty container repositioning (ECR) has recently become one of the burning research issues in supply chain management. Choong et al (2002) discussed the effect of the length of the planning horizon on empty container management for multimodal transportation networks including truck, rail, and barge. A case study of potential container-on-barge operations within the Mississippi River was used to minimize the total cost of empty container flows between locations. Jula et al (2004) developed a mathematical model to optimize empty container reuse in the Los Angeles and Long Beach (LA/LB) port. The proposed model seeks to minimize the total cost of dynamic empty container movements between ports and depots. Song et al (2007) focused on container allocation on shipping routes to optimize the distribution volume at ports for each voyage. They proposed models to determine the container allocation volume at ports and on vessels, and also as a measure for liner companies to make full use of containers and to minimize the operational cost, considering the cargo supplies at the ports on the routes. Wang et al (2008) presented a liner programming model to reduce the cost of empty container allocation and transportation among different ports. They presented a systematic description of the process of empty container allocation and transportation and its characteristics, and explained the major factors and the subjective and objective reasons which result in empty container allocation. Feng and Chang (2008) addressed empty container repositioning problems for intra-Asia liner shipping as a two-stage problem. Stage one identifies and estimates the empty container stock at each port, and stage two models the empty container repositioning plan with shipping service network as a transportation problem. Belmecheri et al (2009) modified a mathematical model to optimize empty containers reuse between several sites, as well as to minimize the local costs of empty containers inland movements. Chandoul et al (2009) focused on the optimisation of the returnable container management problem. They proposed an integer linear program model to minimize the total cost resulting from empty container transportation between sites, purchasing new containers and container storage cost. Lin and Han (2009) used stochastic programming to reposition empty containers under uncertain demand and supply. The proposed mathematical model was used to minimize the total costs of transportation, cost of renting, and cost of storing of empty containers. Sun et al (2009) focused on empty container repositioning problem between seaports, and developed a mathematical model to minimize the total cost of empty container repositioning between two ports in a cycle which includes railway freight, stock change and handling change. Dong and Song (2009) focused on container fleet sizing and empty repositioning problem in multi-vessel, multi-port and multi-voyage shipping systems with dynamic, uncertain and imbalanced customer demands. Xiaolong (2010) analyzed the inland empty container reposition (ECR) problem under certain and uncertain conditions, and established a model based on the random parameters of inland reposition system. Huang (2011) presented a dynamic model based on time expanded to minimize the expected total cost of multi-class empty container repositioning. Gou et al (2011) proposed a model construct of two strategies for empty container allocation in maritime container shipping networks, allocation by minimum cost (AMC) and allocation by shortest distance (ASD), to minimize the total costs including operating costs and capital costs during container transportation in the container shipping network. Song and Dong (2011) addressed the empty container repositioning problem between ports by using two policies: the flexible destination port policy (FDP) and determined destination port policy (DDP)) to evaluate the effectiveness of empty container management for three major shipping routes (Europe-Asia, Trans-Pacific, and Trans-Atlantic).

In this chapter the empty container repositioning problem in South Africa seaports is studied. The main objective of this research is to model empty container repositioning through mathematical programming to minimize the total costs including transportation cost, inventory-holding cost, leasing cost & purchasing new empty containers cost.

4.1.3 Problem Description

Empty container repositioning (ECR) has become one of the important problems faced by seaports and shipping companies, as it is almost impossible to avoid the empty container repositioning and distribution problems between several ports. When the empty containers are transported to the destination ports, they are categorized as exports;,, if the empty containers are received from other ports, they are categorized as imports. Therefore if the number of imported empty containers is less than or greater than the number of exported empty containers, there will be an imbalance. Depending on the level of trade imbalance in terms of the numbers of import and export empty containers between seaports (due to different economic needs in different regions), the empty containers should be repositioned from seaports which have a surplus of empty containers to seaports which have a shortage of empty containers. Sometimes the seaports must lease or purchase new empty containers and store the surplus empty containers in the depots to satisfy customer demand. This chapter focuses on the empty containers repositioning problems in South Africa's seaports (Cape Town, Port Elizabeth, East London, Durban, and Richards Bay) as a case study, and also addresses the distribution problems between seaports and depots. The data shown in Table 4.1.1 shows the empty container flow and the numbers of import (landed) and export (shipped) empty containers into and from South African seaports. These numbers show that empty container flow and imbalance are progressively increasing in South Africa. The imbalance between the numbers of landed and shipped empty containers in 2003 was 2832 TEUs, and the ratio of shipped ECs to landed ECs was 0.989. As of 2011, the imbalance was 345980 TEUs, and the volume of shipped empty containers was double the volume of landed empty containers. Table

4.1.2 shows the number of landed and shipped empty containers from South Africa seaports for the period of JANUARY - DECEMBER 2009. This presents a typical scenario, on a more micro level, of the level of imbalance in the number of containers shipped into and out of South Africa. It can be seen that not only is there imbalance at the annualized aggregate level, but that the imbalance is probably even more pronounced at the monthly level.

	RICHARDS BAY	DURBAN	EAST LONDON	PORT ELIZABETH	CAPE TOWN	TOTAL
			JANUARY - DECEMBER 2011			
LANDED	9 329	153 334	4	59 556	115 537	337 760
SHIPPED	208	482 232	25 624	60 905	114 771	683740
			JANUARY - DECEMBER 2009			
LANDED	2 660	246 039	32	31 943	146 908	427 582
SHIPPED	466	358 352	19 119	67 200	83 336	528473
			JANUARY - DECEMBER 2008			
LANDED	2 765	217 264	4 632	27 676	140 390	392 727
SHIPPED	784	447 981	25 609	102 332	90 785	667491
			JANUARY - DECEMBER 2007			
LANDED	854	173 233	923	31 761	137 321	344 092
SHIPPED	160	451 356	17 613	101 338	121 723	692190
			JANUARY - DECEMBER 2006			
LANDED	454	158 714	1 432	24 014	131 562	316 176
SHIPPED	231	393 173	8 853	94 353	129 019	625629
			JANUARY - DECEMBER 2005			
LANDED	467	147 257	1 123	20 049	126 642	295 538
SHIPPED	203	298 882	10 367	84 519	96 486	490457
			JANUARY - DECEMBER 2004			
LANDED	528	138 889	1 968	16 306	89 156	246 847
SHIPPED	90	220 550	8 318	54 796	61 023	344777
			JANUARY - DECEMBER 2003			
LANDED	551	170 046	1 969	20 011	70 833	263 410
SHIPPED	295	162 490	4 482	52 475	40 836	260578

Table 4.1.1: Number of landed and shipped empty containers in 6M units (TEU'S)

4.1.4 Model Presentation

In this section a model to minimize the total cost of empty container repositioning between several South Africa seaports is presented. The model calculates the total cost as the sum of transportation cost, inventory-holding cost, leasing cost and the cost of purchasing new empty containers.

4.1.4.1 Assumptions

The following assumptions are made in the model:

1. The seaports can be both shippers and customers.
2. The customer's demand (South Africa seaports) for empty containers must be satisfied.
3. Only one type of empty container is used (Twenty-foot Equivalent Unit (TEU) 20×8×8 foot) to transfer goods between seaports and depots.
4. One type of transportation modes is considered (vessel).
5. There is no limitation to the number of leasing and purchasing of empty containers to satisfy the customer's demands.
6. To simplify the model, total cost is calculated (the objective function) for empty containers repositioning as the sum of transportation cost, inventory-holding cost, leasing cost and the cost of purchasing new empty containers. The penalty cost for unmet customer's demand (since all demands are to be met), and lifting-on/lifting-off costs are not calculated.

LANDED EMPTY CONTAINERS			JANUARY - DECEMBER 2009			
	RICHARD S BAY	DURBAN	EAST LONDON	PORT ELIZABETH	CAPE TOWN	TOTAL
JANUARY	4	17 296	0	60	12 802	30 162
FEBRUARY	0	22 401	0	431	15 704	38536
MARCH	0	21 252	0	1 264	19 968	42 484
APRIL	20	17 916	0	1 677	15 833	35446
MAY	0	29 431	0	1 438	18 576	49 445
JUNE	0	27 316	0	5 685	14 320	47321
JULY	0	25 377	20	3 788	9 415	38 600
AUGUST	0	24 355	10	3 402	6 231	33998
SEPTEMBER	390	22 120	2	5 464	8 413	36 389
OCTOBER	365	18 235	0	3 558	7 728	29886
NOVEMBER	1 120	11 282	0	3 229	9 297	24 928
DECEMBER	761	9 058	0	1 947	8 621	20387

TOTAL	2 660	246 039	32	31 943	146 908	
SHIPPED EMPTY CONTAINERS			**JANUARY - DECEMBER 2009**			
	RICHARD S BAY	**DURBAN**	**EAST LONDON**	**PORT ELIZABETH**	**CAPE TOWN**	**TOTAL**
JANUARY	12	39 499	1 284	3 627	4 562	48 984
FEBRUARY	0	40 659	1 880	8 519	9 980	61038
MARCH	15	25 896	1 118	2 256	6 540	35 825
APRIL	0	23 289	1 542	5 642	6 480	36953
MAY	0	23 064	1 056	4 692	6 931	35 743
JUNE	100	23 818	944	6 519	3 362	34743
JULY	0	18 856	1 234	1 528	7 238	28 856
AUGUST	0	21 292	1 403	3 727	5 160	31582
SEPTEMBER	41	23 383	1 173	10 928	7 389	42 914
OCTOBER	0	34 715	3 045	4 370	6 899	49029
NOVEMBER	0	49 252	2 132	10 217	12 528	74 129
DECEMBER	298	34 629	2 308	5 175	6 267	48677
TOTAL	466	358 352	19 119	67 200	83 336	

Table 4.1.2: Number of landed and shipped empty containers within a year in 6M units (TEU'S)

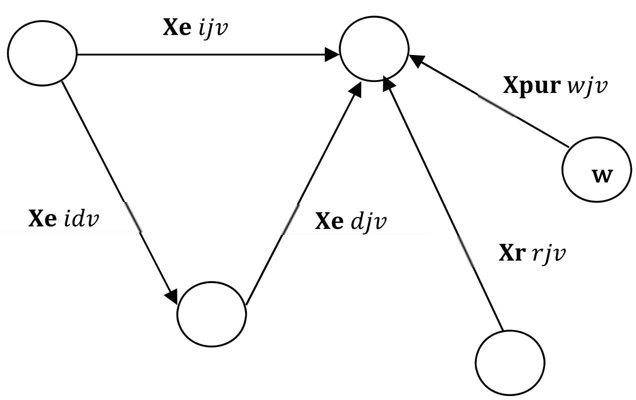


Figure 4.1.1: Container flow schema.

Figure 4.1.1 is a diagrammatic representation of the schema of the flow. Containers can flow from a surplus point, *i*, to a deficit point, *j*, or be kept in a depot, *d*, from where it would later be moved to the deficit point, j. Also, empty container demand at j could be met by either leasing, r, or purchasing, w, from outside. The cost associated with each of these actions is indicated on the arc directed away from it. The objective is to select the best positioning strategy, given all the possible connections between all the shipping points as shown in Figure 4.1.2.

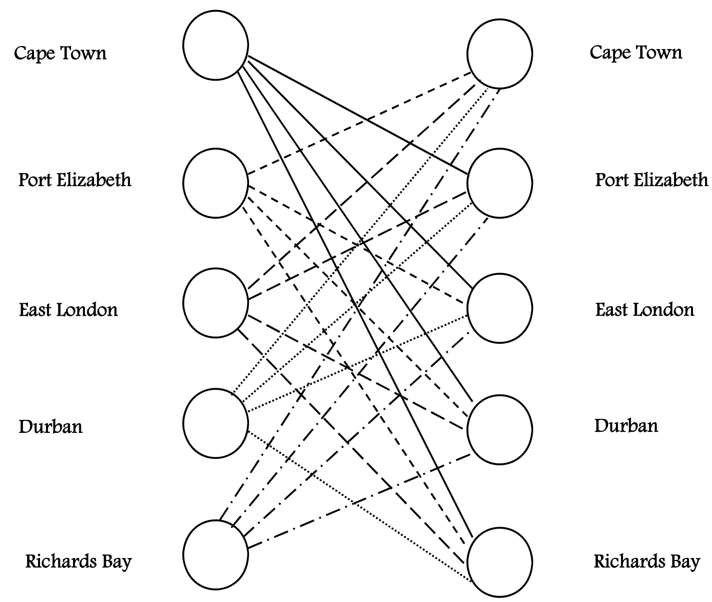


Figure 4.1.2: A depiction of possible links amongst South Africa ports

4.1.4.2 Notation

i ϵ I , j ϵ J , d ϵ D , t ϵ T , v ϵ V , r ϵ R , w ϵ W

I : Set of suppliers (or ports) who supply empty containers, i= 1,2 .... m .

J : Set of shippers (or customers or ports) who need empty containers, j= 1,2 ..... n .

D : Set of depots (or containers yard), d = 1,2 ..... b .

R : Set of leasing companies for empty containers, r =1,2 ... f.

W : Set of companies are selling new empty containers, w = 1,2 ..... y .

T : Time period.

V : Transport mode (vessels, railway, trucks), v = 1,2 ..... c .

Ch d : The inventory holding cost per TEU per day at depot d (Rand/TEU * day).

Ce ijv : The transportation cost per TEU (empty container) per day from port i to port j by transport mode v (Rand/TEU * day).

Cf ijv : The transportation cost per TEU (fully loaded container) per day from port i to port j by transport mode v (Rand/TEU * day).

Ce idv : The transportation cost per TEU (empty container) per day from port i to depot d by transport mode v (Rand/TEU * day).

Ce djv : The transportation cost per TEU (empty container) per day from depot d to port j by transport mode v (Rand/TEU * day).

Cr rj : The leasing cost per TEU per day at leasing company r (Rand/TEU * day).

Cpur wj : The purchasing cost per new TEU at company which selling new empty containers w (Rand/TEU).

Hd : The inventory level of empty containers at depot d (TEUs).

Xe ijv : Number of empty containers moved from port i to port j by transport mode v (TEUs).

Xf ijv : Number of fully loaded containers moved from port i to port j by transport mode v (TEUs).

Xe idv : Number of empty containers moved from port i to depot d by transport mode v (TEUs).

Xe djv : Number of empty containers moved from depot d to port j by transport mode v (TEUs).

Xr rjv : Number of leased empty containers at port j which moved from leasing company r to port j by transport mode v (TEUs).

Xpur wjv : Number of purchased empty containers at port j which moved from the company which selling new empty containers w to port j by transport mode v (TEUs).

A j : Number of empty containers requested by port j to satisfy the demand (TEUs).

B i : Number of empty containers available at port i (TEUs).

Th d : Inventory time of empty containers at depot d (day).

Te ijv : Transportation time of empty containers between port i & port j by transport mode v (day).

Tf ijv : Transportation time of fully loaded containers between port i & port j by transport mode v (day).

Te idv : Transportation time of empty containers between port i & depot d by transport mode v (day).

Te djv : Transportation time of empty containers between depot d & port j by transport mode v (day).

Tr rjv : Leasing time of empty containers moved between leasing company r & port j by transport mode v (day).

4.1.4.3 Objective function:

We propose a mathematical model as follows:

$$\min Z = \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{t=1}^{t=a}\sum_{v=1}^{v=c} \mathbf{Ce}\,ijv \;*\; \mathbf{Xe}\,ijv \;*\; \mathbf{Te}\,ijv$$

$$+\sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{t=1}^{t=a}\sum_{v=1}^{v=c} \mathbf{Cf}\,ijv \;*\; \mathbf{Xf}\,ijv \;*\; \mathbf{Tf}\,ijv$$

$$+\sum_{i=1}^{i=m}\sum_{d=1}^{d=b}\sum_{t=1}^{t=a}\sum_{v=1}^{v=c} \mathbf{Ce}\,idv \;*\; \mathbf{Xe}\,idv \;*\; \mathbf{Te}\,idv$$

$$+\sum_{d=1}^{d=b}\sum_{j=1}^{j=n}\sum_{t=1}^{t=a}\sum_{v=1}^{v=c} \mathbf{Ce}\,djv \;*\; \mathbf{Xe}\,djv \;*\; \mathbf{Te}\,djv$$

$$+\sum_{d=1}^{d=b}\sum_{t=1}^{t=a} \mathbf{Ch}\,d \;*\; \mathbf{Hd} \;*\; \mathbf{Th}\,d$$

$$+\sum_{r=1}^{r=f}\sum_{j=1}^{j=n}\sum_{t=1}^{t=a}\sum_{v=1}^{v=c} \mathbf{Cr}\,rj \;*\; \mathbf{Xr}\,rjv \;*\; \mathbf{Tr}\,rjv$$

$$+\sum_{w=1}^{w=y}\sum_{j=1}^{j=n}\sum_{v=1}^{v=c} \mathbf{Cpur}\,wj \;*\; \mathbf{Xpur}\,wjv$$

The first four terms in the objective function represent the transport cost component. The fifth term is the inventory holding cost for the number of days considered. The sixth term is the cost of leasing containers in cases of shortages, while the last term is the cost of purchasing new containers to be used over the planning horizon. Constraint 1 indicates that all demands must be met, while constraint 2 is imposed to guarantee the balance of flow amongst all supply sources with the total containers made available.

4.1.4.4 Constraints

$$\sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{v=1}^{v=c} \mathbf{Xe}\,ijv + \sum_{i=1}^{i=m}\sum_{d=1}^{d=b}\sum_{v=1}^{v=c} \mathbf{Xe}\,idv = \mathbf{B}i \;\;\ldots 1$$

$$\sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{v=1}^{v=c} \mathbf{Xe}\,ijv + \sum_{d=1}^{d=b}\sum_{j=1}^{j=n}\sum_{v=1}^{v=c} \mathbf{Xe}\,djv + \sum_{r=1}^{r=f}\sum_{j=1}^{j=n}\sum_{v=1}^{v=c} \mathbf{Xr}\,rjv + \sum_{w=1}^{w=y}\sum_{j=1}^{j=n}\sum_{v=1}^{v=c} \mathbf{Xpur}\,wjv = \mathbf{A}j \;\;\ldots 2$$

$\mathbf{Xe}\,ijv, \mathbf{Xe}\,idv, \mathbf{Xe}\,djv, \mathbf{Xr}\,rjv, \mathbf{Xpur}\,wjv, \mathbf{Xf}\,ijv \geq 0$

4.1.5 Calculations and Results

We use different scenarios to demonstrate the application of the model. First, we consider a scenario where there is a balance between the empty containers demanded and supplied among the ports. Next, we consider a scenario where the demand for empty containers is more than the supply for empty containers. Finally, we consider two cases where the supply is more than the demand under two different conditions. We consider the possible transportation network amongst the South Africa seaports as shown in Figure 4.1.3. Table 4.1.3 shows the transportation cost of empty containers between the Supply and demand ports in Rand/TEU. Table 4.1.4 shows the distance between South Africa seaports (Nautical mile), while Table 4.1.5 shows the total shipping time between South Africa seaports in days. All these constitute the remaining inputs parameter to our model.

Cost/TEU			Ports j		
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**
Cape Town	0	1300	1600	2200	2500
Port Elizabeth	1300	0	500	1200	1500
East London	1600	500	0	800	1000
Durban	2200	1200	800	0	400
Richards Bay	2500	1500	1000	400	0

Table 4.1.3: Transportation cost of empty containers between South Africa seaports in Rand/TEU

DISTANCE BETWEEN PORTS (Nautical mile)			Ports j		
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**
Cape Town	0	430	546	801	884
Port Elizabeth	430	0	134	390	473
East London	546	134	0	260	343
Durban	801	390	260	0	89
Richards Bay	884	473	343	89	0

Table 4.1.4: Distance between South Africa seaports in Nautical mile

TOTAL TIME BETWEEN PORTS (Day)			Ports j		
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**
Cape Town	0	1.292	1.625	2.375	2.625
Port Elizabeth	1.292	0	0.417	1.167	1.417
East London	1.625	0.417	0	0.792	1
Durban	2.375	1.167	0.792	0	0.25
Richards Bay	2.625	1.417	1	0.25	0

Table 4.1.5: Total time between South Africa seaports in day

The model was solved for the different scenarios using Microsoft Excel (2007) solver. The solutions obtained are presented in Tables 4.1.6 to 4.1.9, with a brief discussion of the solutions.

4.1.5.1 Scenario 1- When the total supply is equal to the total demand

Table 4.1.6 shows the result from MS Solver when the total supply of empty containers is 10700 TEU, and the total demand is 10700 TEU. The total cost of repositioning between South Africa seaports is 9540000 Rand.

No. Of TEUs			Ports j			
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Supply (TEUs)**
Cape Town	1100	0	0	3200	700	**5000**
Port Elizabeth	0	1600	900	0	0	**2500**
East London	0	0	900	0	300	**1200**
Durban	0	0	0	1000	0	**1000**
Richards Bay	0	0	0	0	1000	**1000**
Demand (TEUs)	**1100**	**1600**	**1800**	**4200**	**2000**	
Total	1100	1600	1800	4200	2000	
Cost	**0**	**0**	**450000**	**7040000**	**2050000**	
Total Cost (Rand)	**9540000**					

Table 4.1.6: Solution for a case of equal demand and supply

4.1.5.2 Scenario 2 - When the total supply is less than the total demand

Table 4.1.7 shows the result when the total supply of empty containers is 9700 TEU, and the total demand is 10700 TEU. The total cost of repositioning between South Africa seaports is 7040000 Rand. In this situation we must lease 1000 TEUs from the leasing company to satisfy the customers' demands. The leasing cost is 18 Rand per TEU per day and the minimum leasing period for ECs is 1 Month (which is a a condition in the leasing company).

Leasing cost = 18 × 30 × 1000 = 540000 Rand
The total cost = 7040000 + 540000 = 7580000 Rand
Richards Bay port must lease 1000 TEUs to meet the customer's requirements.

4.1.5.3 Scenario 3 - When the total supply exceeds the total demand

Table 4.1.8 shows the result for the scenario where the total supply of empty containers is 10700 TEU, and the total demand is 9700 TEU. The total cost of repositioning between South African seaports is 7040000 Rand. In this situation we must store 1000 TEUs in the Cape Town port or send it to the nearest depot or container yard. If we suppose there is space in Cape Town port to store 1000 TEU, then we do not need to add additional inventory holding and/or transport costs to the total cost of repositioning. But if there is no space in Cape Town port to store 1000 TEUs, we must send them to the depot, and we need to add the inventory holding cost (Rand/TEU * day) to the total cost of repositioning.

We see from tables 4.1.7 and 4.1.8, the total cost of repositioning of ECs for two cases are the same (ZAR7040000), because there is no change in repositioning cost of ECs in the demand ports East London and Durban, ZAR300000 and ZAR6740000 respectively for each case. The changes occur only in the quantity of ECs in ports Richards Bay and Cape Town, which are a shortage and a surplus of empty containers respectively, and for this reason the two seaports must lease or purchase new empty containers or store the surplus of empty containers in the depots. We must also add the additional costs of leasing and inventory holding to the total cost of repositioning of ECs.

The table 4.1.9 shows another result when the total supply exceed the total demand in different case. We change the demand quantity of Durban only. The total supply of empty containers is 10700 TEU, and the total demand is 9700 TEU (the same value as the total supply and demand as in previous situations). The total cost of repositioning between South Africa seaports increased to ZAR7340000 because there is additional movement between ports (Cape Town-Richards Bay), and that means, there is additional repositioning cost of ECs (ZAR2500000) in the demand port (Richards Bay). Also, although the repositioning cost of ECs in Durban port decreased to ZAR4540000, the additional movement increased the total cost of repositioning by 34.06%, and by 55.07% compared to the repositioning cost of ECs in Durban port.

No. Of TEUs			Ports j			
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Supply (TEUs)**
Cape Town	1100	0	0	2900	0	**4000**
Port Elizabeth	0	1600	600	300	0	**2500**
East London	0	0	1200	0	0	**1200**
Durban	0	0	0	1000	0	**1000**
Richards Bay	0	0	0	0	1000	**1000**
Dummy	0	0	0	0	1000	**1000**
Demand (TEUs)	**1100**	**1600**	**1800**	**4200**	**2000**	
Total	1100	1600	1800	4200	2000	
Cost	0	0	300000	6740000	0	
Total Cost (Rand)	**7040000**					

Table 4.1.7: Solution for a case where the total supply is less than the total demand

No. Of TEUs			Ports j				
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Dummy**	**Supply (TEUs)**
Cape Town	1100	0	0	2900	0	1000	**5000**
Port Elizabeth	0	1600	600	300	0	0	**2500**
East London	0	0	1200	0	0	0	**1200**
Durban	0	0	0	1000	0	0	**1000**
Richards Bay	0	0	0	0	1000	0	**1000**
Demand (TEUs)	**1100**	**1600**	**1800**	**4200**	**1000**	**1000**	
Total	1100	1600	1800	4200	1000	1000	
Cost	0	0	300000	6740000	0	0	
Total Cost (Rand)	**7040000**						

Table 4.1.8: Solution for the first case where the total supply is more than the total demand

No. Of TEUs			Ports j				
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Dummy**	**Supply (TEUs)**
Cape Town	1100	0	0	1900	1000	1000	**5000**
Port Elizabeth	0	1600	600	300	0	0	**2500**
East London	0	0	1200	0	0	0	**1200**
Durban	0	0	0	1000	0	0	**1000**
Richards Bay	0	0	0	0	1000	0	**1000**
Demand (TEUs)	**1100**	**1600**	**1800**	**3200**	**2000**	**1000**	
Total	1100	1600	1800	3200	2000	1000	
Cost	**0**	**0**	**300000**	**4540000**	**2500000**	**0**	
Total Cost (Rand)	**7340000**						

Table 4.1.9: Solution for the second case where the total supply is more than the total demand

4.1.6 Conclusion

This section discussed the problem of Empty Containers Repositioning in South Africa seaports of Cape Town, Port Elizabeth, East London, Durban, and Richards Bay. The study modelled the empty containers repositioning as a linear program, the objective being to minimize the total expected cost of the repositioning process. Four scenarios were considered for cases of supply and demand balance, where demand exceeds supply and where supply exceeds demand. These scenarios were solved using MS Excel Solver. The solution provides valuable insight for making decisions about repositioning of containers under the different scenarios considered.

Section two: The optimal routes for the vessels to transport empty containers under different shipping service networks design (revised version) [1]

[1]Proceedings of International Conference on Industrial Engineering and Operations Management (IEOM), Dubai, United Arab Emirates, 3-5 March 2015.

4.2.1 INTRODUCTION

Rapid developments in maritime transportation make it essential for container shipping companies to optimize voyage routes for the vessels or carriers to transport and distribute empty and fully loaded containers among ports and depots within short distances and minimum transportation time. Every shipping company needs a mechanism to select the best service route by considering many factors like: supply/demand level, vessel type and capacity, Empty Containers (ECs) distribution prioritization, vessel fleet deployment levels, and ECs movements across shipping service networks. In selecting a suitable voyage route for the shipment of ECs, shippers are concerned with issues such as total transportation cost which include ECs distribution (and re- distribution) cost, port operations (handling on/off, ECs storage services , ... etc), port charge, and the dwelling time in the port as well as its implication on cost. Shipping service network design and routing problems have received the attention of many scholars in recent years because of the centrality of the industry to international trade. Notteboom [2004] presented a review of challenges faced by ports and container shipping companies in terms of activities, operations, facilities, and opportunities to improve the services through cooperation. The author discussed the impact of changes in liner service network design on the major international trade routes. Furthermore, he discussed the need for integration along the supply chain, and the gradual shifting from pure shipping operations to integrated logistics solutions. Hus and Hsieh [2005] developed a two-objective model to minimize the total shipping and inventory costs, to decide whether to route a shipment (ECs) through a hub or directly to its destination. The proposed model evaluates two types of costs in selecting shipping routes between two continents; shipping costs - capital and operating cost, fuel cost, and port charge; as well as inventory costs - waiting time cost and shipping time cost. The results show that the optimal routing decision tends to be direct shipping as container flow between origin and destination ports. The model also provides flexibility for en-route carriers in decision-making, and a tool to analyse the trade-off between shipping cost and inventory cost. Sun and Yang [2006] addressed the imbalance of demand and supply for empty containers between ports, container freight stations (CFS) and containers yards (CY) by establishing a model to determine the optimal cost of empty container distribution and leasing. They compared between the results of many conditions of empty container distribution strategies and empty container leasing strategies and the dependence of these strategies on the volume of demand and supply. The proposed model is based on the loading and unloading costs for containers and transportation cost for the containers returned in addition to empty container storage cost and leasing cost. Shintani et al [2007] addressed container shipping service networks design problem and container ship routing problem, by taking into account empty container repositioning (ECR). They proposed a model based on the shipping costs (operating and capital costs) and the penalty cost due to unmet customer demand and used it to determine the optimal voyage route that maximize profit for a liner shipping company. They used Genetic Algorithm to solve the developed model and to provide insight into the problem of empty container repositioning. Feng and Chang [2008] addressed empty container reposition problems for intra-Asia liner shipping as a two-stage problem. The first stage identifies and estimates the empty container stock at each port, and the second stage models the empty container reposition planning with shipping service network as the Transportation Problem. They proposed a model to estimate the quantity of empty container stock at ports and to minimize the total cost of repositioning empty containers between supply ports and demand points. Imai et al [2009] also presented a mathematical model for ECR to optimize the liner shipping network design by minimizing the total cost associated with capital costs, ECR cost, storage cost, and leasing ECs cost. They applied the model on two typical service networks with different ship sizes to address the container management and the container distribution problems in the Asia-Europe and Asia-North America trade lanes.

Song and Carter [2009] applied four strategies to reduce the total cost of empty containers repositioning (ECR), based on container flow balancing across different shipping service routes (Trans-Pacific, Trans-Atlantic, Europe-Asia), and container fleet sharing among different ocean carriers or shipping lines. They found that the route-coordination strategy is much more beneficial than container-sharing strategy in reducing ECR costs. The route-coordination and container-sharing strategies can also alleviate the degree of ECs movements, but it cannot eliminate the ECR problem. Braekers et al [2010] designed a service network for barge transportation with empty container repositioning, and they determined the optimal shipping route to transport loaded and empty containers among the Albert Canal with four hinterland ports connecting to the port of Antwerp Belgium. The proposed model is based on three different empty container management scenarios between ports to maximize the profit and determine the best location of empty containers in the hinterland ports. Yang and Chen [2010] analysed the network structure of inter-continental container shipping lines and presented a Genetic Algorithm model to minimize the total transportation cost (including the fixed cost of one voyage, fuel cost, port tariff and loading/unloading fees of containers). The proposed model was applied to optimize the container shipping network between ports surrounding Bohai bay in China and two ports in the West of the USA. According to the results, they found the model helpful and useful to shipping companies and to the ports authorities that are mandated to design a shipping network that may generate a win-win scenario for both parties. Reinhardt et al [2010] focused on the shipping network design and routing problems and formulated a mixed integer linear programming model to minimize the transportation cost, transhipping cost, and cost of vessel sailing. The proposed model includes routes depending on capacities, heterogeneous vessel fleet, cost of transhipment, and butterfly routes. They used the Branch-and-Cut method for solving the problems. Meng and Wang [2011] developed a mixed-integer linear programming model to deal with liner shipping service network design problem combined with hub-and-spoke (H and S). The model also addressed multi-port-calling (MPC) operations and empty container repositioning via a case study on Asia–Europe–Oceania shipping operations. The proposed model seeks to minimize the total operating cost, based on Fixed operating cost (bunker consumption cost, canal dues, and the fixed cost of calling at the ports), and variable operating cost (berth occupancy charge and containers handing cost at each port), and empty container repositioning cost. Shi and Xu [2011] addressed the empty containers repositioning problem in a fixed route that covers two ports (as two cases), and analysed the structures of optimal policies of empty repositioning decisions. The first case is the offline case, where the demand information is assumed as a random variable with known distribution, and the second case is an online case, where the demand for information is partially known. They proposed a stochastic dynamic programming model to minimize the total costs, including transportation cost (empty and laden containers), holding cost and penalty cost due to unmet customer demand. Wang and Meng [2012] focused on Liner Ship Fleet Deployment (LSFD) problem with container transhipment operations. They formulated a mixed-integer linear programming model to optimize shipping service route on the Asia-Europe-Oceania shipping network. The proposed model was used to minimize the total cost associated with operating ships and voyages, berth occupancy charge, containers transhipment cost, loading and discharge cost, and cost of chartering in ships. The results show how ship utilization in the optimal solution can be used to redesign liner shipping service route.

4.2.2 PROBLEM DESCRIPTION

The selection of suitable voyage routes for the container vessels sailing across shipping service networks is a complex process especially, if we take into account the imbalance problem between the surplus and deficit ports, limitation of vessel capacities, and the sequence of vessels with schedules to carry the specified number of ECs among seaports. Most container shipping companies want to minimize the total cost related to ECs movements and port operations with minimum transportation time and short distance between origin and destination ports.

This section focuses on how to optimize voyage routes for container carriers and vessels in South Africa seaports, in order to minimize the total expected cost that is associated with ocean transportation cost, handling on/off costs, storage cost, leasing and purchasing costs.

4.2.3 MODEL PRESENTATION

In this section, a model is proposed for the determination of shipping routes based on the expected port operations and the movement of ECs between supply and demand ports, such that the total cost associated with transportation, handling on/off, storage, leasing and purchasing ECs is minimized. The proposed model's objective is to optimize the cost of utilising the voyage routes for the container vessels sailing across shipping service networks among South Africa seaports.

4.2.3.1 Assumptions

The following assumptions are made for the model:

- The seaports can be both supply and demand ports, or shippers and customers.
- Customer demand (South Africa seaports) for empty containers must be satisfied.
- Only one type of empty containers (Twenty-foot Equivalent Unit (TEU) – i.e. 20×8×8 foot) is used to transfer between seaports and depots.
- Only one type of transportation mode (vessel/carrier) is considered.
- The total number of empty containers transported by the vessel may not exceed the vessel's capacity, and maximum capacities of the vessels are 4000 TEU, 5000 TEU, 6000 TEU, 7000 TEU and 8000 TEU.
- There is no limitation to the number of empty containers that could be leased or purchased to satisfy the customer's demands.
- To simplify the model, the total costs (the objective function) are calculated to optimize the voyage routes, including transportation cost, handling on/off cost, storage cost, leasing and purchasing new ECs costs, but the penalty cost for unmet customer's demand. Is neglected.
- All decision variables must be non-negative and integer

4.2.3.2 Notation

Lets: $i \in I$, $j \in J$, $g \in G$, $d \in D$, $v \in V$, $r \in R$, $w \in W$

I : Set of suppliers (or ports) who supply containers (empty and fully loaded), i= 1,2 .... m .

J : Set of shippers (customers or ports) who need containers (empty and fully loaded), j= 1,2 .. n.

G : Types of containers (1= TEU , 2= FEU, 3= High Cube container, 4= Refrigerated container, 5= Tank container ... etc), g= 1,2 ..... q .

D : Set of depots, d = 1,2 ..... b .

R : Set of leasing companies for empty containers, r =1,2 ... f.

W : Set of companies are selling new empty containers, w = 1,2 ..... y .

V : Transport mode (vessels, railway, trucks), v = 1,2 ..... c .

Cet $ijgv$: The transportation cost per empty container type g, per time (day), which moved from port i to port j by transport mode type v (Rand/container * day).

Cf $ijgv$: The transportation cost per fully loaded container type g, per time (day), which moved from port i to port j by transport mode type v (Rand/container * day).

Ce $digv$: The transportation cost per empty container type g, per time (day), which moved from depot d to port i by transport mode v (Rand/container * day).

Ce $djgv$: The transportation cost per empty container type g, per time (day), which moved from depot d to port j by transport mode v (Rand/container * day).

Ce $rigv$: The transportation cost per empty container (leased) type g, per time (day), which moved from leasing company r to port i by transport mode v (Rand/container * day).

Ce $rjgv$: The transportation cost per empty container (leased) type g, per time (day), which moved from leasing company r to port j by transport mode v (Rand/container * day).

Ce $wigv$: The transportation cost per new empty container (purchased) type g, per time (day), which moved from purchasing company w to port i by transport mode v (Rand/container * day).

Ce $wjgv$: The transportation cost per new empty container (purchased) type g, per time (day), which moved from purchasing company w to port j by transport mode v (Rand/container * day).

Cho $ijgv$: The handling -on cost per container (empty or fully loaded) type g, at port i which moved to port j (Rand/container).

