Dry Port Strategies for Congested Port Cities: A Study of Lagos, Nigeria.

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October 2012

This thesis is dedicated to God Almighty,

To Him be the glory!

Acknowledgements

This thesis could not have been completed without the support and guidance from a number of key individuals to whom I remain indebted.

Firstly, I would like to express my sincere gratitude to my supervisors, Prof. Michael G. H. Bell and Prof. Sheila Farrell, for their patient guidance, encouragement and critical review throughout the course of this PhD. Prof. S. Farrell, many thanks for the constructive feedback you provided at my thesis write up stage, from which I may author a book called "Sheila's comments!" (Lol).

Many thanks to Prof. Washington Ochieng for the encouragement and counsel he provided throughout the course of my PhD, and also for reviewing the final draft of my thesis. I would also like to thank Dr Aruna Sivakumar for her assistance in the last stages of the research. I would also like to thank PTV AG, for providing the modelling software used, and particularly Mr. Sergio Grosso, for helping with VISUM related issues in many occasions. Additionally, I would like to thank the team of surveyors who assisted me during the data collection process in Nigeria.

I am extremely grateful to my siblings and friends outside Imperial College who have extended their support through the course of my PhD particularly, Dr. Vivian Ikem, Mr. Anyababa Ikem, Ms. Emmanuella Ikem, Ms. Elizabeth Ikem, Ms. Ify Aniebo and Mr. Richard Key. Many thanks also go to my colleagues and friends at Imperial College who, have at various stages, provided stimulating discussions regarding various aspects of my PhD research or extended emotional/technical support throughout the course of it. Special thanks go to Ms. Solmaz Haji Hosseinloo, Ms. Urszula Kanturska, Mrs. Valentina Trozzi, Dr. Jun Hu and Mr. Xin Liu. Also many thanks to Ms Fionnuala Ni Dhonnabhain and Mrs Jackie Sime for their administrative support.

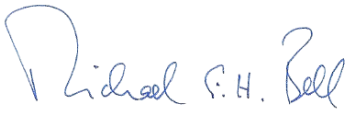
Finally, my deepest and fondest gratitude goes especially to my parents (Mr. Nathaniel Ikem and Dr. Elizabeth Ikem) who encouraged me to start this PhD and have supported me financially and emotionally throughout the process and to my love (Solomon Aiwerioba) for being very understanding and supportive. Truly, this thesis could not have been completed, without their provisions, prayers and support.

Declaration of Contribution

I (Precious Nene Ikem) hereby certify that this thesis has been carried out by myself, with advice from Prof. Michael G. H. Bell (my supervisor) and that all material in this thesis which is not my own work has been properly acknowledged.



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(Prof. Michael G. H. Bell)



(Prof. Washington Ochieng)

Abstract

The issue of congestion along key arteries to maritime terminals, although common around the world, poses a greater problem in Africa, where growth in freight traffic coupled with poor physical and institutional infrastructure affects logistical efficiency and may be detrimental to economic development. As maritime trade increases in such cities, the problem of congestion on arteries to the port becomes a growing issue and research that supports the effective implementation of congestion mitigation measures in the context of the developing countries become crucial. The use of an inland container terminal connected by rail to a port, termed a "dry port", is one of the measures employed to reduce congestion in developed port cities such as New York/New Jersey, Los Angeles and Sydney. This solution is vital to developing cities as it, by alleviating congestion on roads, improves freight logistics which can help facilitate economic development.

Dry port solutions have previously been classified under three main types - close, mid-range and distant - based on the distance of the inland terminal from the port. This thesis aims to quantify the potential road network benefits of diverting containers to a close dry port located at the rim of a developing port city. It does this by exploring the impact of a single close dry port with varying operational characteristics. These operational characteristics (variables) relate to the container allocation patterns employed and the provision of an Empty Depot Service (EDS) and a Freight Distribution Service (FDS) within the facility.

The case of Lagos, Nigeria, is selected for study as it is a developing port city where an increase in freight volume, the location of ports within close proximity to major GDP generators, coupled with poor physical and institutional infrastructure affect logistical efficiency. The research involves developing a container freight traffic model for Nigeria to simulate the current patterns of containerised cargo traffic flows (the reference scenario) as well as that which arises from the introduction of the close dry port solutions (test scenarios). Within this model, the World Bank's HDM IV vehicle operation cost functions are integrated to capture factors that influence freight routing choice in developing countries like Nigeria. The network impact of the containerised cargo traffic patterns derived from the reference and test case scenarios is the output of this model and is measured as the total container-related freight vehicle-km and vehicle-hrs in the road network. This impact is

measured for routes to and from the seaports, routes to and from zones in the port city and for the whole system. The output of the test scenario cases are compared to those from the reference case to obtain the relative network benefit of each test scenario. The relative benefits of the dry port with varying characteristics are then compared to obtain results from which the main conclusion are drawn.

It is found that a dry port solution with an FDS can provide a container-related freight vehicle-km and vehicle-hrs savings of up to 52% more that a dry port solution without an FDS. On the other hand, the benefit of a dry port solution is found to be significantly less sensitive to the empty depot service variable. Furthermore, the network benefit of a dry port solution is found to be sensitive to the container allocation patterns employed. The close dry port is found to present up to 40% higher benefits by serving only zones closer to the dry port than the seaport. However, the results show that the benefit of the dry port varies depending on the part of the network being accessed. For example, the dry ports with an FDS are shown to provide savings of up to 20% to the system (routes to and from all zones in the country) and up to 39% on routes to and from the port city. However, much higher benefits of up to 78% are observed on routes to and from the seaport. In general, it is found that the network benefit of the close dry port increases almost linearly with increase in dry port usage by up to 80% depending on the services provided within the facility, the container allocation methods employed and the parts of the road network being accessed.

The findings contribute to the literature on the impact of dry port characteristics on the efficiency of road networks in developing port cities and can be used to formulate transport policies that address issues of traffic congestion. They present policy makers with insight into the requirements for a dry port solution located at the rim of a port city to reduce congestion and improve the efficiency of the road network. Furthermore, the research highlights some factors which influence freight routing decisions in developing countries that are not normally taken into account in urban freight models and discusses ways of dealing with them. The modelling framework employed shows how it is possible to integrate freight supply chain modelling into urban transport models. The model developed in the thesis can form part of a cost-benefit analysis of individual dry port solutions centred on mitigating congestion in port cities.

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Chapter 1

Introduction

1.1 Background

One of the persistent problems facing port cities around the world is traffic congestion along key arteries to the maritime terminals and city centres. A possible cause of the problem is the increasing conflict between terminal freight traffic and intra urban personal traffic. This problem is critical to port cities considering that pre-20th century arrangements locate major commercial and metropolitan centres adjacent to the dock area, both of which generate a high numbers of vehicle trips.

Congestion occurs when demand for roadway exceeds the traffic capacity. This leads to the interaction of vehicles, that transverse a road in such a way as to reduce speed, increase trip times, induce vehicle queuing and reduce the flow rate of vehicles that transverse a given road section (Lee, 1991). At the point where flows approach the practical capacity of the roadway, drivers are constrained by the speed of other drivers which continually decrease with increase in flow until an unstable point where vehicles travel at jam speed. The relationship between the speed of transverse and vehicle flows have been well researched.

In most port cities facing this problem of congestion, the already significant volume of freight vehicles generated and moving within the city is expected to grow continuously and at a fast rate (Crainic et al, 2004). Over the past two decades, containerized freight in particular has grown at an alarming average rate of about 6.6% per annum (European Commission, 2005). This growth has been linked to the increase in overall global trade volumes and an increase in the share of containerised cargo to about two-thirds of the total general cargo transported. This trend combined with the consistent growth (1.1%) in population leads to increased congestion and pollution levels within such cities. While the contribution of marine activities to road congestion may be low compared to general traffic, the continuous increase of global traffic and containerisation means that more truck trips will be generated in such cities.

As population, levels of activities and freight volumes increases, issues relating to congestion along key arteries to maritime terminals and city centres become more apparent. Examples of cities facing these problems include; Rotterdam, New York, Lagos, Los Angeles, Busan and Sydney. This issue although common around the world poses a greater problem to developing countries where poor inland transport services may be detrimental to the economic development of such regions. In Africa in particular, the issue

of road congestion and growth in freight traffic coupled with poor physical and institutional infrastructure affect logistical efficiency within the network as is apparent in the high level of its freight transport costs (Rizet and Hine, 1993).

In developed cities, a number of approaches have been employed to address the congestion problem. Specifically, the application of intermodal transport systems within the freight network in such cities has been proposed. Intermodal transport in the context of freight refers to the movement of goods in a single loading unit through at least two different successive modes of transport in an integrated manner (ECE, 2001; OECD, 2001). Research has shown that the environmental benefits of such an integrated system can only be promoted by developing effective transport links, intermodal nodes and providing efficient services (Hanaoka, 2011). Particularly, the use of dry ports as intermodal nodes within an intermodal transport system has been proposed by a number of researchers to be a means of reducing congestion and other environmental impacts (Winebrake et al, 2008; Rahimi et al, 2008; Woxenius et al, 2004; Beresford et al, 1990).

While various terms are used interchangeably to refer to dry ports including Inland Container Depots, Freight Terminals, Inland Ports, the definition for a dry port facility have been proposed in a number of studies.

The Economic and Social Commission for Asia and the Pacific (ESCAP) proposed the following working definition: "*A dry port is a facility that provides services for handling and temporary storage of containers and general and/or bulk cargoes that enter or leave the dry port by any mode of transport, including roads, railways, inland waterways or airports. Full customs-related services and other related services such as essential inspection for cargo export and import should be put in place in such a facility" (ESCAP, 2010).*

The UN Economic Commission for Europe (UN ECE, 1998) defines an Inland Depot as: *"A common-user Inland Facility, other than a seaport or an airport with public authority status, equipped with fixed installation and offering services for handling and temporary storage of any kind of goods including containers, carried under customs transit by an applicable mode of inland surface transport, placed under customs control and with customs and other agencies competent to clear goods for home , warehousing, temporary admission, re-export, temporary storage of onward transit and outright export. This definition applies to synonyms like dry ports and Inland container depots".*

Following the increase in global containerisation, the most common dry ports are for container handling. Specific to this type of cargo, Roso (2009) defines the dry port concept

as: "*an intermodal terminal directly connected to a seaport by rail or other high capacity transport means where shippers can leave/collect their goods in intermodal loading units as if directly at the seaports. In addition, such a terminal must provide customs clearing services and other added value services such as storage, consolidation, empty depot and maintenance of containers"*.

It is argued that a fully functional dry port has the potential to increase energy efficiency, relieve road congestion in port cities and improve logistics solution for freight by supporting the shift of freight from road to more efficient traffic modes (Woxenius et al 2004, EPSD, 2006). Roso (2007) found that an implementation of dry ports in Sweden where trucking was replaced by railway transport led to as much as a 25% reduction in CO_2 emissions as well as a reduction in seaport congestion. Research in Taiwan showed that the implementation of intermodal transport lead to a 60% reduction in emissions (Liao et al, 2009). Other studies In London revealed that the establishment of such intermodal nodes leads to a substantial reduction in emissions (Zanni et. al, 2009; TfL, 2007).

To date and with respect to network congestion, there is no documented literature that quantifies the benefits of a dry port within the context of a developing city. Furthermore, existing research relating to environmental benefits (including congestion) of dry ports has been studied through case studies in which the dry ports are explored with fixed characteristics (layout and services provided). However, it is plausible that the characteristics adopted could influence the observed benefits and so should be explored. This research moves a step further to consider the potential impact of the dry port characteristics on its benefit within a traffic network and explores the transferability of the dry port concept to a developing port city in Africa. As postulated by Woxenius et al (2004) a properly implemented dry port should reduce congestion in the immediate vicinity of the seaport and on the routes connecting cities and their hinterlands by encouraging modal shifting from road to rail. This leads to the question - by how much does a dry port reduce congestion and how do its characteristics affect its ability to do this?

As container transport volumes continue to grow, a seaport's hinterland accessibility becomes an even more crucial factor for the seaport's competitive advantage because inland access can easily become a development constraint for a seaport (Roso, 2009). The implementation of a dry port should encourage the use of intermodal transport and thereby reduce the environmental impact of the whole transport system and increase regional transport efficiency (Rahimi et al 2008; Henttu, 2011). Thus, it is important to quantitatively

understand the relative effect of the implementation of various dry port scenarios with the aim to identify the characteristics of an effective dry port solution.

Based on their distance from the seaports, dry ports can be classified under three groups: 'distant', 'mid-range' and 'close'. An example of a distant dry port includes the Isaka dry port, which is located 800km from the port of Dar s Salaam. Mid-range dry ports are located within 100,km and 500km of the port an example of which is the Virginia inland port located 350km from the port of Virginia. The Alameda corridor is considered a good example of 'close' dry ports which includes dry ports located in the immediate hinterland of the port or at the rim of the city. The close dry port solution has very commonly been used within port cities that handle high container volumes, for example, Auckland, New Zealand and Sydney, Australia. It is important to note that dry ports present other added gains and apart from the problem with increased congestion on inland access, their use is driven by other problem facing the seaport and the port city including: a lack of space within the ports to handle growing container traffic and a need to encourage port competition through an improvement in terminal efficiency.

This thesis looks at the impact of a close dry port option on traffic congestion within port cities, and the effect of their characteristics, including their supply chain functions or added value services, on their ability to reduce congestion in the road network. Following a desk study of dry port solutions currently employed by congested port cities, the thesis uses a container distribution simulation to explore the effect of various dry port strategies on congestion. The outputs of the simulation are measures of congestion at system, route and link level. The output for each dry port scenario is compared to that from the do-nothing scenario (i.e. no dry port) to obtain the relative benefits. The relative benefits are the compared to obtain results from which the main conclusions are drawn.

With a lack of literature on the influence of the impact of dry port characteristic/strategies on the efficiency of road network, this thesis gives decision makers general guidance on some necessary specifications required within a dry port solution to reduce congestion and improve the efficiency of the road network. The findings may be of particular use to policy makers in developing countries that are in the early stage of dry port conceptualization and development.

The next two sections outline the objectives and the research questions addressed in this thesis. Section 1.4 outlines the research approach employed in the study and Section 1.5 presents an outline of the rest of the thesis.

1.2 Aims and Objectives

Following the background and motivations outlined in the previous section, the overall research aim is to advance knowledge and quantify the potential impact of dry port solutions on road network congestion by exploring the effect of the characteristics of a dry port solution, termed 'dry port strategies', on its ability to reduce congestion. The following three objectives have been formulated to achieve this aim.

1. Review and compare dry port solutions presently employed in a number of port cities around the world, with the aim to determine the similarities and differences between the dry port strategies employed and identify the key characteristics of dry port solutions employed by such cities.
2. Develop a framework for modelling freight transport in developing countries. That builds outwards from a conventional urban traffic modelling approach by integrating an element of supply chain modelling and applies a generalised cost function within the traffic assignment to account for factors which influence freight routing decisions in a developing country.
3. Quantify the ability of close dry ports to reduce congestion while considering the impact of its characteristics on its ability to do this through the reduction and re-direction of container-related traffic volumes in a road network.
4. Explore the implications of these results for the choices available to decision makers.

1.3 Problem Statement and Research Question

This research places emphasis on road congestion and considers the installation of a close dry port as a potential solution to the problem. It aims to study the rippling effect of such a solution and to gain quantitative insight into the role close range dry ports play in reducing congestion, and whether moving some containers to such a facility would reduce congestion. A number of research questions arose from the motivation and aims outlined in Section 1.2. In particular, the research aims to address the following central questions:

<u>Research question 1 and 2</u>

As container transport volumes continue to grow, a seaport's hinterland accessibility becomes an even more crucial factor for its competitive advantage because bottle necks in

networks can easily become a development constraint for a seaport (Roso, 2009). While the reduction in congestion within ports and their surrounding areas has been suggested to be an advantage of a structured approach, no research has been carried out to quantify the network impact of dry ports in the context of a developing country in Africa or to explore the sensitivity of various levels of dry port utilization on its ability to improve network efficiency. This leads to the questions:

How effective are close dry ports in reducing congestion?

How much impact does the level of dry port utilization have on its ability to improve network efficiency?

Research Question 3, 4 and 5

It has been argued that the implementation of a dry port encourages the use of intermodal transport and so reduces the environmental impact of the whole transport system and increases regional transport efficiency. Considering that no dry port solutions are the same and that different dry port solutions may produce different magnitude of benefits in the same case, Hanaoka (2011) postulates that some instances of dry ports may generate increases in cargo trips leading to an increase in truck hauling and pollution. It therefore becomes interesting to identify characteristics of a dry port solution effective in reducing port city congestion. This leads to the questions:

How do the characteristics of the dry port solution affect its ability to reduce congestion, in particular what are the effects of including a Freight Distribution Service and an Empty Depot Service in the Dry Dort?

What if any are the negative effects of dry ports?

Finally, what are the implications of these results for the choices available to decision makers?

1.4 Research Approach

In order to address the above research questions, the research undertook a detailed study of the case of a hypothetical “close dry port” connected to the ports of Lagos, Nigeria.

This has been accomplished by completing the stages outlined below:

1. Review of literature on dry ports: this step involved identifying, reviewing and synthesising the existing literature on some dry port solutions employed by congested port cities.
2. Comparative analysis of dry port solutions: based on a desk study, a comparative analysis of some dry port solutions currently employed by port cities was carried out.
3. Understanding of the case of the Lagos Nigeria: based on field study, a detailed examination was made of the container supply chain, trade structure and transport system of the selected case study (Lagos, Nigeria). This was done through interviews and other data collection exercises including collating replies to questionnaires.
4. Development of container freight traffic model: this involved building a freight traffic model to simulate container distribution patterns obtained from the existing and proposed container supply chain structure of the study area. An O-D matrix for non-container related traffic was unavailable and could not be derived in this study and so, the model approximates the volume of non-container related traffic on links and fixes it between the reference and dry port cases. For this reason, the finding from this study relates to the impact of the dry port on container-related traffic and does not consider the benefit to other traffic.
5. Undertaking comparative analysis: this involved comparing the effect of the potential dry port solution (proposed inland supply chain structure) with the effect of the present solution (existing inland supply chain structure) within the developed artificial environment to explore the effect of a close range dry port on traffic conditions in the port city. Key insights and policy alternatives relating to the identified impacts are explored and discussed.

A cost benefit analysis has not been undertaken in this research because this is not the focus of the thesis. The focus of the research is to explore the impact of a close dry port on congestion in the road network and this is approached using the stages outlined above.

1.5 Thesis Outline

Chapter 2, “A review of dry ports”, examines the background to the central issue of this thesis and is divided into two sections. The first section provides the reader with a

background of the "dry port" concept and a review of existing dry port literature. It discusses the purposes for which these facilities are developed, explores the characteristics and framework of operations for such facilities, their classifications and discusses the advantages of their existence. The second section reviews dry port strategies employed by port cities. The term strategies relates to the characteristics of the dry port solutions. Some dry port strategies employed by port cities are explored through a desk study of four port cities.

Chapter 3, "Research methodology and background of case study", is structured as follows. The first section places the study in context by exploring the physical, economic and container-related characteristics of the selected study area. It explores the characteristics of national sea-borne trade, the characteristics of the container industry, the structure of the container distribution chain in the country and the impact of freight movement in the port city. Finally, it outlines the location of the dry port to be studied. This section is based on a field study undertaken by the author through a chain of face-to-face interviews, questionnaire handouts and independent collection of data specific to the study area. The final section presents the rationale behind the selected research method, outlines the research method and discusses the method of analysis employed in this study.

Chapter 4, "Container freight traffic modelling- literature review and proposed framework" begins by presenting a literature review on freight transport modelling. The review provides a brief overview of a number of existing freight models and discusses techniques available for freight modelling. The second half of the chapter outlines the framework in which the traffic model used in this study is developed. It discusses the characteristics and the proposed structure of the model and the logic behind their selection. It outlines these characteristic under two headings: the process for obtaining the network demand and the assignment of this demand to the transport network. The latter relates to an assignment model which incorporates the World Bank's HDM IV Vehicle operating cost functions within an algorithm used for the route choice.

Chapter 5, "Container freight traffic modelling-Implementation of modelling framework" discusses the development of the traffic model used for this study. The development process is based on the framework outlined in section two of Chapter 4. It discusses the data collection processes and outlines the assumptions made in the model. It reports on the calibration of the model and validates it. The calibration and validation are based on a set of independent traffic count and side interviews collated for the purpose of

this research.

Chapter 6, "Result and Analysis" undertakes the comparative analysis. It involves comparing the network benefits of the potential dry port solution against the outcomes of the do-nothing situation within the artificial environment of the model. The first two sections quantify the benefits of the dry port solution by exploring the benefits of a dry port solution with alternative operational characteristics. These operational characteristics (variables) relate to the container allocation patterns employed and the provision of an empty depot service (EDS) and freight distribution service (FDS) within the facility. The following sections (6.3 and 6.4) explore the effect of some key assumptions on the findings. Finally, the implications of the findings are discussed.

Chapter 7, "Recommendations and Conclusion", is the chapter where the central findings and arguments are reiterated. The implications of the findings for policy makers are highlighted, issues of practical implementation are discussed and suggestions are made for further research.

Chapter 2

Dry Port Strategies for Port Cities

The purpose of this chapter is to explore the concept of a dry port solution and define the characteristics that make up such a solution (Section 2.1). Also, the chapter identifies the most common characteristics of dry port solutions employed by congested port cities, through a comparative study of four congested port cities and their dry port solutions (Section 2.2). These characteristics are varied within the dry port case explored in this study.

2.1 Review of Dry Port Concept

2.1.1 Container Inland Intermodal Terminals

An inland intermodal freight terminal is a node in the supply chain equipped for the transhipment and storage of loading units between two distinct transport modes e.g. road and rail. These terminals exist in a variety of sizes and provide a combination of value added services such as consolidation, deconsolidation, warehousing, depot storage of empty containers and custom clearance.

Definitions for inland terminals started to evolve in the 1990s, from their association with inland water ports to clusters of logistics and distribution nodes located along inland transportation corridors. UN ECE (1998) defines an inland freight terminal as any facility other than a seaport or an airport operating on a common-user basis, at which cargo in international trade is received or dispatched. Such a facility is located inland and connected within an intermodal transport system. The exact term for the type of inland terminal varies depending on the type of transport connections feeding it, the roles it plays, the services offered at the facility and the country of operation.

Rodrigue (2010) identified the three main functional characteristics of an inland intermodal terminal to be:

- Dominantly linked with the handling of maritime and domestic containers and providing an array of logistical activities to support and organise freight transition, such as consolidation, deconsolidation, transferring and customisation.
- The existence a high capacity corridor connecting the inland terminal to a port terminal. This could be a truck, barge or train services. While barges offer lower costs and improved environmental sustainability, the availability of this solution is based on the existence of useable waterways in a region.

- Through economies of scale in inland distribution, an inland terminal must be capable of handling large volumes of cargo at a lower unit cost than that offered by the ports to shippers. If these criteria are not met, direct services may be perceived as better options leading to reduced demand through the inland port.

Accordingly, the actors in the relevant freight industry operate these terminals under different names, using different expressions to describe terminals with the same functions and so also the same name to describe terminal with different functions. For instance, In Europe (Brussels, Frankfurt, Antwerp, Paris and Strasbourg), "Inland Port" refers to terminals located along inland waterways that provide general port services. Inland ports are defined by NCHRP (2007) as "a remote but connected freight processing facility that provides advanced logistics for road, rail and marine cargo movements outside the normal boundaries of a seaport. The inland port in effect extends a marine port to an off-site, inland location by providing a remote, inland multimodal distribution centre for marine/rail and marine/truck transfers, with a direct rail or barge shuttle that moves cargo between ocean-going vessels at the main port and the intermodal transfer site on a frequent basis." However, the same term in the United States refers generally to a multimodal site located inland that promotes value added services and facilitate goods flow (Harrison et al, 2002). On the other hand, the term "port avancé" is used in France to label such inland terminals performing functions conventionally found at seaports.

Other names used interchangeably with an inland intermodal terminal include dry port, Inland Clearance Depot, Container Freight Stations, off-dock terminals, urban distribution centres, freight village and Inland Freight terminals. The Concept of Inland Container Depots (ICDs) for example was first introduced as an inland terminal handling consolidation of containers and is different from a Container Freight Stations (CFS) which are terminals used for stuffing or stripping cargo. Yet, a CFS function might be a service added to an ICD. Furthermore, unlike CFS, ICDs are often located outside the port city while CFS generally have no geographical restrictions and can be found inside most ports. Generally, the terms used to identify an inland terminal are often an indication of the roles played by the facilities, the available connections to the seaport and its proximity to the port.

As suggested by Rodrigue et al (2010), the reason for the multiplicity of terms used to define similar and often the same concept can be associated with the fact that these

inland terminals emerged in a variety of *geographical settings* and are serving a variety of *functions* under a variety of *actors.* Although various names are used synonymously to describe similar concepts, inland intermodal terminals are often differentiated by the roles they play, the services they provide and their geographical and modal characteristics.