Chf $ijgv$: The handling -off cost per container (empty or fully loaded) type g, at port j which send from port i (Rand/container).
Cw $ijgv$: The inventory holding cost at port i per container (empty or fully loaded) type g, per time (day), which moved to port j by transport mode v (Rand/container * day).

Cr $rigv$: The leasing cost per empty container type g, at leasing company r per time (day), when the container moves from leasing company r to port i (Rand/container * day).

Cr $rjgv$: The leasing cost per empty container type g, at leasing company r per time (day), when the container moves from leasing company r to port j (Rand/container * day).

Cpur $wigv$: The purchasing cost per new empty container type g, at company selling empty containers w, when the container moves from selling company w to port i (Rand/container).

Cpur $wjgv$: The purchasing cost per new empty container type g, at company selling empty containers w, when the container moves from selling company w to port j (Rand/container).

Xet $ijgv$: Number of total empty containers type g, which moved from port i to port j by transport mode type v (TEUs or FEUs ...etc).

Xe $ijgv$: Number of empty containers type g, which moved from port i to port j by transport mode type v (TEUs or FEUs ...etc).

Xf $ijgv$: Number of fully loaded containers type g, which moved from port i to port j by transport mode type v (TEUs or FEUs ... etc).
Xe $digv$: Number of empty containers type g, which moved from depot d to port i by transport mode type v (TEUs or FEUs ...etc).

Xe $djgv$: Number of empty containers type g, which moved from depot d to port j by transport mode type v (TEUs or FEUs ...etc).

Xr $rigv$: Number of leased empty containers type g, which moved from leasing company r to port i by transport mode v (TEUs or FEUs ...etc).

Xr $rjgv$: Number of leased empty containers type g, which moved from leasing company r to port j by transport mode v (TEUs or FEUs ...etc).

Xpur $wigv$: Number of purchased empty containers type g, which moved from selling company w to port i by transport mode v (TEUs or FEUs ...etc).

Xpur $wjgv$: Number of purchased empty containers type g, which moved from selling company w to port j by transport mode v (TEUs or FEUs ...etc).

Xetho $ijgv$: Number of total handling -on empty containers type g, at port i, which moved from port i to port j by transport mode type v (TEUs or FEUs ...etc).

Xfho $ijgv$: Number of handling -on fully loaded containers type g, at port i, which moved from port i to port j by transport mode type v (TEUs or FEUs ...etc).

Xethf $ijgv$: Number of total handling -off empty containers type g, at port j, which moved from port i to port j by transport mode type v (TEUs or FEUs ...etc).

Xfhf $ijgv$: Number of handling -off fully loaded containers type g, at port j, which moved from port i to port j by transport mode type v (TEUs or FEUs ...etc).

A j : Number of containers (empty and fully loaded) that are requested by port j to satisfy the demand (TEUs or FEUs ...etc).

B i : Number of containers (empty and fully loaded) that are sent by port i to satisfy the demand (TEUs or FEUs ...etc).

C id : Number of empty containers that are available at port i and depot d (TEUs or FEUs ...etc).

Tet $ijgv$: The transportation time of empty container type g, that is moved between port i and port j by transport mode v (day).

Tf $ijgv$: The transportation time of fully loaded container type g, that is moved between port i and port j by transport mode v (day).

Te $wigv$: The transportation time of purchased empty container type g, that is moved between selling company w and port i by transport mode v (day).

Te $wjgv$: The transportation time of purchased empty container type g, that is moved between selling company w and port j by transport mode v (day).

Te $digv$: The transportation time of empty container type g, that is moved between depot d and port i by transport mode v (day).

Te $djgv$: The transportation time of empty container type g, that is moved between depot d and port j by transport mode v (day).

Te $rigv$: The transportation time of leased empty container type g, that is moved between leasing company r and port i by transport mode v (day).

Te $rjgv$: The transportation time of leased empty container type g, that is moved between leasing company r and port i by transport mode v (day).

Tr $rigv$: The leasing time of leased empty container type g, that is moved between leasing company r and port i by transport mode v (day).

Tr $rjgv$: The leasing time of leased empty container type g, that is moved between leasing company r and port j by transport mode v (day).

Tw $ijgv$: The inventory time of container (empty or fully loaded) type g at port i, that is moved between port i and port j by transport mode v (day).

$$\textbf{TW} \begin{cases} 1, \text{ if the empty containers purchase from selling company w, and they are moved to port j.} \\ 0, \text{ otherwise.} \end{cases}$$

$$\textbf{WPI} \begin{cases} 1, \text{ if the containers (empty and fully loaded) store at the port i.} \\ 0, \text{ otherwise.} \end{cases}$$

$$\textbf{TD} \begin{cases} 1, \text{ if the empty containers move from depot d to port j.} \\ 0, \text{ otherwise.} \end{cases}$$

$$\textbf{RJ} \begin{cases} 1, \text{ if the leased empty containers lease from leasing company near to the port j.} \\ 0, \text{ otherwise.} \end{cases}$$

$$\begin{cases} 1, \text{ if the empty containers lease from leasing company r, and they are moved to port j.} \end{cases}$$

$$\begin{cases} 1, \text{ if the purchased empty containers purchase from selling company near to the port j.} \end{cases}$$

TR **CJ**

0, otherwise. 0, otherwise.

4.2.3.3 Objective function

We proposed a mathematical model as follows:

$$\min Z = \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Cet}\, ijgv \;*\; \textbf{Xet}\, ijgv \;*\; \textbf{Tet}\, ijgv$$

$$+ \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{g=q}^{g=q}\sum_{v=1}^{v=c} \textbf{Cf}\, ijgv \;*\; \textbf{Xf}\, ijgv \;*\; \textbf{Tf}\, ijgv$$

$$+ \sum_{w=1}^{w=y}\sum_{i=1}^{i=m}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Ce}\, wigv \;*\; \textbf{Xpur}\, wigv \;*\; \textbf{Te}\, wigv$$

$$+ \sum_{d=1}^{d=b}\sum_{i=1}^{i=m}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Ce}\, digv \;*\; \textbf{Xe}\, digv \;*\; \textbf{Te}\, digv$$

$$+ \sum_{r=1}^{r=f}\sum_{i=1}^{i=m}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Ce}\, rigv \;*\; \textbf{Xr}\, rigv \;*\; \textbf{Te}\, rigv$$

$$+ \textbf{TW} \sum_{w=1}^{w=y}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Ce}\, wjgv \;*\; \textbf{Xpur}\, wjgv \;*\; \textbf{Te}\, wjgv$$

$$+ \textbf{TD} \sum_{d=1}^{d=b}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Ce}\, djgv \;*\; \textbf{Xe}\, djgv \;*\; \textbf{Te}\, djgv$$

$$+ \textbf{TR} \sum_{r=1}^{r=f}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Ce}\, rjgv \;*\; \textbf{Xr}\, rjgv \;*\; \textbf{Te}\, rjgv$$

$$+ \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Cho}\, ijgv \;*\; \textbf{Xetho}\, ijgv$$

$$+ \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Cho}\, ijgv \;*\; \textbf{Xfho}\, ijgv$$

$$+ \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Chf}\, ijgv \;*\; \textbf{Xethf}\, ijgv$$

$$+ \sum_{i=1}^{i=m}\sum_{j=1}^{j=n}\sum_{g=1}^{g=q}\sum_{v=1}^{v=c} \textbf{Chf}\, ijgv \;*\; \textbf{Xfhf}\, ijgv$$

$$+ \mathbf{WPI} \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Cw}\, ijgv \, * \, (\mathbf{Xet}\, ijgv \, + \, \mathbf{Xf}\, ijgv) \, * \, \mathbf{Tw}\, ijgv$$

$$+ \sum_{r=1}^{r=f} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Cr}\, rigv \, * \, \mathbf{Xr}\, rigv \, * \, \mathbf{Tr}\, rigv$$

$$+ \mathbf{RJ} \sum_{r=1}^{r=f} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Cr}\, rjgv \, * \, \mathbf{Xr}\, rjgv \, * \, \mathbf{Tr}\, rjgv$$

$$+ \sum_{w=1}^{w=y} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Cpur}\, wigv \, * \, \mathbf{Xpur}\, wigv \, + \, \mathbf{CJ} \sum_{w=1}^{w=y} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Cpur}\, wjgv \, * \, \mathbf{Xpur}\, wjgv$$

4.2.3.4 Constraints

$$\sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xet}\, ijgv \, + \, \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xf}\, ijgv \, = \mathbf{A}j \tag{1}$$

$$\sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xet}\, ijgv$$
$$= \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xe}\, ijgv \, + \, \sum_{w=1}^{w=y} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xpur}\, wigv \, + \, \sum_{d=1}^{d=b} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xe}\, digv$$
$$+ \sum_{r=1}^{r=f} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xr}\, rigv \tag{2}$$

$$\sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xe}\, ijgv \, + \, \sum_{d=1}^{d=b} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xe}\, digv \, = \mathbf{C}id \tag{3}$$

$$\mathbf{C}id \, + \sum_{w=1}^{w=y} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xpur}\, wigv \, + \sum_{r=1}^{r=f} \sum_{i=1}^{i=m} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xr}\, rigv \, + \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xf}\, ijgv \, = \mathbf{B}i \tag{4}$$

$$\mathbf{B}i \, = \mathbf{A}j \tag{5}$$

$$\sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xetho}\, ijgv \, + \, \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xfho}\, ijgv$$
$$= \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xethf}\, ijgv \, + \, \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} \sum_{g=1}^{g=q} \sum_{v=1}^{v=c} \mathbf{Xfhf}\, ijgv \tag{6}$$

$\mathbf{Xe}\ ijgv, \mathbf{Xe}\ digv, \mathbf{Xr}\ rigv, \mathbf{Xpur}\ wigv, \mathbf{Xf}\ ijgv, \mathbf{Xet}\ ijgv, \mathbf{Xe}\ djgv, \mathbf{Xr}\ rjgv, \mathbf{Xpur}\ wjgv, \mathbf{Xetho}\ ijgv, \mathbf{Xfho}\ ijgv,$

$\mathbf{Xethf}\ ijgv, \mathbf{Xfhf}\ ijgv \quad \geq 0$

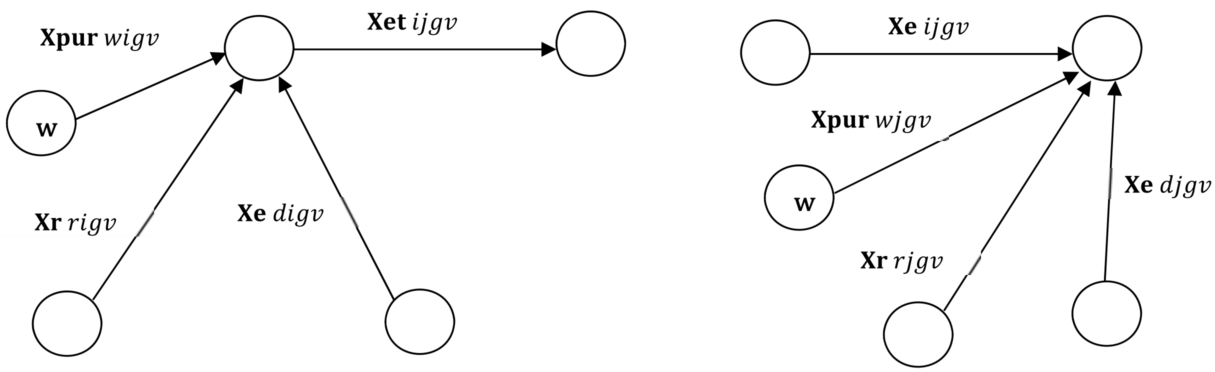


Figure 4.2.1: Transportation networks of empty containers in two scenarios.

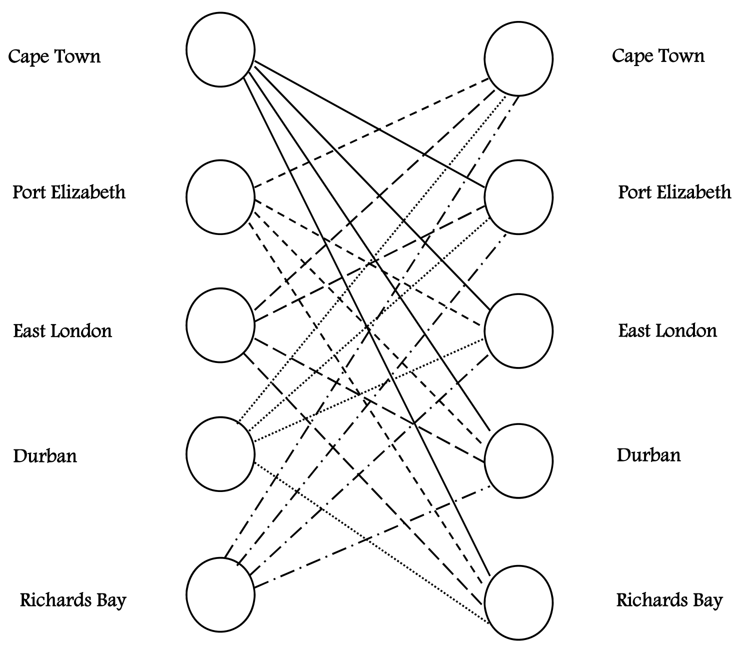


Figure 4.2.2: Network schema of South Africa seaports.

The objective function is used to minimize the total costs that are associated with transportation cost, handling on/off cost, inventory holding cost, leasing ECs cost and purchasing new ECs cost. The objective function consists of seventeenth terms.

The first two terms of the objective function (first term and second term) represent the transportation cost for both empty and fully loaded containers from port i to port j. The third term represents the transportation cost for purchased new empty containers from selling company w to port i. The fourth term represents the transportation cost for empty containers from depot d to port i. The fifth term represents the transportation cost for leased empty containers from leasing company r to port i.

The sixth term represents the transportation cost for purchased new empty containers from selling company w to port j. The seventh term represents the transportation cost for empty containers from depot d to port j. The eighth term represents the transportation cost for leased empty containers from leasing company r to port j. The next two terms (the ninth term and the tenth term) represent the handling –on cost for both empty and fully loaded containers respectively. The eleventh and twelfth terms represent the handling –off cost for both empty and fully loaded containers respectively. The thirteenth term represents the inventory holding cost for both empty and fully loaded containers. The fourteenth and fifteenth terms of the objective function represent the leasing costs for leased empty containers when the empty containers move from leasing company r to port i and port j respectively. The sixteenth and seventeenth terms represent the purchasing costs for purchased new empty containers when the empty containers move from selling company w to port i and port j respectively.

The constraint (1) represents the total number of containers (empty and fully loaded containers) that are requested by port j to satisfy the demand. Constraint (2) represents the total number of empty containers (available, purchased and leased) that are requested by port j to satisfy the demand. Constraint (3) represents the total number of empty containers that are available at port i and depot d. Constraint (4) represents the total number of containers (empty and fully loaded containers) that are sent by port i to port j to satisfy the demand. Constraint (5) ensures that the total number of containers (empty and fully loaded containers) that are sent from port i to port j (from supply port) must be equalled to the total number of containers (empty and fully loaded containers) that are requested by port j (demand port). Constraint (6) ensures that the total number of containers (empty and fully loaded containers) that are handled –on at port i must be equalled to the total number of containers (empty and fully loaded containers) that are handled –off at port j.

4.2.4 Results and Discussions

The proposed model is applied to the scenarios created based on five major South Africa seaports, with different demand conditions and port operations, solved using LINGO 8 and tested on the shipping services network in Figure 4.2.2.

Six different shipping routes for vessels sailing across shipping service networks, varying from each other in terms of quantities of ECs, directions of voyage routes and sequence of vessels, are applied to transfer different quantities of ECs between five supply ports and five demand ports.

Table 4.2.1shows the transportation cost of empty containers between Supply and demand ports (Rand/TEU). Table 4.2.2 shows the distance between South Africa seaports (Nautical mile). Table 4.2.3 shows the total time between South Africa seaports (Day).

Cost/TEU			**Ports j**		
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**
Cape Town	0	1300	1600	2200	2500
Port Elizabeth	1300	0	500	1200	1500
East London	1600	500	0	800	1000
Durban	2200	1200	800	0	400
Richards Bay	2500	1500	1000	400	0

Table 4.2.1: Transportation cost of empty containers between South Africa seaports (Rand/TEU)

DISTANCE BETWEEN PORTS (Nautical mile)			**Ports j**		
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**
Cape Town	0	430	546	801	884
Port Elizabeth	430	0	134	390	473
East London	546	134	0	260	343
Durban	801	390	260	0	89
Richards Bay	884	473	343	89	0

Table 4.2.2: Distance between South Africa seaports (Nautical mile) under vessel speed : 14 knots

TOTAL TIME BETWEEN PORTS (Day)			Ports j		
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**
Cape Town	0	1.292	1.625	2.375	2.625
Port Elizabeth	1.292	0	0.417	1.167	1.417
East London	1.625	0.417	0	0.792	1
Durban	2.375	1.167	0.792	0	0.25
Richards Bay	2.625	1.417	1	0.25	0

Table 4.2.3: Total time between South Africa seaports (Day)

The optimal shipping route1

The total demand of ECs for this Scenario is equal to 12550 TEU, and the demands distribute on shipping service network for SA seaports as (Cape Town: 4000 TEU, Port Elizabeth: 2650 TEU, East London: 1900 TEU, Durban: 500 TEU, and Richards Bay: 3500 TEU). The cost of ECs movements between South Africa seaports is R7, 305,000 (Table 4.2.4) and the total amount of demand supplies from (East London: 5100 TEU, and Durban: 2300 TEU, as a supply ports). The shipping service network for this scenario is shown in the Figure 4.2.3.

No. Of TEUs			Ports j			
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Supply (TEUs)**
Cape Town	650	0	0	0	0	**650**
Port Elizabeth	0	1200	0	0	0	**1200**
East London	3350	1450	1900	0	300	**7000**
Durban	0	0	0	500	2300	**2800**
Richards Bay	0	0	0	0	900	**900**
Demand (TEUs)	**4000**	**2650**	**1900**	**500**	**3500**	
Total	4000	2650	1900	500	3500	
Cost	**5360000**	**725000**	**0**	**0**	**1220000**	
Total Cost (Rand)	**7305000**					

Table 4.2.4: Cost for empty containers distribution among South Africa seaports for shipping route 1

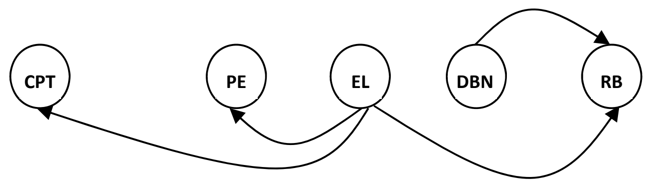


Figure 4.2.3: Shipping service network for the scenario1

In this scenario the handling on/off cost per TEU at SA seaports equal to 250 (Rand/TEU), and the transhipment rate of quay crane at ports is 30-35 TEU/hour, running continuously, and there are two quay cranes used parallel at each port.

Handling-on cost at supply ports = 250 × (the actual total demand of ECs for demand ports from supply ports) = 250 × (5100 TEU from East London port, and 2300 TEU from Durban port as a supply ports)

= 250 × 7400 = R1,850,000.

Handling-off cost at demand ports = 250 × (the actual total demand of ECs for demand ports from supply ports) = 250 × (3350 TEU at Cape Town port, 1450 TEU at Port Elizabeth port, and 2600 TEU at Richards Bay port, as a demand ports)

= 250 × 7400 =R 1,850,000.

The total cost = 7305000 + 1850000 + 1850000

= R11,005,000

The handling on/off cost is equal to 50.7% of the cost of ECs movements between ports, and ≈ 33.62% of the total cost. But, actually, the optimal shipping service network for this scenario is shown in the Figure 4.2.4. That means the vessel can carry 5100 TEU from East London port, and distribute to Port Elizabeth, Cape Town respectively and Richards Bay. The same rule applies to the vessel that leaves Durban port with capacity of 2300 TEU to Richards Bay port. This reduces the total time for the voyage routes, but does not reduce the transportation cost of ECs between ports, because the demand is ordered from supply ports (EL and DBN), and not from demand port or secondary port (PE).

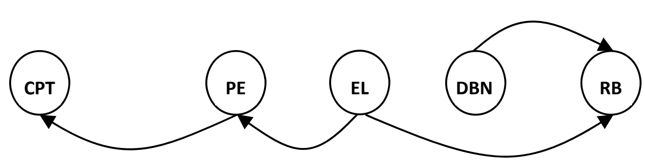


Figure 4.2.4: The optimal shipping service network for the scenario no.1

The total time (day) = transportation time (for ECs between ports) + handling on/off time

= (EL → PE, EL → CPT, EL → RB, DBN → RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (0.417 + 1.625 + 1 + 0.25) + [14800 ÷ (30 × 2)]

= 3.292 + [246.7 hour ÷ 24] = 3.292 + 10.279 = 13.571 day

The optimal total time (day) =

(EL → PE, PE → CPT, EL → RB, DBN → RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (0.417 + 1.292 + 1 + 0.25) + [14800 ÷ (30 × 2)]
= 2.959 + [246.6 hour ÷ 24] = 2.959 + 10.275 = 13.234 day

The optimal total time is less than the total time by 0.337 day or 8.088 hours.

Note : We use vessel with maximum capacity of 5000 TEU to carry 4800 TEU from East London port to Port Elizabeth and Cape Town.

The optimal shipping route 2

The total demand of ECs for this Scenario is equal to 15000 TEU, and the demands distribute on shipping service network for SA seaports as (Cape Town: 750 TEU, Port Elizabeth: 6500 TEU, East London: 6000 TEU, Durban: 950 TEU, and Richards Bay: 800 TEU).

The results obtained is shown in Table 4.2.5, where the cost of ECs movements between South Africa seaports is R12,115,000 and the total amount of demand supplies from (Cape Town: 3750 TEU, Durban: 2650 TEU, and Richards Bay: 4300 TEU as a supply ports). The shipping service network for this scenario is shown in Figure 4.2.5.

No. Of TEUs			Ports j			
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Supply (TEUs)**
Cape Town	750	3750	0	0	0	**4500**
Port Elizabeth	0	700	0	0	0	**700**
East London	0	0	1100	0	0	**1100**
Durban	0	2050	600	950	0	**3600**
Richards Bay	0	0	4300	0	800	**5100**
Demand (TEUs)	**750**	**6500**	**6000**	**950**	**800**	
Total	750	6500	6000	950	800	
Cost	**0**	**7335000**	**4780000**	**0**	**0**	
Total Cost (Rand)	**12115000**					

Table 4.2.5: Cost for empty containers distribution among South Africa seaports for shipping route 2

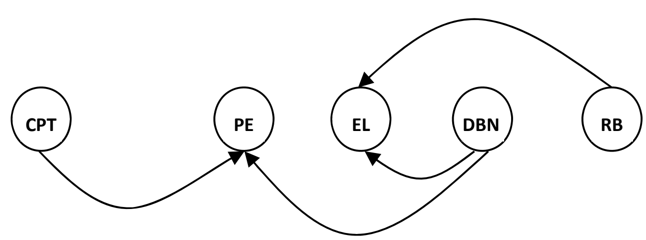


Figure 4.2.5: Shipping service network for the scenario 2

In this scenario we must handle-on 10700 TEU in the vessels at supply seaports to satisfy the demands at demand seaports. We must also handle-off the same number of ECs (10700 TEU) at demand seaports, when the vessels drop off the ECs at seaports.

Handling-on cost at supply ports = 250 × (3750 TEU from Cape Town, 2650 TEU from Durban port, and 4300 TEU from Richards Bay port as a supply ports)
= 250 × 10700 =R 2,675,000.

Handling-off cost at demand ports = 250 × 10700
=R 2,675,000.

The total cost =12115000 + 2675000 + 2675000

=R17,465,000

The handling on/off cost is equal to 44.2% of the cost of ECs movements between ports, and ≈ 30.63% of the total cost.

The optimal shipping service network for this scenario is shown in Figure 4.2.6. That means the vessel can carry 3750 TEU from Cape Town port, and distribute to Port Elizabeth. The same procedure can be used with the vessel that leaves Durban port with capacity of 2650 TEU, to East London and Port Elizabeth respectively, also the vessel that leaves Richards Bay port with capacity of 4300 TEU, to East London port.

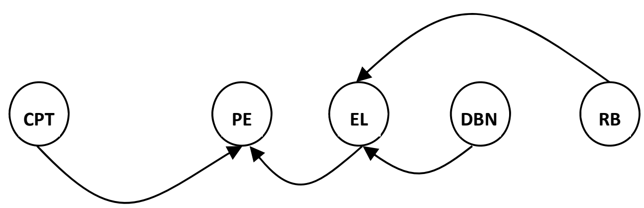


Figure 4.2.6: Optimal shipping service network for the scenario 2

The total time (day) = transportation time (for ECs between ports) + handling on/off time

= (CPT → PE, DBN → EL, DBN → PE, RB → EL)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 0.792 + 1.167 + 1) + [21400 ÷ (30 × 2)]

= 4.251 + [356.7 hour ÷ 24] = 4.251 + 14.8625 = 19.1135 day

The optimal total time (day) =

(CPT → PE, DBN → EL, EL → PE, RB → EL)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 0.792 + 0.417 + 1) + [21400 ÷ (30 × 2)]

= 3.501 + [356.7 hour ÷ 24] = 3.501 + 14.8625 = 18.3635 day

The optimal total time is less than the total time by 0.75 day or 18 hours.

<u>Note :</u> We use vessel with maximum capacity of 5000 TEU to carry 4300 TEU from Richards Bay port to East London port.

The optimal shipping route 3

The total demand of ECs for this Scenario is equal to 10360 TEU, and the demands distribute on shipping service network for SA seaports as (Cape Town: 300 TEU, Port Elizabeth: 3000 TEU, East London: 900 TEU, Durban: 2250 TEU, and Richards Bay: 3910 TEU).

The results obtained from LINGO are shown in Table 4.2.6, where the cost of ECs movements between South Africa seaports is R15,125,000 and the total all demands are supplied from Cape Town only (Cape Town: 7700 TEU as a supply port). The shipping service network for this scenario is shown in the Figure 4.2.7.

No. Of TEUs			**Ports j**			
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Supply (TEUs)**
Cape Town	300	2750	500	1250	3200	**8000**
Port Elizabeth	0	250	0	0	0	**250**
East London	0	0	400	0	0	**400**
Durban	0	0	0	1000	0	**1000**
Richards Bay	0	0	0	0	710	**710**
Demand (TEUs)	**300**	**3000**	**900**	**2250**	**3910**	
Total	300	3000	900	2250	3910	
Cost	**0**	**3575000**	**800000**	**2750000**	**8000000**	
Total Cost (Rand)	**15125000**					

Table 4.2.6: Cost for empty containers distribution among South Africa seaports for shipping route 3

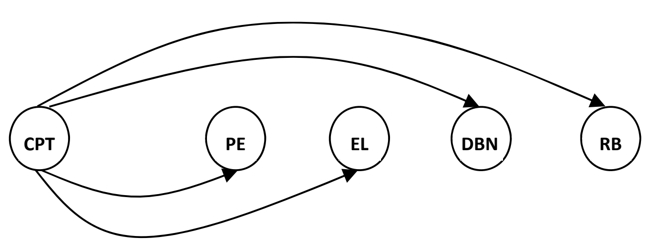


Figure 4.2.7: Shipping service network for the scenario 3

In this scenario we must handle-on 7700 TEU in the vessels at supply port to satisfy the demands at demand ports. We must also handle-off the same number of ECs (7700 TEU) at demand ports, when the vessels drop off the ECs at seaports.

Handling-on cost at supply port = 250 × (7700 TEU from Cape Town port, as a supply ports)
= 250 × 7700 = R 1,925,000.

Handling-off cost at demand ports = 250 × 7700
= R 1,925,000.

The total cost =15125000 + 1925000 + 1925000
= R 18,975,000

The handling on/off cost is equal to 25.45% of the cost of ECs movements between ports, and ≈ 20.3% of the total cost.

The optimal shipping service network for this scenario is shown in the Figure 4.2.8. That means the vessels can carry 7700 TEU from Cape Town port, and distribute to Port Elizabeth, East London, Durban, and Richards Bay as necessary.

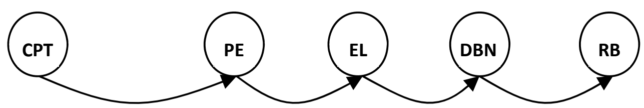


Figure 4.2.8: Optimal shipping service network for the scenario 3

<u>Note :</u> We use vessel with maximum capacity of 8000 TEU to carry 7700 TEU from Cape Town port to Port Elizabeth, East London, Durban, and Richards Bay respectively, or we can use two vessels with 4000 TEU to each either, to carry 4000 TEU from Cape Town port to Port Elizabeth and Durban respectively, and to carry 3700 TEU from Cape Town port to East London and Richards Bay. The second optimal shipping service network for this scenario is shown in the Figures 4.2.8 and .4.2.9.

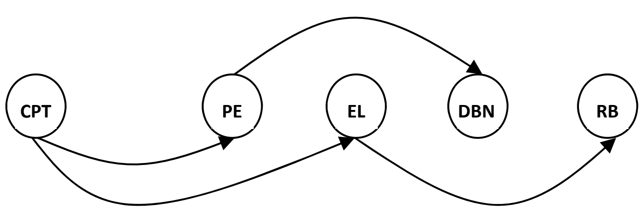


Figure 4.2.9: Second optimal shipping service network for the scenario 3

The total time (day) = transportation time (for ECs between ports) + handling on/off time

= (CPT → PE, CPT → EL, CPT → DBN, CPT → RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 1.625 + 2.375 + 2.625) + [15400 ÷ (30 × 2)]

= 7.917 + [256.7 hour ÷ 24] = 7.917 + 10.6958 = 18.6128 day

The optimal total time (day) =

(CPT → PE, PE → EL, EL → DBN, DBN → RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 0.417 + 0.792 + 0.25) + [15400 ÷ (30 × 2)]

= 2.751 + [256.7 hour ÷ 24] = 2.751 + 10.6958 = 13.4468 day

The optimal total time is less than the total time by 5.166 day or ≈ 124 hours.

The second optimal total time (day) =

(CPT → PE, PE → DBN, CPT → EL, EL → RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 1.167 + 1.625 + 1) + [15400 ÷ (30 × 2)]

= 5.084 + [256.7 hour ÷ 24] = 5.084 + 10.6958 = 15.7798 day

The second optimal total time is less than the total time by 2.833 day or ≈ 68 hours.

Note: The first optimal shipping service network for the scenario 3 is better than the second optimal shipping service network.

The optimal shipping route 4

The total demand of ECs for this Scenario is equal to 9815 TEU, and the demand is distributed on shipping service network for SA seaports as (Cape Town: 2995 TEU, Port Elizabeth: 790 TEU, East London: 3300 TEU, Durban: 630 TEU, and Richards Bay: 2100 TEU).

The results obtained is shown in Table 4.2.7, where the cost of ECs movements between South Africa seaports is R 6,601,000, and the total amount of demand supplies from (Port Elizabeth:

2660 TEU, and Durban: 4420 TEU as a supply ports). The shipping service network for this scenario is shown in the Figure 4.2.10.

No. Of TEUs			**Ports j**			
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Supply (TEUs)**
Cape Town	210	0	0	0	0	**210**
Port Elizabeth	2660	790	0	0	0	**3450**
East London	0	0	425	0	0	**425**
Durban	125	0	2875	630	1420	**5050**
Richards Bay	0	0	0	0	680	**680**
Demand (TEUs)	**2995**	**790**	**3300**	**630**	**2100**	
Total	2995	790	3300	630	2100	
Cost	**3733000**	**0**	**2300000**	**0**	**568000**	
Total Cost (Rand)	**6601000**					

Table 4.2.7: Cost for empty containers distribution among South Africa seaports for shipping route 4

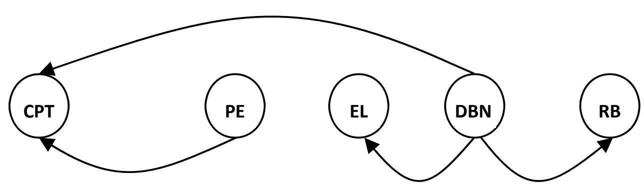


Figure 4.2.10: Shipping service network for the scenario 4

In this scenario we must handle-on 7080 TEU in the vessels at supply ports to satisfy the demands at demand ports. We must also handle-off the same number of ECs (7080 TEU) at demand ports, when the vessels drop off the ECs at seaports.

Handling-on cost at supply ports = 250 × (2660 TEU from Port Elizabeth, 4420 TEU from Durban port, as a supply ports)

$$= 250 \times 7080 = R1,770,000.$$

Handling-off cost at demand ports = 250 × 7080
= R1,770,000.

The total cost = 6601000 + 1770000 + 1770000
= R10,141,000

The handling on/off cost is equal to 53.63% of the cost of ECs movements between ports, and ≈ 35% of the total cost.

Note: actually, transferring 125 TEU from Durban port to Cape Town port by the vessel is uneconomical method, so it's best to lease these empty containers from the nearest leasing company to Cape Town port.

The leasing cost is R 18 per TEU per day (Rand/TEU * day), and the minimum leasing period for ECs is one Month (as a condition in the leasing company).

Leasing cost = 18 × 30 × 125 =R 67,500

Transportation cost = 125 × 2200 =R 275,000

The leasing cost for (125 TEU) is equal to 24.55% of the transportation cost of ECs movement between Durban and Cape Town ports.

The optimal shipping service network for this scenario is shown in the Figure 4.2.11. That means the vessel can carry 2660 TEU from Port Elizabeth port, and distribute to Cape Town. The same logic can be used with the vessels that leave Durban port with capacity of 4420 TEU, to East London, Richards Bay, and Cape Town ports.

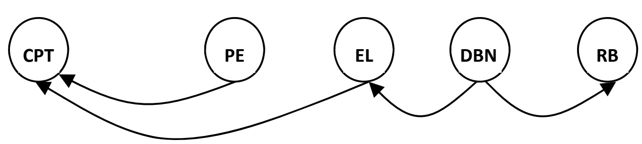


Figure 4.2.11: Optimal shipping service network for the scenario no.4

The total time (day) = transportation time (for ECs between ports) + handling on/off time

= (PE $\rightarrow$ CPT, DBN $\rightarrow$ CPT, DBN $\rightarrow$ EL, DBN $\rightarrow$ RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 2.375 + 0.792 + 0.25) + [14160 ÷ (30 × 2)]
= 4.709 + [236 hour ÷ 24] = 4.709 + 9.833 = 14.542 day

The optimal total time (day) =

= (PE → CPT, EL → CPT, DBN → EL, DBN → RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 1.625 + 0.792 + 0.25) + [14160 ÷ (30 × 2)]
= 3.959 + [236 hour ÷ 24] = 3.959 + 9.833 = 13.792 day

The optimal total time is less than the total time by 0.75 day or ≈ 18 hours.

The optimal shipping route 5

The total demand of ECs for this Scenario is equal to 10350 TEU, and the demand are distributed on shipping service network for SA seaports as (Cape Town: 1500 TEU, Port Elizabeth: 2800 TEU, East London: 3200 TEU, Durban: 850 TEU, and Richards Bay: 2000 TEU). The results obtained from lingo are shown in Table 4.2.8, where the cost of ECs movements between South Africa seaports is R 5,724,000, and the total amount of demand supplies from (Cape Town: 2640 TEU, and Durban: 3450 TEU as a supply ports). The shipping service network for this scenario is shown in Figure 4.2.12.

No. Of TEUs			**Ports j**				
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Dummy**	**Supply (TEUs)**
Cape Town	1500	2200	440	0	0	560	**4700**
Port Elizabeth	0	600	0	0	0	0	**600**
East London	0	0	810	0	0	0	**810**
Durban	0	0	1950	850	1500	0	**4300**
Richards Bay	0	0	0	0	500	0	**500**
Demand (TEUs)	**1500**	**2800**	**3200**	**850**	**2000**	**560**	
Total	1500	2800	3200	850	2000	560	
Cost	**0**	**2860000**	**2264000**	**0**	**600000**	**0**	
Total Cost (Rand)	**5724000**						

Table 4.2.8 : Cost for empty containers distribution among South Africa seaports for shipping route 5

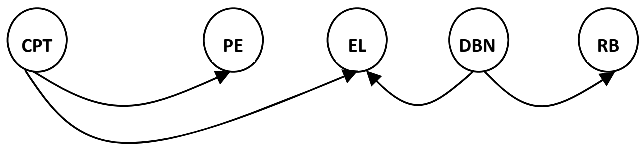


Figure 4.2.12: Shipping service network for the scenario 5

In this scenario we must handle-on 6090 TEU in the vessels at supply ports to satisfy the demands at demand ports. We must also handle-off the same number of ECs (6090 TEU) at demand ports, when the vessels drop off the ECs at seaports.