2.1.1.1 Drivers for Inland Intermodal Terminals

The existence of inland intermodal terminals is often driven by the presence of certain deficiencies in the conventional freight distribution process. These include:

- *Limitations to availability of land around the port*. This implies a restriction to the physical expansion of the seaport. The lack of available land for expansion favours the search for a less costly location that supports less intensive freight activities.
- *Capacity restriction.* Land shortage restrictions often limit the capacity of the ports. This can be further complicated by long dwell times in less efficient ports. The implication is that ports reach their storage capacity limits before they approach the quay capacity limits. This is synonymous with the case in Lagos Nigeria where high dwell times limit the capacity of the port. Inland intermodal terminals allow the container to be removed quickly from the port thus freeing up container storage space in the yard, relieving the storage capacity constraints and increasing the overall capacity of the seaport.
- *Congestion within and beyond the seaport terminals*. At a certain level of freight activity, congestion, pollution and empty container repositioning by road becoming strong incentives for Inland intermodal terminals. This most often appears to be the main driver of inland development since the terminals increase the intermodal capacity of inland freight distribution. Enfield Intermodal Terminal in Sydney, Australia is an example of one of the most recent inland terminal developments implemented with the aim to relieve the port and adjacent roads from congestion (Sydney port Corporation, 2006).
- *Restricted access to the hinterlands***.** The high capacity inland transport corridors connected to the inland port increase the cargo base which the port can serve by penetrating the hinterlands of competing ports. This is possible because the inland terminal presents a higher level of accessibility through reduced local distribution costs thus, making them more competitive for import and export, and allowing

domestic cargo to be cleared more quickly and increasing the port's capacity. For instance, the Zaragoza Maritime Terminal, an initiative of the port of Barcelona, was set up mainly to compete with the port of Valencia for services to the region of Madrid. The terminal is in the centre of two strategic corridors; the Ebro Corridor (Barcelona-Zaragoza-North of Spain) and the transversal Iberian corridor (Barcelona-Zaragoza-Madrid-Lisbon) and is located within an area that cumulatively accounts for 70% of the Spanish GDP. These inland transport corridors allow the port of Barcelona to penetrate the hinterland of Port Valencia and so increase its import, export and intermodal use.

- *Limitations within container supply chain management*. In addition to capacity and accessibility issues in the ports, there may be the need for improvement of logistical capabilities through an increase in warehousing facilities, logistic capability and improvements within the cargo clearing framework. By providing such facilities, an inland terminal becomes a buffer in the supply chain acting as a temporary storage facility.
- *No direct access to sea bodies*. This refers to regions with no access to water bodies and is only applicable to landlocked countries. Development of dry ports is particularly important for facilitating trade and transport of landlocked countries which, due to their geographical locations, have particular difficulties conducting international trade.
- *Imbalance in container flows*. Trade imbalance is a common phenomenon in most economies. Whether developing or developed, there are numerous instances where a country's import trade remains higher than its export trade (or vice-versa). An inland terminal may therefore be developed with physical and logistical capabilities to reposition empty containers effectively within the supply chain when necessary. For instance, the Port of Los Angeles has developed its inland terminals to include trans-loading facilities where contents in three 40-footers are transferred into two domestic 53 footer containers. The empty 40-footers are redirected to the port terminal for export while the domestic containers are transported via rail to inland destinations.

2.1.2 Dry Port Concept

This concept is synonymous with that of an inland intermodal terminal. Although not new, the concept of a dry port has been explored in detail by a number of scholars in the last decade (Woxenius *et al.*, 2004; Roso *et al.*, 2008; Roso, 2009) and by itself suggests certain characteristics of the Inland terminal. Inter Baltic (2008), defined a dry port as "extended gates" for seaports through which transport flows can be better controlled and adjusted to match conditions in the port itself. Thus, the terminals can help to improve land access to ports in both physical and physiological terms. Dry ports like these are developed to function as a port extension where port functions are outsourced, to improve the efficiency and effectiveness of a logistic chain and relieve congestion within the existing network by promoting a modal shift.

In general, a dry port is an inland terminal linked with an intermodal transport system and acts as an intermodal gateway connected only to seaports and equipped with a number of value added services including, stuffing, stripping, and warehousing but especially customs clearing. European Commission (2001) describes a dry port simply as an inland terminal linked directly to a maritime port. Leveque and Roso (2002) go on to provide a more operational and precise definition of the dry port concept, identifying a dry port as "an inland intermodal terminal directly connected to seaport(s) with high capacity transport means, where customers can leave/pick up their standardised units as if directly from the port. Where rail is used as the high capacity mode connecting port to dry port, the quality of the rail interface, the frequency of the services and the quality of road access to the dry port, influence the level of the terminal performance". They emphasise the dry port as a type of inland intermodal terminal stressing that the term should only be applied to inland terminal facilities with direct links to seaports, high capacity land transport links and with the ability to offer services that would normally be found in a seaport, including customs inspection and clearing services. This custom clearing service provided at a dry port distinguishes it from a conventional inland terminal. Other typical added value services include container handling, container storage and repair, packing and repacking, warehousing, and distribution.

As explored earlier, the concept of dry port is often used interchangeably with Inland terminal and inland container depots. However, whatever the term used by the actors in a terminal, the author categorises an inland terminal as a dry port if it has the characteristics

outlined by Leveque and Roso (2002). Thus, in the context of this thesis, Dry Ports refer particularly to inland container intermodal terminals located away from waterways and connected directly to a seaport via a high capacity "dry" corridor (i.e. rail or road). The strategies employed in any dry port solution distinguish one solution from another. These strategies range from the added value services provided by the equipment available on site, its proximity to the seaport and the transport modes available for connection to the seaport. These characteristics are discussed in Section 2.1.3.

2.1.2.1 Dry Ports in Container Freight Distribution Chain

Container freight movement can be conceptualised as the process of moving loose manufactured cargo in unit loads from the factory of production to the retail store or point of use. The steps in the process can be characterised under two transportation movements; the sea leg and the landside/inland moves. From this perspective, Wakeman (2008) uses a three tier system to represent the typical container distribution chain within the landside transportation system. As represented in Figure 2.1, the berth to terminal move represents Tier I while Tier II represents the truck movement from port terminal to the first point of rest, whether it be distribution centre or warehouse. Tier III is the final truck move of containerized goods to specified locations for storage, sale or consumption.

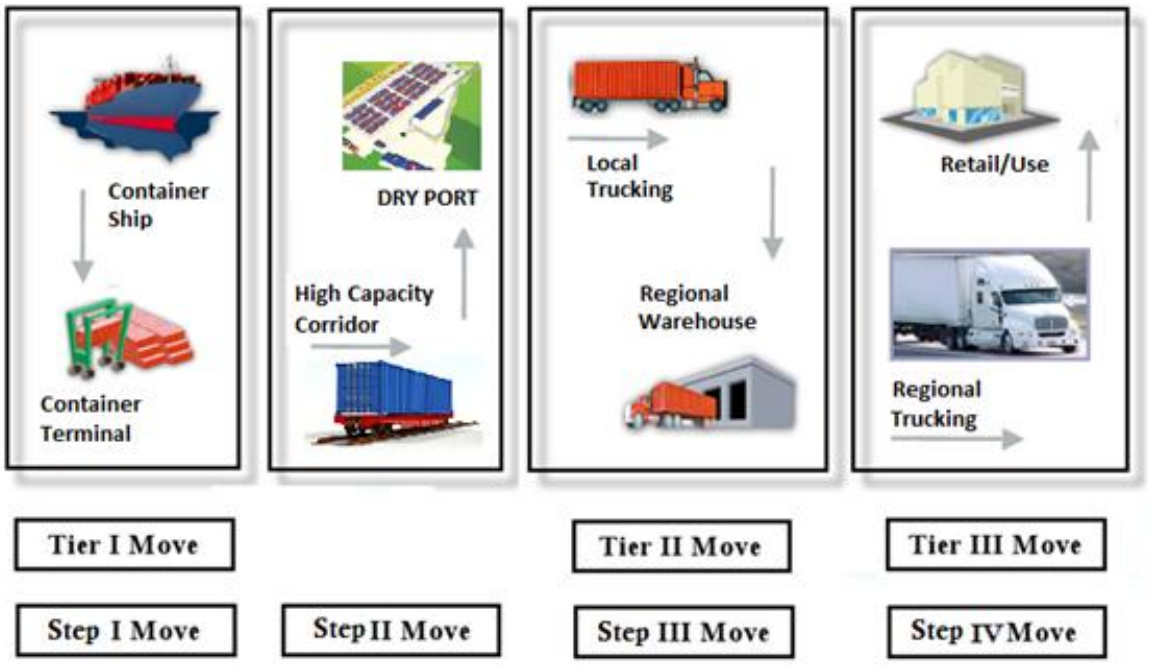


Figure 2.1: Inland container freight movement (adapted from Wakeman, 2008)

However, this basic pattern is not always followed as common deficiencies in the

freight supply chain and economic characteristics as discussed earlier may force the creation of intermediary nodes which could help to buffer, increase port handling capacity and generally improve the fluidity of distribution. Dry ports in this context act as such intermediary nodes created in a basic container distribution chain. The position of a dry port in the landside container supply chain presents an extra step in the chain as is illustrated in Figure 2.1. The Rail movement from terminal to dry port occurs after the Tier I move but before the Tier II move discussed by Wakeman (2008). The introduction of such a facility therefore creates an extra leg in the chain. Thus, with dry ports in place, this three tier system is revised to a four step system which is applicable only to users of the facility.

This extra step has been argued by some to have the potential to present added burden due to double handling and so higher handling costs per container. However, such a process can be competitive and economically viable if the increase in handling costs is outweighed by a reduction in transport costs (UNCTAD, 1991).

2.1.3 The Concept of Dry Port Strategies

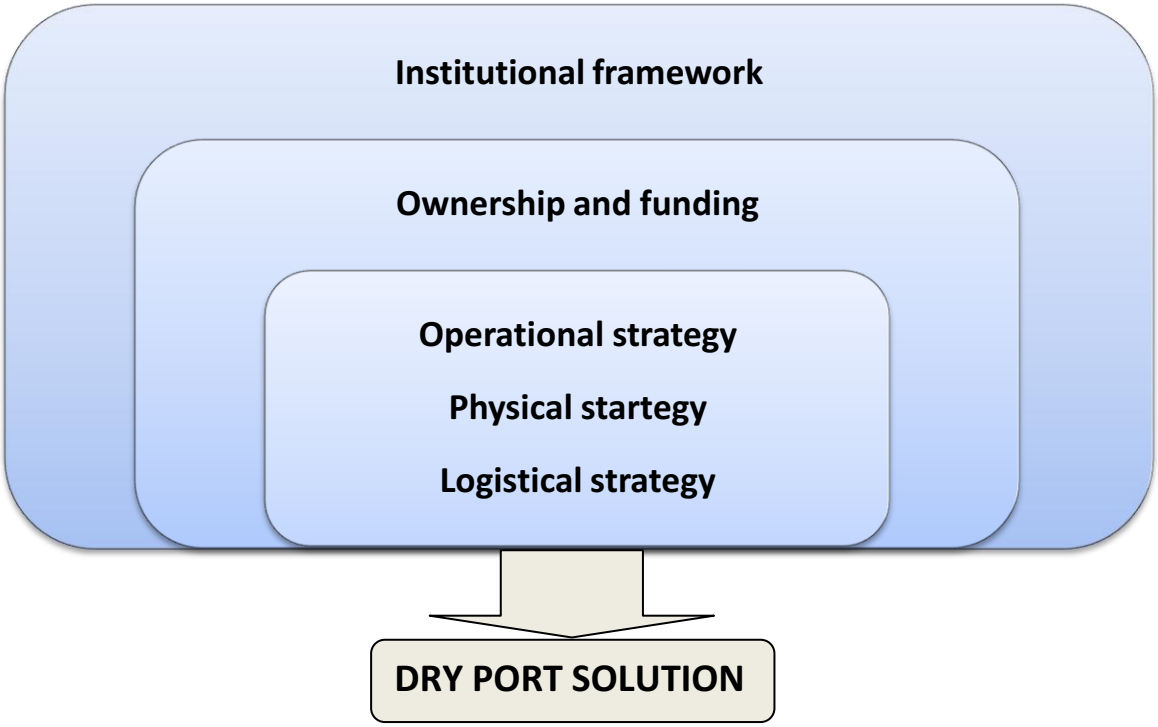


Figure 2.2: The concept of dry port strategies

An implemented dry port solution constitutes of a set of dry port strategies. The term “dry ports strategies” refers to the characteristics of the proposed or existing dry port solution and its framework of operations and can be classified under operational, physical

and logistics strategies. These strategies are influenced by the institutional framework, governance and ownership of the dry port solution. The institutional framework influences the governance/ownership and all strategies while the governance/ownership influences the dry port strategies. Figure 2.2 above illustrates this relationship.

2.1.3.1 Institutional/Governance Framework

The term "institutional framework" with regard to dry ports refers to the structure of the policies that regulate dry port development or operations and the public institutions that direct them. Legislation and regulation for dry ports implementations set out by government bodies shape up the characteristics and strategies of dry port implementations. Planning, development and operations regulations relating to dry ports involve amongst others, guidelines on investment, land use and operations. Governments have traditionally taken on the main governing roles in many areas of transport yet, the extent of their roles vary from country to country and has changed over time. Laws and policies governing dry port implementation is outlined by a country's government and are often embedded in regulations on land, transport, trade, infrastructure, environmental, logistics, port and investment. The link between the policies/regulations and dry port development is illustrated in Figure2.3 and discussed in Table 2.1 below.

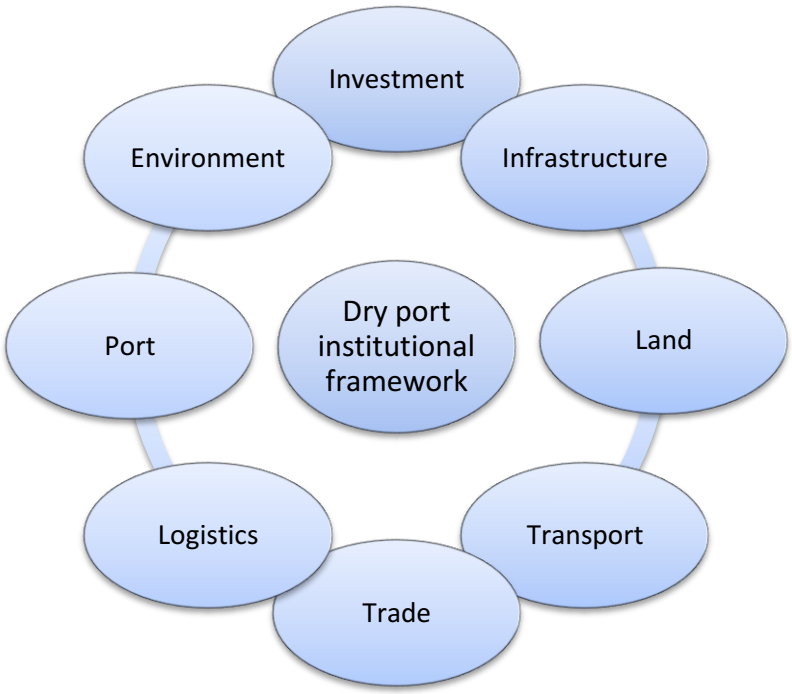


Figure 2.3: Structure of dry port institutional framework

The institutional framework for dry port development can be explored through policies and regulations governing the development of dry ports in a country. Generally, the laws, policies, regulations and legislations relating to these sectors are identified by various municipal departments and agencies who are often involved in the planning and approval stage of the dry port project. For example in Indonesia, the Ministry of Transportation, Ministry of Finance and Governor of West Java were involved in approving the Cikarang dry port project. The location, construction and operation permit was issued by the Ministry of Transportation, while the Ministry of Finance issued permit for temporary storage areas (TPS) and implementation of the Customs Advance Trade System (UN ESCAP, 2010b).

The policies and regulations set out by these departments and agencies drive and influence all other strategies employed in the dry port solution. The institutional strategy constitutes a combination of all the policies and regulations relevant to dry ports. Since these policies impact the characteristics of the dry port, it is important to note that the institutional strategy represent a framework through which the government can influence the total dry port strategy employed. Furthermore, the institutional framework directing the way the dry ports are developed and operated is indicative of the potential to explore new market opportunities where available. The importance of a streamlined institutional framework for dry port development has been emphasized in presentations made by delegations from China and the Republic of Korea (UN ESCAP, 2010).

Table 2.1: Policies in dry port development

Policies/ Regulations	**Discussion**
Land:	This refers to the restrictions on land for construction. It defines whether a land can be used for dry port development and so has direct implications on the potential locations for a dry port and also the costs. For instance in India a restricted minimum land holding of about 12,000m^2 (3 acres) if outside city or 4000m^2(1 acre) if inside city limits or port areas is required.
Transport:	Dry ports are nodes within the freight transport distribution chain. Thus, transport policies and regulations would influence its connectivity and so its importance in the transport chain. For instance, a dry port connected via rail can only be implemented if relevant railway authorities approve the use of the rail line assuming railway connections are available.
Trade:	Restriction to trade procedures may limit the role and services made available at dry ports. For example, custom clearance is relevant for inspection facilities at dry ports. However, whether this is available depends on the trade policies of the country concerned.

Infrastructure:	In countries where dry ports are classified as infrastructure the relevant policies are applicable to the development of such facilities. For instance, in India ICDs fall under the jurisdiction of Container Corporation of India Ltd (CONCOR) a separate government-owned corporate body setup to, amongst other things, build and operate infrastructure (including road and rail network) linkages for rapid and accelerated inland penetration of containerized international trade. (UN ESCAP, 2006).
Environment:	While a dry port may represent an environmentally friendly solution as it encourages a shift from road to rail, its development inevitably presents a negative environmental impact on its surrounding area during construction and operation. They will thus have to follow environmental guidelines outlined by governing bodies.
Logistics:	In countries where dry ports are characterised as logistic centres, relevant logistics policies and regulations will apply. Every year, the Korean government addresses a set of logistic policies referred to as "Basic plan on logistics improvement". It regulates factors such as the development and operation of logistic centres, development of inter-regional transport network and the establishment of information systems for logistics.
Investment:	Investment policies often directly decide the actors and parties that can invest in a dry port and influence the ownership. For instance, some countries allow foreign investments for dry ports while others encourage local investments. Under this, the government may encourage a single public/ private ownership or a public-private partnership. In Hong King for example, foreign investors can establish companies without approval from authority while Singapore ensures a one-stop service for foreign investment and provides a flexible tax incentive rate for investment (UN ESCAP, 2005a). These encourage the dry port actors to include foreign companies and agencies.
Port:	In some countries, relevant port policies and regulations may apply to dry port development. This may be in the form of physical, functional or operational regulations. For instance, the Indian Port Customs Manual specifies that like a port, an Inland container depot must have a public authority status, be equipped with fixed installations, offer services for handling and temporary storage of import/export laden and empty containers carried under customs transit and must provide activities related to clearance of goods.

Various policy makers influence and regulate the development of dry port solutions as illustrated above. However, this power to exert influence is generally spread over various public authorities at different levels of government. Based on case studies, Spies and Notteboom (2011) have stressed the importance of centralising the plan for dry port implementation suggesting that it will lead to a rationalisation. They encourage the need to create intermediate power levels that provide regional governance over dry port implementations, suggesting that such would improve relationships between the dry port actors and the existing policy makers.

2.1.3.2 Ownership/ Funding Structure

The ownership or governance strategy is defined by existing institutional policies and regulations. Like the institutional strategy, the ownership drives all other strategies (excluding institutional) as it shapes the modes of operations, financing and functioning. The ownership is shared in various proportions (0-100%) between actors in a regional or international freight industry. These actors are parties with common goals having individual strategies depending on their core business, their roles and stakes in the dry port. Actors include the port and public authorities, terminal operators, shipping lines, and logistic operators including freight forwarders, rail operators and hauliers. The ownership of a dry port can be considered in two parts: ownership of dry port infrastructure and operational management. Depending on the governing policies, both of these can be can be executed by the public and private actors.

The funding is directly linked with the ownership as clearly projects are funded by their owners. Thus, three different initiatives for dry port funding may occur; public, private or public-private partnership (PPP), each of which has advantages and disadvantages. In the public service dry ports, the government and public authorities are responsible for all necessary investments. Although such an arrangement can pose a substantial burden on public funds, these initiatives could present users with fairer treatments in regards to tariffs and profiteering, and provide alternative modes for cargo transportation due to its rigid non-profit driven intermodal network. Conversely, the public agency may face a lack of expertise in the management of such facilities and may also be restricted by the budget available for use. Public initiatives are most often set out by the government to develop the freight distribution within the regional economies. They are generally heavily subsidised by the government. Virginia inland port is an example of a public initiative. It is owned and operated by the port of Virginia and was created to expand the hinterland of the port of Virginia and so provide a competitive advantage.

A large number of dry port operations in India are based on this type of ownership, specifically an improvised public landlord model where the dry port owner outsources its services to several operators (Chandrakant, 2011). In the landlord model, the public authority in charge of the dry port acts as a landlord and plays the central role by making investments in related infrastructures such as terminal sites, transport infrastructure and access. The terminal site is then leased to a terminal operator for a fee. With this set up,

profit maximization is usually not the aim for the public body but rather, throughput maximization and contributions to economic development and trade (Brooks and Cullinane, 2007). In India, dry port implementations falls under the jurisdiction of the government owned Container Corporation of India Ltd (CONCOR) whose objectives are to facilitate and promote multimodal transport (UN ESCAP, 2006).

The case of private initiatives extends from encouraged private investments where the dry port is owned and operated by the private company who are responsible for the cost of development. The greatest benefit of such private initiatives lies in the ability to utilize private resources for the development of publically used infrastructure. Additionally, private initiatives could provide an improvement in the trading culture and encourage a positive change of the pattern in terminal operations and the supply of services. Private initiatives lead to more market – oriented decision as they are linked with supply chains quite unrelated to regional economies and are strongly financed through revenues generated. The United Kingdom is an example of a heavily privatised economy having most of its seaports, rail services and inland terminals privately owned.

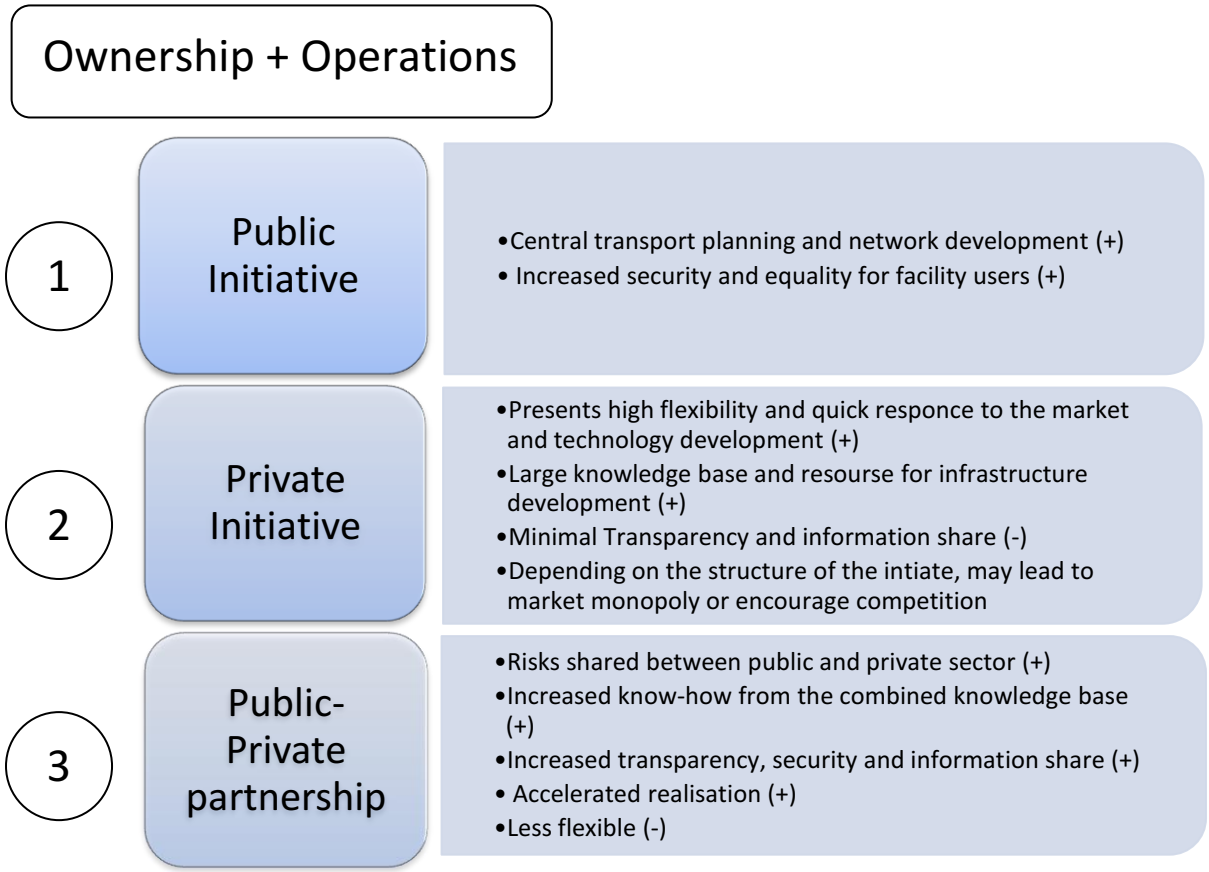


Figure 2.4: Ownership and funding initiatives

The public private Partnership (PPP) represents an arguably good balance between the former two initiatives as it provides greater flexibility achieved through cooperation between the two sectors-private and public. While the private sector adds value through its greater know-how, the public body ensures a balanced economic and legal framework. Figure 2.4 summarises some pros (+) and cons (-) of the three initiatives.