Handling-on cost at supply ports = 250 × (2640 TEU from Cape Town, 3450 TEU from Durban port, as a supply ports)

= 250 × 6090 = R 1,522,500.

Handling-off cost at demand ports = 250 × 6090

=R 1,522,500.

The total cost = 5724000 + 1522500 + 1522500

=R 8,769,000

The handling on/off cost is equal to 53.2% of the cost of ECs movements between ports, and ≈ 34.72% of the total cost. For this scenario the vessel can carry 2640 TEU from Cape Town port, and distribute to Port Elizabeth and East London respectively. The same procedure can be used with the vessels that leave Durban port with capacity of 3450 TEU, to East London and Richards Bay ports. The optimal shipping service network for this scenario is shown in the Figure 4.2.13.

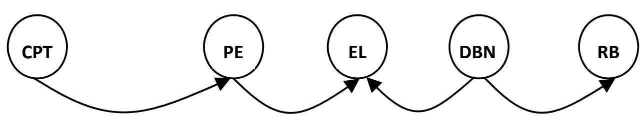


Figure 4.2.13: The optimal shipping service network for the scenario 5

The total time (day) = transportation time (for ECs between ports) + handling on/off time

= (CPT→PE, CPT →EL, DBN→ EL, DBN→ RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.292 + 1.625 + 0.792 + 0.25) + [12180 ÷ (30 × 2)]

= 4.709 + [203 hour ÷ 24] = 3.959 + 8.4583 = 12.4173 day

The optimal total time (day) =

= (CPT→PE, PE→EL, DBN→EL, DBN→ RB)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

$$= (1.292 + 0.417 + 0.792 + 0.25) + [12180 \div (30 \times 2)]$$

$$= 2.751 + [203 \text{ hour} \div 24] = 2.751 + 8.4583 = 11.2093 \text{ day}$$

The optimal total time is less than the total time by 1.208 day or ≈ 29 hours.

The optimal shipping route no.6

The total demand of ECs for this Scenario is equal to 9150 TEU, and the demands are distributed on shipping service network for SA seaports as (Cape Town: 800 TEU, Port Elizabeth: 1000 TEU, East London: 2600 TEU, Durban: 4000 TEU, and Richards Bay: 750 TEU). The result obtained from LINGO is shown in Table 4.2.9, where the cost of ECs movements between South Africa seaports is 5,999,000 and the total amount of demand supplies from (Cape Town: 2020 TEU, Port Elizabeth: 1850 TEU, and Richards Bay: 2250 as a supply ports). The shipping service network for this scenario is shown in the Figure 4.2.14.

No. Of TEUs			**Ports j**				
Ports i	**Cape Town**	**Port Elizabeth**	**East London**	**Durban**	**Richards Bay**	**Dummy**	**Supply (TEUs)**
Cape Town	800	0	450	1570	0	1080	**3900**
Port Elizabeth	0	1000	1850	0	0	0	**2850**
East London	0	0	300	0	0	0	**300**
Durban	0	0	0	180	0	0	**180**
Richards Bay	0	0	0	2250	750	0	**3000**
Demand (TEUs)	**800**	**1000**	**2600**	**4000**	**750**	**1080**	
Total	800	1000	2600	4000	750	1080	
Cost	**0**	**0**	**1645000**	**4354000**	**0**	**0**	
Total Cost (Rand)	**5999000**						

Table 4.2.9: Cost for empty containers distribution among South Africa seaports for shipping route 6

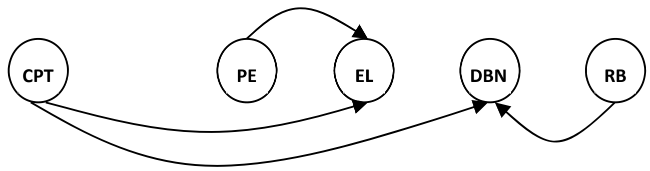


Figure 4.2.14: Shipping service network for the scenario 6

In this scenario we must handle-on 6120 TEU in the vessels at supply seaports to satisfy the demands at demand seaports. We must also handle-off the same number of ECs (6120 TEU) at demand seaports, when the vessels drop off the ECs at seaports.

Handling-on cost at supply ports = 250 × (2020 TEU from Cape Town, 1850 TEU from Port Elizabeth port, and 2250 TEU from Richards Bay port as a supply ports)
= 250 × 6120 =R 1,530,000.

Handling-off cost at demand ports = 250 × 6120
=R 1,530,000.

The total cost =5999000 + 1530000 + 1530000
=R 9,059,000

The handling on/off cost is equal to 51% of the cost of ECs movements between ports, and ≈ 33.78% of the total cost.

The optimal shipping service network for this scenario is shown in the Figure 4.2.16. That means the vessel can carry 2020 TEU from Cape Town port, and distribute to East London and Durban respectively. The same procedure can be used with the vessel that leaves Port Elizabeth port with capacity of 1850 TEU, to East London, and also the vessel that leaves Richards Bay port with capacity of 2250 TEU, to Durban port.

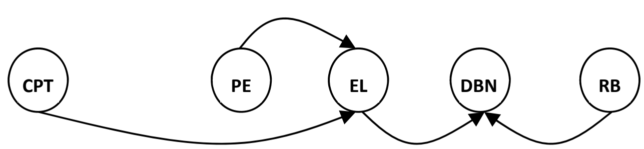


Figure 4.2.16: The optimal shipping service network for the scenario 6

The total time (day) = transportation time (for ECs between ports) + handling on/off time

= (CPT→EL, CPT→DBN, PE→EL, RB →DBN)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.625 + 2.375 + 0.417 + 0.25) + [12240 ÷ (30 × 2)]

= 4.667 + [204 hour ÷ 24] = 4.667 + 8.5 = 13.167 day

The optimal total time (day) =

= (CPT→ EL, EL→ DBN, PE →EL, RB →DBN)

+ [Handling on/off capacity of ECs ÷ (Transhipment rate of quay crane × no. of cranes at ports)]

= (1.625 + 0.792 + 0.417 + 0.25) + [12240 ÷ (30 × 2)]

= 3.084 + [204 hour ÷ 24] = 3.084 + 8.5 = 11.584 day

The optimal total time is less than the total time by 1.583 day or ≈ 38 hours.

4.2.5 Conclusions

This chapter addressed the problem of routing and shipping service network design in maritime transportation considering a case study of South Africa seaports. The proposed model is used to optimize the voyage routes for the container vessels sailing across shipping service networks. It is based on ECs movements between supply and demand ports and port operations, to minimize the total cost associated with transportation cost, handling on/off cost, storage cost, leasing and purchasing ECs costs. Based on the results from different shipping routes of vessels, by using LINGO, the study found that the model is efficient and accurate in solving problems, and that it offers flexibility for shipping company in route decision making. The results, in general, show that the optimal total time for the six scenarios is less than the total time, and the reduction varies from (8.088 to 124 hours). The handling on/off cost, relative to ECs movement cost, varies from 25.45% to 53.63%. The handling on/off cost, relative to the total cost, varies from 20.3% to 35%, due to several factors such as supply/demand level, shipping service network design, vessels fleet deployment, vessels capacities and sequence on shipping service network. Furthermore, also it is possible to decide whether to transfer ECs directly to the demand ports or lease ECs from the nearest leasing companies to the demand ports, depending on which method is economical in saving cost, or shipping company policy. It is also possible to re-optimize the optimal shipping service network, taken from LINGO software. This procedure reduces the total time for the voyage routes, and gives shorter distance between supply and demand ports, especially if the demand is ordered from a supply port and distributed to a series of demand ports on the shipping service network.

Chapter 5

Section one: The optimization of container stacking process under the impact of synchronization of seaport container terminal operations (revised version) [1]

[1]Proceedings of the International Conference on Industrial Engineering and Operations Management Pretoria / Johannesburg, South Africa, October 29 – November 1, 2018.

5.1.1 Introduction

Efficient stacking strategy in a container terminal is an essential task affecting competitiveness in many seaports especially because this singular action may influence many of the conflicting objectives, like minimizing the reshuffles (unproductive moves) and number of future relocations of containers in storage yard, maximizing the yard density, and capacity utilization of stacking area. Any delay or deficiency in the synchronization and sequencing of daily operations and activities between the seaside and landside of a terminal will affect the stacking process in the container yard and may lead to the interference of terminal operations and lack of control in the scheduling of concurrent operations, in addition to associated activities during the management of inbound and outbound containers.

In section one, a seaport container terminal is modelled as a queuing system to obtain the service level parameters. A multi-server queue in tandem consisting of three stages was considered: the first stage being the relations between the arrival containers or the inbound containers at seaport and the handling-off process; the second stage being the relations between the handling-off process and the transportation process, and the third stage being the relations between transportation process and stacking process. The section also presents 20 different scenarios of container stacking inside a container terminal to evaluate the performance of the queuing model. These scenarios vary from each other in terms of quantities of containers, durations of stay for the vessels in the seaport and number of equipment (quay cranes, yard trucks and yard cranes) that are used to perform the operations.

In section two, the problem of assignment of suitable berths to vessels is considered amidst different scenarios of vessel berthing policy and priorities, as well as vessels serving or container handling-off. The discharge of vessels in the berth as queuing system with non-pre-emptive priority to optimize the service level and to maximize berth utilization is delineated. Thirty-two different scenarios are applied for the berthing processes of vessels and unloading containers at container terminals to evaluate the performance of the queuing model and to obtain the optimal service level parameters.

In general, the experimental results show that the values of $\mathbf{E(W_k)}$, $\mathbf{E(L_k^q)}$, $\mathbf{E(L_k)}$ and $\mathbf{E(S_k)}$ are affected by changing the values of $\boldsymbol{\lambda_k}$ and $\boldsymbol{\mu_k}$ or the values of $\boldsymbol{\rho_k}$. As well as the authors find when increase the service rate of service centers (quay cranes) for container class (k) $\boldsymbol{\mu_k}$ with the increment in the number of arrival containers class (k) $\boldsymbol{\lambda_k}$ respectively (while keeping the values of $\boldsymbol{\lambda_{k-1}}$ and $\boldsymbol{\mu_{k-1}}$ unchanged, or the values of other class), will leads to reduce the values of all $\mathbf{E(W_k)}$, $\mathbf{E(L_k^q)}$, $\mathbf{E(L_k)}$ and $\mathbf{E(S_k)}$ respectively.

5.1.2 Problem description

When inbound containers arrive at a container yard, they are initially stacked in the stacking area for temporary storage. Usually, the stacking area is made up of many blocks, and the containers are arranged in each block by rows (stacks), columns (bays) and tiers. At the container yard, the containers are lifted-off from yard trucks by yard cranes, and they are stacked in several blocks in 3D arrays. Each block can handle a mass of containers and the yard crane is used to move the containers within the same block or within the same bay. The movement of containers within the stacking area (within blocks or bays) is called rehandling, whereas the movement of containers from the bays to the vessels or the containerships is called retrieving. A schematic diagram of a typical container terminal is shown in Figure (5.1.1). In seaports, container yard configuration and layout are determined by the type of stacking strategy that is used to store, stack, arrange and manage the containers within the yard. There are various stacking strategies that are applied in seaports and depots such as segregation strategy, scattering strategy, category strategy and residence time strategy. These strategies are used to achieve the efficient usage of storage area, and to avoid the unproductive moves of containers and yard cranes. The concept of container stacking problem is concerned with how to find suitable storage locations for inbound containers within the assigned blocks in order to minimize future relocations. The temporary storage location for a container within a block may remain the same during the full period of storage until the container is sent to its final destination, or it may be changed to a new storage location within the same block. That means the initial locations of containers (temporary locations) may be the permanent storage locations or may change to some new locations. Delays due to the sequencing of operations in the seaport container terminal will lead to deficiency in the scheduling and management of terminal operations in the flow of containers between quay side and yard side. Therefore, it will affect the stacking process in the container yard. Also, deficiency in the synchronization and sequence of daily operations and activities between the seaside and landside of a terminal will affect the stacking process in the container yard and may lead to interference of terminal operations and lack of control when scheduling concurrent operations of inbound and outbound flows of containers.

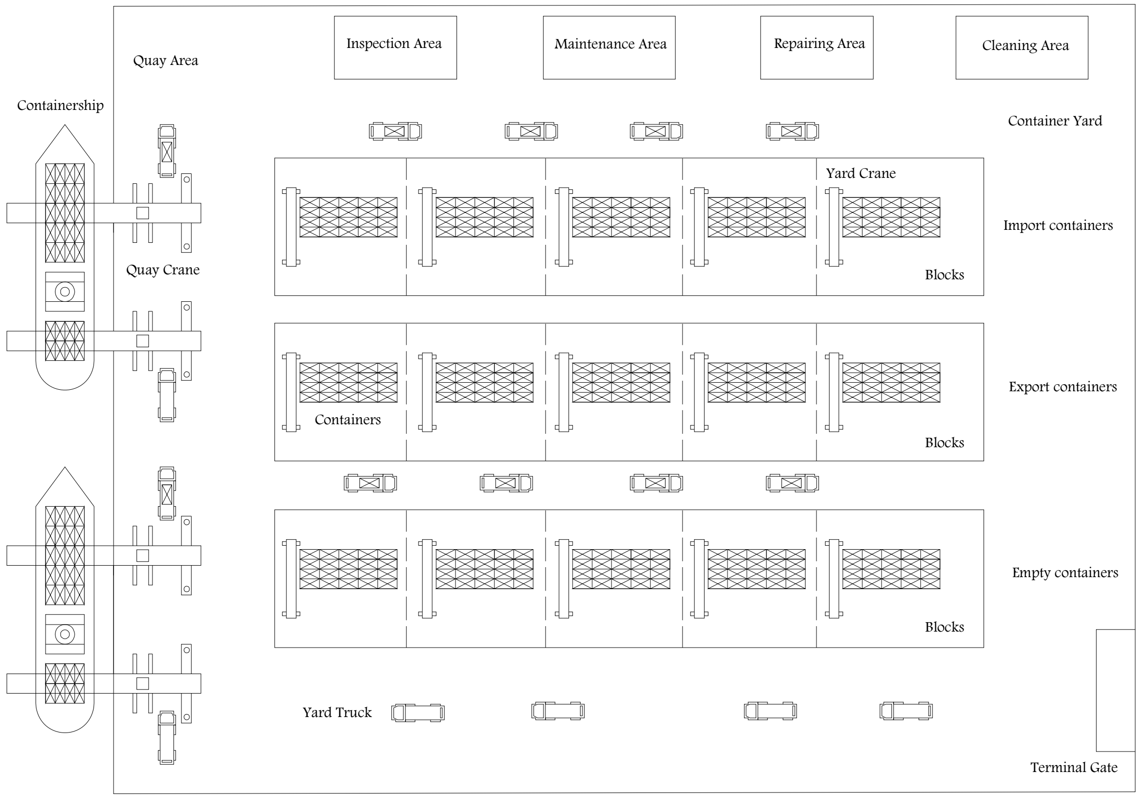


Figure 5.1.1: A schematic layout of a container terminal (Authors)

5.1.3 Mathematical model:

In this section, the problem can be modelled as a queuing system to understand the behaviour and characteristics of container stacking problem under the impact of synchronization or sequence of seaport container terminal operations. When the inbound containers arrive at quay side, they are served by quay cranes, luffing cranes or portainers. i.e. the containers are unloaded from containership by cranes, and then they are moved from quay side to the container yard by trucks, Automated Guided Vehicles (AGVs) or Straddle carriers. At stacking area in container yard, the yard cranes (Rubber Tired Gantry Crane (RTGC), Automated Stacking Crane (ASC) or Rail Mounted Gantry Crane (RMGC)) are used to stack the containers in many blocks.

Usually, the arrival containers or the inbound containers at seaport have arrival rate λ and the inter-arrival time (the average interval between consecutive container arrivals) or average time between arrivals (containers) can be expressed as $1/\lambda$. We suppose the first stage is the handling-off process. i.e. the arrival rate of containers (λ) is the number of containers in the vessel or containership to be unloaded within a specified time period, and the service rate of containers ($\mu\mathbf{h}$) is performed by quay cranes. The second stage is the transportation process. i.e. the arrival rate of containers ($\mu\mathbf{h}$) at this stage is the same output of the previous stage - handling-off process-, and the service rate of containers ($\mu\mathbf{t}$) is performed by yard trucks. The third stage is the stacking process. i.e. the arrival rate of containers (μt) at this stage is the same output of the previous stage - transportation process-, and the service rate of containers (μs) is performed by yard cranes. The inter-service time or average service time per server (quay crane, yard truck and yard crane) at any stage can be expressed as $1/\mu$ or $1/\mu h$, $1/\mu t$, $1/\mu s$ the average service time for handling-off station, transportation station and stacking station respectively.

The average utilization (or the utilization factor) of the system is the ratio between the arrival rate and service rate, and can be expressed as $\rho = \frac{\lambda}{\mu}$ or $\rho = \frac{\lambda}{r * \mu}$, where $\mathbf{r}$ the number of servers in the system. The utilization factor or the occupancy rate for the first stage (handling-off station) can be expressed as $\rho_h = \frac{\lambda}{\mu h}$. The utilization factor or the occupancy rate for the second stage (transportation station) can be expressed as $\rho_t = \frac{\mu h}{\mu t}$. The utilization factor or the occupancy rate for the third stage (stacking station) can be expressed as $\rho_s = \frac{\mu t}{\mu s}$.

Actually, in queuing system, there are one or more servers that provide service to the arriving customers. In our case study, the customers are containers and the servers are quay cranes, yard trucks (vehicles) and yard cranes. We assume the sequence of operations inside seaport like queues in tandem, i.e. multi-server queues in tandem, the input of each queue except the first (when the inbound containers arrive at quay side) is the output of the previous queue. The tandem system in our case study consists of three stages, the first stage is the relation between the arrival containers or the inbound containers at seaport and the handling-off process, the second stage is the relation between the handling-off process and the transportation process, the third stage is the relation between transportation process and stacking process. In this queuing system (Multi-server queuing model), we assume the arrivals follow a Poisson probability distribution at an average (λ : containers per unit time (hour)). Also we assume the service times are distributed exponentially with an average (μ : containers per unit time (hour)). The service in the system (queue discipline) is First-in, First-out (FIFO) or First-come, First-served (FCFS), and all servers in each stage or station are assumed to perform at the same rate. Figures 5.1.2A and 5.1.2B represent the queues in tandem system.

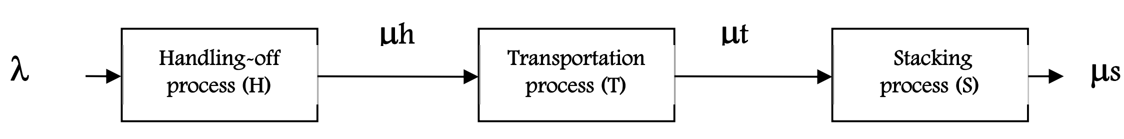


Figure 5.1.2A: Three stage tandem queue system at a container terminal

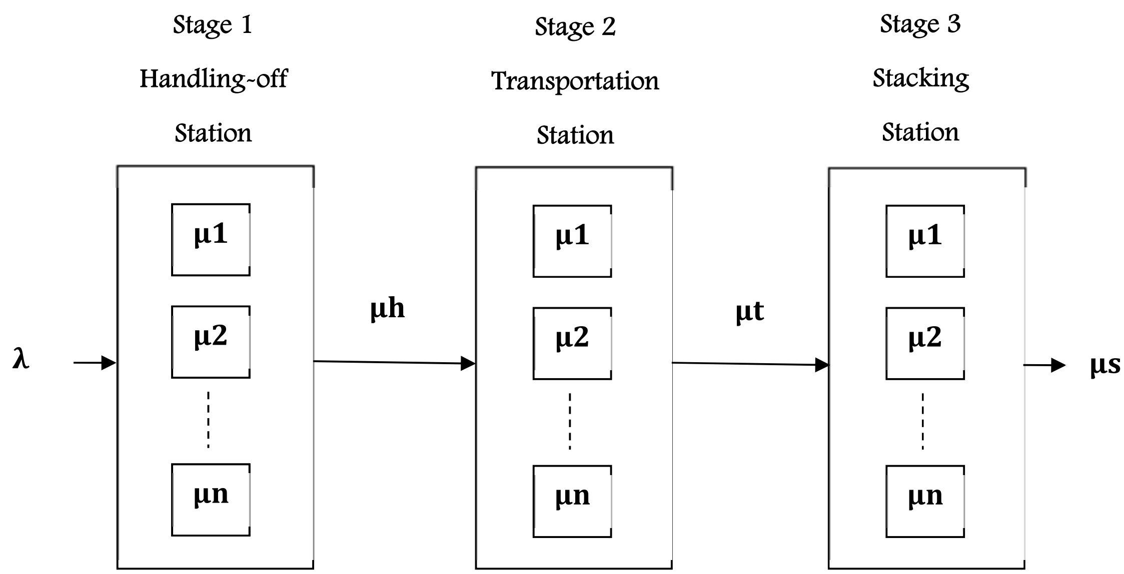


Figure 5.1.2B: Three stage multi-server tandem queue system at a container terminal

We use the state transition diagrams as shown down below to formulate the state balance equations for the three stages multi-server tandem queue system at a container terminal. We suppose the following Notation:

P_h : The probability that h containers at handling-off station.

P_t : The probability that t containers at transportation station.

P_s : The probability that s containers at stacking station.

$P_{0,0,0}$: The probability that no containers at any station (handling-off , transportation and stacking).

$P_{h,0,0}$: The probability that containers at handling-off station and no containers at transportation and stacking stations.

$P_{0,t,0}$: The probability that containers at transportation station and no containers at handling-off and stacking stations.

$P_{0,0,s}$: The probability that containers at stacking station and no containers at handling-off and transportation stations.

$P_{h,t,0}$: The probability that containers at handling-off station and containers at transportation station and no containers at stacking station.

$P_{h,0,s}$: The probability that containers at handling-off station and containers at stacking station and no containers at transportation station.

$P_{0,t,s}$: The probability that containers at transportation station and containers at stacking station and no containers at handling-off station.

$P_{h,t,s}$: The probability that containers at handling-off station and containers at transportation station and containers at stacking station.

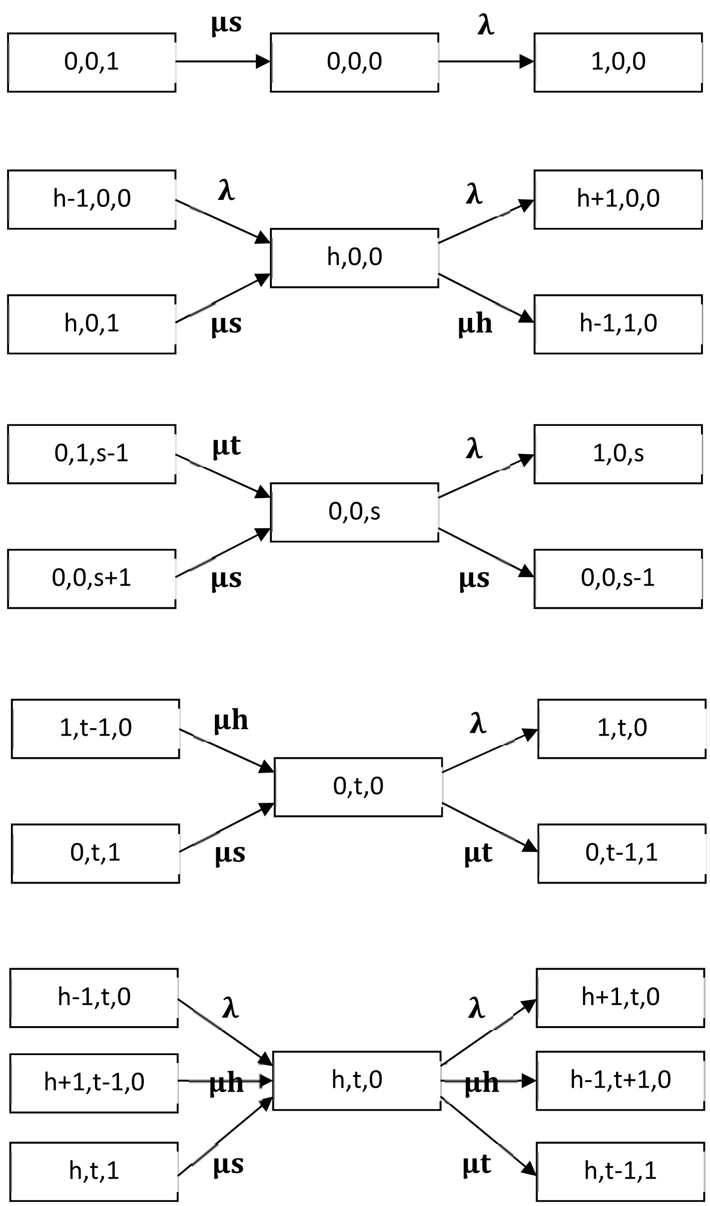


Figure 5.1.3: State transition diagram for multi-server tandem queue system at a container terminal

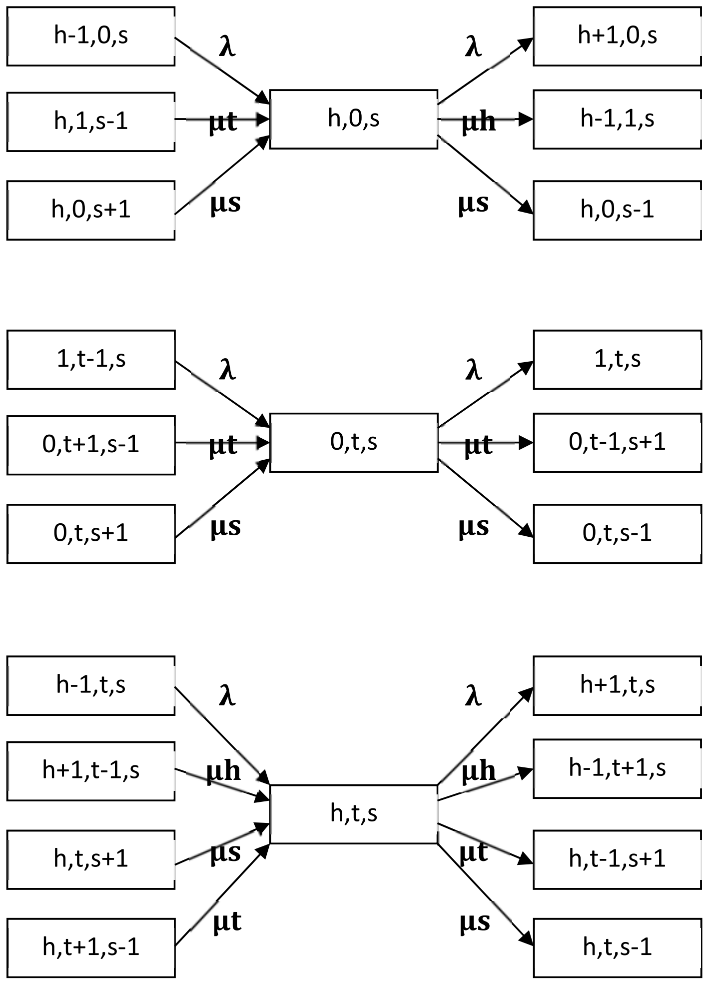


Figure 5.1.4: State transition diagram for multi-server tandem queue system at a container terminal

The steady state balance equations according to figures 5.1.3 and 5.1.4 are:

$$\lambda\, P_{0,0,0} = \mu s\, P_{0,0,1} \tag{1}$$

$$(\lambda + \mu s\,)P_{0,0,s} = \lambda\, P_{0,1,s-1} + \mu h\, P_{0,0,t+1} \tag{2}$$

$$(\lambda + \mu h\,)P_{h,0,0} = \lambda\, P_{h-1,0,0} + \mu s\, P_{h,0,1} \tag{3}$$

$$(\lambda + \mu t)P_{0,t,0} = \mu h\, P_{0,t-1,0} + \mu s\, P_{0,t,1} \tag{4}$$

$$(\lambda + \mu h + \mu t)P_{h,t,0} = \lambda\, P_{h-1,t,0} + \mu h\, P_{h+1,t-1,0} + \mu s\, P_{h,t,1} \tag{5}$$

$$(\lambda + \mu h + \mu s)P_{h,0,s} = \lambda\, P_{h-1,0,s} + \mu t\, P_{h,1,s-1} + \mu s\, P_{h,0,s+1} \tag{6}$$

$$(\lambda + \mu t + \mu s)P_{0,t,s} = \mu h\, P_{1,t-1,s} + \mu t\, P_{0,t+1,s-1} + \mu s\, P_{0,t,s+1} \tag{7}$$

$$(\lambda + \mu h + \mu t + \mu s)P_{h,t,s} = \lambda\, P_{h-1,t,s} + \mu h\, P_{h+1,t-1,s} + \mu s\, P_{h,t,s} + \mu t\, P_{h,t+1,s-1} \tag{8}$$

where $h, t, s \geq 0$, number of containers are independent random variables

$$\sum_{h}\sum_{t}\sum_{s} P_{h,t,s} = 1 \tag{9}$$

The probability that h containers at handling-off (H) station.

$$P_h = \left[\frac{\lambda}{\mu h}\right]^h \left[1 - \frac{\lambda}{\mu h}\right] \tag{10}$$

The probability that t containers at transportation (T) station.

$$P_t = \left[\frac{\lambda}{\mu t}\right]^t \left[1 - \frac{\lambda}{\mu t}\right] \tag{11}$$

The probability that s containers at stacking (S) station.

$$P_s = \left[\frac{\lambda}{\mu s}\right]^s \left[1 - \frac{\lambda}{\mu s}\right] \tag{12}$$

The probability that (h) containers at handling-off station and (t) containers at transportation station and (s) containers at stacking station.

$$P_{h,t,s} = P_h * P_t * P_s \tag{13 a}$$

$$P_{h,t,s} = \left[\frac{\lambda}{\mu h}\right]^h \left[1 - \frac{\lambda}{\mu h}\right] \left[\frac{\lambda}{\mu t}\right]^t \left[1 - \frac{\lambda}{\mu t}\right] \left[\frac{\lambda}{\mu s}\right]^s \left[1 - \frac{\lambda}{\mu s}\right] \tag{13 b}$$

$$P_{h,t,s} = \left[\frac{\lambda}{\mu h}\right]^h \left[\frac{\lambda}{\mu t}\right]^t \left[\frac{\lambda}{\mu s}\right]^s \left[1 - \frac{\lambda}{\mu h}\right] \left[1 - \frac{\lambda}{\mu t}\right] \left[1 - \frac{\lambda}{\mu s}\right] \tag{13 c}$$

$$P_{h,t,s} = \lambda^{h+t+s} \left[\frac{\mu h - \lambda}{\mu h^{h+1}}\right] \left[\frac{\mu t - \lambda}{\mu t^{t+1}}\right] \left[\frac{\mu s - \lambda}{\mu s^{s+1}}\right] \tag{13 d}$$

The probability that no containers at any station (handling-off (H), transportation (T) and stacking (S)), or the probability that the three stations (H,T and S) are idle.

$$P_{0,0,0} = \left[\frac{\lambda}{\mu h}\right]^0 \left[1 - \frac{\lambda}{\mu h}\right] \left[\frac{\lambda}{\mu t}\right]^0 \left[1 - \frac{\lambda}{\mu t}\right] \left[\frac{\lambda}{\mu s}\right]^0 \left[1 - \frac{\lambda}{\mu s}\right] \tag{14 a}$$

$$P_{0,0,0} = \left[1 - \frac{\lambda}{\mu h}\right] \left[1 - \frac{\lambda}{\mu t}\right] \left[1 - \frac{\lambda}{\mu s}\right] \tag{14 b}$$

$$P_{0,0,0} = \left[\frac{\mu h - \lambda}{\mu h}\right] \left[\frac{\mu t - \lambda}{\mu t}\right] \left[\frac{\mu s - \lambda}{\mu s}\right] \tag{14 c}$$

The probability that (h) containers at handling-off station and no containers at transportation (T) and stacking (S) stations.

$$P_{h,0,0} = \left[\frac{\lambda}{\mu h}\right]^{h}\left[1-\frac{\lambda}{\mu h}\right]\left[\frac{\lambda}{\mu t}\right]^{0}\left[1-\frac{\lambda}{\mu t}\right]\left[\frac{\lambda}{\mu s}\right]^{0}\left[1-\frac{\lambda}{\mu s}\right] \tag{15 a}$$

$$P_{h,0,0} = \left[\frac{\lambda}{\mu h}\right]^{h}\left[1-\frac{\lambda}{\mu h}\right]\left[1-\frac{\lambda}{\mu t}\right]\left[1-\frac{\lambda}{\mu s}\right] \tag{15 b}$$

$$P_{h,0,0} = \lambda^{h}\left[\frac{\mu h-\lambda}{\mu h^{h+1}}\right]\left[\frac{\mu t-\lambda}{\mu t}\right]\left[\frac{\mu s-\lambda}{\mu s}\right] \tag{15 c}$$

The probability that (t) containers at transportation station and no containers at handling-off (H) and stacking (S) stations.

$$P_{0,t,0} = \left[\frac{\lambda}{\mu h}\right]^{0}\left[1-\frac{\lambda}{\mu h}\right]\left[\frac{\lambda}{\mu t}\right]^{t}\left[1-\frac{\lambda}{\mu t}\right]\left[\frac{\lambda}{\mu s}\right]^{0}\left[1-\frac{\lambda}{\mu s}\right] \tag{16 a}$$

$$P_{0,t,0} = \left[\frac{\lambda}{\mu t}\right]^{t}\left[1-\frac{\lambda}{\mu h}\right]\left[1-\frac{\lambda}{\mu t}\right]\left[1-\frac{\lambda}{\mu s}\right] \tag{16 b}$$

$$P_{0,t,0} = \lambda^{t}\left[\frac{\mu h-\lambda}{\mu h}\right]\left[\frac{\mu t-\lambda}{\mu t^{t+1}}\right]\left[\frac{\mu s-\lambda}{\mu s}\right] \tag{16 c}$$

The probability that (s) containers at stacking station and no containers at handling-off (H) and transportation (T) stations.

$$P_{0,0,s} = \left[\frac{\lambda}{\mu h}\right]^{0}\left[1-\frac{\lambda}{\mu h}\right]\left[\frac{\lambda}{\mu t}\right]^{0}\left[1-\frac{\lambda}{\mu t}\right]\left[\frac{\lambda}{\mu s}\right]^{s}\left[1-\frac{\lambda}{\mu s}\right] \tag{17 a}$$

$$P_{0,0,s} = \left[\frac{\lambda}{\mu s}\right]^{s}\left[1-\frac{\lambda}{\mu h}\right]\left[1-\frac{\lambda}{\mu t}\right]\left[1-\frac{\lambda}{\mu s}\right] \tag{17 b}$$

$$P_{0,0,s} = \lambda^{s}\left[\frac{\mu h-\lambda}{\mu h}\right]\left[\frac{\mu t-\lambda}{\mu t}\right]\left[\frac{\mu s-\lambda}{\mu s^{s+1}}\right] \tag{17 c}$$

The probability that (h) containers at handling-off station and (s) containers at stacking station and no containers at transportation (T) station.

$$P_{h,0,s} = \left[\frac{\lambda}{\mu h}\right]^{h}\left[1-\frac{\lambda}{\mu h}\right]\left[\frac{\lambda}{\mu t}\right]^{0}\left[1-\frac{\lambda}{\mu t}\right]\left[\frac{\lambda}{\mu s}\right]^{s}\left[1-\frac{\lambda}{\mu s}\right] \tag{18 a}$$

$$P_{h,0,s} = \left[\frac{\lambda}{\mu h}\right]^{h}\left[\frac{\lambda}{\mu s}\right]^{s}\left[1-\frac{\lambda}{\mu h}\right]\left[1-\frac{\lambda}{\mu t}\right]\left[1-\frac{\lambda}{\mu s}\right] \tag{18 b}$$

$$P_{h,0,s} = \lambda^{h+s}\left[\frac{\mu h-\lambda}{\mu h^{h+1}}\right]\left[\frac{\mu t-\lambda}{\mu t}\right]\left[\frac{\mu s-\lambda}{\mu s^{s+1}}\right] \tag{18 c}$$

The probability that (h) containers at handling-off station and (t) containers at transportation station and no containers at stacking (S) station.