Spies and Notteboom (2011) describe different types of PPP model that can be applied to dry ports, identifying them as supply and management contracts, Turnkey, Lease agreement, concessions and principle agent models. Yet, the most commonly used form of PPP used is the concession. In concessions, public authorities invest in the general dry port infrastructure and the selected operating company pays a concession fee so as to operate the terminal for a fixed period of time. The government or public authority holds the leasing rights of the facility and receives payments on its investment assets throughout the concession period. Responsibilities in relation to infrastructure investment differ between concessions. In some cases, all are taken on by the public sector while in others some are taken on by the private terminal operators. The other models vary based on the roles played by both parties (public and private) in financing the dry port implementation. In general, PPPs are good tools for governments who wish to take advantage of private sector expertise and finance for transport infrastructure without losing too much control.

Depending on the interest of actors under PPP, various funding arrangements can be employed including BOT (Build, Operate, Transfer), BOOT (Build, Own, Operate, Transfer), BOO (Build, Own, Operate); and BOOST (Build, Own, Operate, Share, Transfer) (UN ESCAP, 2007). BOT is the basic form of the above arrangements where the private company undertakes the project to build all or part of the dry port and then operates it for a specified period of time, at the end of which, it is transferred back to the government. The others are variations of this arrangement. Table 2.2 presents examples of ownership structures in a number of countries.

Table 2.2: Example of ownership structures

Country	**Cases**	**Type**
Nepal	• Government owns and runs Birgunj dry port	Public
China	• Hutchison Port Holdings invests and operates Shenzhen Hutchison Inland Container Depots (SHICD)	Private
Iran	• Iranian Railways operates Sarakhs Multimodal Transportation Centre and Bafq Multimodal Transportation Centre	Public

Malaysia	• Malaysian State Railway (KTM) and four other public companies (port authorities) have invested in Ipoh ICD	Public
India	• The Container Corporation of India (CONCOR) invests and operates numerous dry ports in the country. • CONCOR and Maersk jointly invested in, and operate, India's largest inland container depot (ICD) with a 1-million TEU capacity at Dadri near New Delhi • Faridabad Inland Container Depot is privately owned and operated	Public PPP Private
Thailand	• The State Railway of Thailand (SRT) is the landlord of Lat Krabang ICD. The Government invests in terminal infrastructure and retains ownership while the private sector invests in cargo handling and transport equipment needed at the facility and operates them.	Public
Korea	• For Uiwang (near Seoul) and Yangsan (near Busan), the Government provides the land and road/rail access to the gate of the facility while private sector contractors build, equip, manage and operate the site for a specified time (BOT).	PPP
Rotterdam	• Venlo Inland terminal was initiated by the European Container Terminal limited liability company (ECT). ECT is an entity set up by the organizations- Rotterdam Municipal Port Management, Hutchinson Netherland and financing banks (ABN AMRO).	PPP
USA	• Virginia Inland Port (VIP) was initiated by the Virginia Port Authority (VPA) and operated by Virginia International Terminal (VIT) a company set up by VPA. • The New York (NY): Port Inland Distribution Network (PIDN) was set up by a number of actors- The port authority of New York & New Jersey, feeder port operators and some state and local government agencies.	Public PPP

Private market players often embrace the use of dry port solutions because of physical restrictions on land within the port, the need for lower inland transport costs and the need to increase their competitive edge. Such solutions will therefore be profit driven and more market oriented. On the other hand, public authorities and policy makers may embrace the use of dry port solutions for attracting logistic activities to promote local economic development or to promote sustainable environmental gains by encouraging modal shift and reducing traffic congestion. The interests and goals of both public and private actors interact to influence the characteristics of the dry port implementation. These characteristics constitute what we refer to as dry port strategies. For instance, a dry port operated by a freight forwarding agent would be more inclined to provide door to door

services, warehousing and container freight centre for consolidation and deconsolidation within the facility. On the other hand, a dry port operated by a shipping line may be more inclined to provide an empty depot to help facilitate container repositioning. Clearly, the type of ownership will affect the dry port strategies employed. Some currently employed dry port strategies are discussed in the following sections.

2.1.3.3 Operational Strategy

This refers to the operational functions provided and the processes adopted within a dry port. The operational functions refer to the roles played and activities carried out in the dry port, which are hugely dependent on the purpose for the dry port's existence. These roles are often defined by the owners and the institutional framework in place at the time of development. The operational functions of the dry port facility can be split into transport and supply chain functions. From the transport system view point, Rodrigue and Notteboom (2010) outline three major roles of a dry port service.

- *Acting as a satellite terminal*: in this context, a satellite terminal is a facility within close proximity to a seaport acting as an inland extension of the port terminal to accommodate additional growing traffic and to facilitate activities of lower added value such as storage, warehousing and empty container depot. These are most commonly serviced by truck shuttles yet short rail and barge services are possible. For gateways with high import components, such a terminal can also serve for trans-loading maritime containers into domestic containers or truck loads.
- *Acting as a load centre*: a dry port can be located within a regional production and consumption market to provide shippers with easy access and direct connection via an intermodal corridor to the port terminal. This commonly corresponds to areas where clusters of facilities serve intermodal, warehousing, distribution and logistics functions e.g. logistics parks and free trade zones. In this case, container loads carried along the corridor are integrated or disintegrated at the dry port facility. The dry port is thus the load centre of the regional market.
- *Acting as a transmodal centre*: The inland terminals act as a strategic element in the freight distribution system by supporting key transmodal activities like intermodal transhipment. Although the existence of this function remains minimal around

world, ongoing development of international freight distribution systems is indicative of continuous growth in the existence of such transmodal terminals.

On the other hand, the supply chain functions relate to the added value activities performed that have otherwise become expensive to provide at ports (Rodrigue et al, 2010). These functions vary from dry port to dry port and are dependent on the driving reasons for its existence.

- *Warehousing/buffering*: Through availability of dwell time, an inland terminal offers the opportunity for a just-in-time freight routing by providing warehousing facilities. This is particularly useful for shippers who use the port terminals as their distribution centre through which they distribute to outlet stores.
- *Transloading*: This activity is necessary for regions with specific regulator constraints to specific freight loads, for instance relating to container size. Inland terminals can function as logistic centres where maritime containerised units are transloaded into domestic units or the reverse. For example, transloading facilities are provided at the Los Angeles and Long Beach ports for transferring contents of a maritime 40 footer container to domestic 53 footer containers. The container are then carried to rail terminals and transferred to inland destinations.
- *Consolidation/deconsolidation*: These are synonymous with the stripping and stuffing of containers. Consolidation refers to the grouping of multiple small shipments into single more efficient large shipments or delivered products. This is typical for Less than Container loads (LTL), export containers, and truck/rail transloading. The function is commonly used when delivering shipments to computer retailers or retail packages of seasonal promotions. Deconsolidation in the simplest term is the act of splitting large shipments into smaller shipments for local delivery. In this case, the dry port acts as a distribution centre. This relates to Container Freight Stations (CFS), inbound Trucking of Less than truck loads, inbound rail/truck transloading for local deliveries, and wholesale to retail distribution centres.
- *Empty Depots/ Empty repositioning*: Approximately 20% of worldwide marine container traffic consists of empty moves, according to a study by Drewry Shipping. In many ports and their hinterland complex, laden containers are delivered to consignees, and the empty containers returned to the empty depot, only to be

trucked out again for stuffing with export cargo. Inland port can certainly eliminate such costly empty moves by providing convenient location for storage, and exchange.

- *Cargo transformation*: Inland terminal can also provide facilities for various forms of cargo transformation including packaging, relabeling, refining, sorting, testing, assembling, alteration and any other services that may increase the value of the goods. Classic examples include milling grains in flour, packaging bulk goods for retailing, light manufacturing and assembling of manufactured goods.

While dry ports service a combination of these functions, the services available depend on the trade characteristics of its host country. For example, if the exportation and manufacturing level are low, the need for processing and transformation function may be low and so making the function unnecessary. The functions to be included in a dry port are often decided upon in accordance with existing/ forecast market demand and policies. While small scale dry ports may need fewer functions, larger scale ones may require all supply chain functions. The processes involved in a dry port are linked with their functions and the services provided at the facility. For example, a generic import procedure outlined in UNCTAD (1991), as presented in Figure 2.5 below, shows the link between the stages of the procedure and the areas in the dry port where the activities or services are provided.

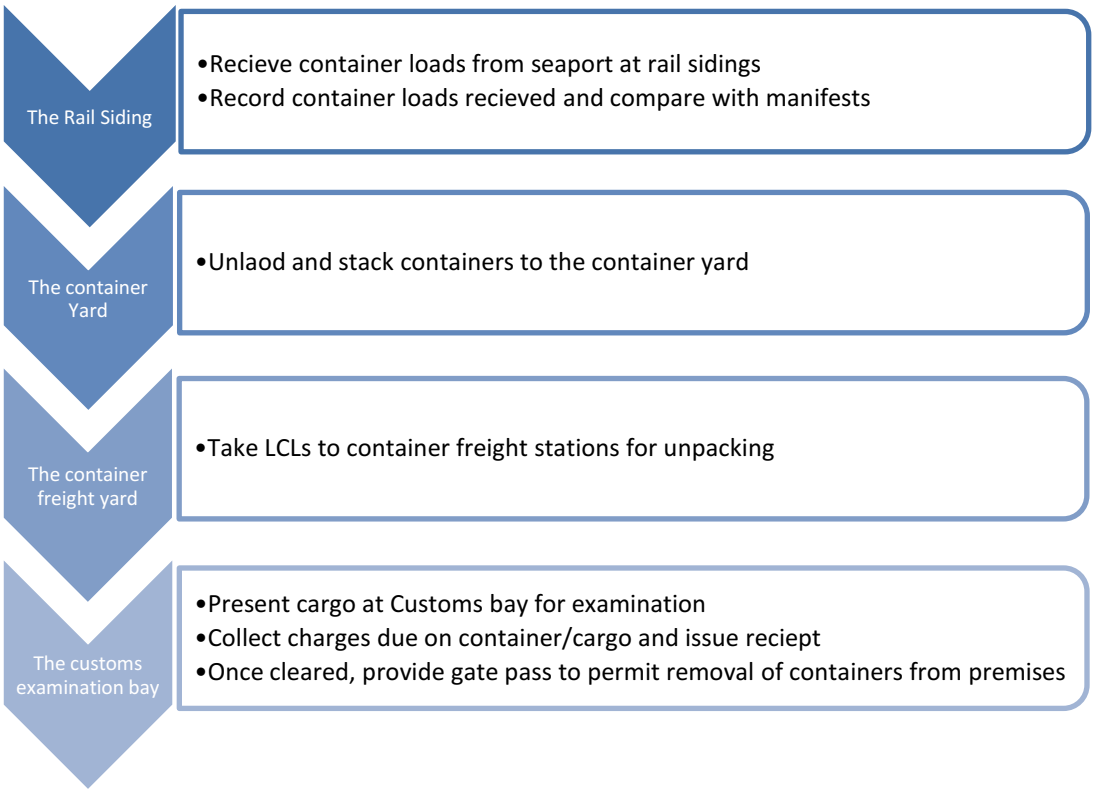


Figure 2.5: Dry port facilities connected with import process (adopted from UNCTAD, 1991)

Clearly, the procedures and processes adopted in a dry port will vary from one to another and will depend on the services provided at the facilities and the layout of the dry port. The process list is not exhausted as it can include processes/procedures as basic as record keeping, data storage, billing, cash collection, and security checks.

2.1.3.4 Physical Strategy

Physical strategy represents the implemented physical characteristics of the dry port. These relate to its geographical location, the capacity of facility, the layout of the facility and the type of equipments available. Clearly this will vary from one dry port to another.

Geographical location

The decision on where to build a dry port is in most cases taken directly by the government who may propose the dry port initiative as necessary to promote the growth of the regional economies. In other cases, the choice of the location may be driven by purely business related motives. A number of institutions have recognised the importance of the location of dry ports and have outlined factors to consider when selecting a location. UNCTAD (1991) has outlined common factors influencing the location of a dry port to include; the proximity to seaports, connections to transport modes, cost of construction, cost of operations, proximity to hinterland market, land value, ease of land acquisition and geological suitability. UN ESCAP (2010a) in particular has suggested the following criteria as most important: location of state/ inland capitals, existing and potential commercial and industrial centres and major intersection of existing highways, railways and inland waterways. Clearly, there exists an overlap of analysis. Clearly, the variables which affect site location are many, diverse and can be of a qualitative or quantitative manner (Chen and Notteboom, 2011).