$$P_{h,t,0} = \left[\frac{\lambda}{\mu h}\right]^{h}\left[1-\frac{\lambda}{\mu h}\right]\left[\frac{\lambda}{\mu t}\right]^{t}\left[1-\frac{\lambda}{\mu t}\right]\left[\frac{\lambda}{\mu s}\right]^{0}\left[1-\frac{\lambda}{\mu s}\right] \tag{19 a}$$

$$P_{h,t,0} = \left[\frac{\lambda}{\mu h}\right]^{h}\left[\frac{\lambda}{\mu t}\right]^{t}\left[1-\frac{\lambda}{\mu h}\right]\left[1-\frac{\lambda}{\mu t}\right]\left[1-\frac{\lambda}{\mu s}\right] \tag{19 b}$$

$$P_{h,t,0} = \lambda^{h+t}\left[\frac{\mu h-\lambda}{\mu h^{h+1}}\right]\left[\frac{\mu t-\lambda}{\mu t^{t+1}}\right]\left[\frac{\mu s-\lambda}{\mu s}\right] \tag{19 c}$$

The probability that (t) containers at transportation station and (s) containers at stacking station and no containers at handling-off (H) station.

$$P_{0,t,s} = \left[\frac{\lambda}{\mu h}\right]^{0}\left[1-\frac{\lambda}{\mu h}\right]\left[\frac{\lambda}{\mu t}\right]^{t}\left[1-\frac{\lambda}{\mu t}\right]\left[\frac{\lambda}{\mu s}\right]^{s}\left[1-\frac{\lambda}{\mu s}\right] \tag{20 a}$$

$$P_{0,t,s} = \left[\frac{\lambda}{\mu t}\right]^{t}\left[\frac{\lambda}{\mu s}\right]^{s}\left[1-\frac{\lambda}{\mu h}\right]\left[1-\frac{\lambda}{\mu t}\right]\left[1-\frac{\lambda}{\mu s}\right] \tag{20 b}$$

$$P_{0,t,s} = \lambda^{t+s} \left[\frac{\mu h - \lambda}{\mu h}\right] \left[\frac{\mu t - \lambda}{\mu t^{t+1}}\right] \left[\frac{\mu s - \lambda}{\mu s^{s+1}}\right] \tag{20 c}$$

The probability that the containers at handling-off station, transportation station and stacking station excel the number of (h), (t) and (s).

$$P_{i>h,j>t,k>s} = \sum_{i=h+1}^{i=\infty} P_i + \sum_{j=t+1}^{j=\infty} P_j + \sum_{k=s+1}^{k=\infty} P_k \tag{21 a}$$

$$P_{i>h,j>t,k>s} = \left[\frac{\lambda}{\mu h}\right]^{h+1} \left[\frac{\lambda}{\mu t}\right]^{t+1} \left[\frac{\lambda}{\mu s}\right]^{s+1} \tag{21 b}$$

$$P_{i>h,j>t,k>s} = \frac{\lambda^{h+t+s+3}}{\mu h^{h+1} \ \mu t^{t+1} \ \mu s^{s+1}} \tag{21 c}$$

The average number of containers waiting in the queue or line $\mathbf{L_Q}$ can be expressed as:

$$L_Q = \sum_{h=1}^{h=\infty} (h-1) P_h + \sum_{t=1}^{t=\infty} (t-1) \ P_t + \sum_{s=1}^{s=\infty} (s-1) \ P_s \tag{22 a}$$

$$L_Q = \frac{\lambda}{\mu h} * \frac{\lambda}{\mu h - \lambda} + \frac{\lambda}{\mu t} * \frac{\lambda}{\mu t - \lambda} + \frac{\lambda}{\mu s} * \frac{\lambda}{\mu s - \lambda} \tag{22 b}$$

$$L_Q = \lambda^2 \left[\frac{1}{\mu h \ (\mu h - \lambda)} + \frac{1}{\mu t \ (\mu t - \lambda)} + \frac{1}{\mu s \ (\mu s - \lambda)}\right] \tag{22 c}$$

The average time of container spent waiting in the queue or line $\mathbf{W_Q}$ can be expressed as:

$$W_Q = \frac{L_Q}{\lambda} \tag{23 a}$$

$$W_Q = \lambda \left[\frac{1}{\mu h\,(\mu h - \lambda)} + \frac{1}{\mu t\,(\mu t - \lambda)} + \frac{1}{\mu s\,(\mu s - \lambda)}\right] \tag{23 b}$$

The average number of containers in the service system $\mathbf{L_{ct}}$ can be expressed as:

$$L_{ct} = \sum_{h=0}^{h=\infty} h * P_h + \sum_{t=0}^{t=\infty} t * P_t + \sum_{s=0}^{s=\infty} s * P_s \tag{24 a}$$

$$L_{ct} = \sum_{h=0}^{h=\infty} h * \left[\frac{\lambda}{\mu h}\right]^h \left[1 - \frac{\lambda}{\mu h}\right] + \sum_{t=0}^{t=\infty} t * \left[\frac{\lambda}{\mu t}\right]^t \left[1 - \frac{\lambda}{\mu t}\right] + \sum_{s=0}^{s=\infty} s * \left[\frac{\lambda}{\mu s}\right]^s \left[1 - \frac{\lambda}{\mu s}\right] \tag{24 b}$$

$$L_{ct} = \frac{\lambda}{\mu h - \lambda} + \frac{\lambda}{\mu t - \lambda} + \frac{\lambda}{\mu s - \lambda} \tag{24 c}$$

The average time of container spent waiting in the system, including service $\mathbf{W_{ct}}$ can be expressed as:

$$W_{ct} = \frac{1}{\lambda} * L_{ct} \tag{25 a}$$

$$W_{ct} = \frac{1}{\mu h - \lambda} + \frac{1}{\mu t - \lambda} + \frac{1}{\mu s - \lambda} \tag{25 b}$$

$$W_{ct} = W_Q + \frac{1}{\mu h} + \frac{1}{\mu t} + \frac{1}{\mu s} \tag{25 c}$$

5.1.3.1 Assumptions

The following assumptions are made for the model:

1- We assume there is enough storage space in stacking area to store all types of containers according to their blocks.

2- We consider that in the ideal condition, there are enough equipment (cranes, trucks, vehicles etc) to perform all tasks, functions and operations at a container terminal. That means there is no delay or waiting in the performance of those tasks or functions in terms of lack in the number of equipment inside a container terminal.

3- To achieve the stability of the container terminal (service system) in queuing theory, we consider that in the ideal stacking process of containers, the service rate of quay cranes ($\boldsymbol{\mu h}$) must be less than the service rate of yard trucks or vehicles ($\boldsymbol{\mu t}$), also the service rate of yard trucks or vehicles must be less than the service rate of yard cranes ($\boldsymbol{\mu s}$). That means, there is no waiting and delay in the sequences of operations inside container terminal. i.e.

$$\mu h < \mu t < \mu s$$

$$\sum_{c=1}^{c=n} \mu h_c < \sum_{p=1}^{p=e} \mu t_p < \sum_{u=1}^{u=m} \mu s_u$$

Where,

C: Represents the set of Quay Cranes (QCs) at quay area, that are deal with loading and unloading of containers from/to the containerships (1= Quay crane, 2= Luffing crane, 3= portainers … etc), c= 1,2 .... n.

P : Represents the set of Yard Trucks (YTs) or Vehicles, that are used to transfer the containers from quay area to container yard or vice versa (1= Yard Trucks (YTs), 2= Automated Guided Vehicles (AGVs), 3= Multi Trailer System (MTS) ... etc), p = 1,2 .... e.

U : Represents the set of Yard Cranes (YCs) at container yard, that are used for lifting the containers or stacking the containers into the blocks at container yard (1= Rubber Tyred Gantry cranes (RTG), 2= Rail Mounted Gantry cranes (RMG), 3= Automated Stacking Cranes (ASCs) ... etc), u =1,2 ... m.

4- To achieve the best container stacking strategy, the containers must be stacked in blocks, as near as possible as to the berthing positions of vessels, to reduce the transportation time of containers from the quay area to the yard area and vice versa.

5- The containers must be arranged with sufficient leeway in staking area, and they must not be squeezed to capacity, otherwise the number of unproductive moves (reshuffles) will increase due to increase in the number of tiers.

6- We assume the layout of berths in a container terminal is Discrete. That means, the quay is divided into a finite set of berths, and each vessel in this layout can occupy a suitable berth within a specific time. After berthing, the containers are stacked and arranged in the container yard separately according to the import, export and empty containers conditions. Service time for the service centers (quay cranes, yard trucks and yard cranes) is constant, i.e. static. The arrival of vessels is Dynamic and the vessels cannot berth before the expected arrival time. That means fixed arrival times are given for the vessels for berthing times, or all vessels to be scheduled for berthing have not yet arrived but arrival times are know in advance.

5.1.4 Experimental Results and Discussion

Twenty different scenarios for container stacking inside container terminal are applied to find the optimal service level and to achieve maximum efficiency of service stations. These scenarios are varying from each other in terms of quantities of containers, durations of stay for the vessels in the seaport and no. of equipment (quay cranes, yard trucks and yard cranes) that are used to perform the operations. Tables 5.1.1 and 5.1.2 show the analysis and performance measures of the multi-server queues in tandem (or tandem queuing system, multi-stage series queuing system) at a container terminal. Generally, the experimental results show that the increment in the number of service centers (quay cranes in the first stage, yard trucks in the second stage and yard cranes in the third stage) leads to reduce the total waiting time of containers in the queue, the total waiting time for containers that are serviced in the system, the average number of containers that are waiting in the queue and the system respectively, as well as reduce the average utilization of the system (the average utilization of the stations). That means, we can reduce the waiting cost of containers in the system when we increase the service level (service capacity level), but this procedure increases the service cost or incurs additional expenses, especially if we need to improve the productivity of container terminal.

Table 5.1.3 Shows the average waiting times of containers in the queue and in the system (container terminal), as well as the average service times at the stations (handling-off, transportation and stacking). In the scenarios no. (1) to no. (14), we find there is a difference between the values of waiting time especially in scenarios that have the same number of containers. That difference is due to the relationship between the arrival rate of containers λ and the service rate of handling-off station (stage 1) $\boldsymbol{\mu h}$. That means, when the value of the arrival rate approaches the value of service rate at the first service station, the waiting times of containers in the queue and in the system respectively are increased comparing with the waiting times of containers for the scenarios with a significant difference between values of the arrival rate and service rate of the first service station in container terminal (see the difference between the values for scenarios no. (1) and no. (2), no. (3) and no. (4), no. (5) and no. (6), no. (7) and no. (8), no. (9) and no. (10), no. (11) and no. (12), as well as no. (13) and no. (14)). Also that difference leads to increase the average number of containers waiting in the queue and in the service system. The experimental results show that there is direct proportion between the utilization factor of the handling-off station (ρ_h) and the average waiting times of containers in the queue ($\mathbf{W_Q}$) and system ($\mathbf{W_{ct}}$).

The scenarios from no. (15) to no. (20) give appropriate indications of container terminal behavior under changing the available resources (quay cranes, yard trucks and yard cranes) that are used inside a seaport to determine the optimal condition of sequence of operations and the relation between activities and functions of quay and container yard areas. We see when the number of service centers in transportation station (yard trucks in the second stage) increase, all the waiting times (in the queue and in the service system), the average utilization of the transportation station and the number of containers in queue and in the service system will decrease. The figure 5.1.5 represents the relations between all outputs that are obtained by using queuing theory for multi-stage series of the container stacking process at a seaport container terminal for the scenarios from no. (15) to no. (20). The figures from 5.1.6 to 5.1.8 give more details to understand the behavior of container terminal under a specific service level to anticipate the performance level of service stations for scenario no. (20). We found that the probability that (h) containers at handling-off station ($\mathbf{P_h}$) and the probability that (h) containers at handling-off station and no containers at transportation and stacking stations ($\mathbf{P_{h,0,0}}$) are decreased when the number of containers in the station increased up to the number of containers in the arrival rate (λ). The results show that the value of the probability ($\mathbf{P_h}$) is more than the value of the probability ($\mathbf{P_{h,0,0}}$) by $\mathbf{57.866\ P_h}$ % (see figures (5.1.6a and 5.1.6b)).

The probability that (t) containers at transportation station ($\mathbf{P_t}$) and the probability that (t) containers at transportation station and no containers at handling-off and stacking stations ($\mathbf{P_{0,t,0}}$) are decreased when the number of containers in the second station increased up to the number of containers in the arrival rate of the second station ($\boldsymbol{\mu}\mathbf{h}$). The results show that the value of the probability ($\mathbf{P_t}$) is more than the value of the probability ($\mathbf{P_{0,t,0}}$) by $\mathbf{94.733\ P_t}$ % (see figures (5.1.6c and 5.1.6d)). As well as, we found that the probability that (s) containers at stacking station ($\mathbf{P_s}$) and the probability that (s) containers at stacking station and no containers at transportation and handling-off stations ($\mathbf{P_{0,0,s}}$) are decreased when the number of containers in the third station increased up to the number of containers in the arrival rate of the third station ($\boldsymbol{\mu}\mathbf{t}$). The results show that the value of the probability ($\mathbf{P_s}$) is more than the value of he probability ($\mathbf{P_{0,0,s}}$) by $\mathbf{96.444\ P_s}$ % (see figures 5.1.6e and 5.1.6f)).
Finally, the figures 5.1.7a, 5.1.7b, 5.1.7c, 5.1.8a and 5.1.8b illustrate the effect of number of containers in the stations (h,t,s) on the probabilities ($\mathbf{P_{h,0,s}}$), ($\mathbf{P_{h,t,0}}$), ($\mathbf{P_{0,t,s}}$), ($\mathbf{P_{h,t,0}}$) and ($\mathbf{P_{h,P_{i>h,j>t,k>s}}\ _{0,0}}$). We see the variation in values of the probabilities depending on the number of containers in each station, and it leads to effect on the outputs and performance measures of the service system.

scenario	No. of inbound containers X (TEU)	The max. duration of stay for the vessel in the seaport R (day)		No. of quay cranes	μ TEU/hr for the quay crane (QC)	μh TEU/hr The output of quay cranes as arrivals to the YTs or 2^{ND} stage	No. of yard trucks	μ TEU/hr for the yard truck (YT)	μt TEU/hr The output of yard trucks as arrivals to the YCs or 3^{ND} stage	No. of yard cranes	μ TEU/hr for the yard crane (YC)	μs TEU/hr The output of yard cranes
1	1000	1	42	2	30	60	15	6	90	6	20	120
2	1000	1	42	3	30	90	20	6	120	6	20	120
3	2000	1.5	56	2	30	60	15	6	90	10	20	200
4	2000	2	42	2	30	60	15	6	90	10	20	200
5	2000	1	84	3	30	90	20	6	120	10	20	200
6	2000	1.5	56	3	30	90	20	6	120	10	20	200
7	3000	2	63	3	30	90	20	6	120	16	20	320
8	3000	2.5	50	2	30	60	15	6	90	16	20	320
9	3000	3	42	3	30	90	20	6	120	16	20	320
10	3000	1.5	84	4	30	120	25	6	150	16	20	320
11	4000	3	56	2	30	60	15	6	90	20	20	400
12	4000	2.5	67	3	30	90	20	6	120	20	20	400
13	4000	1.5	112	4	30	120	25	6	150	20	20	400
14	4000	4	42	2	30	60	15	6	90	20	20	400
15	4000	2	84	3	30	90	20	6	120	20	20	400
16	4000	2	84	3	30	90	22	6	132	20	20	400
17	4000	2	84	3	30	90	24	6	144	20	20	400
18	4000	2	84	3	30	90	26	6	156	20	20	400
19	4000	2	84	3	30	90	28	6	168	20	20	400
20	4000	2	84	3	30	90	30	6	180	20	20	400

Table 5.1.1: The analysis of the multi-server queuing system in tandem at a container terminal

scenario	No. of containers X(TEU)	[illegible] (λ) TEU/	μh TEU/hr The output of quay cranes as arrivals to the YTs or 2^{ND} stage	μt TEU/hr The output of yard trucks as arrivals to the YCs or 3^{ND} stage	μs TEU/hr The output of yard cranes	The utilization factor for the first stage ρ_h	The utilization factor for the second stage ρ_t	The utilization factor for the third stage ρ_s	L_Q average no. of TEUs in the queue (waiting)	W_Q average time a TEU spends waiting in the queue (hr)	L_{ct} average no. of TEUs in the system	W_{ct} average time of TEU spends waiting in the system (hr)
1	**1000**	42	**60**	**90**	**120**	**0.7**	**0.66666**	**0.75**	**2.230128205**	**0.053098**	**3.746795**	**0.089209**
2	**1000**	42	**90**	**120**	**120**	**0.4666**	**0.75**	**1**	**0.78525641**	**0.018697**	**1.951923**	**0.046474**
3	**2000**	56	**60**	**90**	**200**	**0.9333**	**0.66666**	**0.45**	**14.20039216**	**0.253578**	**16.03595**	**0.286356**
4	**2000**	42	**60**	**90**	**200**	**0.7**	**0.66666**	**0.45**	**2.097489451**	**0.04994**	**3.474156**	**0.082718**
5	**2000**	84	**90**	**120**	**200**	**0.9333**	**0.75**	**0.6**	**15.00413793**	**0.178621**	**17.05747**	**0.203065**
6	**2000**	56	**90**	**120**	**200**	**0.6222**	**0.75**	**0.6**	**1.542058824**	**0.027537**	**2.910948**	**0.051981**
7	**3000**	63	**90**	**120**	**320**	**0.7**	**0.75**	**0.375**	**2.261857678**	**0.035903**	**3.683733**	**0.058472**
8	**3000**	50	**60**	**90**	**320**	**0.8333**	**0.66666**	**0.2813**	**4.890046296**	**0.097801**	**6.435185**	**0.128704**
9	**3000**	42	**90**	**120**	**320**	**0.4666**	**0.75**	**0.375**	**0.616624008**	**0.014682**	**1.564541**	**0.037251**
10	**3000**	84	**120**	**150**	**320**	**0.7**	**0.8**	**0.4688**	**2.439492809**	**0.029042**	**3.961993**	**0.047167**
11	**4000**	56	**60**	**90**	**400**	**0.9333**	**0.66666**	**0.225**	**14.11429397**	**0.252041**	**15.80985**	**0.282319**
12	**4000**	67	**90**	**120**	**400**	**0.7444**	**0.75**	**0.3**	**2.908117845**	**0.043405**	**4.378396**	**0.065349**
13	**4000**	112	**120**	**150**	**400**	**0.9333**	**0.8**	**0.375**	**15.37625731**	**0.137288**	**17.33626**	**0.154788**
14	**4000**	42	**60**	**90**	**400**	**0.7**	**0.66666**	**0.225**	**2.053985102**	**0.048904**	**3.325652**	**0.079182**
15	**4000**	84	**90**	**120**	**400**	**0.9333**	**0.75**	**0.3**	**14.75582278**	**0.175665**	**16.59916**	**0.197609**
16	**4000**	84	**90**	**132**	**400**	**0.9333**	**0.68182**	**0.33**	**14.23612582**	**0.169478**	**16.01582**	**0.190665**
17	**4000**	84	**90**	**144**	**400**	**0.9333**	**0.625**	**0.36**	**13.93915612**	**0.165942**	**15.66582**	**0.186498**
18	**4000**	84	**90**	**156**	**400**	**0.9333**	**0.57692**	**0.39**	**13.75069458**	**0.163699**	**15.43249**	**0.18372**
19	**4000**	84	**90**	**168**	**400**	**0.9333**	**0.53571**	**0.42**	**13.62248945**	**0.162172**	**15.26582**	**0.181736**
20	**4000**	84	**90**	**180**	**400**	**0.9333**	**0.5**	**0.45**	**13.53082278**	**0.161081**	**15.14082**	**0.180248**

Table 5.1.2: The performance measures of the multi-server queuing system in tandem at a container terminal

scenario	No. of containers X (TEU)	The max. duration of stay for the vessel in the seaport R (day)	$1/\lambda$ average interval between consecutive container arrivals (minute)	$1/\mu h$ average service time at the first station (minute)	$1/\mu t$ average service time at the second station (minute)	$1/\mu s$ average service time at the third station (minute)	W_Q average time a TEU spends waiting in the queue (minute)	W_{ct} average time of TEU spends waiting in the system including service (minute)
1	1000	1	1.428571429	1	0.666666667	0.5	3.185897436	5.352564103
2	1000	1	1.428571429	0.666666667	0.5	0.5	1.121794872	2.788461538
3	2000	1.5	1.071428571	1	0.666666667	0.3	15.21470588	17.18137255
4	2000	2	1.428571429	1	0.666666667	0.3	2.996413502	4.963080169
5	2000	1	0.714285714	0.666666667	0.5	0.3	10.71724138	12.18390805
6	2000	1.5	1.071428571	0.666666667	0.5	0.3	1.652205882	3.118872549
7	3000	2	0.952380952	0.666666667	0.5	0.1875	2.15415017	3.508316836
8	3000	2.5	1.2	1	0.666666667	0.1875	5.868055556	7.722222222
9	3000	3	1.428571429	0.666666667	0.5	0.1875	0.880891441	2.235058107
10	3000	1.5	0.714285714	0.5	0.4	0.1875	1.742494864	2.829994864
11	4000	3	1.071428571	1	0.666666667	0.15	15.12245782	16.93912449
12	4000	2.5	0.895522388	0.666666667	0.5	0.15	2.604284637	3.920951304
13	4000	1.5	0.535714286	0.5	0.4	0.15	8.237280702	9.287280702
14	4000	4	1.428571429	1	0.666666667	0.15	2.934264432	4.750931099
15	4000	2	0.714285714	0.666666667	0.5	0.15	10.53987342	11.85654008
16	4000	2	0.714285714	0.666666667	0.454545455	0.15	10.1686613	11.43987342
17	4000	2	0.714285714	0.666666667	0.416666667	0.15	9.956540084	11.18987342
18	4000	2	0.714285714	0.666666667	0.384615385	0.15	9.8219247	11.02320675
19	4000	2	0.714285714	0.666666667	0.357142857	0.15	9.730349608	10.90415913
20	4000	2	0.714285714	0.666666667	0.333333333	0.15	9.664873418	10.81487342

Table 5.1.3: The average waiting times of containers in the queue and in container terminal, as well as the average service times at the stations

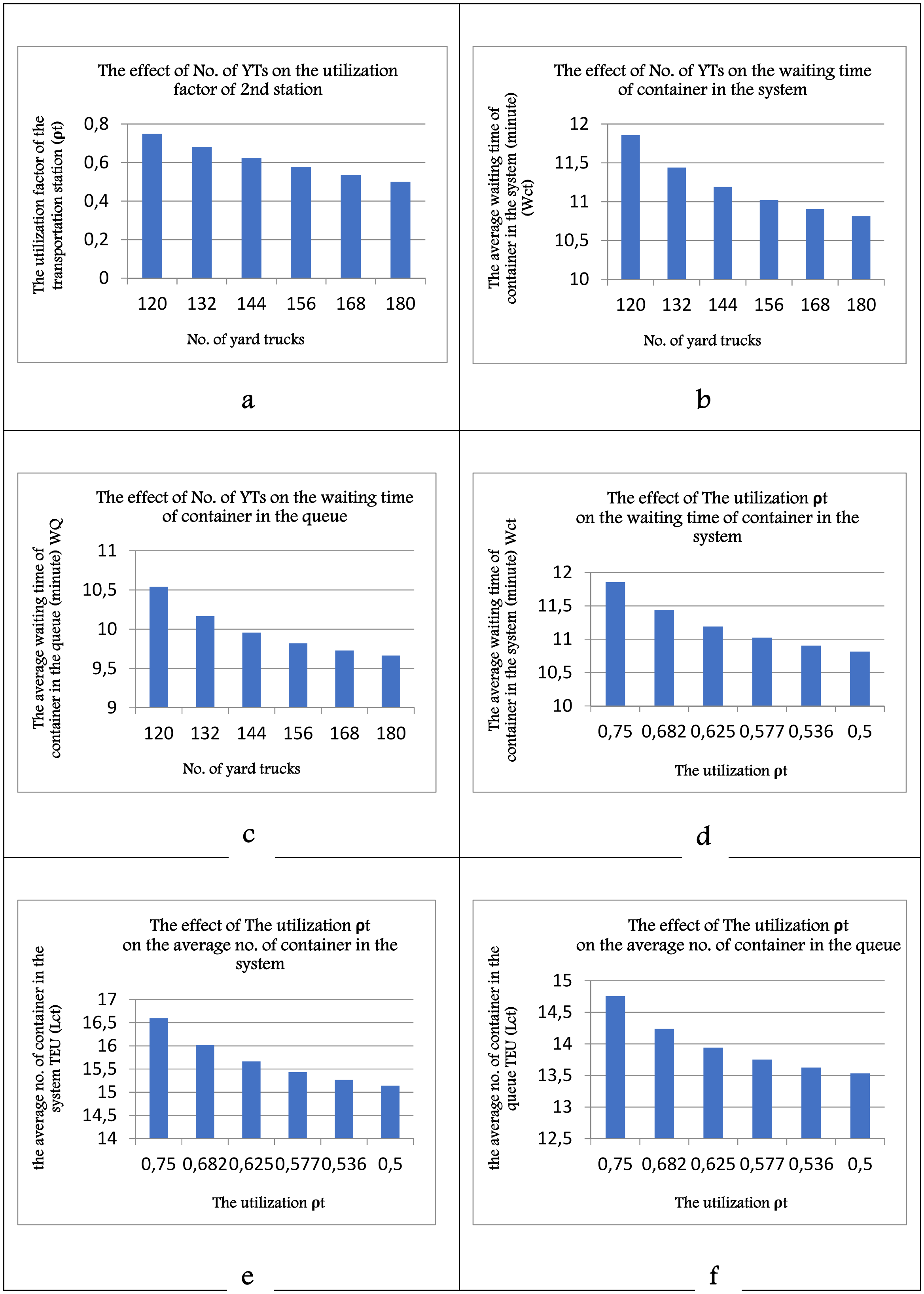


Figure 5.1.5: The relations between all outputs that are obtained by using queuing theory for multi-stage series of the container stacking process (for the scenarios from no. (15) to no. (20))

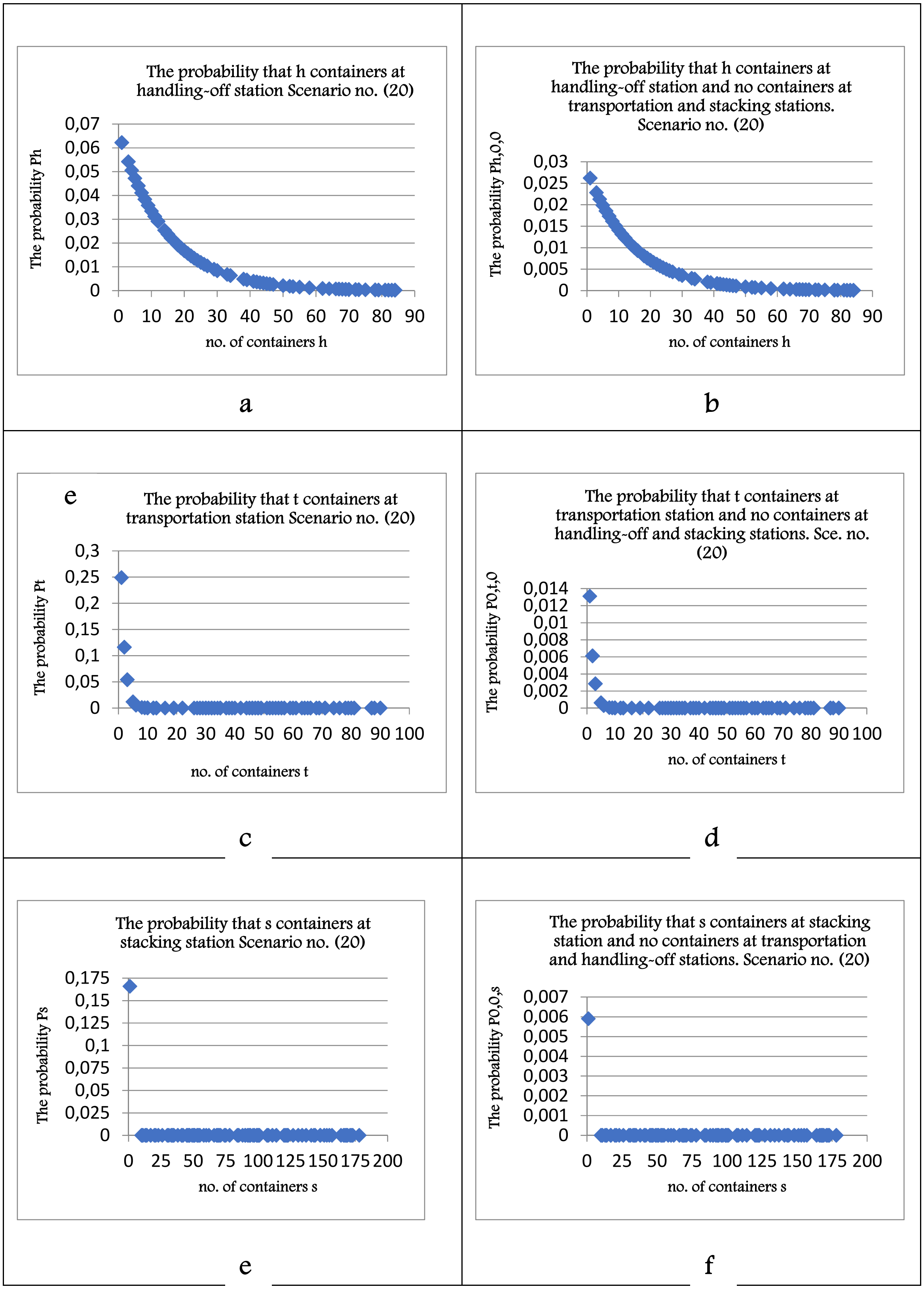


Figure 5.1.6: The relations between all outputs that are obtained by using queuing theory for Scenario no. (20)

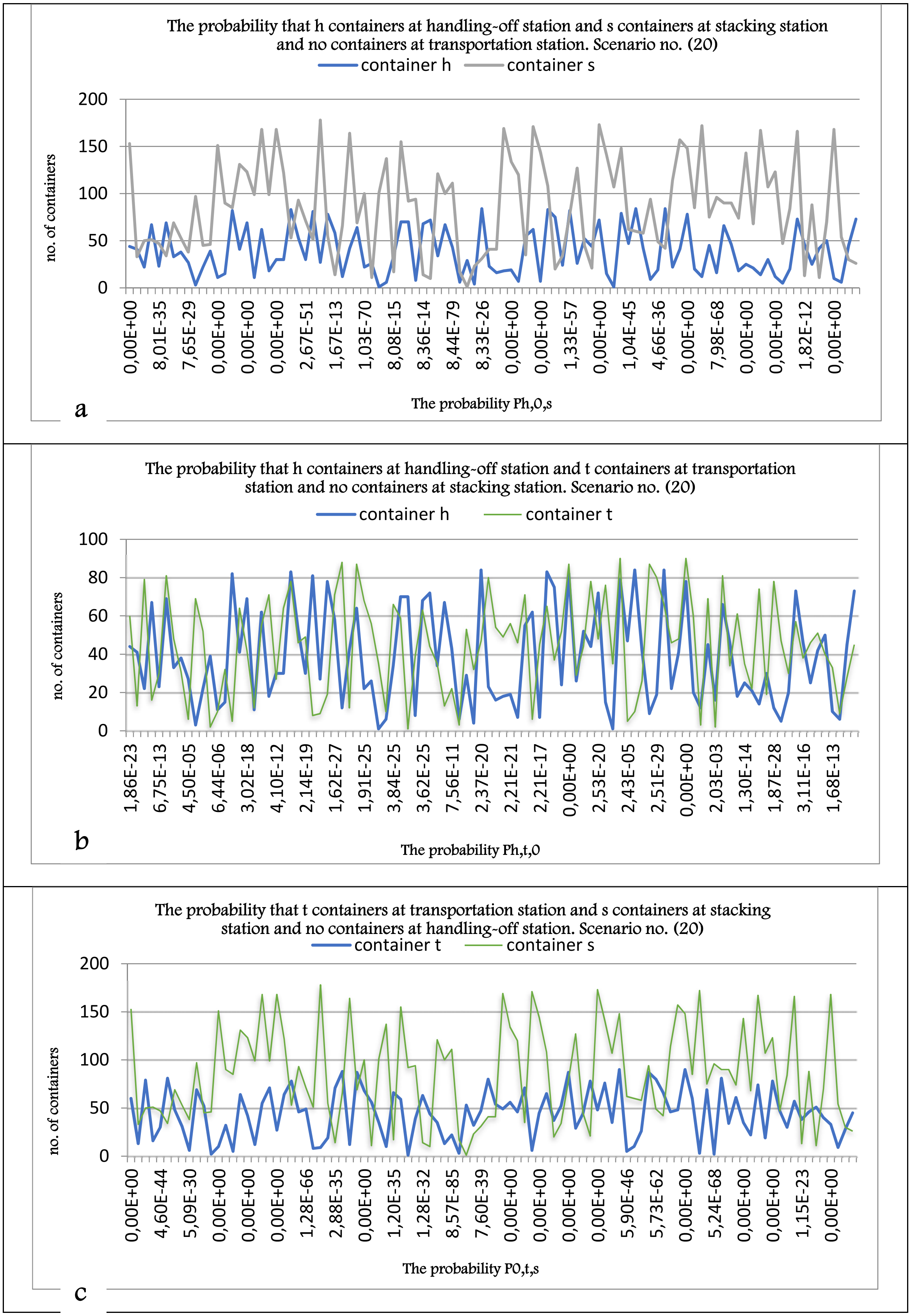
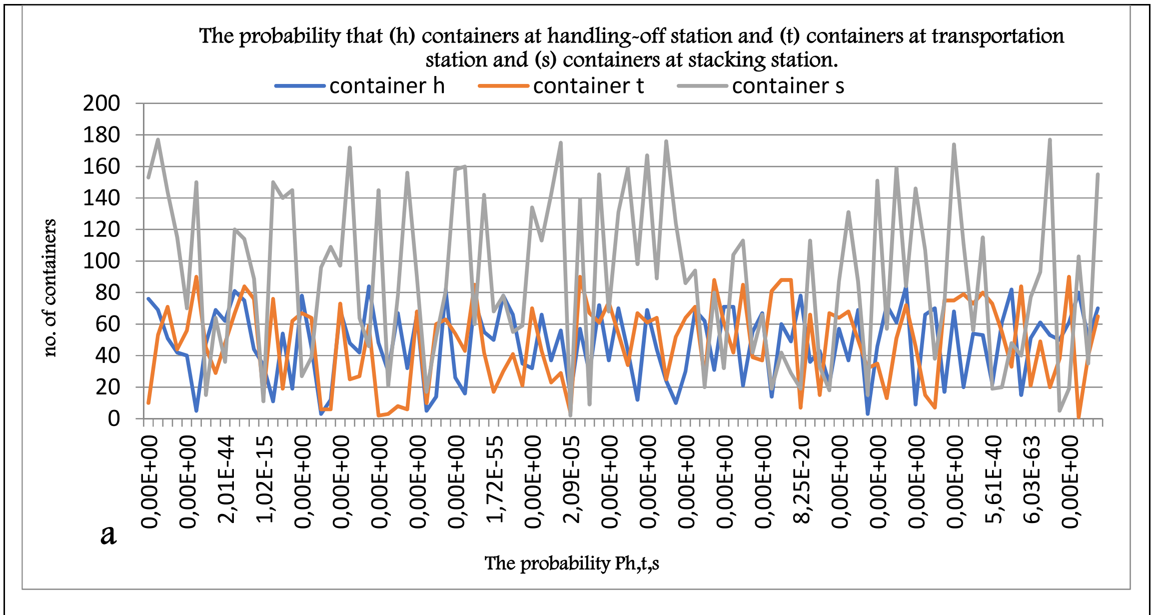


Figure 5.1.7: The relations between all outputs that are obtained by using queuing theory for Scenario no. (20)



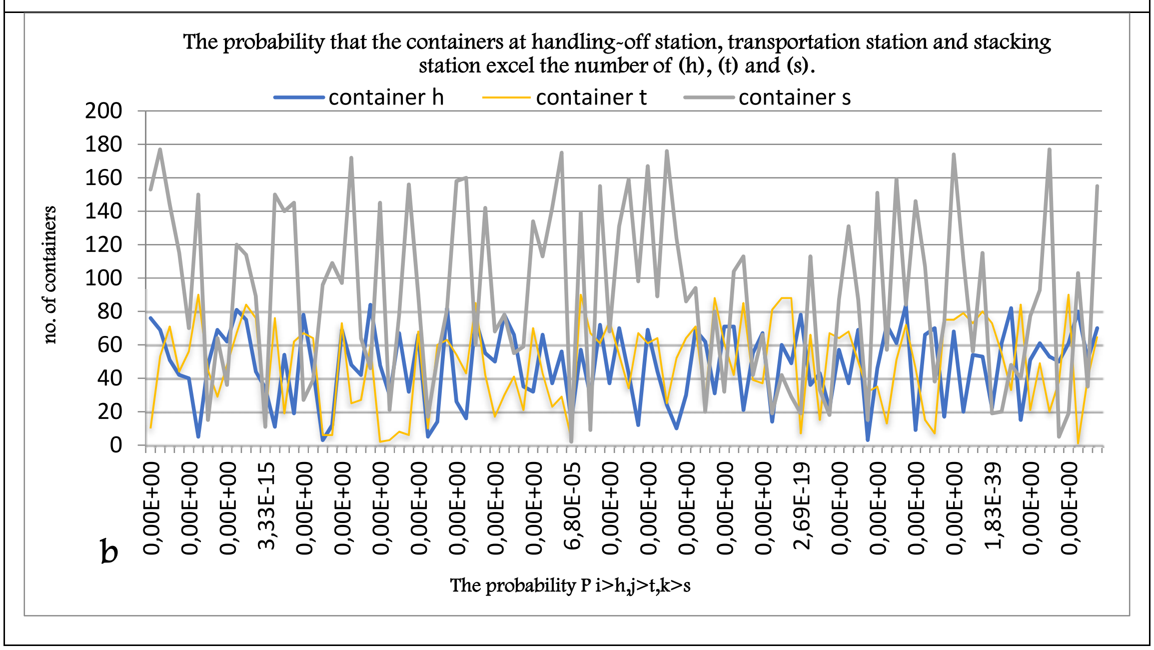


Figure 5.1.8: The relations between all outputs that are obtained by using queuing theory for Scenario no. (20)

5.1.5 Conclusions

This study aims to find the optimal service level with optimal efficiency and service condition (system parameters) for the container stacking process in a seaport container terminal and the impact of synchronization and the sequence of daily operations and activities between seaside and landside of terminal.

The system is a typical tandem queuing system (the container stacking problem that is associated with functional operations and sub-operations at a typical container terminal is represented as multi-server queues in tandem, consisting of three stages, the first stage being the relationship between the arrival containers or the inbound containers at seaport and the handling-off process, the second stage being the relationship between the handling-off process and the transportation process, and the third stage being the relationship between transportation process and stacking process. This procedure is useful for the design of container terminals in terms of layout, capacities and control. A comparison was made between the results of many scenarios for the container stacking inside a container terminal to evaluate the performance of the formulated model. According to the outputs, the study's findings were that when the value of the arrival rate approaches the value of service rate at the first service station, the waiting times of containers in the queue and in the system are increased in comparison to the waiting times of containers for the scenarios with a significant difference between values of the arrival rate and service rate of the first service station in a container terminal. . Also, there is direct proportion between the utilization factor of the handling-off station (ρ_h) and the average waiting times of containers in the queue ($\mathbf{W_Q}$) and system ($\mathbf{W_{ct}}$).

The proposed approach by using Queuing theory as an analytical technique to deal with container stacking problem is a suitable tool to provide a valuable guide for seaport authorities and decision makers to analyze and discover all possibilities to achieve the optimal service level with optimal utilization of the service system.

In future work, the effects of varying arrival rate of containers on the service level in a seaport container terminal will be studied, as well as on the congestion of containers inside the container yard, in order to find the optimal arrival and service rates to perform all functions that are associated with container stacking process. Also, the blocked service stations of tandem queues system will be an area of focus as well as the service discipline or the possibilities for the containers to enter service in the container terminal (e.g the service under priorities, random order) on the service level inside seaport.

Section two: The assignment of suitable berths to the vessels under different berthing priorities

5.2.1 Introduction

The Berth Allocation Problem (BAP) is the dominant issue in a seaport container terminal. It incurs much attention in the maritime industry by many seaports authorities and terminal operators to improve the terminal efficiency and operations planning, or to minimize the waiting time of vessels and maximize the berth utilization. There are a lot of incoming vessels or containerships arriving at seaport container terminals at all times, and these vessels need a number of berths along a quay. Each berth can serve one vessel within a few days depending on variables such as vessel type and size, container handling volume, the available number of quay cranes in berthing area, service priority, and berth allocation policy.

Usually, the arriving vessels must wait in a queue until the berths are available to service them. That means, before berthing, the seaport authority assigns a berthing position and a berthing time to each vessel. Most seaports aim to minimize the waiting time of queuing vessels from the time they arrive at the seaport until container handling operations (loading\unloading) begin. After berthing, the vessels stay within the boundaries of the assigned berths, and then the containers (fully loaded and empty) are unloaded (loaded) from\to the vessels. When the handling process or service is completed, the vessels emerge from their assigned berths and depart from the seaport. The deviation between the actual arrival time and the scheduled arrival time (or the expected arrival time) of the vessels often results in changes to the planning and organizing of quay side and yard side operations, viz, there are many scenarios that deal with how to approach vessel arrival times. When they arrive earlier than the expected a time, they are berthed immediately, or they are kept waiting at a container terminal for a period of time before berthing. This type of arrival time is called the Static Arrival, i.e. there are no arrival times given for the vessels on the berthing times. A different approach is used when the vessels cannot berth before the expected arrival time, i.e. the arrival times for berthing are fixed. This type of arrival time of vessels is called the Dynamic Arrival.

There are few studies focused on berth allocation problem, and some studies deal with both berth allocation and quay crane assignment. The following literature review provides more details on this topic: Kim and Moon (2003), suggested a simulated annealing algorithm, and formulated a mixed integer linear programming model to minimize the total costs (including the cost due to the non-optimal berthing location of vessels in a container terminal, and penalty cost due to delays in the departures of vessels). According to the experimental results that were obtained by using a simulated annealing algorithm and LINDO package for the formulated model, the researchers found that the simulated annealing algorithm obtains solutions that are similar to the optimal solutions found by the mixed integer linear programming model, and the results of the algorithm were near-optimal solutions and the computational time was within the limits of practical usage. Dai et al (2004), studied the berth allocation problem and focused on berth allocation planning optimization in a container terminal. Many scenarios and policies are applied to design a berthing system to allocate berthing space to vessels in real time close to their preferred locations at the terminal. The researchers used a simulation model to evaluate the performance of their proposed approach, and they found that the results show that the performance varies according to the various policy parameters adopted by the terminal operator. Furthermore, according to the moderate load scenario, the proposed approach is able to allocate space to over 90% of vessels upon arrival, with more than 80% of them being assigned to the preferred berthing location. Imai et al (2005), addressed the berth allocation problem in multi-user container terminals (the busy container ports with heavy container traffic), by establishing a heuristic algorithm to minimize the total service times for all ships (the time from arrival to departure and waiting time). The proposed heuristic algorithm is used to solve the problem in two stages; the first stage identifies a solution given the number of partitioned berths, and the second stage relocates the ships that may overlap or be located sparsely in a scheduling space. The scholars found that the algorithm can improve the terminal operation and that it yields a feasible solution to the Berth Allocation Problem (BAP).

Boile et al (2006), formulated a mixed integer programming model based on a heuristic algorithm to optimize berth allocation with service priorities in a multi-user terminal. The formulated model is used to minimize the weighted total service time (berthing time and handling time), and to find the optimal berth schedule for the assignment of ships to the berthing areas along a quay. The numerical experiments show that the heuristic algorithm is useful to obtain a new berth allocation scheme to deal with the changes in ship arrival times.

Moorthy and Teo (2006), studied the berth allocation problem, and analysed the impact of the berth template design problem on container terminal operations. The researchers proposed a robust model and used two methods to evaluate the robustness of the berth template (service level-waiting time and operational cost connectivity). They compared between the results that were obtained by using two models (robust and deterministic) and found that the average delays in the deterministic mode is 1.65 h with a variance of 2.75, whereas the average delay in the robust model is 0.75 h with a variance of 1.13. Furthermore, 27 vessels in the robust model's template have an expected delay of 0 h, as opposed to 13 vessels in the deterministic mode. The results indicate that the robust model is the better choice to solve the problem, and that it is able to find new templates with slightly better waiting time performance, and to keep the number of overlaps between vessels with minimum number during actual operations in a container terminal. Krcum et al (2007), developed a multi-objective genetic algorithm (based on Matlab software package) to deal with berth and quay cranes assignment problems, and to minimize the total costs due to the berthing and quay crane operation (handling operation). The proposed algorithm is a useful technique for finding near-optimal solutions for the problems, and it is used to determine the berthing time and position of each vessel, and the number of cranes to be allocated to the vessel. Theofanis et al (2007), suggested a genetic algorithm heuristic to optimize the Berth Allocation Problem (BAP), and formulated a linear mixed integer programming model to minimize the total weighted service time of all vessels. The scholars studied the Discrete BAP and Dynamic BAP that deal with calling vessels with various service priorities. The experimental results show that the Optimization Based Genetic Algorithm (OBGA) heuristic is more efficient than the Genetic Algorithm heuristic without the optimization component in terms of the variance and minimum values of objective function. Imai et al (2008), proposed a genetic algorithm-based heuristic to address the simultaneous berth and quay allocation problem. The formulated model is used to minimize the total service time (waiting and handling times), and to find the efficient scheduling process of simultaneous berth and crane allocation at a container terminal. The computational experiments show that the proposed algorithm is applicable to solving the problem and to determine the berth scheduling and quay crane scheduling at the same time.

Colias et al (2009), studied the berth allocation problem, and formulated a mixed integer programming model to optimize the vessel arrival time. The proposed model is used to minimize the total waiting and delayed departure time for all vessels. The scholars compared between the numerical results of a Genetic Algorithm (GA-based heuristic) and CPLEX to investigate the performance of the GA heuristic. The scholars found that the developed algorithm can be more beneficial for both the carrier and the terminal operator under the proposed berth scheduling policy. Javanshir et al (2010), modified a mixed integer nonlinear programming model to address the Continues Berth Allocation Problem (CBAP), and to achieve the best service time in a container terminal. The modified model is used to minimize the service times of the ships (the time spent from arrival to departure including the waiting time). Many numerical experiments are carried out to find the optimal berthing time and berthing location of each ship, as well as the expected ship delay. According to the outputs and results, the researchers found that the modified model provided better analysis of the berth allocation problem in a more acceptable computational time.

Zeng et al (2011), studied the disruption management problem of berth allocation in a container terminal, and developed a mixed integer programming model and a simulation optimization algorithm to optimize the simultaneous berth allocation (berthing position and berthing order of each vessel) and quay crane scheduling problems. The objective of the paper is to decrease the influence of unforeseen disruptions to operation system and decrease the additional cost resulting from disruptions. The scholars applied a simulation optimization approach to assess the influence of disruptions and optimize the new berth schedule coping with disruptions. The numerical experiments indicate that the algorithm based on local rescheduling and Tabu search can improve the computation efficiency. Shan (2012), applied a genetic algorithm (coded in LINGO 11.0) to optimize the dynamic berth allocation with a discrete layout. The optimization model is used to minimize the total service time (waiting time and handling time) of all ships with the consideration of ships service priority. The proposed algorithm is useful for improving the container terminal management, and it can find a better solution to the problem. Ma et al (2012), focused on berth allocation planning and proposed an integrated model of combining berth allocation problems and quay cranes assignments, to improve container terminal performances. The proposed model is used to minimize the total service time (vessel waiting time and handling time) and vessel transfer rate.

It is based on a Two-Level Genetic Algorithm (TLGA) to maximize the performance of the terminal in terms of service quality. The numerical experiments show that the proposed (TLGA) can achieve better solutions for BAP and QCA in serving more important customers, and that it is capable of solving the two problems simultaneously.

Hendriks et al (2013), formulated a Mixed Integer Quadratic Program (MIQP) to deal with both the Berth Allocation Problem (BAP) and Yard Planning Problem (YPP) or Yard Allocation Problem (YAP) simultaneously (case study in PSA Antwerp Terminal). An alternating BAP-YAP heuristic is used to solve the formulated model, and the model is used to minimize the overall straddle carrier travel distance between quay and yard, and between yard and hinterland. According to the results that were obtained by using CPLEX 11 to solve the problems, the researchers found that the alternating procedure yields significant reductions in the total straddle carrier driving distance compared with the initial condition. Sheikholeslami et al (2013), proposed a simulation model (based on ARENA package software) to address the problem of Integrating Berth Allocation and Quay Crane Assignment. The proposed simulation is applied on Rajaee Port in IRAN, and it is used to evaluate the berth allocation planning and the problems in this domain. Three different policies of berth allocation (randomized allocation, length-based allocation, draft-based allocation) are examined by simulation model to test the performance of berth allocation plans. According to the results that were obtained by using the simulation model, the researchers found that the strategies of length-based allocation and draft-based allocation are dominated by random allocation scenario according to wait time and average anchorage queue length. Most of the researches and studies focused on the optimization of berth allocation problem, and they proposed many models to minimize the total service time for the vessels that arrive at container terminals. The proposed models are based on waiting time, handling time, and delay time.

In this section the queuing theory (queuing system with non-pre-emptive priority) is used to understand the behavior and characteristics of berth allocation problem, as well as to understand the assignment of suitable berths to the vessels under different scenarios of berthing policy or priorities and vessel serving. The outline of this study is organized as follows: section (2) discusses and describes briefly the problem of berthing process of vessels at container terminals. In section (3) a model is proposed to deal with the problem, and to find the system characteristics of the berthing process of vessels, from the time they arrive until the time they leave the boundaries of the seaport. In section (4) the numerical experiments are presented and discuss the experimental results are discussed. Finally, in section (5) the study is summarized and concluded.

5.2.2 Problem description

When vessels or containerships arrive at a seaport container terminal, they are required to be in a queue before berthing. There are usually a set of incoming vessels that must wait in queue until the berths are available. The quay of a container terminal consists of many berths, each of which can serve one vessel within a few days (see figure 5.2.1). Sometimes the berth can handle two small vessels or more, and sometimes, large vessels require two berths along a quay in order to load\unload their containers. Prior to berthing, the expected time of arrival for each visiting vessel depends on several factors such as the departure time of the vessel from the previous seaport, the distance between the origin seaport and the destination seaport, the average operating speed of vessel, weather conditions and other unforeseen events. There are some vessels which arrive at the seaport container terminal earlier or later than the expected time. When the seaport authority assigns a set of berths to a set of vessels, the terminal operator will then allow the vessels to moor at the berths according to the berths scheduling policy and priority. The selection of suitable berths to the vessels depends on many factors such as the length the drafts, and the size of vessels (capacities), the type of service, type and number of quay cranes, the lengths and the depth of berths. Most of container terminals aim to moor the vessels in berthing positions that are as near as possible to the preferable container stacking area, in order to facilitate container transhipment from\to the vessels, and to minimize the handling time. After berthing, usually, the incoming vessels are stationed at the assigned berths for a few days for the de-lashing containers and container handling (loading\unloading) processes. Sometimes, before berthing at the assigned berths, the vessels wait for a short term at lay-by berths., There are many operations and activities that are associated with the arrival of vessels at the seaport (from the time they arrive until the time they leave the boundaries of the seaport). Any delay in the sequence of operations and activities of the vessel berthing process leads to seaport congestion and disruptions in container terminals. Furthermore, the delays incur an additional expenditure, especially if the waiting time of vessels and equipment (Quay Cranes, Yard Trucks, Yard Cranes) are taken into account. The container terminal cannot avoid the seaport congestion or the accumulation problem of large numbers of vessels inside the seaport when the arrival rate of vessels is high. That means the terminal operator must institute many kinds of berthing priorities to serve all vessels such as: Berthing On Arrival (BOA), Largest Vessel-First (LVF), Smallest Vessel-First (SVF), and Shortest Service Time First (SSTF). An objective of this research is to apply queuing theory to optimize the vessel berthing process and to improve performance.

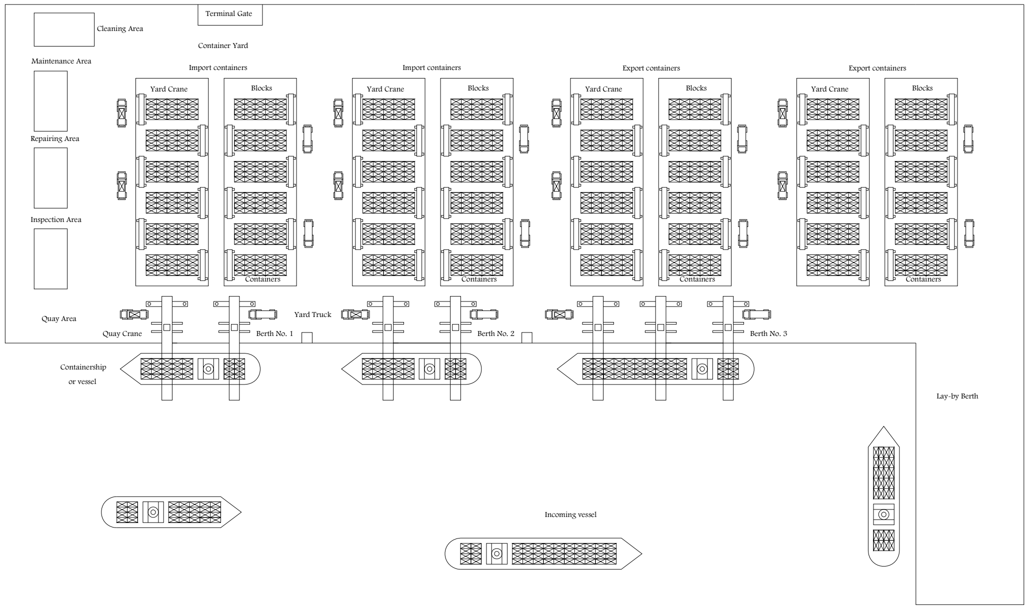


Figure 5.2.1: The process of vessels berthing inside a container terminal (Authors).

5.2.3 Mathematical model

In this section, the problem can be modelled as a queuing system to understand the behaviour and characteristics of berth allocation problem or the assignment of suitable berths to the vessels under different scenarios of berthing policy or priorities and of vessel serving. When the incoming vessels (or containerships) arrive at the container terminal, they are assigned to berthing positions at determined schedules. The seaports authorities and container terminal operators have to decide how many berths and quay cranes are assigned to these vessels. Usually, the visiting vessels must wait in a queue until the berths are available to service them, and sometimes the vessels must be subjected to the berth allocation policy or service priority specially, particularly when there are a lot of incoming vessels or containerships arriving at the seaport container terminals. That means the vessels must be spend times in a queue, until the seaport authority assigns a berthing position and a berthing time to each vessel according to the berthing priorities. In general, the incoming vessels must be moored and served within the boundaries of the quay. When the inbound containers arrive at quay side, they are de-lashed and then served by quay cranes, luffing cranes or portainers. i.e. the containers are de-lashed and unloaded from vessel or containership by cranes, and then they are moved from quay side to the container yard or stacking area by trucks, Automated Guided Vehicles (AGVs) or Straddle carriers.

The arrival of containers, or the inbound containers, at seaport have arrival rate λ and the inter-arrival time (the average interval between consecutive container arrivals) or average time between arrivals (containers) can be expressed as ${}^{1}/_{\lambda}$. When the arrival vessels (that carry the inbound containers) are subjected to the berth allocation priority, then the arrival rate under priority class k becomes λ_k and the average time between arrivals (containers) under priority class k can be expressed as $^{1}/_{\lambda_k}$. After berthing, the vessels discharged or the containers (fully loaded and empty) are unloaded from the vessels, and the service rate of handling-off process (under priority class k) is performed by quay cranes, and can be expressed as (μ_k), and the mean service time (under priority class k) can be expressed as $^{1}/_{\mu_k}$.

The average utilization (or the utilization factor) of the system is the ratio between the arrival rate and service rate or the ratio between mean service time $^{1}/_{\mu}$ and mean inter-arrival time $^{1}/_{\lambda}$, and can be expressed as $\rho = \frac{\lambda}{\mu}$ or $\rho = \frac{\lambda}{\mathbf{r} * \mu}$, where **r** the number of servers in the system. The utilization factor under priority class k can be expressed as $\rho_k = \frac{\lambda_k}{\mu_k}$.

$$\rho = \sum_{k=1}^{k=\mathrm{p}} \rho_k \quad \text{, where } k = 1{,}2 \ldots \mathrm{p}$$

$$\lambda = \sum_{k=1}^{k=\mathrm{p}} \lambda_k \quad \text{, where } k = 1{,}2 \ldots \mathrm{p}$$

$$\mu = \sum_{k=1}^{k=\mathrm{p}} \mu_k \quad \text{, where } k = 1{,}2 \ldots \mathrm{p}$$

Actually, in queuing system, there are one or more servers that provide service to the arriving customers. In our case study, the customers are containers and the servers are quay cranes. We assume the queuing system in our case study as single server non-pre-emptive with 2-Priorities. In this queuing system, we assume the arrivals follow a Poisson probability distribution at an average (λ : containers per unit time (hour)). Also, we assume the service times are distributed exponentially with an average (μ : containers per unit time (hour)). We use the state transition diagrams as shown down below (5.2.2) to formulate the state balance equations for single server non-pre-emptive priority system at a container terminal, and we derive the steady-state probabilities by the Markov process method.

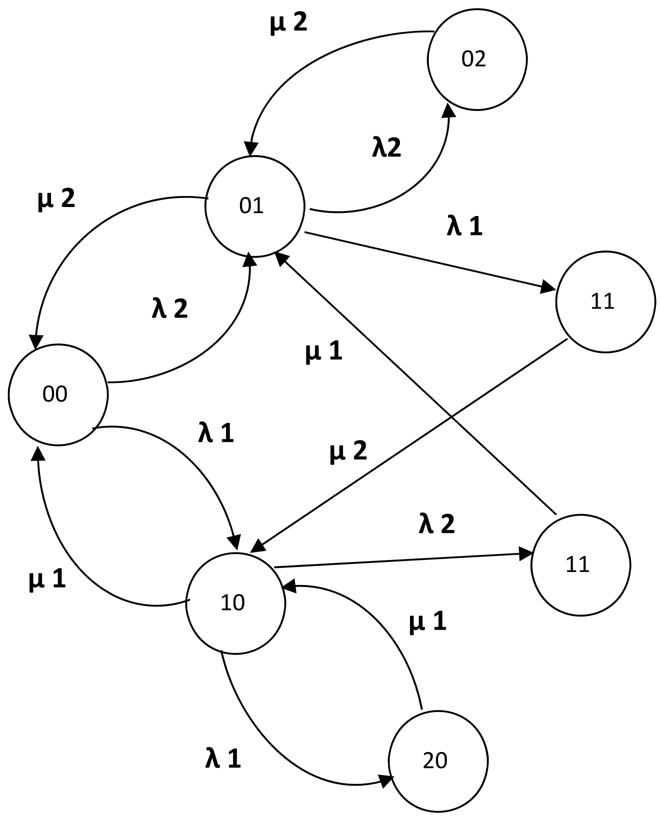


Figure 5.2.2: State transition diagram for a 2-Priority, non-preemptive M/M/1/2 queue

Let (N) to be maximum number of vessels (or containers) in the system, and (n) to be current number of vessels (or containers) in the system. In our case study N=2.

P (n) = the probability that there are (n) vessels (or containers) in the system.

$$(\lambda 1 + \lambda 2)P_{0,0,0} = \mu 2\ P_{0,1,2} + \mu 1\ P_{1,0,1} \tag{1}$$

$$(\lambda 1 + \lambda 2 + \mu 2\ )P_{0,1,2} = \lambda 2\ P_{0,0,0} + \mu 2\ P_{0,2,2} \tag{2}$$

$$(\lambda 1 + \lambda 2 + \mu 1\ )P_{1,0,1} = \lambda 1\ P_{0,0,0} + \mu 1\ P_{2,0,1} + \mu 2\ P_{1,1,2} \tag{3}$$

$$\mu 1\ P_{1,1,1} = \lambda 2\ P_{1,0,1} \tag{4}$$

$$\mu 2\ P_{0,2,2} = \lambda 2\ P_{0,1,2} \tag{5}$$

$$\mu 2\ P_{1,1,2} = \lambda 1\ P_{0,1,2} \tag{6}$$

$$\mu 1\ P_{2,0,1} = \lambda 1\ P_{1,0,1} \tag{7}$$

$$P_{0,0,0} + P_{1,0,1} + P_{2,0,1} + P_{1,1,1} + P_{0,1,2} + P_{0,2,2} + P_{1,1,2} = 1 \tag{8}$$

To simplify the solution for the above steady-state equations, we suppose $\mathbf{P_{0,2,2} = Z}$

$$P_{0,2,2} = Z \tag{9}$$

Substituting equation 9 into equation 5, we get

$$\mu 2\ P_{0,2,2} = \lambda 2\ P_{0,1,2}$$

$$\mu 2\ Z = \lambda 2\ P_{0,1,2}$$

$$P_{0,1,2} = \frac{\mu 2\ Z}{\lambda 2} \tag{10}$$

Substituting equations 9 and 10 into equation 2, we get

$$(\lambda 1 + \lambda 2 + \mu 2\ )P_{0,1,2} = \lambda 2\ P_{0,0,0} + \mu 2\ P_{0,2,2}$$

$$(\lambda 1 + \lambda 2 + \mu 2\ )\frac{\mu 2\ Z}{\lambda 2} = \lambda 2\ P_{0,0,0} + \mu 2\ Z$$

$$\lambda 2\ P_{0,0,0} = (\lambda 1 + \lambda 2 + \mu 2\ )\frac{\mu 2\ Z}{\lambda 2} - \mu 2\ Z$$

$$\lambda 2\ P_{0,0,0} = \frac{(\lambda 1\mu 2 + \lambda 2\mu 2 + \mu 2^2)\ Z}{\lambda 2} - \mu 2\ Z$$

$$P_{0,0,0} = \frac{(\lambda 1\mu 2 + \lambda 2\mu 2 + \mu 2^2)\ Z}{\lambda 2^2} - \frac{\mu 2\ Z}{\lambda 2}$$

$$P_{0,0,0} = \frac{\lambda1\mu2\ Z}{\lambda2^2} + \frac{\lambda2\mu2\ Z}{\lambda2^2} + \frac{\mu2^2\ Z}{\lambda2^2} - \frac{\mu2\ Z}{\lambda2}$$

$$P_{0,0,0} = \frac{\lambda1\mu2\ Z}{\lambda2^2} + \frac{\mu2\ Z}{\lambda2} + \frac{\mu2^2\ Z}{\lambda2^2} - \frac{\mu2\ Z}{\lambda2}$$

$$P_{0,0,0} = \frac{\lambda1\mu2\ Z}{\lambda2^2} + \frac{\mu2^2\ Z}{\lambda2^2}$$

$$P_{0,0,0} = \frac{(\lambda1\mu2 + \mu2^2)Z}{\lambda2^2} \tag{11}$$

Putting equations 10 and 11 into equation 1, we get

$$(\lambda1 + \lambda2)P_{0,0,0} = \mu2\ P_{0,1,2} + \mu1\ P_{1,0,1}$$

$$(\lambda1 + \lambda2)\frac{(\lambda1\mu2 + \mu2^2)Z}{\lambda2^2} = \mu2\ \frac{\mu2\ Z}{\lambda2} + \mu1\ P_{1,0,1}$$

$$\mu1\ P_{1,0,1} = (\lambda1 + \lambda2)\frac{(\lambda1\mu2 + \mu2^2)Z}{\lambda2^2} - \mu2\ \frac{\mu2\ Z}{\lambda2}$$

$$\mu1\ P_{1,0,1} = \frac{(\lambda1 + \lambda2)\ (\lambda1\mu2 + \mu2^2)Z}{\lambda2^2} - \frac{\mu2^2\ Z}{\lambda2}$$

$$P_{1,0,1} = \frac{(\lambda1 + \lambda2)\ (\lambda1\mu2 + \mu2^2)Z}{\mu1\ \lambda2^2} - \frac{\mu2^2\ Z}{\mu1\ \lambda2} \tag{12}$$

From equation 7 and equation 12, we obtain

$$\mu1\ P_{2,0,1} = \lambda1\ P_{1,0,1}$$

$$\mu1\ P_{2,0,1} = \lambda1\ \left(\frac{(\lambda1 + \lambda2)\ (\lambda1\mu2 + \mu2^2)Z}{\mu1\ \lambda2^2} - \frac{\mu2^2\ Z}{\mu1\ \lambda2}\right)$$

$$P_{2,0,1} = \left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1 + \lambda2)\ (\lambda1\mu2 + \mu2^2)Z}{\mu1\ \lambda2^2} - \frac{\mu2^2\ Z}{\mu1\ \lambda2}\right) \tag{13}$$

Substituting equation 10 into equation 6, we get

$$\mu 2 \ P_{1,1,2} = \lambda 1 \ P_{0,1,2}$$

$$\mu 2 \ P_{1,1,2} = \lambda 1 \ \frac{\mu 2 \ Z}{\lambda 2}$$

$$\mu 2 \ P_{1,1,2} = \frac{\lambda 1 \ \mu 2 \ Z}{\lambda 2}$$

$$P_{1,1,2} = \frac{\lambda 1 \ \mu 2 \ Z}{\mu 2 \ \lambda 2} \tag{14}$$

Finally, putting equation 12 into equation 4, then we get

$$\mu 1 \ P_{1,1,1} = \lambda 2 \ P_{1,0,1}$$

$$\mu 1 \ P_{1,1,1} = \lambda 2 \ (\frac{(\lambda 1 + \lambda 2)\ (\lambda 1 \mu 2 + \ \mu 2^2)Z}{\mu 1 \ \lambda 2^2} - \frac{\mu 2^2 Z}{\mu 1 \ \lambda 2})$$

$$P_{1,1,1} = \frac{\lambda 2}{\mu 1} \ (\frac{(\lambda 1 + \lambda 2)\ (\lambda 1 \mu 2 + \ \mu 2^2)Z}{\mu 1 \ \lambda 2^2} - \frac{\mu 2^2 \ Z}{\mu 1 \ \lambda 2}) \tag{15}$$

From the equation 8, we can find the value of z by using the equations of the probability

$$P_{0,0,0} + P_{1,0,1} + P_{2,0,1} + P_{1,1,1} + P_{0,1,2} + P_{0,2,2} + P_{1,1,2} = 1$$

$$\begin{aligned}&\left(\frac{(\lambda 1 \mu 2 + \ \mu 2^2)Z}{\lambda 2^2}\right) + \left(\frac{(\lambda 1 + \lambda 2)\ (\lambda 1 \mu 2 + \ \mu 2^2)Z}{\mu 1 \ \lambda 2^2} - \frac{\mu 2^2 \ Z}{\mu 1 \ \lambda 2}\right) \\ &+ \left(\left(\frac{\lambda 1}{\mu 1}\right)\left(\frac{(\lambda 1 + \lambda 2)\ (\lambda 1 \mu 2 + \ \mu 2^2)Z}{\mu 1 \ \lambda 2^2} - \frac{\mu 2^2 \ Z}{\mu 1 \ \lambda 2}\right)\right) \\ &+ \left((\frac{\lambda 2}{\mu 1})\ (\frac{(\lambda 1 + \lambda 2)\ (\lambda 1 \mu 2 + \ \mu 2^2)Z}{\mu 1 \ \lambda 2^2} - \frac{\mu 2^2 \ Z}{\mu 1 \ \lambda 2})\right) + \left(\frac{\mu 2 \ Z}{\lambda 2}\right) + \ (Z) + \left(\frac{\lambda 1 \ \mu 2 \ Z}{\mu 2 \ \lambda 2}\right) \\ &= 1\end{aligned} \tag{16}$$

$$Z\left(\left(\frac{(\lambda1\mu2+\ \mu2^2)}{\lambda2^2}\right)+\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right.$$
$$+\left(\left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right)$$
$$\left.+\left((\frac{\lambda2}{\mu1})\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right)+\left(\frac{\mu2}{\lambda2}\right)+\ (1)+\left(\frac{\lambda1\ \mu2}{\mu2\ \lambda2}\right)\right)$$
$$=1 \tag{16a}$$

$$Z=1/\left(\left(\frac{(\lambda1\mu2+\ \mu2^2)}{\lambda2^2}\right)+\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right.$$
$$+\left(\left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right)$$
$$+\left(\left(\frac{\lambda2}{\mu1}\right)\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right)+\left(\frac{\mu2}{\lambda2}\right)+\ (1)$$
$$\left.+\left(\frac{\lambda1\ \mu2}{\mu2\ \lambda2}\right)\right) \tag{16b}$$

$$Z=\left(\left(\frac{(\lambda1\mu2+\ \mu2^2)}{\lambda2^2}\right)+\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right.$$
$$+\left(\left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right)$$
$$+\left((\frac{\lambda2}{\mu1})\left(\frac{(\lambda1+\lambda2)\ (\lambda1\mu2+\ \mu2^2)}{\mu1\ \lambda2^2}-\frac{\mu2^2}{\mu1\ \lambda2}\right)\right)+\left(\frac{\mu2}{\lambda2}\right)+\ (1)$$
$$\left.+\left(\frac{\lambda1\ \mu2}{\mu2\ \lambda2}\right)\right)^{-1} \tag{16c}$$

Then the steady-state probabilities are:

$$P_{0,2,2} = \left(\left(\frac{(\lambda1\mu2 + \mu2^2)}{\lambda2^2}\right) + \left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right) + \left(\left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right)\right) + \left(\frac{\lambda2}{\mu1}\left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right)\right) + \left(\frac{\mu2}{\lambda2}\right) + (1) + \left(\frac{\lambda1\,\mu2}{\mu2\,\lambda2}\right)\right)^{-1} \quad (17)$$

$$P_{0,1,2} = \frac{\mu2}{\lambda2} * \left(\left(\frac{(\lambda1\mu2 + \mu2^2)}{\lambda2^2}\right) + \left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right) + \left(\left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right)\right) + \left(\frac{\lambda2}{\mu1}\left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right)\right) + \left(\frac{\mu2}{\lambda2}\right) + (1) + \left(\frac{\lambda1\,\mu2}{\mu2\,\lambda2}\right)\right)^{-1} \quad (18)$$

$$P_{0,0,0} = \frac{(\lambda1\mu2 + \mu2^2)}{\lambda2^2} * \left(\left(\frac{(\lambda1\mu2 + \mu2^2)}{\lambda2^2}\right) + \left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right) + \left(\left(\frac{\lambda1}{\mu1}\right)\left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right)\right) + \left(\frac{\lambda2}{\mu1}\left(\frac{(\lambda1 + \lambda2)\,(\lambda1\mu2 + \mu2^2)}{\mu1\,\lambda2^2} - \frac{\mu2^2}{\mu1\,\lambda2}\right)\right) + \left(\frac{\mu2}{\lambda2}\right) + (1) + \left(\frac{\lambda1\,\mu2}{\mu2\,\lambda2}\right)\right)^{-1} \quad (19)$$

$$P_{1,0,1} = \left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right) * \left(\left(\frac{(\lambda 1\mu 2 + \mu 2^2)}{\lambda 2^2}\right) + \left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right) + \left(\left(\frac{\lambda 1}{\mu 1}\right)\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right)\right) + \left(\frac{\lambda 2}{\mu 1}\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right)\right) + \left(\frac{\mu 2}{\lambda 2}\right) + (1) + \left(\frac{\lambda 1\,\mu 2}{\mu 2\,\lambda 2}\right)\right)^{-1} \tag{20}$$

$$P_{2,0,1} = \left(\frac{\lambda 1}{\mu 1}\right)\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right) * \left(\left(\frac{(\lambda 1\mu 2 + \mu 2^2)}{\lambda 2^2}\right) + \left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right) + \left(\left(\frac{\lambda 1}{\mu 1}\right)\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right)\right) + \left(\frac{\lambda 2}{\mu 1}\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right)\right) + \left(\frac{\mu 2}{\lambda 2}\right) + (1) + \left(\frac{\lambda 1\,\mu 2}{\mu 2\,\lambda 2}\right)\right)^{-1} \tag{21}$$

$$P_{1,1,2} = \frac{\lambda 1\,\mu 2}{\mu 2\,\lambda 2} * \left(\left(\frac{(\lambda 1\mu 2 + \mu 2^2)}{\lambda 2^2}\right) + \left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right) + \left(\left(\frac{\lambda 1}{\mu 1}\right)\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right)\right) + \left(\frac{\lambda 2}{\mu 1}\left(\frac{(\lambda 1 + \lambda 2)\,(\lambda 1\mu 2 + \mu 2^2)}{\mu 1\,\lambda 2^2} - \frac{\mu 2^2}{\mu 1\,\lambda 2}\right)\right) + \left(\frac{\mu 2}{\lambda 2}\right) + (1) + \left(\frac{\lambda 1\,\mu 2}{\mu 2\,\lambda 2}\right)\right)^{-1} \tag{22}$$

$$P_{1,1,1} = \left(\frac{\lambda 2}{\mu 1}\left(\frac{(\lambda 1+\lambda 2)\,(\lambda 1\mu 2+\ \mu 2^2)}{\mu 1\ \lambda 2^2} - \frac{\mu 2^2}{\mu 1\ \lambda 2}\right)\right)$$
$$* \left(\left(\left(\frac{(\lambda 1\mu 2+\ \mu 2^2)}{\lambda 2^2}\right) + \left(\frac{(\lambda 1+\lambda 2)\,(\lambda 1\mu 2+\ \mu 2^2)}{\mu 1\ \lambda 2^2} - \frac{\mu 2^2}{\mu 1\ \lambda 2}\right)\right.\right.$$
$$+ \left(\left(\frac{\lambda 1}{\mu 1}\right)\left(\frac{(\lambda 1+\lambda 2)\,(\lambda 1\mu 2+\ \mu 2^2)}{\mu 1\ \lambda 2^2} - \frac{\mu 2^2}{\mu 1\ \lambda 2}\right)\right)$$
$$+ \left(\frac{\lambda 2}{\mu 1}\left(\frac{(\lambda 1+\lambda 2)\,(\lambda 1\mu 2+\ \mu 2^2)}{\mu 1\ \lambda 2^2} - \frac{\mu 2^2}{\mu 1\ \lambda 2}\right)\right) + \left(\frac{\mu 2}{\lambda 2}\right) + (1)$$
$$\left. + \left(\frac{\lambda 1\ \mu 2}{\mu 2\ \lambda 2}\right)\right)^{-1} \tag{23}$$

We suppose the following notations:

$\mathbf{E(W_{\mathit{k}})}$ **:** The average time of container spent waiting in the queue or line under priority class k.