ReVelle and Eiselt (2005); Owen and Daskin (1998) both present detailed reviews of the literature surrounding location analysis of such facilities. Chen (2001) constructed a fuzzy preference relation matrix used in ranking a potential location. Christopher et al. (2006) postulated a supply chain strategy which considers the demand and supply characteristics of the customer base.Other independent researchers have undertaken detailed studies on optimizing the location of inland terminals. While Rahimi et al (2008), employed a methodology that minimizes truck-miles, Racunica and Wynter (2005)

presented a model based on the hub location problem. Lv et al, 2009 and Wei 2010 have proposed a method for selecting the location of dry ports. They propose the use of a slight variation to the Analytic Network Process (ANP) developed by Saaty (2008) in his work on multicriteria decision making.

The location of a dry port can have significant bearing on the efficiency of the supply chain specifically in relation to connectivity and so on transportation costs. Thus, in selecting a location, the fundamental question resides not only in the nature, origin and destination of cargoes but more importantly on how they are moving (Hesse and Rodrigue, 2004). As transportation remains the most significant component of logistics cost, it is essential that the inland port is located on a site with adequate access to the transport network, whether it be road, rail or water and sufficient land for expansion. The facility should also be conveniently linked to a large population base generating the import and export activities handled by the inland port. A minimum population base of three million people has been estimated to be needed for an inland port while a sufficient land area of 20 to 40km^2 is deemed as sufficient for a dry port (Leitner and Harrison, 2001).

While strategies relating to capacities and equipment are by nature short-term and can be adjusted to respond to demand in the near future, location and layout are difficult, if not impossible to reverse in the short to medium-term period. For this reason, the location strategy is one of the most important strategies to define. The deciding actors must consider the long-term purpose for such a facility when taking this decision as it can result in wasted finances and can ultimately affect the pricing and competitiveness of a regional market.

Capacity and layout

The physical layout of a dry port depends on the functions, locations, capacity and transport modes for access. For instance, a dry port accessed only by road will need sufficient road access for trucks while a dry port accessed by rail would require a rail siding. In both cases, the ideal locations for the access points would determine the layout of the facility. In choosing to provide a substantial container freight station as well as an empty container depot within the facility, the need to locate an empty depot closer to the rail sidings may drive the positioning of the warehouses and CFS. Figure 2.6 illustrates an example of a generalised dry port accessed via rail. CFS transit sheds and CFS sheds are used to store longer and shorter dwell time. The container repair area is provided for the added

function of making minor repair to containers.

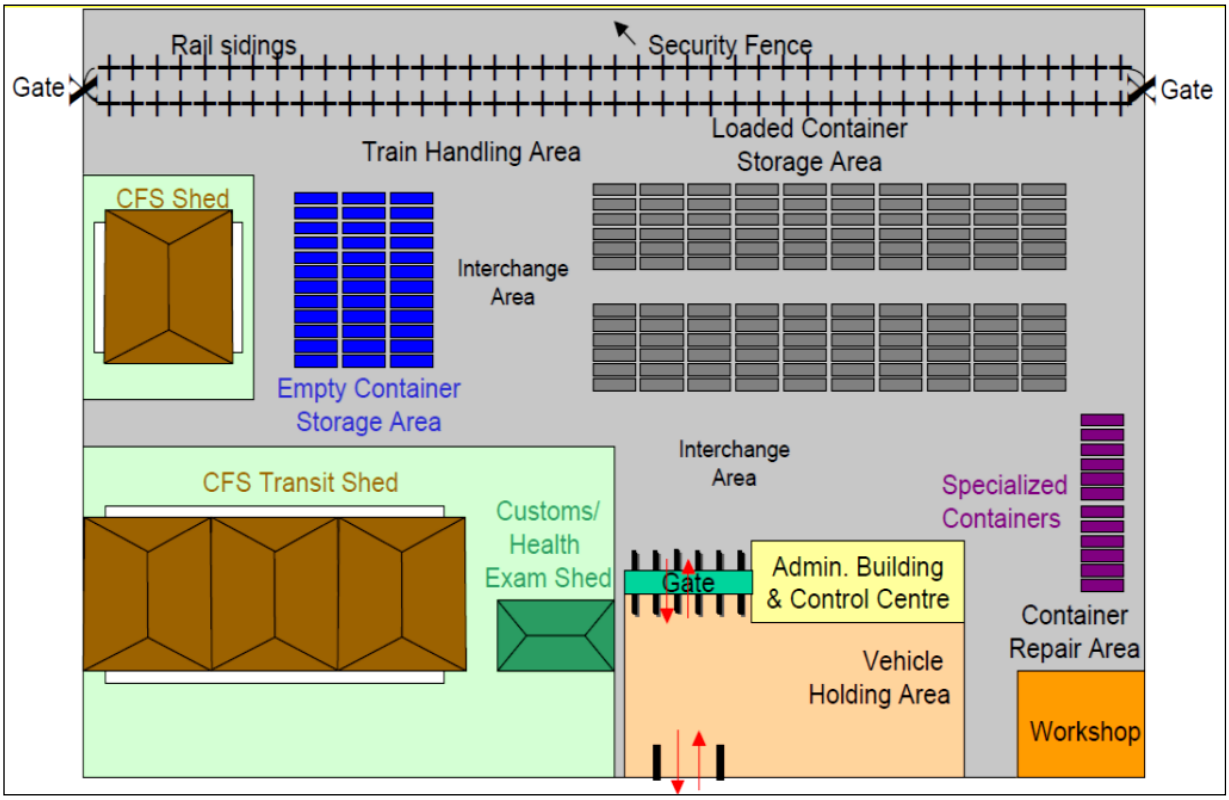


Figure 2.6: Generic dry port layout (Source: UN ESCAP/UNDP, 1992)

Equipment

There are different handling systems and equipment available for dry ports to employ in loading and unloading containers. Each system has to be judged in terms of its merits and its practical use for particular operations within the conditions of regional trade, terminal design and layout. The uses of some handling equipment are detailed in Table2.3 below. The choice of handling systems and equipment will depend on the funding available, the layout of the premises, the regional trade patterns and the expected level of throughput.

Table 2.3: Dry port equipment

Handling system	**Description**
Tractor-Trailer system	These are used for horizontal transport over long distances for example between the railhead/berth and the container yard. They are typically used with hoist or gantry cranes like the Rubber Tired Gantry (RTG) Cranes and Rail Mounted Gantry (RMG) Cranes. The Tractor-trailer units are used to deliver containers to/from the stacking area. This system is known for its speed manoeuvrability and reliability.

Lift Truck systems	These include heavy forklift trucks and reach stackers. These are used with fixed or mobile frames and provide an option for side lift and top lift spreaders. The system occupies large spaces within container yard layouts consisting of narrow blocks and so are a relatively poor utilization of space. Furthermore, in the case of heavy forklifts, their heavy front axle load requires heavy duty surfacing and solid foundations. On the other hand, they are considered to be versatile handling machines that require easy maintenance. They are as a result popular for use at dry ports with small volumes of containers and a variety of cargo types..
Gantry Crane systems	These exist as Rubber Tired Gantry (RTG) or Rail Mounted Gantry (RMG) and are delivered to specific spans- for RMGs up to 50m and for RTGs up to 25m. Gantry cranes are known for their lifting and stacking efficiency. They are very space efficient because of their high stacking ability and the compactness of the storage block. In this system, the lift of containers from the railhead is carried out by tractor-trailer units while the gantry cranes are restricted for use in the container yard. These systems are operationally effective as they combine the benefits of tractor trailer unit and gantry cranes. Using this system, the container handling operations can be very rapid, especially if there are a multiple number of cranes in use at the premises. These are however expensive machineries and can be justified only with high throughput levels.
Straddle carriers	These lift up containers and move with them. They can be used to move containers between points in an operation and to stack containers up to four tier storage. They are known to carry out container handling operations in a fast and flexible manner. However, they have been linked with low performance records mostly resulting from break down of their hydraulic mechanism and traction systems.

2.1.3.5 Logistical Strategy

In a general sense, Logistics considers the wide set of activities dedicated to the transformation and circulation of goods, such as the material supply of production, the core distribution and transport function, wholesale and retail and distribution to households for consumption (Handfield and Nichols, 1999). In the context of dry ports it refers to the core distribution component of the general term Logistics (Hesse et al, 2004). It is a collective term for the set of activities involved in the movement of goods which in this case are containerised. Dry port logistics strategies are the approaches relating to transfer and

distribution. It constitutes the when and how of container distribution at different stages of the supply chain and can be split into physical or tangible aspects (e.g. access to transport links) and non-tangible aspects linked to time related positioning and coordination of container distribution. Both aspects are directed by policies set out by the government or by the procedures /processes outlined by the dry port operators/owners. Some logistic strategies are discussed below.

The tangible aspect relates to the method of distribution and refers to the how through transport modes. Most commonly, this may be through the use of inland distribution networks, rail corridors and waterway access where available. The choice of the method depends on the transport mode available for use within the region. Often this is driven by geographical characteristics and regional development. For example the option to use barges can only be available to regions with waterway access. Some examples of tangible strategies currently being adopted include the rail shuttle running between Enfield dry port and Port Botany, the Port Inland Distribution Network of New York/New Jersey, the Alameda corridor of Los Angeles and Long Beach port and the Virginia inland waterway. On the other hand, non-tangible aspect refers to the coordination of container movement through the inland supply chain to the hinterlands. This relates to strategies employed to ensure a timely arrival and delivery of container to and from the dry port. Some of such strategies include vehicle scheduling and booking systems, route planning, Shipment and vehicle tracking, adequate Information and Communication technologies, and advanced technology information sharing.

The basic reasons for poor quality of hinterland access and disruptions to coordination can be linked to the lack of willingness of the actors to invest. For dry port implementation run by public initiatives of poorer developing countries, this could be linked with a lack of available funding. On the other hand, in private initiatives, disruption to logistic coordination can be linked to the fear of fuelling competitors and so leading to discrepancies between investment and benefits for actors. For instance, a terminal operator may not invest in a road access link because of the benefits to be gained by his competitor within the surrounding area. Actors will most often concentrate on their own processes putting less effort in resourcing the general coordination problems of the chain as a whole. Based on some economic theories using the behavioural assumption of bounded rationality and opportunistic behaviour, Van der Horst and Lan (2008), discusses some effective strategies that can be used to improve coordination in the transport chain.

Incentive strategies:

These strategies employ the use of incentives to influence the behaviour of actors. They can be used to align the interest of actors to the efficiency of the overall transport chain. These include the use of both monetary and non-monetary schemes. Some examples include bonus/penalty systems that force the required behaviour and tariff differentiation systems e.g. price discounts for customers that can guarantee use of rail shuttles over a long period of time. Non-monetary strategies on the other hand may include time rewards as in with booking systems where promises of short waiting times are made to trucks that arrive at particular times for a fixed window of collection.

Alliance or change of scope strategies:

The alliance strategies are based on agreed commitment between various companies and are useful in cases where various actors are responsible for the problem with coordination. Nottebom (1999) defines alliances as a general term representing an inter-firm cooperation that goes beyond their mere market interaction. For example the horizontal alliances formed between barge operators in the Dutch container barging on the Rhine and between Rotterdam and Antwerp were established to exchange cargo in a joint cargo pool. The main motive was to generate adequate economies of scale through increased vessel utilization and so also reduce the number of barges with small call sizes. The change of scope is a step away from the alliance as it involves a change in the firm's organisation. This may be through vertical integration or disintegration and introducing intermediary actors such as agents and chain managers with the aim to improve coordination. This is a firm level strategy.

Collective action strategy:

This type relates to collective rather than individual benefits. For investments that provide collective rather than individual benefits, each involved actor will derive only a limited incentive to contribute to investments that improve logistics. For this reason, a collective action can be taken and is generally spearheaded by public bodies/organisation. De Langen (2008) suggests that the Port authorities and public bodies can effectively improve coordination and utilization of infrastructure by setting rules and regulations for infrastructure access and possibly attaching these to contracts where applicable. These added rules specifically aim to improve efficiency of the utilization of infrastructure,

sustainability and more coordination in hinterland supply chain can be referred to as infrastructure access and contract rules. Often, these might be embedded in port and logistic policies.