$\mathbf{E(L_{\mathit{k}}^{\mathit{q}})}$ **:** The average number of containers waiting in the queue or line under priority class k.

$\mathbf{E(S_{\mathit{k}})}$ **:** The average time of container spent waiting in the system, including service under priority class k.

$\mathbf{E(L_{\mathit{k}})}$ **:** The average number of containers in the service system under priority class k.

Let $\boldsymbol{\rho_k} = \boldsymbol{\lambda_k}\ \mathbf{E(B_{\mathit{k}})}$ The utilization factor under priority class k.

Then according to the PASTA property (Poisson Arrivals See Time Averages), can we find $\mathbf{E(L_{\mathit{k}}^{\mathit{q}})}$**.** First we find the characteristic of queuing system for the container of class 1. The container of class 1 must wait for the containers of its own class that arrived before and also for the container (if any) in handling-off process (in service).

$$E(W_1) = E(L_1^q) * E(B_1) + \sum_{k=1}^{k=p} \rho_k\, E(R_k) \tag{24}$$

$$\rho = \sum_{k=1}^{k=p} \rho_k \quad , \text{where } k = 1,2 \ldots p \tag{25}$$

$$E(R) = \sum_{k=1}^{k=p} \frac{\rho_k}{\rho}\, E(R_k)\ , \text{where } k = 1,2 \ldots p \tag{26}$$

Substituting equations 25 and 26 into equation 24, we get

$$\mathrm{E}(\mathrm{W}_1) = \mathrm{E}(\mathrm{L}_1^q) * \mathrm{E}(\mathrm{B}_1) + \rho \ \mathrm{E}(\mathrm{R}) \tag{27}$$

The term $\boldsymbol{\rho} \ \mathbf{E}(\mathbf{R})$ represents the expected remaining amount of work currently present at the server (quay crane), i.e handling-off process.

From Little's formula down below and utilization factor under priority class k $\mathbf{E}(\mathbf{B_1})$, we can find $\mathbf{E}(\mathbf{W_1})$.

$$\mathrm{E}(\mathrm{L}_1^q) = \lambda_1 \ \mathrm{E}(\mathrm{W}_1) \tag{28}$$

$$\mathrm{E}(\mathrm{W}_1) = \lambda_1 \ \mathrm{E}(\mathrm{W}_1) * \frac{\rho_1}{\lambda_1} + \rho \ \mathrm{E}(\mathrm{R}) \tag{27a}$$

$$\mathrm{E}(\mathrm{W}_1) = \mathrm{E}(\mathrm{W}_1) * \rho_1 + \rho \ \mathrm{E}(\mathrm{R}) \tag{27b}$$

$$\mathrm{E}(\mathrm{W}_1) - \rho_1 \ \mathrm{E}(\mathrm{W}_1) = \rho \ \mathrm{E}(\mathrm{R}) \tag{27c}$$

$$\mathrm{E}(\mathrm{W}_1) \left(1 - \rho_1\right) = \rho \ \mathrm{E}(\mathrm{R}) \tag{27d}$$

$$\mathrm{E}(\mathrm{W}_1) = \frac{\rho \ \mathrm{E}(\mathrm{R})}{1 - \rho_1} \tag{29}$$

From equation 28, we can find the average number of containers class 1 waiting in the queue or line $\mathbf{E}(\mathbf{L}_1^q)$.

$$\mathrm{E}(\mathrm{L}_1^q) = \lambda_1 * \frac{\rho \ \mathrm{E}(\mathrm{R})}{1 - \rho_1} \tag{30}$$

The average time of container class 1 spent waiting in the system, including service $\mathbf{E}(\mathbf{S_1})$ can be expressed as:

$$\mathrm{E}(\mathrm{S}_1) = \mathrm{E}(\mathrm{W}_1) + \mathrm{E}(\mathrm{B}_1) \tag{31}$$

$$\mathrm{E}(\mathrm{S}_1) = \frac{\rho \ \mathrm{E}(\mathrm{R})}{1 - \rho_1} + \frac{\rho_1}{\lambda_1} \tag{31a}$$

The average number of containers class 1 in the service system$\mathbf{E(L_1)}$ can be expressed as:

$$E(L_1) = E(L_1^q) + \rho_1 \tag{32}$$

$$E(L_1) = \lambda_1 * \frac{\rho \ E(R)}{1 - \rho_1} + \rho_1 \tag{32a}$$

We can find the characteristic of queuing system for the container of class 2 as shown down below. While the container from this class waits in the queue, also it must wait for the containers for higher priority that arrive late.

$$E(W_k) = \sum_{r=1}^{r=k} E(L_r^q) * E(B_r) + \rho \ E(R) + E(W_k) \sum_{r=1}^{r=k-1} \rho_r \tag{33}$$

$$E(W_k) - E(W_k) \sum_{r=1}^{r=k-1} \rho_r = \sum_{r=1}^{r=k} E(L_r^q) * E(B_r) + \rho \ E(R) \tag{33a}$$

$$E(W_k) \left(1 - \sum_{r=1}^{r=k-1} \rho_r\right) = \sum_{r=1}^{r=k} E(L_r^q) * E(B_r) + \rho \ E(R) \tag{33b}$$

From Little's formula down below and, we can find $(\mathbf{W_k})$.

$$E(L_k^q) = \lambda_k \ E(W_k)$$

$$E(W_k) \left(1 - \sum_{r=1}^{r=k} \rho_r\right) = \sum_{r=1}^{r=k-1} E(L_r^q) * E(B_r) + \rho \ E(R) \tag{33c}$$

By replaced k to k-1 from equation 33b.

$$E(W_k) \left(1 - \sum_{r=1}^{r=k} \rho_r\right) = \sum_{r=1}^{r=k-1} E(L_r^q) * E(B_r) + \rho \ E(R) = E(W_{k-1}) \left(1 - \sum_{r=1}^{r=k-2} \rho_r\right) \tag{33d}$$

From the expression $(\mathbf{W}_k)$, we easily drive recursively

$$\mathrm{E}(\mathrm{W}_k) = \rho \ \mathrm{E}(\mathrm{R}) / (1 - \sum_{r=1}^{r=k} \rho_r)(1 - \sum_{r=1}^{r=k-1} \rho_r) \quad , \text{where } k = 1,2, \dots p \tag{34}$$

From Little's formula, we can find the average number of containers class 2 (**k=2**) waiting in the queue or line $\mathbf{E}(\mathbf{L}_k^q)$.

$$\mathrm{E}(\mathrm{L}_k^q) = \lambda_k * (\rho \ \mathrm{E}(\mathrm{R}) / (1 - \sum_{r=1}^{r=k} \rho_r)(1 - \sum_{r=1}^{r=k-1} \rho_r)) \tag{35}$$

The average time of container class 2 spent waiting in the system, including service $\mathbf{E}(\mathbf{S}_k)$ can be expressed as: **k=2**

$$\mathrm{E}(\mathrm{S}_k) = \mathrm{E}(\mathrm{W}_k) + \mathrm{E}(\mathrm{B}_k) \tag{36}$$

$$\mathrm{E}(\mathrm{S}_2) = \rho \ \mathrm{E}(\mathrm{R}) / (1 - \sum_{r=1}^{r=k} \rho_r)(1 - \sum_{r=1}^{r=k-1} \rho_r) + \frac{\rho_k}{\lambda_k} \tag{36a}$$

The average number of containers class 2(**k=2**) in the service system$\mathbf{E}(\mathbf{L}_k)$ can be expressed as:

$$\mathrm{E}(\mathrm{L}_k) = \mathrm{E}(\mathrm{L}_k^q) + \rho_k \tag{37}$$

$$\mathrm{E}(\mathrm{L}_k) = \lambda_k * (\rho \ \mathrm{E}(\mathrm{R}) / (1 - \sum_{r=1}^{r=k} \rho_r)(1 - \sum_{r=1}^{r=k-1} \rho_r)) + \rho_k \tag{37a}$$

5.2.3.1 Assumptions

The following assumptions are imposed for the model:

1- We consider that each berth along the quay can serve one vessel within a specific time, and there is no overlap in the assigned berths for the vessels. That means, the berth cannot handle two small vessels (or more), or the large vessel cannot occupy two berths (or more) along a quay.

2- The length of berth must be longer than the length of vessel, and the clearance (or the space) between two vessels along a quay must be approximately equal to the width of the biggest vessel, it also must be included 15 m for both sides of vessel (the front and the rear of the vessel) to avoid the overlap of vessels in terms of the orientation of the vessels locations within the boundaries of berths.

3- The depth of berth must be deeper than the draft (draught) of vessel, and the clearance between the keel of the vessel and the channel bottom must be within the guaranteed depth. The depth of berth depends on many factors like: draft of vessel, water level in the channel, sinkage due to vessel speed, unevenness keel due to loading conditions, wave levels, tidal levels, dredged level.

4- We consider that in the ideal condition, there are enough equipment (cranes, trucks, vehicles etc) to perform all tasks, functions and operations at a container terminal. That means there is no delay or waiting in the performance of those tasks or functions in terms of lack in the number of equipment inside a container terminal.

5- When the handling process or service is completed, the vessels leave (depart) the berths and the seaport immediately.

6- The speed of handling off/on containers from/to the vessel, depends on no. of quay cranes, the transshipment rate of quay cranes, the simultaneous operations between quay cranes and yard trucks or Automated Guided Vehicles (AGVs) … etc. we assume the service rate of handling-off process for vessels with high priority is the same that with vessels with low priority. i.e $\boldsymbol{\mu} = \mu_{\boldsymbol{kh}} = \mu_{\boldsymbol{kl}}$.

7- When the vessel with high priority arrives to the container terminal, it can move ahead of all the low priority vessels waiting in the queue, but low priority vessels in service are not interrupted by high priority vessels, or a vessel in service is allowed to complete its service normally even if a vessel of higher priority enters the queue while its service is going on.

8- When the vessels arrive at the seaport earlier than the expected time of arrival, the terminal operator will decide the vessels which will be continue in berthing process if there are available berths, and do not have an effect on overall berthing strategy.

9- We assume all the vessels moor in berthing positions or locations near to the preferable container stacking area.

10- We assume the layout of berths in a container terminal is Discrete. That means, the quay is divided into a finite set of berths, and each vessel or containership in this layout can occupy a suitable berth within a specific time. Service time for the service centers (de-lashing process, quay cranes and yard trucks) is constant, i.e. static. The arrival of vessels is Dynamic and the vessels cannot berth before the expected arrival time. That means fixed arrival times are given for the vessels for berthing times, or all vessels to be scheduled for berthing have not yet arrived but arrival times are know in advance.

5.2.4 Experimental Results and Discussion

Thirty-two different scenarios for berthing process of vessels and unloading containers at container terminal are applied to find the optimal service level and to achieve maximum efficiency of service stations. These scenarios are varying from each other in terms of quantities of incoming containers, no. of quay cranes (handling-off) that are used to perform the operations, berthing policy and priorities as well as vessel serving.

Tables no. (5.2.1a), (5.2.1b) and no. (5.2.2), show the analysis and the probabilities of the single server non-pre-emptive priority queuing system at a container terminal. Table no. (5.2.3), shows the average waiting times of containers in the queue and in the system (container terminal), as well as the average number of containers waiting in the queue and in the system. Generally, the experimental results show that the increment in the number of arrival containers according to each priority (high or low) leads to increase the average waiting times of containers in the queue and in the system respectively as well as increase the average number of containers waiting in the queue and in the system (when the service centers has the same values of service rate). In the scenarios no. (1) to no. (8), we find the increment in the number of arrival containers class 2 (when the number of arrival containers class 1 the same number in all scenarios) leads to increase all $\mathbf{E(W_2)}$, $\mathbf{E(L_2^q)}$, $\mathbf{E(L_2)}$ and $\mathbf{E(S_2)}$ respectively as shown in figure (5.2.3). In the scenarios no. (9) to no. (16), we find also the increment in the number of arrival containers class 1 (when the number of arrival containers class 2 the same number in all scenarios) leads to increase all $\mathbf{E(W_1)}$, $\mathbf{E(L_1^q)}$, $\mathbf{E(L_1)}$ and $\mathbf{E(S_1)}$ respectively more than the values that in the in the scenarios no. (1) to no. (8), as shown in figure (5.2.4). Also the values of $\mathbf{E(W_2)}$, $\mathbf{E(L_2^q)}$, $\mathbf{E(L_2)}$ and $\mathbf{E(S_2)}$ respectively in the scenarios no. (9) to no. (16) are less than that values in previous scenarios no. (1) to no. (8). That difference is due to the increment in the values of $\boldsymbol{\rho_1}$ and $\boldsymbol{\rho_2}$ for the above scenarios.

In scenarios from no. (19) to no. (24), we find when we increase the service rate of service centers (quay cranes) for container class 1 $\boldsymbol{\mu_1}$ with the increment in the number of arrival containers class 1 $\boldsymbol{\lambda_1}$ respectively (while keeping the values of $\boldsymbol{\lambda_2}$ and $\boldsymbol{\mu_2}$ unchanged), will leads to reduce the values of all $\mathbf{E(W_1)}$, $\mathbf{E(L_1^q)}$, $\mathbf{E(L_1)}$ and $\mathbf{E(S_1)}$ respectively as shown in figure (5.2.5). In the same procedure for scenarios from no. (25) to no. (32), Also the increment in the service rate of service centers (quay cranes) for container class 2 $\boldsymbol{\mu_2}$ with the increment in the number of arrival containers class 2 $\boldsymbol{\lambda_2}$ respectively (while keeping the values of $\boldsymbol{\lambda_1}$ and $\boldsymbol{\mu_1}$ unchanged), will leads to reduce the values of all $\mathbf{E(W_2)}$, $\mathbf{E(L_2^q)}$, $\mathbf{E(L_2)}$ and $\mathbf{E(S_2)}$ respectively as shown in figure (5.2.6). That means, when the values of $\boldsymbol{\rho_1}$ and $\boldsymbol{\rho_2}$ for the scenarios from no. (19) to no. (32), increase, we see all the values of $\mathbf{E(W_k)}$, $\mathbf{E(L_k^q)}$, $\mathbf{E(L_k)}$ and $\mathbf{E(S_k)}$ decrease respectively.

Scenario	λ1	λ2	µ1	µ2	ρ1=λ1/µ1	ρ2=λ2/µ2	1/λ1	1/λ2	1/µ1
1	0.4	0.42	1.2	1.2	0.3333	0.3500	2.5000	2.3810	0.8333
2	0.4	0.43	1.2	1.2	0.3333	0.3583	2.5000	2.3256	0.8333
3	0.4	0.44	1.2	1.2	0.3333	0.3667	2.5000	2.2727	0.8333
4	0.4	0.45	1.2	1.2	0.3333	0.3750	2.5000	2.2222	0.8333
5	0.4	0.46	1.2	1.2	0.3333	0.3833	2.5000	2.1739	0.8333
6	0.4	0.47	1.2	1.2	0.3333	0.3917	2.5000	2.1277	0.8333
7	0.4	0.48	1.2	1.2	0.3333	0.4000	2.5000	2.0833	0.8333
8	0.4	0.49	1.2	1.2	0.3333	0.4083	2.5000	2.0408	0.8333
9	0.42	0.4	1.2	1.2	0.3500	0.3333	2.3810	2.5000	0.8333
10	0.43	0.4	1.2	1.2	0.3583	0.3333	2.3256	2.5000	0.8333
11	0.44	0.4	1.2	1.2	0.3667	0.3333	2.2727	2.5000	0.8333
12	0.45	0.4	1.2	1.2	0.3750	0.3333	2.2222	2.5000	0.8333
13	0.46	0.4	1.2	1.2	0.3833	0.3333	2.1739	2.5000	0.8333
14	0.47	0.4	1.2	1.2	0.3917	0.3333	2.1277	2.5000	0.8333
15	0.48	0.4	1.2	1.2	0.4000	0.3333	2.0833	2.5000	0.8333
16	0.49	0.4	1.2	1.2	0.4083	0.3333	2.0408	2.5000	0.8333
17	0.72	0.7	1.6	1.5	0.4500	0.4667	1.3889	1.4286	0.6250
18	0.73	0.7	1.65	1.5	0.4424	0.4667	1.3699	1.4286	0.6061
19	0.74	0.7	1.7	1.5	0.4353	0.4667	1.3514	1.4286	0.5882
20	0.75	0.7	1.75	1.5	0.4286	0.4667	1.3333	1.4286	0.5714
21	0.76	0.7	1.8	1.5	0.4222	0.4667	1.3158	1.4286	0.5556
22	0.77	0.7	1.85	1.5	0.4162	0.4667	1.2987	1.4286	0.5405
23	0.78	0.7	1.9	1.5	0.4105	0.4667	1.2821	1.4286	0.5263
24	0.79	0.7	1.95	1.5	0.4051	0.4667	1.2658	1.4286	0.5128
25	0.7	0.72	1.5	1.6	0.4667	0.4500	1.4286	1.3889	0.6667

26	0.7	0.73	1.5	1.65	0.4667	0.4424	1.4286	1.3699	0.6667
27	0.7	0.74	1.5	1.7	0.4667	0.4353	1.4286	1.3514	0.6667
28	0.7	0.75	1.5	1.75	0.4667	0.4286	1.4286	1.3333	0.6667
29	0.7	0.76	1.5	1.8	0.4667	0.4222	1.4286	1.3158	0.6667
30	0.7	0.77	1.5	1.85	0.4667	0.4162	1.4286	1.2987	0.6667
31	0.7	0.78	1.5	1.9	0.4667	0.4105	1.4286	1.2821	0.6667
32	0.7	0.79	1.5	1.95	0.4667	0.4051	1.4286	1.2658	0.6667

Table (5.2.1a) : The analysis of the single server non-preemptive priority queuing system at a container terminal.

Scenario	1/μ2	ρ1/ρ2	ρ2/ρ1	λ=λ1+λ2	μ=μ1+μ2	ρ=λ/μ	ρ1/ρ	ρ2/ρ	value of Z
1	0.8333	0.9524	1.0500	0.82	2.4	0.3417	0.9756	1.0244	0.0427
2	0.8333	0.9302	1.0750	0.83	2.4	0.3458	0.9639	1.0361	0.0444
3	0.8333	0.9091	1.1000	0.84	2.4	0.3500	0.9524	1.0476	0.0460
4	0.8333	0.8889	1.1250	0.85	2.4	0.3542	0.9412	1.0588	0.0477
5	0.8333	0.8696	1.1500	0.86	2.4	0.3583	0.9302	1.0698	0.0494
6	0.8333	0.8511	1.1750	0.87	2.4	0.3625	0.9195	1.0805	0.0511
7	0.8333	0.8333	1.2000	0.88	2.4	0.3667	0.9091	1.0909	0.0528
8	0.8333	0.8163	1.2250	0.89	2.4	0.3708	0.8989	1.1011	0.0546
9	0.8333	1.0500	0.9524	0.82	2.4	0.3417	1.0244	0.9756	0.0383
10	0.8333	1.0750	0.9302	0.83	2.4	0.3458	1.0361	0.9639	0.0377
11	0.8333	1.1000	0.9091	0.84	2.4	0.3500	1.0476	0.9524	0.0371
12	0.8333	1.1250	0.8889	0.85	2.4	0.3542	1.0588	0.9412	0.0366
13	0.8333	1.1500	0.8696	0.86	2.4	0.3583	1.0698	0.9302	0.0360
14	0.8333	1.1750	0.8511	0.87	2.4	0.3625	1.0805	0.9195	0.0355
15	0.8333	1.2000	0.8333	0.88	2.4	0.3667	1.0909	0.9091	0.0349
16	0.8333	1.2250	0.8163	0.89	2.4	0.3708	1.1011	0.8989	0.0344

17	0.6667	0.9643	1.0370	1.42	3.1	0.4581	0.9824	1.0188	0.0539
18	0.6667	0.9481	1.0548	1.43	3.15	0.4540	0.9746	1.0280	0.0543
19	0.6667	0.9328	1.0721	1.44	3.2	0.4500	0.9673	1.0370	0.0547
20	0.6667	0.9184	1.0889	1.45	3.25	0.4462	0.9606	1.0460	0.0550
21	0.6667	0.9048	1.1053	1.46	3.3	0.4424	0.9543	1.0548	0.0553
22	0.6667	0.8919	1.1212	1.47	3.35	0.4388	0.9485	1.0635	0.0556
23	0.6667	0.8797	1.1368	1.48	3.4	0.4353	0.9431	1.0721	0.0559
24	0.6667	0.8681	1.1519	1.49	3.45	0.4319	0.9380	1.0805	0.0561
25	0.6250	1.0370	0.9643	1.42	3.1	0.4581	1.0188	0.9824	0.0506
26	0.6061	1.0548	0.9481	1.43	3.15	0.4540	1.0280	0.9746	0.0495
27	0.5882	1.0721	0.9328	1.44	3.2	0.4500	1.0370	0.9673	0.0485
28	0.5714	1.0889	0.9184	1.45	3.25	0.4462	1.0460	0.9606	0.0476
29	0.5556	1.1053	0.9048	1.46	3.3	0.4424	1.0548	0.9543	0.0467
30	0.5405	1.1212	0.8919	1.47	3.35	0.4388	1.0635	0.9485	0.0458
31	0.5263	1.1368	0.8797	1.48	3.4	0.4353	1.0721	0.9431	0.0450
32	0.5128	1.1519	0.8681	1.49	3.45	0.4319	1.0805	0.9380	0.0442

Table (5.2.1b) : The analysis of the single server non-preemptive priority queuing system at a container terminal.

scenario	P 000	P 101	P 201	P 111	P 012	P 022	P 112	Σ P (N)
1	0.46506	0.19571	0.06524	0.06850	0.12208	0.04273	0.04069	1
2	0.46081	0.19489	0.06496	0.06983	0.12384	0.04438	0.04128	1
3	0.45662	0.19406	0.06469	0.07116	0.12557	0.04604	0.04186	1
4	0.45247	0.19324	0.06441	0.07247	0.12726	0.04772	0.04242	1
5	0.44837	0.19243	0.06414	0.07376	0.12891	0.04941	0.04297	1
6	0.44432	0.19161	0.06387	0.07505	0.13052	0.05112	0.04351	1
7	0.44031	0.19080	0.06360	0.07632	0.13209	0.05284	0.04403	1
8	0.43635	0.18999	0.06333	0.07758	0.13363	0.05457	0.04454	1
9	0.46506	0.20296	0.07104	0.06765	0.11483	0.03828	0.04019	1
10	0.46081	0.20565	0.07369	0.06855	0.11308	0.03769	0.04052	1
11	0.45662	0.20826	0.07636	0.06942	0.11137	0.03712	0.04084	1
12	0.45247	0.21081	0.07905	0.07027	0.10969	0.03656	0.04113	1
13	0.44837	0.21329	0.08176	0.07110	0.10804	0.03601	0.04142	1
14	0.44432	0.21571	0.08449	0.07190	0.10642	0.03547	0.04168	1
15	0.44031	0.21806	0.08722	0.07269	0.10484	0.03495	0.04193	1
16	0.43635	0.22035	0.08998	0.07345	0.10328	0.03443	0.04217	1
17	0.36616	0.21673	0.09753	0.09482	0.11546	0.05388	0.05542	1
18	0.37061	0.21544	0.09531	0.09140	0.11634	0.05429	0.05662	1
19	0.37485	0.21416	0.09322	0.08818	0.11714	0.05466	0.05779	1
20	0.37888	0.21290	0.09124	0.08516	0.11787	0.05501	0.05894	1
21	0.38274	0.21165	0.08936	0.08231	0.11855	0.05532	0.06006	1
22	0.38642	0.21043	0.08759	0.07962	0.11916	0.05561	0.06117	1
23	0.38995	0.20923	0.08589	0.07709	0.11972	0.05587	0.06225	1
24	0.39332	0.20805	0.08429	0.07469	0.12023	0.05611	0.06332	1

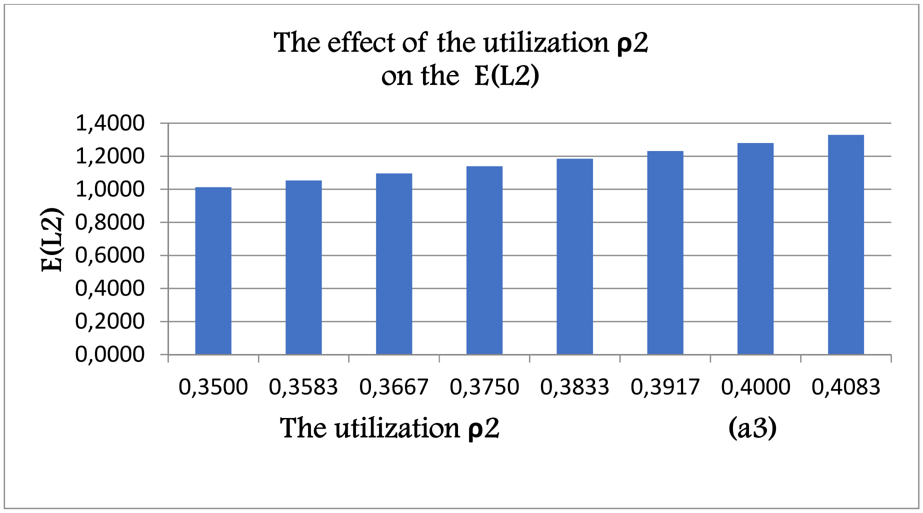
25	0.35923	0.22012	0.10272	0.10566	0.11246	0.05061	0.04920	1
26	0.36042	0.22044	0.10287	0.10728	0.11196	0.04953	0.04750	1
27	0.36151	0.22072	0.10300	0.10889	0.11146	0.04852	0.04590	1
28	0.36252	0.22096	0.10312	0.11048	0.11097	0.04756	0.04439	1
29	0.36345	0.22117	0.10321	0.11206	0.11049	0.04665	0.04297	1
30	0.36431	0.22135	0.10330	0.11363	0.11001	0.04579	0.04162	1
31	0.36511	0.22150	0.10337	0.11518	0.10953	0.04497	0.04035	1
32	0.36584	0.22162	0.10342	0.11672	0.10906	0.04418	0.03915	1

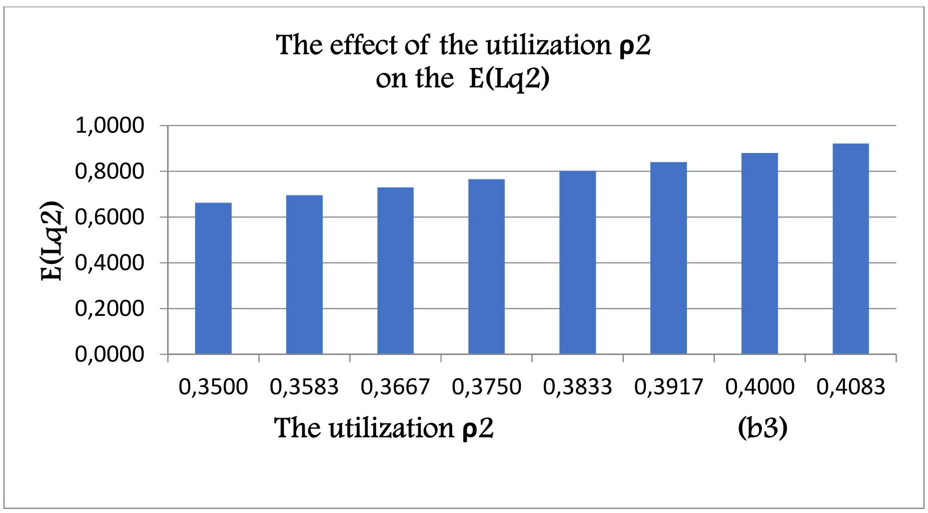
Table (5.2.2) : The probabilities of the single server non-preemptive priority queuing system at a container terminal.

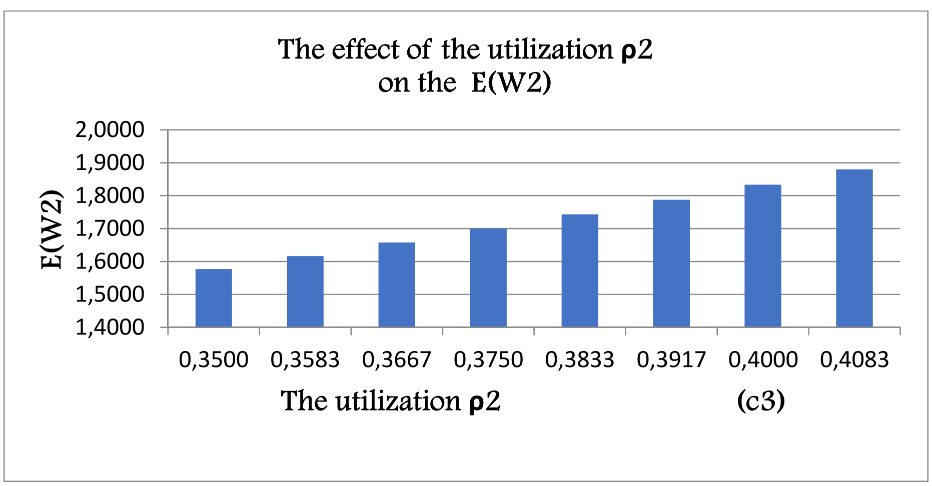
scenario	E(W1)	E(Lq1)	E(S1)	E(L1)	E(W2)	E(Lq2)	E(S2)	E(L2)
1	1.0250	0.4100	1.8583	0.7433	1.5769	0.6623	2.4103	1.0123
2	1.0375	0.4150	1.8708	0.7483	1.6169	0.6953	2.4502	1.0536
3	1.0500	0.4200	1.8833	0.7533	1.6579	0.7295	2.4912	1.0961
4	1.0625	0.4250	1.8958	0.7583	1.7000	0.7650	2.5333	1.1400
5	1.0750	0.4300	1.9083	0.7633	1.7432	0.8019	2.5766	1.1852
6	1.0875	0.4350	1.9208	0.7683	1.7877	0.8402	2.6210	1.2319
7	1.1000	0.4400	1.9333	0.7733	1.8333	0.8800	2.6667	1.2800
8	1.1125	0.4450	1.9458	0.7783	1.8803	0.9213	2.7136	1.3297
9	1.0513	0.4415	1.8846	0.7915	1.5769	0.6308	2.4103	0.9641
10	1.0779	0.4635	1.9113	0.8218	1.6169	0.6468	2.4502	0.9801
11	1.1053	0.4863	1.9386	0.8530	1.6579	0.6632	2.4912	0.9965
12	1.1333	0.5100	1.9667	0.8850	1.7000	0.6800	2.5333	1.0133

13	1.1622	0.5346	1.9955	0.9179	1.7432	0.6973	2.5766	1.0306
14	1.1918	0.5601	2.0251	0.9518	1.7877	0.7151	2.6210	1.0484
15	1.2222	0.5867	2.0556	0.9867	1.8333	0.7333	2.6667	1.0667
16	1.2535	0.6142	2.0869	1.0226	1.8803	0.7521	2.7136	1.0854
17	1.6667	1.2000	2.2917	1.6500	3.1250	2.1875	3.7917	2.6542
18	1.6304	1.1902	2.2365	1.6326	3.0571	2.1399	3.7237	2.6066
19	1.5972	1.1819	2.1855	1.6172	2.9948	2.0964	3.6615	2.5630
20	1.5667	1.1750	2.1381	1.6036	2.9375	2.0563	3.6042	2.5229
21	1.5385	1.1692	2.0940	1.5915	2.8846	2.0192	3.5513	2.4859
22	1.5123	1.1645	2.0529	1.5807	2.8356	1.9850	3.5023	2.4516
23	1.4881	1.1607	2.0144	1.5712	2.7902	1.9531	3.4568	2.4198
24	1.4655	1.1578	1.9783	1.5629	2.7478	1.9235	3.4145	2.3902
25	1.7188	1.2031	2.3854	1.6698	3.1250	2.2500	3.7500	2.7000
26	1.7045	1.1932	2.3712	1.6598	3.0571	2.2317	3.6631	2.6741
27	1.6912	1.1838	2.3578	1.6505	2.9948	2.2161	3.5830	2.6514
28	1.6786	1.1750	2.3452	1.6417	2.9375	2.2031	3.5089	2.6317
29	1.6667	1.1667	2.3333	1.6333	2.8846	2.1923	3.4402	2.6145
30	1.6554	1.1588	2.3221	1.6255	2.8356	2.1834	3.3762	2.5997
31	1.6447	1.1513	2.3114	1.6180	2.7902	2.1763	3.3165	2.5869
32	1.6346	1.1442	2.3013	1.6109	2.7478	2.1708	3.2607	2.5759

Table (5.2.3): The performance measures of the single server non-preemptive priority queuing system at a container terminal.


The effect of the utilization ρ2
on the E(L2)
E(L2)
1,4000
1,2000
1,0000
0,8000
0,6000
0,4000
0,2000
0,0000
0,3500 0,3583 0,3667 0,3750 0,3833 0,3917 0,4000 0,4083
The utilization ρ2
(a3)


The effect of the utilization ρ2
on the E(Lq2)
E(Lq2)
1,0000
0,8000
0,6000
0,4000
0,2000
0,0000
0,3500 0,3583 0,3667 0,3750 0,3833 0,3917 0,4000 0,4083
The utilization ρ2
(b3)


The effect of the utilization ρ2
on the E(W2)
E(W2)
2,0000
1,9000
1,8000
1,7000
1,6000
1,5000
1,4000
0,3500 0,3583 0,3667 0,3750 0,3833 0,3917 0,4000 0,4083
The utilization ρ2
(c3)

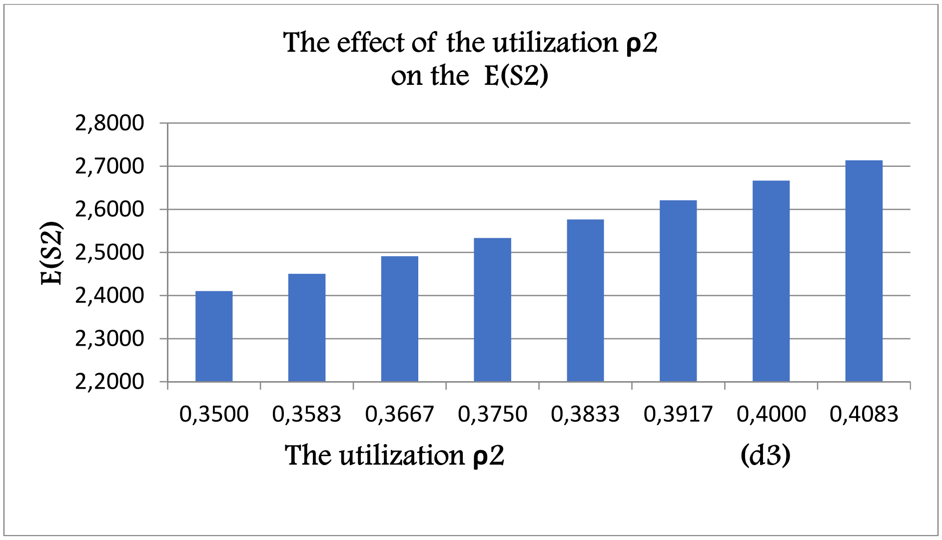
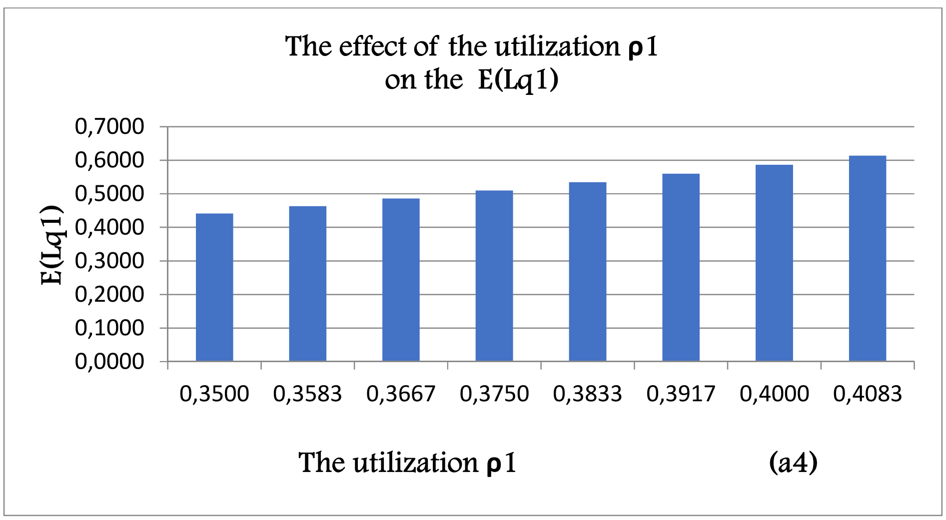
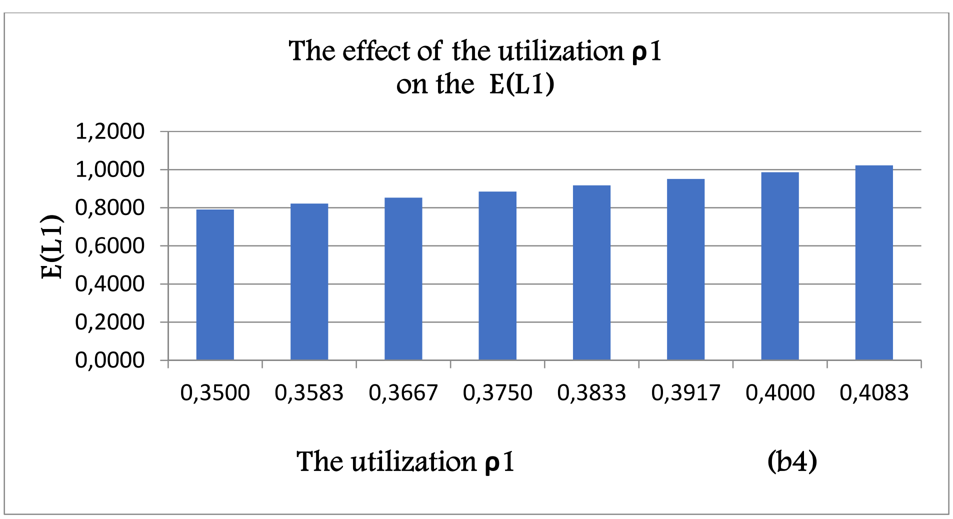
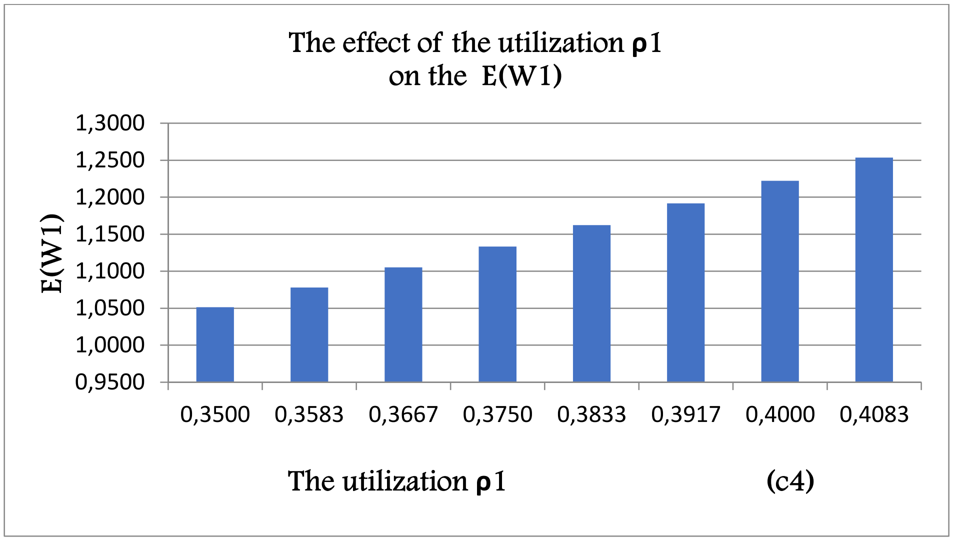


Figure 5.2.3: The relations between all outputs for Scenarios from no. (1) to (8)







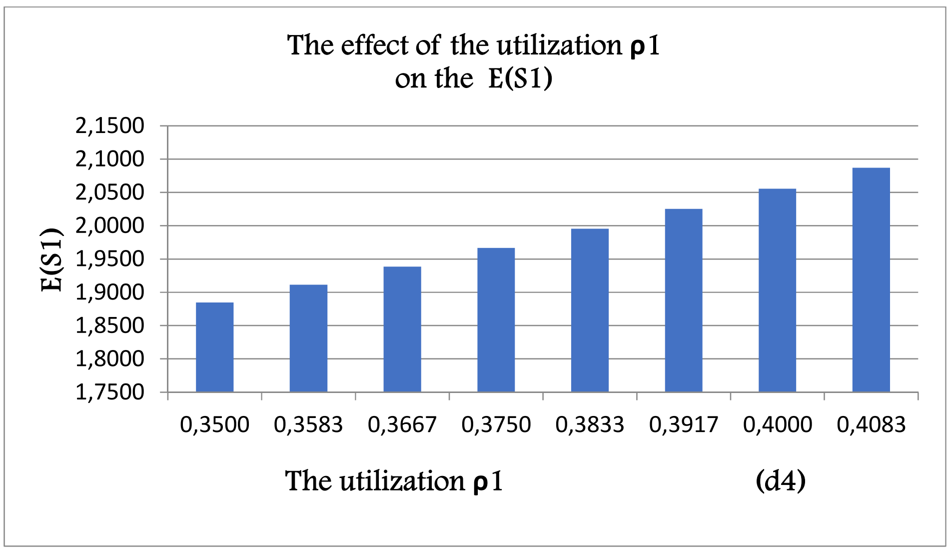
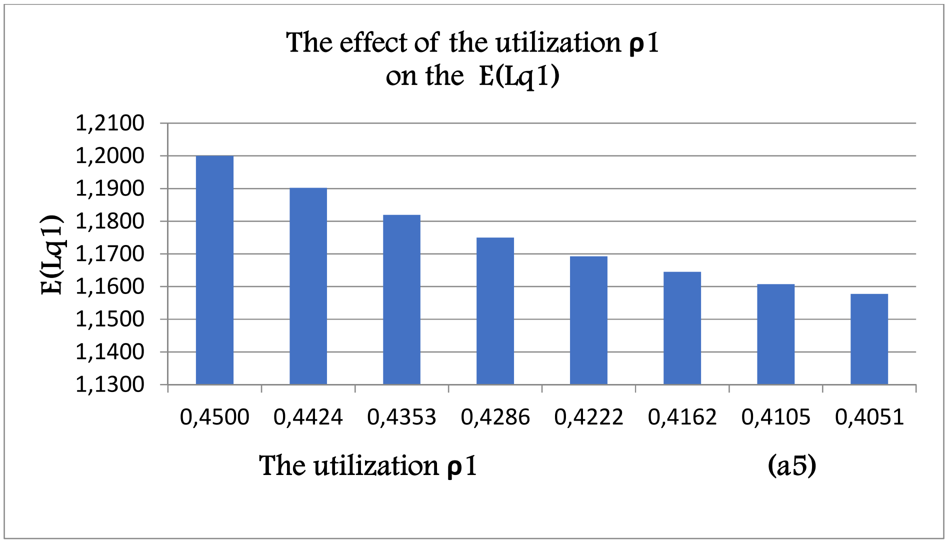
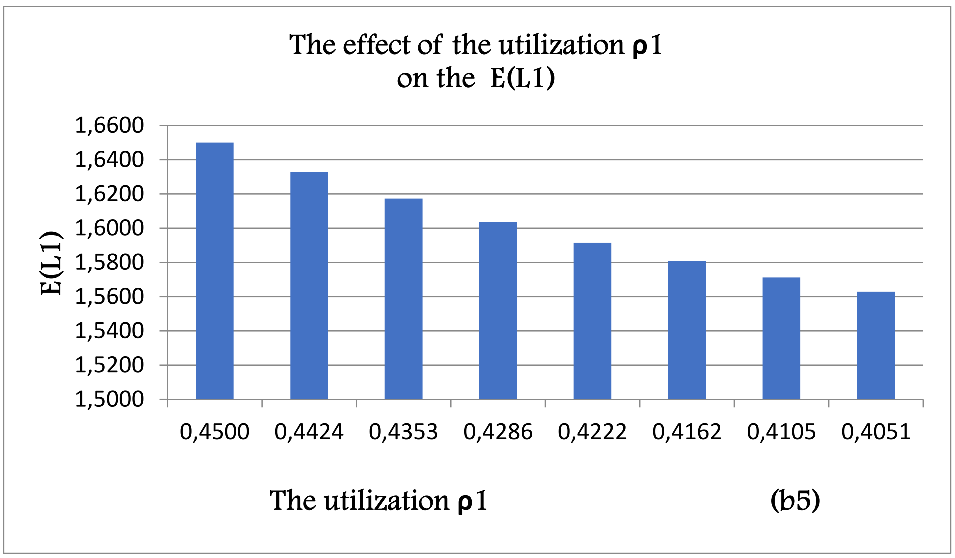
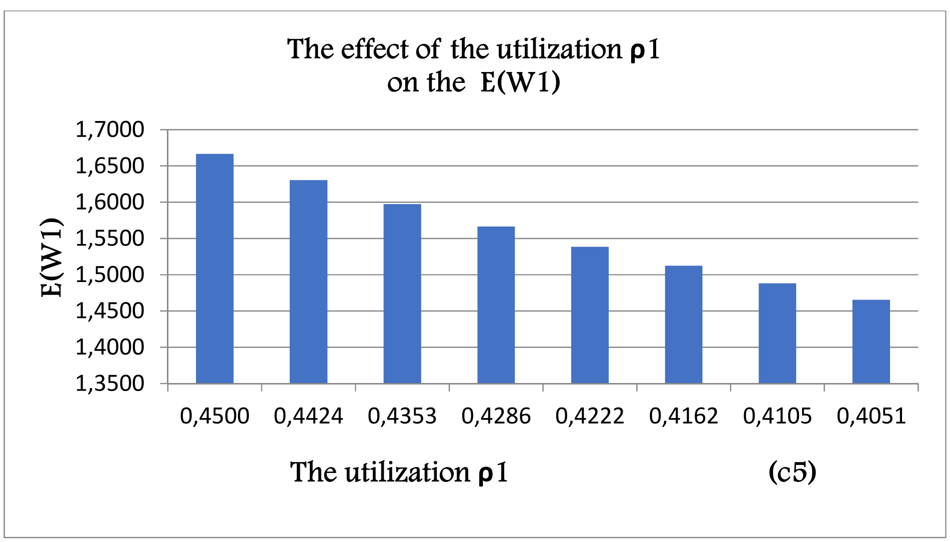


Figure 5.2.4: The relations between all outputs for Scenarios from no. (9) to (16)


The effect of the utilization ρ1
on the E(Lq1)
E(Lq1)
1,2100
1,2000
1,1900
1,1800
1,1700
1,1600
1,1500
1,1400
1,1300
0,4500
0,4424
0,4353
0,4286
0,4222
0,4162
0,4105
0,4051
The utilization ρ1
(a5)


The effect of the utilization ρ1
on the E(L1)
E(L1)
1,6600
1,6400
1,6200
1,6000
1,5800
1,5600
1,5400
1,5200
1,5000
0,4500
0,4424
0,4353
0,4286
0,4222
0,4162
0,4105
0,4051
The utilization ρ1
(b5)


The effect of the utilization ρ1
on the E(W1)
E(W1)
1,7000
1,6500
1,6000
1,5500
1,5000
1,4500
1,4000
1,3500
0,4500
0,4424
0,4353
0,4286
0,4222
0,4162
0,4105
0,4051
The utilization ρ1
(c5)

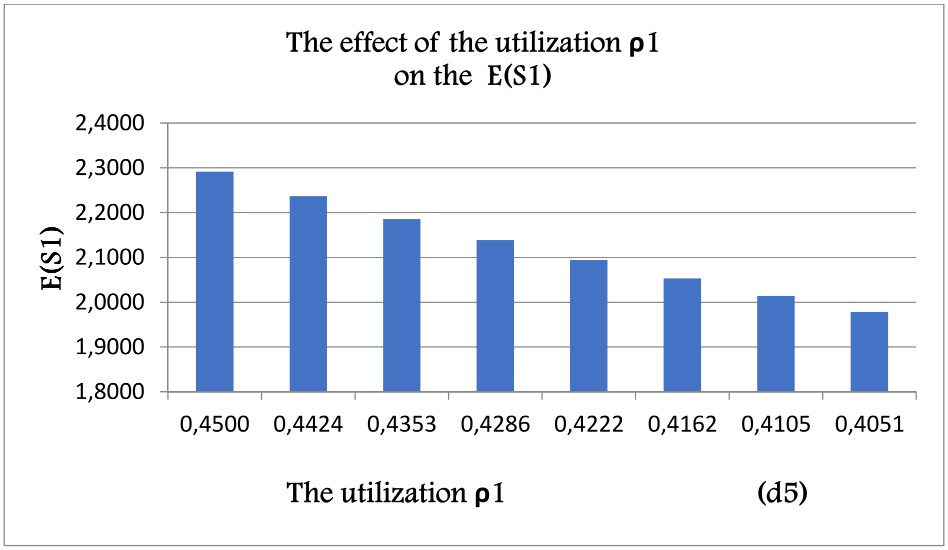
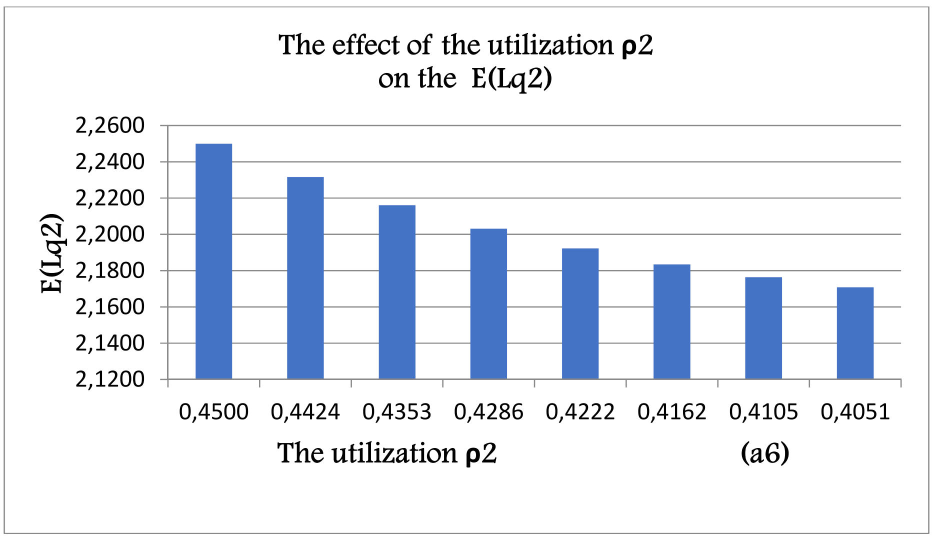
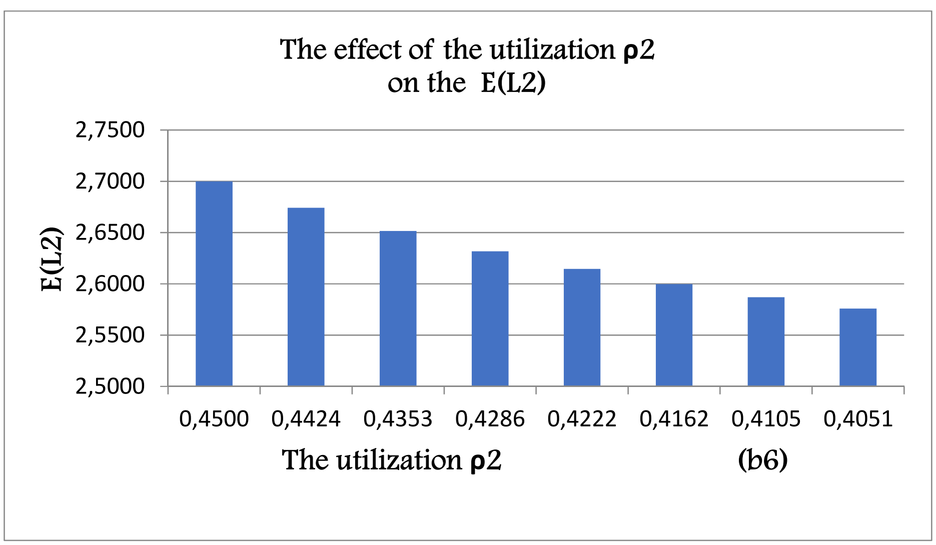
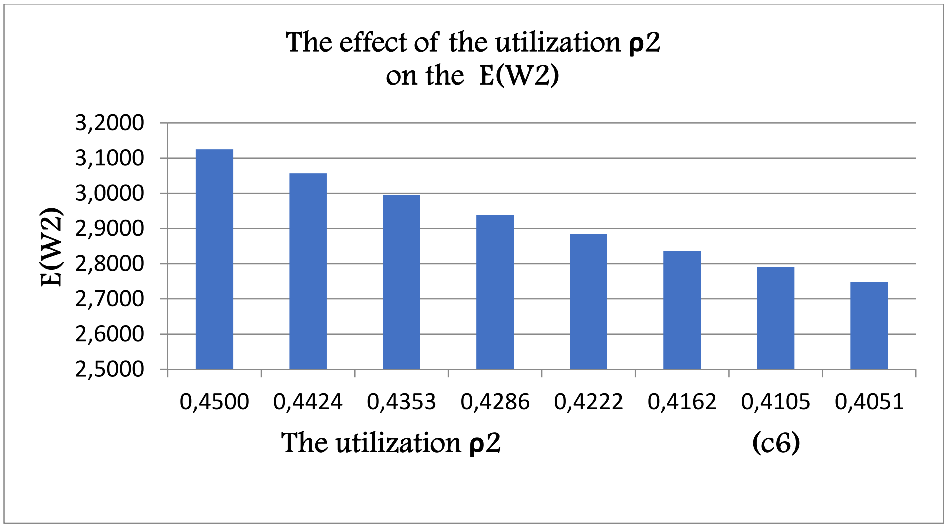


Figure 5.2.5: The relations between all outputs for Scenarios from no. (17) to (24)







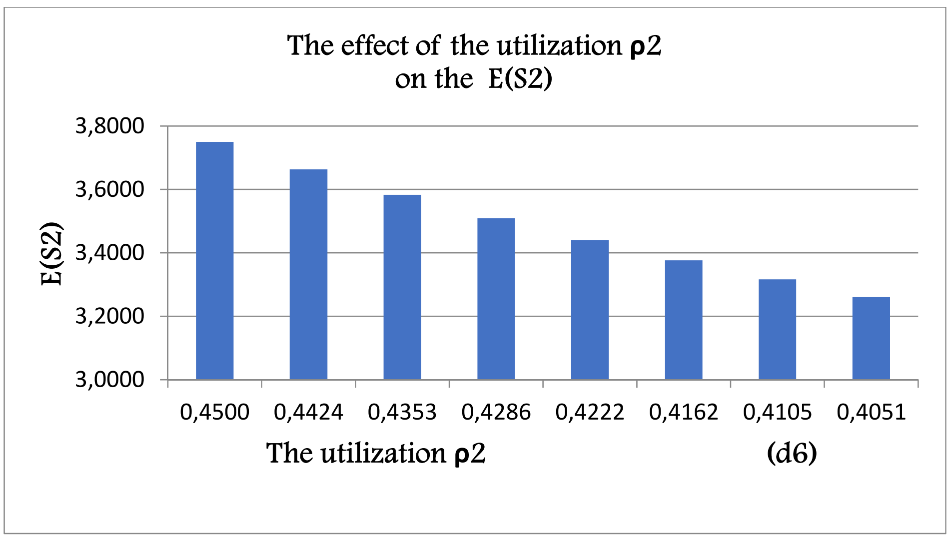


Figure 5.2.6: The relations between all outputs for Scenarios from no. (25) to (32)

5.2.5 Conclusions

This paper investigates the problem of assignment the suitable berth to the incoming vessel under different scenarios of berthing policy and priorities to discharge vessel. Usually, within a container terminal, the seaport authority assigns a set of berths to a set of incoming vessels, the terminal operator will then allow the vessels to moor at the berths according to the berths scheduling policy and priority

Our objective of this research is to apply queuing theory to optimize the service level of vessels berthing process and to improve the performance. We apply thirty-two different scenarios for berthing process of vessels and unloading containers at container terminal to find the optimal service level and to achieve maximum efficiency of service stations. We found the change in the values of $\boldsymbol{\rho_1}$ and $\boldsymbol{\rho_2}$ will lead to change the values of $\mathbf{E(W_{\boldsymbol{k}}),\ E(L_{\boldsymbol{k}}^{\boldsymbol{q}}),\ E(L_{\boldsymbol{k}})}$ and $\mathbf{E(S_{\boldsymbol{k}})}$ for all scenarios. Also the increment in the values of $\boldsymbol{\lambda_k}$ and $\boldsymbol{\mu_k}$ will lead sometimes to decrease the values of $\mathbf{E(W_{\boldsymbol{k}}),\ E(L_{\boldsymbol{k}}^{\boldsymbol{q}}),\ E(L_{\boldsymbol{k}})}$ and $\mathbf{E(S_{\boldsymbol{k}})}$ for some scenarios.

In future work, we will study the queuing system with multiple server non-pre-emptive priority or with blocking.

Chapter 6

Conclusions and Recommendations

Globalisation is the hallmark of our modern world. It leads to high growth in international trade and the integration of markets in the global economy. Recent developments in international trade have led to a new perception of production, distribution, marketing, and management, and have pushed markets toward global commonality.

Due to different economic needs in different regions, the moving of cargos between markets is of highly priority, and shipping containers are the means by which to reach the wider world. Containers transformed how goods and products move around the world to satisfy customer demand under different levels of cyclic (and acyclic) fluctuation in demand and market requirements.

Containers are a key development of maritime trade, and they are a technological innovation, which now dominates maritime trade and contributes to globalization. With the development of the maritime industry and containerization, the seaport operations management remain a challenging issue, particularly when the seaports become centres of distribution and logistics with very complex and dynamic entities. The seaport is a gateway to trade and a link in the transport chain between sea and land. It is also a center of organizing, monitoring and controlling the various operations and activities with highly dynamic interactions between these operations and activities.

Given the reality of globalization and the widespread use of containerization due to high growth in international trade and maritime industry, managing or controlling container (empty and full-loaded) movements during the whole container logistics cycle is a challenging issue and a complex process in the flow of containers within the shipping service networks. Therefore, the rapid growth in global trade leads to the trade imbalance, i.e. increase the trade volume among the major trading regions and causes movement of cargo to one direction over time from regions of production to regions of consumption. In the maritime industry, globalization is containerization.

The objective of this thesis is to discover the challenges in the seaport operations management and empty container movements during the entire empty container logistics cycle and finding solutions to some problems that arise at container terminals due to incomplete knowledge about future events.

The thesis devotes special attention to establishing new models or to modify and develop the existing models to address the problems that arise in the seaside and landside of seaport container terminals.

Returnable empty container management, with repositioning as a reverse logistics problem, is presented in chapter 3. The proposed model is used to determine the optimum lot size for the multi-type container movements and repositioning for both the procured and returned containers under different scenarios of storage capacity constraints and shared cost of shipping. In the same chapter, an integrated optimal lot sizing model of multi-type container return management - in which some of the containers are repaired in a facility with shared repair capacity and limited storage capacity - was presented. The proposed models are used to determine the total managing cost including inventory cost (return and procurement), purchasing cost, ordering cost, return cost, repairing cost, as well as to determine the optimum return quantity, the optimum replenishment order quantity, the optimum repair quantity, and the optimum common replenishment cycle time for all containers. The studies and researches provided in the field of returnable empty containers are limited. Many scholars focused on lot sizing models for returnable items or products. The contribution of this study's approach contributes to providing a clear conception for both seaports authorities and seaport managers in decision making on how to manage returnable multi-type containers.

The solutions for empty container repositioning problem in chapter 4 provide a valuable insight for making decisions under the different scenarios considered. Linear programming models are used to optimize the repositioning process with minimizing the total cost of empty containers movements between South Africa seaports, as well as to optimize the voyage routes to transfer empty containers by the vessels or containerships across shipping service networks. The proposed models are used minimize the total cost associated with transportation, handling on/off, storage, leasing and the cost of purchasing empty containers. By using the LINGO software, the proposed solution can re-optimize the optimal shipping service network. This procedure reduces the total time for voyage routes, and proposes shorter distances between supply and demand ports, especially if the demand is ordered from a supply port and distributed to a series of demand ports on the shipping service network. In general, the models are efficient and accurate in solving problems, and provide flexibility for shipping companies in route decision making and the repositioning process.

In chapter 5, the proposed queuing models are used to optimize the service level and to improve or develop the container stacking system as well as the usage of storage space in the yard area. It also presented the proposed queuing models to optimize the service level of discharging vessels under different scenarios of berthing policy and priorities, in addition to maximizing the berth utilization. This approach found the optimal service level with optimal efficiency and service condition for both the container stacking process and the assignment of suitable berths to vessels in a seaport container terminal by considering the impact of synchronization and sequence of daily terminal operations as well as different berthing priorities, respectively. The study used the queuing theory (as decision making techniques to help seaport operators and managers to develop policies to provide high level of container-service or high competitive service) to examine the problems of congestion and delays in the synchronization and sequencing of daily operations and the functions between seaside and landside of terminal due to the interference of terminal operations and lack of control in the scheduling of concurrent operations and activities during the management of inbound and outbound containers. There is a wide range of studies on container stacking and berth allocation problems, but these studies have never focused on dealing with the seaport as a whole queuing system, and instead dealt with seaport system as a set of individual problems.

The findings of this study can be very useful and helpful for seaport authorities and terminal operators to help reduce unproductive movements and times while simultaneously reducing vessel turnaround time in seaport. Furthermore, the queuing theory as presented in this study can be a key indicator of service efficiency or a kind of balance between service expectations and the actual delivery of those services.

The study found many answers to the research questions and some solutions to address some common problems in seaports, especially those related to: re-optimizing the optimal shipping service networks for the distribution /redistribution or repositioning/positioning of empty containers among depots and seaports, managing or scheduling the sequence of daily operations of container terminals in order to optimize strategies for container stacking amidst different conflicting objectives, improving/developing the management of returnable containers, and the discharge of vessels according to priority

The study suggests that the following problems are dealt with in future researches:

- Using Bi-objective or Multi-objective optimization methods (Pareto optimal solutions) to optimize empty container repositioning.
- The effect of changing the arrival rate of containers and the service rate of terminal service stations on the congestion of containers inside the container yard and finding the optimal arrival and service rates to perform all functions that are associated with container stacking process.
- The integration of berth allocation problem and quay crane assignment problem.
- The queuing system with multiple server non-pre-emptive priority or queuing system with blocking to optimize berth allocation problem.
- The effect of blocked service stations of tandem queue systems (the de-lashing containers and container handling) on berth allocation problem.
- The effect of timetable optimization and formulating a terminal operations scheduling model to minimize the weighted times of sequence of activities, tasks, functions and sub-operations that are associated with the elementary operations at a seaport container terminal.
- The effect of blocked service stations of tandem queues system for the container terminal, or study the effect of service discipline or the possibilities for the containers to enter service in the container terminal (the service under priorities, random order) on the service level inside seaport.
- Establishing forecasting models according to historical data of seaport problems to provide long-term strategic planning and to predicting future events that might impact the forecasts as accurately as possible.

Bibliography:

1. Akyuz, Hakan and Lee, Chung-Yee, “Service Level Assignment and Container Routing for Liner Shipping Service Networks”, International Multi Conference of Engineers and Computer Scientists, IMECS 2014, The Royal Garden Hotel Kowloon, Hong Kong, 12-14 March 2014.
2. Alderton P, “Port Management and Operations”, 2nd edition, Informa Publications, London UK, (2005).
3. Altena E, “Optimization of modal shift and container (re-)positioning at Maersk Line”, Master thesis, Delft University of Technology\ Faculty of Civil Engineering, April, 2013.
4. Ambrosino D, Paolucci M and Sciomachen A, “A MIP heuristic for multi port stowage planning”, Transportation Research Procedia 10 (2015) pp 725 – 734, www.elsevier.com/locate/procedia.
5. Ambrosino D, Sciomachen A and Tanfani E, “Stowing a containership: the master bay plan problem”, Transportation Research Part A: Policy and Practice, Volume 38, Issue 2, February 2004, Pages 81-99.
6. Asperen E. V., Borgman B, Dekker R, “Evaluating Container Stacking Rules Using Simulation”, Proceedings of the 2010 Winter Simulation Conference, 978-1-4244-9864-2/10/$26.00 ©2010 IEEE.
7. Asperen E. V., Borgman B, Dekker R, “Evaluating Container Stacking Rules Using Simulation”, Proceedings of the 2010 Winter Simulation Conference, 978-1-4244-9864-2/10/$26.00 ©2010 IEEE, pp. 1924-1933.
8. Bean W. L. and Joubert J. W., “Planning Empty Container Relocations Under Uncertainty”, South African Journal of Industrial Engineering May 2010 Vol. 21(1): pp 113-122, http://sajie.journals.ac.za.
9. Belmecheri F, Cagniart T, Amodeo L, Farouk Yalaoui F, Prins C, “Modelling and optimization of empty container reuse: a real case study “, 978-1-4244-4136-5/09/$25.00©2009IEEE, 1106-1109.
10. Bichou K, “Port operations, planning and logistics: Lloyd’s Practical Shipping Guides”, Website: www.informaprofessional.com/port, Informa Law from Routledge (2009).
11. Bichou K, “Port Operations, Planning and Logistics”, Published by Informa Law from Routledge, 2013.
12. Bish E. K., Chen F. Y., Leong Y. T., Nelson B. L., Ng J. W. C., and David Simchi-Levi, “Dispatching vehicles in a mega container terminal”, OR Spectrum (2005) 27: pp. 491–506, © Springer-Verlag 2005.
13. Boile M, Theofanis S and Golias M, "Berth Allocation with Service Priorities: A Linear Reformulation", Proceedings of the 5th WSEAS Int. Conf. on System Science and Simulation in Engineering, Tenerife, Canary Islands, Spain, December 16-18, pp 72-77 (2006).
14. Borjian S, Manshadi V. H., Barnhart C, Jaillet P, “Dynamic Stochastic Optimization of Relocations in Container Terminals”, June 25, 2013.
15. Böse J. W., **“**Handbook of Terminal Planning**”,** Springer New York Dordrecht Heidelberg London, www.Springer.com, (2011).
16. Braekers K, Janssens G. K., Caris A, “Determining Optimal Shipping Routes for Barge Transport with Empty Container Repositioning”, Transportation Research Institute (IMOB) – Hasselt University, Belgium , 2010.
17. Branch A. E., “Elements OF Shipping”, Routledge taylor & francis group, Eighth edition (2007).

18. Branislav D, Kyu P. N., Young K. J., Romeo M, "A Study of Yard Truck Dynamic Planning at a Container Terminal", 12th WCTR, July 11-15, 2010 – Lisbon, Portugal, pp. 1-19.
19. Burns M. G., "Port Management and Operations", Taylor & Francis Group, www.taylorandfrancis.com (2015).
20. Carrasco-Gallego R, Ponce-Cueto E, "Forecasting the returns in reusable containers' closed-loop supply chains. A case in the LPG industry", 3rd International Conference on Industrial Engineering and Industrial Management, Barcelona-Terrassa, September 2nd-4th 2009, pp. 311-320.
21. Chandoul A, Cung V, Mangione F, "Reusable containers within reverse logistic context", https://hal.archives-ouvertes.fr/hal-00331836, 2008, pp. 1-25.
22. Chandoul A, Cung V. D., Mangione F, "Optimal Repositioning and Purchasing Policies in Returnable Container Management", 978-1-4244-4870-8/09/$26.00 ©2009 IEEE, 1439-1443.
23. Chen C, Chao S, "A Time-Space Network Model for Allocating Yard Storage Space for Export Containers", Transportation Planning Journal, Vo1. 33 No. 2, June 2004, PP. 227-248.
24. Chew E. P., Lee L. H., Long Y, "Sample Average Approximation for Stochastic Empty Container Repositioning", INFOCOMP (2011): The First International Conference on Advanced Communications and Computation, 86-91, (c) IARIA, 2011. ISBN: 978-1-61208-161-8.
25. Choong S. T., Cole M. H., Kutanoglu E., "Empty container management for intermodal transportation networks ", Transportation Research Part E 38 (2002) 423–438.
26. Choong S. T., Cole M. H., Kutanoglu E. "Empty Container Management for Container-on-Barge (COB) Transportation: Planning Horizon Effects on Empty Container Management in a Multi-Modal Transportation Network", 2003.
27. Chou C, Gou R, Tsai C, Tsou M, Wong C, Yu H, "Application of a mixed fuzzy decision making and optimization programming model to the empty container allocation ", Applied Soft Computing 10 (2010) 1071–1079.
28. Chu C, Huang W, "Determining container terminal capacity on the basis of an adopted yard handling system", Transport Reviews, Vol. 25, No. 2, pp. 181-199, march (2005).
29. Clausen U, Kaffka J, Meier F, "CONTSIM– Container Terminal Management with Simulation", Procedia - Social and Behavioral Sciences, (2012), pp. 1–9, www.sciencedirect.com.
30. Cobb B. R., "Inventory control for returnable transport items in a closed-loop supply chain", Transportation Research Part E 86 (2016) pp. 53–68, www.elsevier.com/locate/tre.
31. Cohen MA, Pierskalla WP and Nahmias S, "A dynamic inventory system with recycling", (1980) Naval Research Logistics Quarterly, 27(1), 289 – 296.
32. Cordeau J, Gaudioso M, Laporte G, Moccia L, "The service allocation problem at the Gioia Tauro Maritime Terminal", European Journal of Operational Research 176 (2007) 1167–1184, www.elsevier.com/locate/ejor.
33. Cullinane K, "International Handbook of Maritime Business", Published by Edward Elgar Publishing Limited UK, Edward Elgar Publishing Inc. USA, 2010.
34. Dai J, Lin W, Moorthy R, Teo C, "Berth Allocation Planning Optimization in Container Terminal", June 2004, National University of Singapore Academic Research Grant R-314-000-030-112.
35. Dang Q. V., Yun W. Y. and Kopfer H, "Positioning empty containers under dependent demand process", Computers & Industrial Engineering 62 (2012) pp 708–715, www.elsevier.com/ locate/caie.