2.1.4 Classification of Dry Ports

Dry ports can be classified base on their proximity to the seaport, the transport modes served, the function of the dry port and the services provided within the facility. Rotterdam and Notteboom (2011) classify dry port by functions using three main headings namely: Saletllite terminals, Load centre, and Transhipment hub (as discussed in Section 2.1.3.3). UN ESCAP (2010b) classifies dry ports under four different classes using the functions, facilities and services provided by a dry port. Based on the transport mode served, dry ports can also be classified under rail-based or road-based. However this is not a good categorisation as dry ports are most often served by a combination of both modes. The most popularly accepted classification is based on proximity. A classification pushed forward by Woxenius (2004) and Roso (2009) under three main headings namely: Distant Mid-range and close range dry port.

2.1.4.1 Distant Dry Port

Referring to Figure 2.7 below, a distant dry port extends the gates of the seaport and provides an interface between the shippers in a distant hinterland, seaport and shipping lines. It has been argued that such dry ports like ports compete not only by performance efficiency and pricings but also be in terms of speed and reliability of shipments through them (Mourao et al, 2002). However, Van Klink and Van den Berg (1998) postulates that this can only be achieved if large volumes are handled over long distances leading to cost saving through economies of scales and an increase in frequency of transport services. At this point, rail transport costs become comparative to road transport costs and the distant dry port acts as an extended gateway to the hinterlands. During operation, the need for rail services to be reliable and frequent influences the competitiveness of the dry port (Kreukels and Wever, 1998).

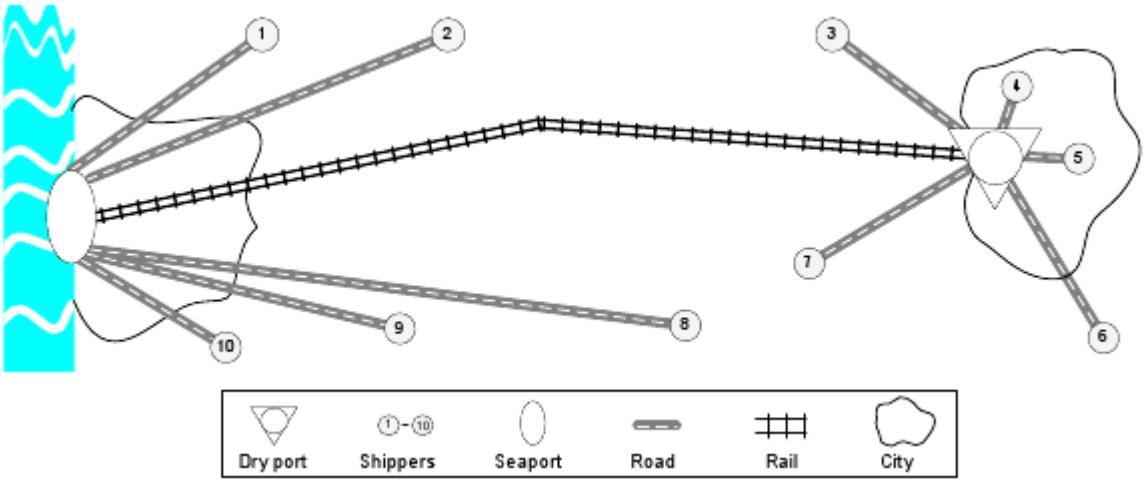


Figure 2.7: Seaport connected to a distant dry port (Source: Woxenius et al, 2004)

While rail operator benefit directly from the gain of economies of scale, the road haulage industry benefits indirectly from the transfer of cargo to rail through reduced crowding at the port gates and a reduction in queue times implying that less time is spent between loading and offloading and so more net revenues. Yet, this advantage is only exploitable for as long as the shipping market demand remains lucrative and the haulage market supply remain constant.

Isaka dry Port is an example of a distant dry port connected to the port of Dares Salaam (800km away) via the Mwanza railway link. It serves the land locked countries of Burundi and provides a convenient interface for container traffic to the North Eastern Democratic Republic of Congo and Rwanda. Since obtaining its dry port status in 1999, clearing and other custom documentations are handled within the facility, an arrangement that reduced the length of the custom clearing period, and improved the overall efficiency of the seaport (Roso, 2009). Isaka dry port has very recently faced problems with the collapse of the privatised rail services which has lead to reduction in container volumes handled by the facility.

2.1.4.2 Close Dry Port

In this option, a dry port is located at the rim of the port city, usually less than 100km from the port. Road transport to and from consignees are consolidated outside the city area by rail shuttle replacement services. Figure 2.8 illustrates the concept as described by Woxenius (2004) and Roso (2009). While the shippers 1 -3 and 7 - 10 use the dry port, the road transport linked to the seaport generates less traffic. Roso (2009), argues that unlike

the other two types, a close range dry port offers the largest possibilities for buffering containers and even loading then on the rail shuttle in sequence to synchronise with the off-loading of the vessels at the ports. Yet, the buffering of containers can be argued to cause double handling and in some cases, may multiply container trips and so transport cost to shippers. For example, it would be logical to assume that due to the proximity of shipper 1 and 10 to port, the cost of collecting the consignment from the port would be lower than the cost of collecting from the dry port and the reverse can be argued for shippers 3 and 7.

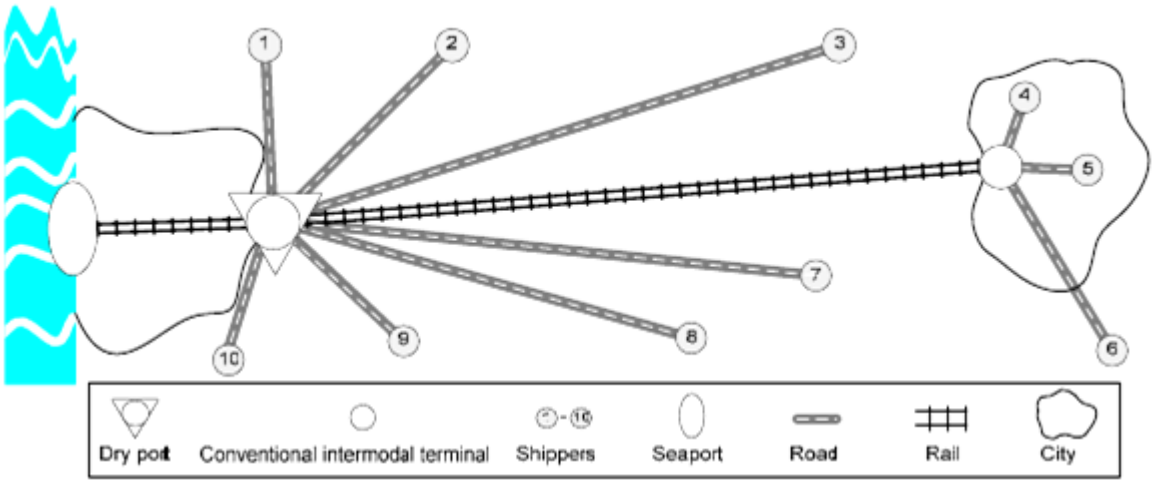


Figure 2.8: Seaport connected to a close dry port (Source: Woxenius et al, 2004)

Although Van Klink and Vann den Berg (1998) suggest rail services to be competitive at distances above 500km, the concept of close dry ports in a number of cases has been argued to succeed in reducing congestion and increase capacity as many shippers choose to use the rail alternative. The case of Enfield dry port in Sydney, Australia is an example of a close dry port designed to relieve congestion within and beyond the Sydney harbour port complex. Situated 18km form the complex, this close range option complements the distribution pattern where 85% of containers originate from or are destined to areas within 40km of the complex (Sydney Ports Corporation, 2006). The six close intermodal terminals connected to the Port Botany by rail within a radius of 50km, suggest a continuous successful introduction of the dry port concept.

2.1.4.3 Midrange Dry Port

A midrange dry port is one situated within a distance from the port generally covered by road transport (Roso and Lumsden 2010). They provide depot facility and are situated between the distance of a close and distant dry port, approximately 100-500km

away from the port. It serves as a consolidation point for different rail services allowing consolidated containers in one vessel to be loaded in a dedicated train and relieves the seaports stacking area. The consolidation role implies that administration and technical equipment required for the import/export procedure for example x-ray scanners needed for custom inspections can be provided in only one terminal.

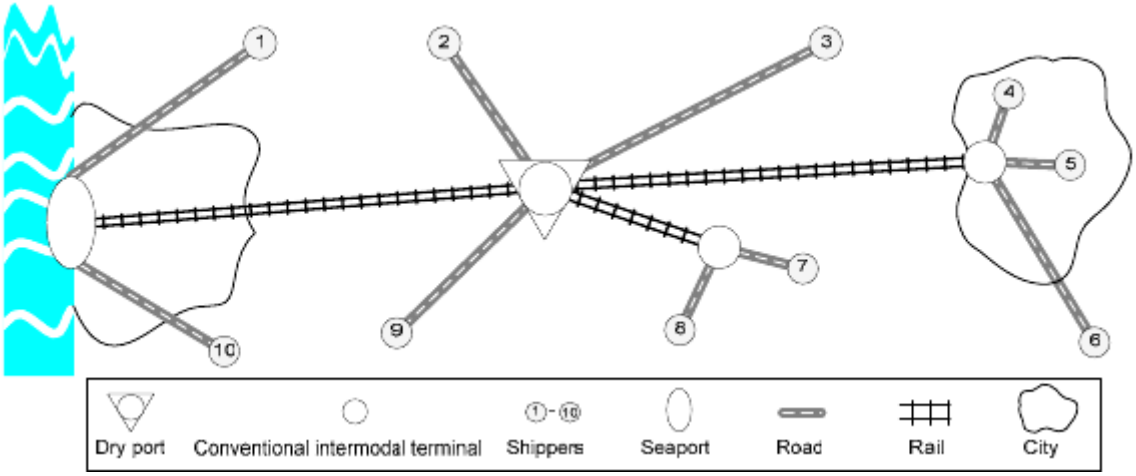


Figure 2.9: Seaport connected to a midrange dry port (Source: Woxenius et al, 2004)

2.1.5 Dry Port Benefits

Apart from modal shift from road to rail, implementation of dry ports increases the seaport capacity and with it the potential for increased productivity since bigger ships can now be handled at the seaport. A dry port could also improve competitiveness of the connected seaport by expanding the hinterland to areas beyond the traditional hinterland by offering more reliable quality services. Yet, in such cases where inland terminals are developed to accommodate capacity restriction at ports, a decline in maritime traffic, terminal expansion or an improvement in terminal infrastructure leading to the improvement in port performance may change the commercial viability of the dry port. This may lead to the port terminal recapturing the existing inland terminal market. The benefits of dry ports in relation to different actors are summarized in the table below.

Table 2.4: Impact of dry port solution on supply chain actors

Actors	**Potential benefits from dry port solutions**
Seaports	• Increased port capacity without physically expanding the port • Reduced congestion within port facilities implying higher productivity • Expanding the port hinterlands implying an increase in market share

Seaport Cities	• Reduced road congestion • Alternative use for land in city
Rail Operators	• Opportunity for economies of scale as handling volume increases • Opportunity to gain market share as long as quality services are provided and unit costs are relatively low.
Road Operators	• Reduced queuing periods on roads and at terminals
Shippers	• Improved seaport and inland access • Improved market interaction through improved efficiency in the supply chain
Community	• Lower environmental impact (greener solution) • More job opportunities • Encourages regional development particularly in the case of distant and midrange dry ports

For these benefits to be achieved, certain condition must be in place. Roso (2009) outlines the most significant one to be that the flows are large enough to facilitate efficient terminal and rail operations by economies of scale. Rodrigue et al. (2010) supports this by postulating that such a facility can only be competitive if it permits economies of scale by offering a lower unit cost through its ability to handle large volumes.

While direct benefits are perceived by the shippers, the benefits to the logistic sectors are obtained through an increase in business opportunities. Road hauliers may lose a marginal market share due to a modal switch to rail but benefit from the advantages of speedier terminal operations. Tsilingiris and Laguardia (2007) propose the main benefit of a dry port to include induced lower container handling costs, increased efficiency of operations leading to positive monetary implications and from a network point of view a decrease in the transport cost of containers.

Generally, dry ports service a combination of various functions at once. Rodrigue et. al. (2010) outlines that, the provision of a number of supply chain functions within a dry Port, enables new forms of rationalisation through modal shift and offers better access to inland markets. Yet, the effectiveness of a dry port to fulfil its role, whatever they maybe, may be hindered by location and physical limitations, discrepancies with logistic coordination in effective positioning and cargo turn around, and restrictions to regional trade. It is therefore necessary to ensure that all strategies constituting the dry port implementation supports the purpose for which it exists.