36. De Brito M. P. and Konings R, “The reverse logistics of empty maritime containers”, 1st INTERNATIONAL CONFERENCE OF LOGISTICS, INTLOG 2006, PP. 1-11, https://www.researchgate.net/publication/322487797.
37. Delgado A, Jensen R. M., and Schulte C, “Generating Optimal Stowage Plans for Container Vessel Bays”, I.P. Gent (Ed.): CP 2009, Lecture Notes in Computer Science LNCS Vol. 5732, pp. 6–20, 2009. Springer-Verlag Berlin Heidelberg 2009.
38. Do Ngoc A and Moon Il-K, “The storage capacity expansion and space leasing for container depots”, Flex Serv Manuf J (2011) 23:364–384, DOI 10.1007/s10696-011-9075-6.
39. Dobos I, “An alternative solution to an economic order quantities for recoverable item inventory systems”, Social and Management Sciences, 19/2 (2011) pp. 87–96, web: http://www.pp.bme.hu/so.
40. Dong J. X., Song D. P., “Container fleet sizing and empty repositioning in liner shipping systems “,Transportation Research Part E 45 (2009) 860–877.
41. Dong-Wook Song D. W., Panayides P. M., “Maritime Logistics: Contemporary Issues”, Emerald Group Publishing limited (2012).
42. Esmer S, “Performance Measurements of Container Terminal Operations”, Dokuz Eylul University, Maritime Business and Administration School, (2008) 238–255.
43. Fan L, Low M. Y. H., Ying H. S., Jing H. W., Min Z and Aye W. C., “Stowage Planning of Large Containership with Tradeoff between Crane Workload Balance and Ship Stability”, Proceedings of the international Multi Conference of Engineering and Computer Scientists 2010 Vol. 3, IMECS 2010, March 17-19 2010, Hong Kong.
44. Fan X, Gong Y, Xu X, Zou B, “Optimal decisions in reducing loss rate of returnable transport items”, Journal of Cleaner Production 214 (2019) pp. 1050-1060, www.elsevier.com/locate/jclepro.
45. Fan X, Xu X, Zou B, Bai Q, “Returnable containers management in a single-vendor multi-buyer supply chain with investment in reducing the loss fraction”, Measurement (2018), pp. 1-25, https://doi.org/10.1016/j.measurement.2018.12.003.
46. Feng C. M. And Chang C. H., “Empty container reposition planning for intra-Asia liner shipping“ ,Maritime Policy and Management, OCTOBER 2008, VOL. 35, NO. 5, 469–489.
47. Fleischmann M, Bloemhof-Ruwaard J. M., Dekker R, Erwin van der Laan, Jo A.E.E. van Nunen, Luk N. Van Wassenhove, “Quantitative models for reverse logistics: A review”, European Journal of Operational Rcsearch 103 (1997) pp.1-17, © 1997 Elsevier Science B.V.
48. Francesco M. D., Crainic T. G., Zuddas P, “The effect of Multi-Scenario Policies on Empty Container Repositioning under uncertainty and data shortage”, Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation, June 2008, pp. 1-24, CIRRELT-2008-21.
49. Froylan G, Koch T, Megow N, Duane E and Wren H, “Optimizing the landside operation of a container terminal”, OR Spectrum (2008) 30:53–75.
50. Froyland G, Koch T, Megow N, Duane E, Wren H, “Optimizing the landside operation of a container terminal”, OR Spectrum (2008) 30:53–75.
51. Furió S, Andrés C, Adenso-Díaz B and Lozano S, “Optimization of empty container movements using street-turn: Application to Valencia hinterland”, Computers & Industrial Engineering (2013), 66, 909–917.
52. Furió S, Andrés C, Lozano S, Adenso-Díaz B, “Mathematical Model to Optimize Land Empty Container Movements”, 2009.

53. Gençer H and Demir M. H., “An Overview of Empty Container Repositioning Studies and Research Opportunities”, Macrothink Institute, Business and Management Horizons, 2019, Vol. 7, No. 1, pa 1-22.
54. Gencer H, “An Overview of Empty Container Repositioning Studies and Research Opportunities” (2019), Business and Management Horizons, Vol. 7, No. 1.
55. Ghanbari M. R., Azimi P, Abdollahi F, “Simulation-Based Optimization in Performance Evaluation of Marshaling Yard Storage Policy in a Container Port”, World Academy of Science, Engineering and Technology, Vol:67 2012-07-25, pp 1042-1049.
56. Gharehgozi A. H., “Developing New Methods for Efficient Container Stacking Operations”, PhD thesis, Erasmus University Rotterdam, 27 November 2012.
57. Golias M. M., Saharidis G. K., Boile M, Theofanis S and M. G., "The berth allocation problem: Optimizing vessel arrival time", Maritime Economics & Logistics Vol. 11, 4, 358–377, www.palgrave-journals.com/mel/.
58. Guan C. Q., “Analysis of Marine Container Terminal Gate Congestion, Truck Waiting Cost, and System Optimization”, PhD thesis, New Jersey Institute of Technology, Newark, NJ, 2009.
59. Gümüs M, Kaminsky P, Tiemroth P. E. and Ayik M,” A Multi-stage Decomposition Heuristic for the Container Stowage Problem”, March 2008, www.researchgate.net.
60. Gujjula R, Günther H. O., “The impact of storage block assignment for import containers on AGV dispatching in highly automated seaport container terminals”, Proceedings of the 2008 IEEE IEEM, pp 1739-1743, ©2008 IEEE.
61. Guldogan E. U., “Port Operations and Container Terminal Management”, VDM Verlag Dr. Müller GmbH and Co. KG, (2011).
62. Guo P, Cheng W and Liang J, “Particle Swarm Optimization for Gantry Crane Scheduling with Interference Constraints”, Research Journal of Applied Sciences, Engineering and Technology 4(9), 2012, pp. 1117-1123.
63. Guo Z, Wang W, Tang G, Huang j, “A recursive model for static empty container allocation “, Front. Comput. Sci. China 2011, 5(4): 486–495, DOI 10.1007/s11704-011-1013-y.
64. Gusah L, Cameron-Rogers R., and Thompson R. G., “A systems analysis of empty container logistics – a case study of Melbourne, Australia”, Transportation Research Procedia 39 (2019) 92–103.
65. Gusah L., Cameron-Rogers R. and Thompson RG , “A systems analysis of empty container logistics – a case study of Melbourne, Australia”, Transportation Research Procedia (2019), 39, 92–103.
66. Hajeeh M. A. and Behbehani W, “Optimizing Empty Containers Distribution among Ports”, Journal of Mathematics and Statistics 7 (3): 216-221, 2011. ISSN 1549-3644, © 2011 Science Publications.
67. Hakam M. H., Solvang W. D.. (2013) Container ports sustainability - a literature review. 2013 IEEE 4th International Conference on Cognitive Infocommunications (CogInfoCom), pages 803-810.
68. Handbook on the management and operation of dry ports, United Nations Conference on Trade and Development (UNCTAD), Geneva (1991).
69. Hartmann S, “Generating scenarios for simulation and optimization of container terminal logistics“, OR Spectrum (2004) 26, pp. 171-192.
70. Hendriks M. P. M., Lefeber E., Udding J. T., "Simultaneous berth allocation and yard planning at tactical level", OR Spectrum (2013) 35:441–456, DOI 10.1007/s00291-012-0305-4, Published online: 9 September 2012, © Springer-Verlag 2012.

71. Henesey L. E., “Multi-Agent Systems for Container Terminal Management”, PhD thesis, Department of Systems and Software Engineering, School of Engineering, Blekinge Institute of Technology, SWEDEN (2006).
72. Hjortnaes T, “Repositioning of empty containers in the Dutch hinterland: How to achieve cost savings at Empty Depots in Rotterdam?”, Master Thesis, Delft University of Technology, October 2014.
73. Hoshino S and Ota J, “Design of an Automated Transportation System in a Seaport Container Terminal for the Reliability of Operating Robots”, Proceeding of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, San Digo, CA, USA, Oct 29-Nov 2, 2007, pp 4259-4264.
74. Hsu C and Hsieh Y, “Direct Versus Terminal Routing on a Maritime Hub and-Spoke Container Network”, Journal of Marine Science and Technology, Vol. 13, No. 3, pp. 209-217 (2005).
75. Hsu C and Hsieh Y, “Shipping Economic Analysis for Ultra Large Containership”, Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 936 - 951, 2005.
76. Hu W, Hu Z, Shi L, Luo P and Song W, "Combinatorial Optimization and Strategy for Ship Stowage and Loading Schedule of Container Terminal". Journal of computers, vol. 7, NO. 8, August 2012.
77. Huang C, “The Optimization of Empty Shipping Container Reposition Based on the Network Simplex Method”, 978-1-4244-6581-1/11/$26.00 ©2011 IEEE.
78. Huang J, Wang F, Shi N, “Resource Allocation Problems in Port Operations: A Literature Review”, 2014 Seventh International Joint Conference on Computational Sciences and Optimization, Pages 154–158.
79. Imai A, Chen H. C., Nishimura E, Papadimitriou S, " The simultaneous berth and quay crane allocation problem ", Transportation Research Part E 44 (2008) 900–920, www.elsevier.com/locate/tre.
80. Imai A, Shintani K, Papadimitriou S, “Multi-port vs. Hub-and-Spoke port calls by containerships”, Transportation Research Part E 45 (2009) 740–757, www.elsevier.com/locate/tre .
81. Imai A, Sun X, Nishimura E, Papadimitriou S, " Berth allocation in a container port: using a continuous location space approach", Transportation Research Part B 39 (2005) 199–221, www.elsevier.com/locate/trb.
82. Imre D, “The generalization of Schrady's model: with repair”, Research Gate 2002, pp. 1-12, https://www.researchgate.net/publication/277997766.
83. Ioannou P. A., “Intelligent Freight Transportation”, CRC Press, Taylor and Francis Group (2008).
84. Javanshir H, Ganji S. R. S., “Optimal Allocation of Ships to Quay Length in Container Ports”, Journal of Industrial and Systems Engineering, Vol. 3, No. 4, 2010, pp 275-290.
85. Jensen R. M., Leknes E, and Bebbington T, “Fast Interactive Decision Support for Modifying Stowage Plans Using Binary Decision Diagrams”, Proceedings of the international Multi Conference of Engineering and Computer Scientists 2012 Vol. 2, IMECS 2012, March 14-16 2012, Hong Kong.
86. Jeong Y, Saha S, Chatterjee D and Moon I, “Direct shipping service routes with an empty container management strategy”, Transportation Research Part E 118 (2018) 123–142.
87. Jiang G, “An Uncertain Chance-Constrained Programming Model for Empty Container Allocation”, (2012), INFORMATION Volume 15, Number 12, pp.259-264, ISSN 1343-4500, (c) 2012 International Information Institute.
88. Jiangang J, “Storage Yard Management for Container Transshipment Terminals”, National University of Singapore\ Department of Civil and Environmental Engineering, PhD thesis, 2012.

89. Jovanovic R, Voß S, “A chain heuristic for the Blocks Relocation Problem”, Computers & Industrial Engineering 75 (2014) 79–86, www.elsevier.com/ locate/caie.
90. Jula H, Chassiakos A, Ioannou P, “Port dynamic empty container reuse“, Transportation Research Part E 42 (2006) 43-60. www.elsevier.com/locate/tre .
91. Katephap N and Limnararat S, “The Operational, Economic and Environmental Benefits of Returnable Packaging Under Various Reverse Logistics Arrangements”, International Journal of Intelligent Engineering and Systems, Vol.10, No.5, 2017, pp.210-219.
92. Kefi M, Korbaa O, Ghedira K, Yim P, “Heuristic-Based Model for Container Stacking Problem”, 19th International Conference on Production Research, 2010, http://www.icpr19.cl/mswl/Papers/121.pdf.
93. Kemme N, “Design and Operation of Automated Container Storage Systems”, Springer-Verlag Berlin Heidelberg, www.Springer.com, 2013.
94. Kim T, Glock C. H., “On the use of RFID in the management of reusable containers in closed loop supply chains under stochastic container return quantities”, Transportation Research Part E 64 (2014) 12–27, www.elsevier.com/locate/tre.
95. Kim K. H., “An Optimal Scheduling Method for Leasing and Purchasing Containers in Shipping Liners”, Proceedings of the Fifth Asia Pacific Industrial Engineering and Management Systems Conference 2004, pp 7.2.1 – 7.2.8.
96. Kim K. H., Günther H. O., “Container Terminals and Cargo Systems”, Springer-Verlag Berlin Heidelberg, www.Springer.com, 2010.
97. Kim K. H., Moon K. C., "Berth scheduling by simulated annealing", Transportation Research Part B 37 (2003) 541–560. www.elsevier.com/locate/trb.
98. Koh S-G, Hwang H, Sohn K-I and Ko C-S, “An optimal ordering and recovery policy for reusable items”, Computers and Industrial Engineering (2002), 43, 59 – 73.
99. Kolar P., Schramm H-J and Prockl G., “Intermodal transport and repositioning of empty containers in Central and Eastern Europe hinterland”, Journal of Transport Geography (2018), 69, 73–82.
100. Krčum M, Gudelj A, Vlahinić S, " Genetic Algorithm for Solving Berth and Quay Cranes Assignment problems", 2nd International Conference on Ports and Waterways – POWA 2007, supported by the Ministry of Science, Education and Sports of the Republic of Croatia.
101. Kroer C, Svendsen M. K., Jensen R. M., Kiniry J and Leknes E, “Symbolic Configuration for Interactive Container Ship Stowage Planning”, April 19, 2014, IMECS 2012, pp 1-30.
102. Kumar N. R. and Kumar R. M. S., “Closed Loop Supply Chain Management and Reverse Logistics -A Literature Review”, International Journal of Engineering Research and Technology, Volume 6, Number 4 (2013), pp. 455-468, http://www.irphouse.com.
103. Kuzmicz KA and Pesch E , “Approaches to empty container repositioning problems in the context of Eurasian intermodal transportation”, Omega (2019), 85, 194-213.
104. Lee B. H. A., “Empty Container Logistics Optimization: An Implementation Framework and Methods”, Master thesis, Massachusetts Institute of Technology, Jan 17, 2014.
105. Lee C-Y and Song D-P, “Ocean container transport in global supply chains: Overview and research opportunities”, Transportation Research Part B (2016), 95, 442–474.
106. Lee D, Jin J. G., Chen J. H., “The integrated bay allocation and yard crane scheduling problem for transshipment containers”, TRB 2011 Annual Meeting.
107. Lee L. H., Chew E. P., Luo Y, “Inventory-Based Empty Container Repositioning in a Multi-Port System”, INFOCOMP 2011: The First International Conference on Advanced Communications and Computation, Copyright (c) IARIA, 2011, pp 80-85.

108. Legato P and Mazza R. M.,"Managing Container Reshuffling in Vessel Loading by Simulation", Proceedings of the 2013 Winter Simulation Conference, 2013 IEEE.
109. Le-Griffin H. D., Murphy M, "Container Terminal Productivity: Experiences at the Ports of Los Angeles and Long Beach", Conference Feb. 2006, pp. 1-21.
110. Leong T, Lau H. C., "Generating Job Schedules for Vessel Operations in a Container Terminal ", MISTA 2007, Singapore Management University, pp. 328–335.
111. Li F, Han S, "The Marine Reposition of Empty Containers under Uncertain Demand and Supply ", 978-1-4244-3662-0/09/$25.00 ©2009 IEEE, 479-482.
112. Li J, Leung S. C. H., Wu Y, Liu K, "Allocation of empty containers between multi-ports", European Journal of Operational Research, 182 (2007) pp. 400-412, www.elsevier.com/locate/ejor.
113. Ligteringen H and Velsink H, "Ports and Terminals", Published by VSSD, www.vssd.nl/hlf, first edition (2012).
114. Liu J. J., "Supply Chain Management and Transport Logistics" Routledge taylor & francis group, First published (2012).
115. Lopez E, "How do ocean carriers organize the empty containers reposition activity in the USA?", Maritime Policy and Management, OCTOBER–DECEMBER 2003, VOL. 30, NO. 4, pp 339–355, Taylor and Francis Ltd, http://www.tandf.co.uk/journals.
116. Lun Y. H, Lai K. H., Cheng T. C. E.,"Shipping and Logistics Management", Springer London Dordrecht Heidelberg New York, www.Springer.com, (2010).
117. Luo J, Wu Y, Halldorsson A and Song X, "Storage and stacking logistics problems in container terminals", OR Insight December 2011, Volume 24, pp 256–275, https://doi.org/10.1057/ori.2011.10
118. Ma H. L., Chan F. T. S., Chung S. H. and Wong C. S., " Berth Allocation Planning for Improving Container Terminal Performances ", Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management Istanbul, Turkey, July 3 – 6, 2012. pp 502-508.
119. Mabini, M., Pintelon, L., & Gelders, L., "EOQ type formulations for controlling repairable inventories", International Journal of Production Economics (1992), 28(2), 1-33.
120. Mak K. L., Sun D, "A New Hybrid Genetic Algorithm and Tabu Search Method for Yard Cranes Scheduling with Inter-crane Interference", Proceedings of the World Congress on Engineering 2009 Vol. I, WCE 2009, July 1 - 3, 2009, London, U.K.
121. Maleki1 R. A. and Reimche J, "Managing Returnable Containers Logistics - A Case Study Part I - Physical and Information Flow Analysis", international Journal of Engineering Business Management, vol.3 , no. 2 (2011), pp. 1-8,www.intechopen.com.
122. Martins P. T., Lobo V. J.A.S., Vairinhos V, "Container Stowage Problem Solution for Short Sea Shipping", IO 2009 – 14º Congresso da APDIO, 7 a 9 de Setembro de 2009.
123. Meisel F., "Seaside Operations Planning in Container Terminals", Springer Dordrecht Heidelberg London, New York, www.Springer.com, (2010).
124. Meng Q, Wang S, "Liner shipping service network design with empty container repositioning", Transportation Research Part E 47 (2011) 695–708. www.elsevier.com/locate/tre .
125. Mhonyai C, Suthikarnnarunai N and Rattanawong W, "Container Supply Chain Management: Facts, Problems, Solution", Proceedings of the World Congress on Engineering and Computer Science 2011 Vol II WCECS 2011, October 19-21, 2011, San Francisco, USA.
126. Min Z, Low M. Y. H., Jing H. W., Ying H. S., Fan L, Aye W. C., "Improving Ship Stability in Automated Stowage Planning for Large Containerships", Proceedings of the

international Multi Conference of Engineers and Computer Scientists 2010 Vol. 3, IMECS 2010, March 17-19 2010, Hong Kong.

127. Mingkun L and Shiying L,"An effective heuristic for yard template design in land-scarce container terminals", 2011 IEEE International Conference on Industrial Engineering and Engineering Management, pp 908 – 912.

128. Moghadam M. K., Noori R, "Cost Function Modelling for Semi-automated SC, RTG and Automated and Semi-automated RMG Container Yard Operating Systems", International Journal of Business and Development Studies Vol. 3, No. 1, (2011) pp.85-122.

129. Moon I and Hong H, "Repositioning of empty containers using both standard and foldable containers", Maritime Economics & Logistics (2016) 18, 61–77.

130. Moon I, Do Ngoc A, Konings R, "Foldable and standard containers in empty container repositioning", Transportation Research Part E 49 (2012) 107–124, www.elsevier.com/locate/tre.

131. Moon Il-K, Ngoc A. D., Hur Y, "Positioning empty containers among multiple ports with leasing and purchasing considerations " , OR Spectrum (2010) 32:765–786.

132. Moorthy R, Teo C, "Berth management in container terminal: the template design problem", OR Spectrum, October 2006, Volume 28, Issue 4, pp 495-518.

133. Moura A and Oliveira J. F., "A GRASP Approach to the Container Loading Problem", IEEE Intelligent Systems, vol. 20, no. , pp. 50-57, July/August 2005, doi:10.1109/MIS.2005.57.

134. Murty K. G., Liu J, Wan Y, Linn R, "A decision support system for operations in a container terminal", Decision Support Systems, pp. 1-24 (2004). www.elsevier.com/locate/dsw.

135. National Research Council (U.S.). Committee for a Study of the Effects of Regulatory Reform on Technological Innovation in Marine Container Shipping, Transportation Research Board, "Intermodal Marine Container Transportation: Impediments and Opportunities", 1992.

136. Ndiaye N. F., Yassine A and Diarrassouba I, "A hybrid ant colony and genetic algorithm to solve the container stacking problem at seaport terminal", 2014 International Conference on Advanced Logistics and Transport (ICALT).

137. Ng W.C., Mak K.L., "Yard crane scheduling in port container terminals", Applied Mathematical Modelling 29 (2005) 263–276, www.elsevier.com/locate/apm.

138. Nieuwkoop F, Corman F, Negenborn R. R., Lodewijks G, "Determining Inter Terminal Transport configurations at Maasvlakte 1 and 2 by integer programming", In Bijdragen Vervoerslogistieke Werkdagen 2013 (VLW 2013), Venlo, The Netherlands, pp. 433-448, November 2013.

139. Notteboom T, "Current Issues in Port Logistics and Intermodality", distributed by Coronet Books Inc., 2002.

140. Notteboom T. E., "Container Shipping And Ports: An Overview", Review of Network Economics, Vol.3, Issue 2, pa 86-106, June 2004.

141. Olivo A, Zuddas P, M. Francesco M. D., Manca A, "An Operational Model for Empty Container Management", (2005) Maritime Economics and Logistics, 7, pp 199-222.

142. Ozdemir U, Guneroglu A, Köse S and Demirel F.B., "A Survey of Empty Container Flow Balance in Turkish Ports", Turkish Journal of Maritime and Marine Sciences Volume: 1 Issue: 1 (2015) 18-29.

143. Pacino D, "Fast Generation of Container Vessel Stowage Plans: using mixed integer programming for optimal master planning and constraint based local search for slot planning", PhD thesis, IT University of Copenhagen, June 12, 2012.
144. Pacino, Dario and Jensen R. M., "Constraint-based local search for container stowage slot planning". Proceedings of the international Multi Conference of Engineering and Computer Scientists IMECS, volume 2, (14-16 March 2012). PP1467-1472.
145. Park N. K., Dragović B, Kim J. Y., "Dynamic Equipment Deployment at a Container Terminal: Transfer System Based on Real-Time Positioning", Strojniški vestnik - Journal of Mechanical Engineering 55(2009)2, 83-94.
146. Petering. M. E. H., Murty K. G., "Effect of block length and yard crane deployment systems on overall performance at a seaport container transshipment terminal", Computers and Operations Research, Volume 36, Issue 5, May 2009, Pages 1711–1725.
147. Poo M C-P and Yip TL, "An optimization model for container inventory management", Annals of Operations Research (2019), 273, 433–453.
148. Ramphul M., Ramesh V, Jaunky V. C., "The Impact of Foldable/ Collapsible Containers on Empty Container Management: A Case Study at Port Louis", International Journal of Management and Applied Science, ISSN: 2394-7926 Volume-3, Issue-11, Nov.-2017, pp. 32-39.
149. Reinhardt L. B., Kallehauge B, Pisinger D, "A Branch and Cut algorithm for the container shipping network design problem" Technical University of Denmark, Department of Management Engineering, pa 1-18, December 10, 2010.
150. Rensburg J. J., He Y. and Kleywegt A. J., "A Computer Simulation Model of Container Movement by Sea", Proceedings of the 2005 Winter Simulation Conference, M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.
151. Rodrigue J. P., Comtois C, Slack B, "The Geography of Transport Systems", Routledge, Sep. 27, 2006.
152. Rodrigue, JP. And Notteboom, T. "The geography of containerization: half a century of revolution, adaptation and diffusion", GeoJournal (2009) 74: 1.
153. Salido M. A., Sapena O, Rodriguez M, Barber F, "A Planning Tool for Minimizing Reshuffles in Container Terminals", ACOMP/2009/178 Generalitat Valenciana, and by the Technical University of Valencia, research projects TIN2007-67943-C02-01.
154. Schmidt F. A., Yazdani R, Young R, "Visualising Layout and Operation of a Container Terminal", Proceedings 19th European Conference on Modelling and Simulation. Yuri Merkuryev, Richard Zobel, Eugène Kerckhoffs © ECMS, 2005. ISBN 1-84233-112-4 (Set) / ISBN 1-84233-113-2 (CD).
155. Schrady DA , "A deterministic inventory model for reparable items", Naval Research Logistics Quarterly (1967), 14(3), 391–398.
156. Seyed-Hosseini S, Damghani K. K., "Fuzzy containers allocation problem in maritime terminal", Journal of Industrial Engineering and Management, vol. 2, no. 2, 2009, pp. 323-336, www.jiem.org.
157. Sha M and Huang X, "A system dynamics model for port operation system based on time, quality and profit", 2010 International Conference on Logistics Systems and Intelligent Management (ICLSIM), Volume: 3, pa 1669- pa 1673, IEEE Xplore.
158. Shah N. H., Patel D. G., Shah D. B., "model for returned/reworked inventories during imperfect production process under pricesensitive stock-dependent demand", operation research international journal (2018), 18: pp. 343–359, Springer-Verlag Berlin Heidelberg.
159. Shan T, "Genetic Algorithm for Dynamic Berth Allocation Problem with Discrete Layout", The 2nd International Conference on Computer Application and System Modeling (2012), Published by Atlantis Press, Paris, France, PP 261-264.

160. Sharif O, Huynh N, Chowdhury M, Vidal J. M., "An Agent-Based Solution Framework for Inter-Block Yard Crane Scheduling Problems", International Journal of Transportation Science and Technology · vol. 1 · no. 2 · 2012 – pages 109 – 130.
161. Sheikholeslami A, Ilati G, Hassannayebi E, "A Simulation Model for the Problem in Integrated Berth Allocation and Quay Crane Assignment", Journal of Basic and Applied Scientific Research, 3(8) pp343-354, 2013, www.textroad.com.
162. Shen S, and Ko F, "A Study of Modeling the Simultaneous Berth and Crane Allocation Problem", Proceedings of the International Multi Conference of Engineers and Computer Scientists 2013 Vol. II, IMECS 2013, March 13 - 15, 2013, Hong Kong.
163. Shi1 N and Xu D, "A Markov Decision Process Model for an Online Empty Container Repositioning Problem in a Two-port Fixed Route", International Journal of Operations Research Vol. 8, No. 2, 8-17 (2011).
164. Shintani K, Imai A, Nishimura E, Papadimitriou S, " The container shipping network design problem with empty container repositioning", Transportation Research Part E 43 (2007) 39–59. www.elsevier.com/locate/tre .
165. Shintani K, Konings R and Imai A "Combinable containers: A container innovation to save container fleet and empty container repositioning costs", Transportation Research Part E 130, 248–272, (2019).
166. Sibbesen L. K., "Mathematical models and heuristic solutions for container positioning problems in port terminals", PhD thesis, Technical University of Denmark\ Department of Management Engineering, February 2008.
167. Sinha S, Ganesan V. K., "Enhancing Operational Efficiency of a Container Operator: a Simulation Optimization Approach", Proceedings of the 2011 Winter Simulation Conference, pp 1727-1738, ©2011 IEEE.
168. Song D and Carter J, "Empty container repositioning in liner shipping", Maritime Policy and Management ISSN 0308–8839 print/ISSN 1464–5254 Taylor and Francis , VOL. 36, NO. 4, 291–307, AUGUST2009. http://www.tandf.co.uk/journals.
169. Song D and Zhang Q, "Impact of Dynamic Information on Empty Container Repositioning in a Seaport with Uncertainties", pp 3300-3305, 978-1-4244-3872-3/09/$25.00 ©2009 IEEE, 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference, Shanghai, P.R. China, December 16-18, 2009.
170. Song D. P., Dong J. X., "Effectiveness of an empty container repositioning policy with flexible destination ports ", Transport Policy 18 (2011) 92–101, journal homepage: www.elsevier.com/locate/tranpol.
171. Song D. W., Lee E. S., "Maritime Logistics Value and Knowledge Management", Routledge, First published (2015).
172. Song D. W., Panayides P. M, "Maritime Logistics", Kogan Page Limited, www.koganpage.com, first published (2012).
173. Song P, Mingming F, Jing L, Jun S, "A Study on Container Allocation on Shipping Routes for Liner Companies ", 1-4244-0885-7/07/$20.00 ©2007 IEEE.
174. Soriguera F, Espinet D, Robuste F, "A simulation model for straddle carrier operational assessment in a marine container terminal", Journal of Maritime Research, vol. 3, no.2, pp. 19-34 (2006).
175. Sriphrabu P, Sethanan K, and Arnonkijpanich B, "A Solution of the Container Stacking Problem by Genetic Algorithm", IACSIT International Journal of Engineering and Technology, Vol. 5, No. 1, February 2013, pages 45 – 49.
176. Sterzik S and Kopfer H, "A Tabu Search Heuristic for the Inland Container Transportation Problem", January 2012, University of Bremen, http://www.logistik.uni-bremen.de, pp.1-26.

177. Sterzik S and Kopfer H, “A Tabu Search Heuristic for the Inland Container Transportation Problem”, Computers & Operations Research (2013) 40 (2013) 953–962.
178. Sun J, Yang Z, “Analysis on the Synthetical Application of Empty Container Distribution and Leasing Strategy “,Proceedings of the Fifth International Conference on Machine Learning and Cybernetics, Dalian, 13-16 August 2006 ,1-4244-0060-0/06/$20.00 ©2006 IEEE, 2485- 2492.
179. Sun M, Wang X, Chen X, Cao L, “Study on Empty Container Repositioning Problem under Sea-rail Through Transport “,2009 Second International Conference on Intelligent Computation Technology and Automation,978-0-7695-3804-4/09 $26.00 © 2009 IEEE, DOI 10.1109/ICICTA.2009.651 , 769- 772.
180. Sunhal A. S. and Mangal D, “Analysis of Inventory Management in a Supply Chain by Using Economic Order Quantity (EOQ) Model, International Journal of Engineering Sciences and Research Technology, 2017 6(10) pp.303-309 ,www.ijesrt.com.
181. Tack C.C., Huat L. H., “Containers, Containerships & Quay Cranes”, Genesis Typesetting & Publication Services, 2000.
182. Tang C. S., Teo C. P., Wei K. K., “Supply Chain Analysis: A Handbook on the Interaction of Information, System and Optimization”, www.Springer.com, (2008).
183. Tavasszy L, Minderhoud M, Perrin J, Notteboom T, “A strategic network choice model for global container flows: specification, estimation and application”, Journal of Transport Geography, Volume 19, Issue 6, November 2011, Pages 1163–1172.
184. Theofanis S and Boile M, “Empty marine container logistics: facts, and management strategies”, GeoJournal (2009) 74: pp 51–65, DOI 10.1007/s10708-008-9214-0.
185. Theofanis S, Boile M, and Golias M, “An Optimization Based Genetic Algorithm Heuristic for the Berth Allocation Problem”, pp 4439-4445, 2007 IEEE Congress on Evolutionary Computation (CEC 2007).
186. Thoroe L and Melski A and Schumann M, “The impact of RFID on management of returnable containers”, Electron Markets (2009) 19:115–124, DOI 10.1007/s12525-009-0013-3, Published online: 10 July 2009, Springerlink.com.
187. Tian D, Huang L and Huang C, “The Impact of Port Infrastructure on Port Handling Capacity in China”, 2009 International Conference on Management and Service Science (ICMSS), IEEE.
188. Tierney K, Áskelsdóttir B, Jensen R. M., and Pisinger D, “Solving the Liner Shipping Fleet Repositioning Problem with Cargo Flows”, ©2010 Informs, Transportation Science May 23, 2014, PP 1-23.
189. Tsinker G. P., “Port Engineering : Planning, Construction, Maintenance, and Security”, Published by John Wiley & Sons, Inc., Hoboken, New Jersey, (2004).
190. Vacca I, “Container Terminal Management: Integrated Models and Large-Scale Optimization Algorithms”, PhD thesis, Ecole Polytechnique F´ed´erale de Lausanne (EPFL), Switzerland, February 2011.
191. Vacca I, Bierlaire M, Salani M, “Optimization at Container Terminals: Status, Trends and Perspectives “, 7th Swiss Transport Research Conference, 12-14 September 2007, pp. 1–21.

192. Vacca I, Salani M, Bierlaire M, “Optimization of operations in container terminals: hierarchical vs integrated approaches”, STRC 2010, September 2010, pp. 1-15.
193. Vidal J. M., Huynh N, “Building Agent-Based Models of Seaport Container Terminals, Proc. of 6th Workshop on Agents in Traffic and Transportation, Kluegl, Ossowski, Chaib-Draa and Bazzan (eds.), May, 11, 2010, Toronto, Canada.

194. Vis I. F. A., Koster R, "Transshipment of containers at a container terminal: An overview", European Journal of Operational Research 147 (2003) 1–16. www.elsevier.com/locate/dsw.
195. Vojdani, N., Lootz, F., & Rösner, R., "Optimizing empty container logistics based on a collaborative network approach", Maritime Economics & Logistics (2013), *15*(4), 467–493.
196. Voß S, Pahl J, Schwarze S, "Logistik Management: Systeme, Methoden, Integration", Springer Science & Business Media, Aug. 21, 2009.
197. Tsinker G, "Handbook of Port and Harbor Engineering: Geotechnical and Structural Aspects", Springer, Nov. 14, 2014.
198. Wang R, Zhao X, Yu W, Zou W, "The Study on Empty Containers Allocation in the Container Transportation ", 978-1-4244-2630-0/08/$25.00 ©2008 IEEE, 1678-1683.
199. Wang S and Meng Q, "Liner ship fleet deployment with container transshipment operations", Transportation Research Part E 48 (2012) 470–484, www.elsevier.com/locate/tre .
200. Wang Y, Huang Y, Zheng H, Chang D, "Quay Crane Allocation of Container Terminal Based on Cluster Analysis", Journal of Software, Vol. 8, No 5 (2013), 1201-1208, May 2013, http://ojs.academypublisher.com.
201. Wang Y, Kim K. H., "A quay crane scheduling algorithm considering the workload of yard cranes in a container yard", Journal of Intelligent Manufacturing, June 2011, Volume 22, Issue 3, pp 459-470.
202. Wong A and Kozan E, "Optimization of container process at seaport terminals", Journal of the Operational Research Society, vol. 61, pp. 658-665, 2010.
203. Xiaolong H, "Logistic Planning and Decision under Uncertainty – 2 Phases-Stochastic Simulation GA for inland empty container Reposition", 978-0-7695-4252-2/10/$26.00 ©2010 IEEE.
204. Xie Y, Liang X, Mac L and Yanb H, "Empty container management and coordination in intermodal transport", European Journal of Operational Research 257 (2017) 223–232.
205. XINJIA J, "Space-Sharing Strategies for Storage Yard Management in a Transhipment Hub Port", PhD thesis, National University of Singapore\ Department of Industrial and Systems Engineering, 2012.
206. YANG Z and CHEN K, "Optimization of Shipping Network of Trunk and Feeder Lines for Inter-Regional and Intra-Regional Container Transport", Journal of the Eastern Asia Society for Transportation Studies, Vol.8, 2010, pp. 1-14.
207. YI L, "Maritime Empty Container Repositioning With Inventory-Based Control", PhD thesis, National University of Singapore\Department of Industrial and Systems Engineering, 2012.
208. Yu, M., Fransoo , J. C., and Lee, C.-Y., "Detention decisions for empty containers in the hinterland transportation system", Transportation Research Part B (2018), 110, 188–208.
209. Zeng M, Low M. Y. H., Hsu W. J., Huang S. Y., Liu F and Win C. A., "Automated Stowage Planning for Large Containership with Improved Safety and Stability", Proceedings of the 2010 Winter Simulation Conference, 978-1-4244-9864-2/10/$26.00 ©2010 IEEE ,pp1976-1989.
210. Zeng Q, Hu X, Wang W. J. and Fang Y, "Disruption Management Model and its Algorithms for Berth Allocation Problem in Container Terminals", International Journal of Innovative Computing, Information and Control, Volume 7, Number 5(B), May 2011, pp. 2763-2773.

211. Zenzerović Z, Bešlić S, "Optimization of Cargo Transport with a View to Cost Efficient Operation of Container Ship", 25th Int. Conf. Information Technology Interfaces ITI 2003, June 16-19, 2003, Cavtat, Croatia.
212. Zhao N, Mi W, Mi C and Chai J, "Study on vessel slot planning problem in stowage process of outbound containers", Journal of Applied Sciences, Volume13 (Issue 20) 2013, pages 4278-4285.
213. Zhao N, Shen Y, Xia M, and Jin J, "A novel strategy for stowage planning of 40 feet containers in container terminals", Journal of Marine Science and Technology, Vol. 24, No. 1, pp. 61-74 (2016).