Roso (2009) suggests that a strategy combing the three types of dry ports may in fact alleviate congestion on road connections within the city. Yet, diverting all shippers within

the city to the close range dry port may in fact only delocalize the bottlenecks to alternative locations – to the rim of the city. She suggests that more work be into understanding the impact of dry port strategies employed to mitigate congestion, as the findings can direct the implementation framework.

2.2 Review of Dry Port Solutions for Congested Port Cities

Haven discussed the concept of dry ports in the previous section; this section aims to review dry port strategies employed by congested/populous port cities in particular. This section undertakes a case study approach to explore the characteristics of 'Port cities' facing port related road congestion and the dry port solutions employed to tackle this deficiency. It begins by exploring the definition of a 'Port city" in the context of this research and concludes by outlining the key characteristics of dry port solutions employed by port cities. The findings form the basis on which operational functions are selected for study in this research.

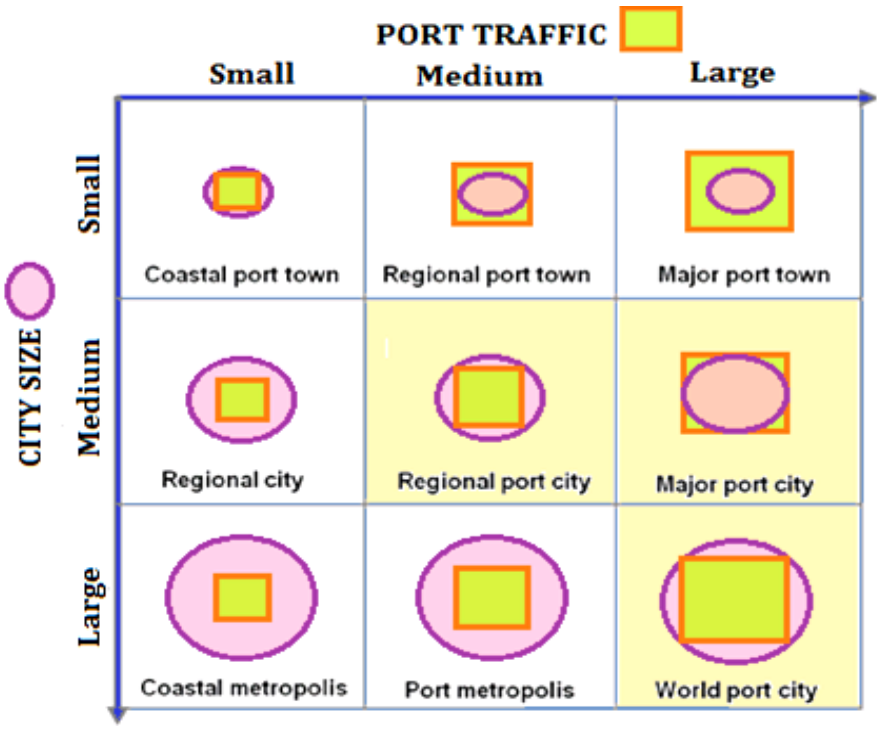


Figure 2.10: Topology of port cities (adapted from Ducruet, 2003)

Ducruet (2003) identified port cities using a factor he classed as the city's gradient of insertion in the global transport chain. This factor is based on level of logistic activities, port throughput and infrastructure. His hierarchy of port cities is outlined in Figure 2.10 above. In this context, port cities are defined as medium to large cities with a high gradient of

insertion in the global transport chain and having their ports located in the metropolitan centre.

In Africa, dry port solutions are either non-existent or just in the start of development. Many African seaports are themselves still struggling with high shipping costs, low productivity and shallow drafts. Land locked countries in particular are stricken by limited development in trade and industry owing to the unusually high freight transport costs and the onus delays surrounding freight distribution. Elsewhere in the world, dry port solutions are at different stages of development. Asia, Australia, Europe and United States have a number of dry ports that are in full operation. Other dry ports are well in the development stages or are in the early stage of operation with minute levels of international containers.

This review considers port cities that have implemented dry port solutions with the central goal to reduce congestion within the port and its surrounding area whether partially or wholly. It will outline the similarities and differences between the dry port strategies used by some port cities. It will explore some patterns relating the city demographics and trade characteristics to the selected port strategies. It also explores the effectiveness of the dry port solution in achieving the purpose for which it was built. This review is based mainly on desk studies and so, the case choices were made solely on the basis of data availability and relevance. On this basis, the cases outlined in Table 2.5 were selected for study. Other examples of such dry ports solutions include Lat Krabang ICD in Malaysia, Cikang ICD in Indonesia and Los Angeles Alameda Corridor.

Table 2.5: Port cities and their dry port solution

Port city, region	**Port**	**Dry port solution**
Busan, Korea	Port of Busan	Euiwang ICD
New York/New Jersey, USA	Port of New York New Jersey	Port Inland Distribution Network
Auckland, New Zealand	Port of Auckland	Wiri Inland Port
Sydney, Australia	Port of Botany	Enfield intermodal terminal

2.2.1 Busan, Korea

2.2.1.1 The City Demographics



Figure 2.11: Map of Busan, Korea (Source: Perry-Castañeda Library Map Collection, 2012)

Busan is Korea's second largest city and houses the largest international container port in Korea. It is strategically located at the south-eastern tip of the Korean peninsula and is situated 430km from Korea's capital city of Seoul. Province of Seoul city is the most important growth area in Korea. It holds 46.3% of the country's total population and accounts for 12.7 percent of the country's GDP. Owing to this strategic location, it serves a major gateway to Korea connecting the Pacific Ocean and the Eurasian continents. Its trading activity, import of major material and export of manufactures, accounts for more than 80% of Korea's GDP (OECD, 2011).

Busan metropolitan area has a population of around 3.6 million, representing 7.5% of the total population of South Korea and a population density of 4,666 per km^2. It composes of 15 districts (called gu) and one rural unit of government (called gun) covering an area of 766.1km^2 or 0.8% of the total nation's territory. Busan can be classified into three areas: west (Gangseo-gu), east (Gijang-gun) and downtown Busan (other gus) with the old port of Busan located within the down town region of Busan.

The city is one of South Korea's hubs of industry, commerce and trade, housing industries for shipbuilding, seafood processing, textile, footwear, software and automobile manufacturing. Busan also houses one of the two Free Trade Zones in South Korea the other is in the city of Incheon located within the province of Seoul city. The road conditions in Koreas are generally good with the total length of 86,989km of which 2,659km are expressway standards and 64,809km is paved as of 2002.

2.2.1.2 Container Trade Structure

The port is situated at the south-eastern part of the Korean Peninsula. This geographical location is beneficial and key to the development of this port. The location presents deep water, minimal tide range an easy connection to three major arterial sea routes and serves as a major gateway connecting the Pacific Ocean to the Eurasian continents.

The port of Busan is the largest port in the republic of Korea and is the fifth largest container port in the world, handling 14.2 million TEUs in 2010 alone. The port has 113 berths, a quay length of 21,854m and a handling capacity of 3.8 million TEUs which is to be upgraded to 8.1 million TEUs by 2011. Busan port accounts for 66% of the total import and export through Korea with transhipment container accounting for 44% of its total traffic. As

of 2010 import, export, empty and transhipment account for 27%, 28%, 18% and 44% of the throughput respectively (BPA, 2010). The port has handled no less than 11.8million TEUs per annum between the years 2005 to 2011. Most of which are destined for the Seoul metropolitan city and its surrounding areas where over half of Korea's total population reside. Likewise, most containers exported from the port originate from the Seoul city and its surrounding areas (OECD, 2011).

Busan is essentially an international seaport with about 46% of its total container foreign trade from or to North-East Asia. The port of Busan links with Japan and China operates routes to all ports in Japan and provides a number of shipping services a week to china. Its excellent connectivity and lower competitive shipping charges has in the past encouraged importers and manufactures in Japan and china to move their logistics centres to the hinterlands of the port or connect them directly with the port. The attraction of the shipping companies to the port can also be linked with its excellent port facilities and high productivity, which enables each berth to handle more than 700,000 TEUs.

Due to space limitations in the container yard, a number of off-dock container yards were developed around Busan to support the function of the port and make up for the limitations to the container yard capacity in the ports. These off-dock yards unlike the dry port are not connected by rail to the seaport. While these off-dock yards support the port functions, the movement of container trailers between the off-dock yards and the port of Busan contribute to the issues of congestion on roads in the City of Busan. The Busan new port is being developed to facilitate the handling of increased container traffic loads and has been in service since 2007. While the Busan old port struggles with capacity constraints due to land restrictions and uses the off-dock yards, the Busan new port has a large amount of land available to it.

2.2.1.3 The Dry Port Solution

Driving force

Issues with the transport system are one of the city's most pressing problems and are linked to the level of both port and urban traffic generated. The transport system moves over 6.6 million individual trips and over 7,000 container TEUs per day. An underdevelopment in the mass transit system forces the inhabitants to rely mainly on private transportation and port cargo moving from downtown through the city increases

congestion (AUICK, 1994). The Dongseo elevated highway in South Korea carries approximately 86,000 vehicles daily, including trucks, container trailers and passenger cars. It is an example of a link constantly plagued by chronic traffic congestion, the cost of which is estimated to be the equivalence of around 5.3 million GBP per year.

Busan's Intermodal transportation Network plan (2000-2019) was set up to boost national competitiveness and to secure transport system sufficient enough to handle the expected intermodal freight (UN ESCAP, 2009a). Under this, the government outlined two Inland container depots primarily to distribute freight from the country's two main ports (Busan and Gwangyang). Euiwang and Yangsan are the two main ICDs in Korea and both have road and rail access. Euiwang ICD is the major freight facility of the two and can be classified as a dry port given that it provides full customs clearing services, is directly connected to the port of Busan through a rail and road transport links and acts as an extension of the port. The depot went into full operation in July 1993 and is particularly designed to service container cargo bound for the Seoul, the capital area of Korea. The containers are temporarily stored on site before onward transportation to this area.

The Euiwang dry port solution was developed to reduce the traffic congestion problem generated between the off-dock container yards and the port of Busan. The Inland Container Depot is strategically located close to road and rail links and was established as a means of enhancing the validation of a shift in transportation from road to rail intermodal system since; they are more efficient than using off-dock yards which provide only a single mode of transport (MLTM ROK, 2009).

Institutional framework and ownership structure

The institutional framework that governs ICD development in the Republic of Korea is centred on the Ministry of Land, Transport and Maritime Affairs (MLTM). This regulatory authority encourages private investment in the development of dry port and logistics centres. The Public and Private Infrastructure Investment Management Centre (PIMAC) reviews dry port proposal from the private sector against relevant rules and regulations to ensure that they correspond with the government's long term plan and investment priorities.

The Euiwang ICD was developed under a public-private partnership and financed as a Build-Own-Operate (BOO) or Build-Own-Transfer (BOT) basis. According to Lim and Ko (2005): "Large-scale integrated freight terminals and inland container depots are being

developed to reduced logistics cost via improved cargo distribution systems. These solutions are being implemented as private investment projects with government supporting with the construction of roads, railroads, water pipes, and major facilities as well as loans for land purchasing and/or project costs." In the case or Euwiang ICD, 25% is owned by the Korean National Railroad (KNR) - a government agency while 75% is owned by private transport companies.

Operational and functional strategies

The facility is designed to perform customs clearance, freight collection, storage, classification, simplification, rail transport interchange, issuance of Bill of Laden to shipping companies and plant quarantine. It houses a customs shed, an empty container depot, banks, and the offices for shipping companies from which to handle tariff refunds and Bill of Laden related issues. The rail link from the port to the ICD is a simplified bonded transportation during which the payment of duties and taxes are suspended until arrival at custom bays within the ICD.

The Euiwang ICD provides customs clearing services and can be considered as functioning as a satellite terminal where truck trips are generated and custom clearance realised. It also acts as a load centre for the metropolitan area of Seoul and handles about 45% of its traffic. This facility acts as a buffer for export cargo generated at Seoul which is Korea's largest city and a significant manufacturing hub this facility acts as a buffer for export cargo generated in this area. The facility also houses a Container Freight Station for consolidation/deconsolidation, storage and warehousing of export/import cargo.

Physical strategy

The ICD is located 25km south of Seoul while the City of Seoul is located about 350km from the Port of Busan. The facility covers 735,000 m^2 of land and has a total capacity of about 1.5m TEU but handled a total of 1.9 million TEUs (UN ESCAP, 2007b). The terminal has two container yards each having an intermodal rail siding connected to the port of Busan. Its hinterlands are accessed by 75% road and 25% rail transport. The main equipment in operation are reach stackers, cranes and forklifts.

Logistical strategy

In 1987, the Korean government set up a freight distribution modernization policy. It commissioned the build of five Integrated Freight terminals (IFTs) to act as supporting

logistic centres to the two ICDs (Euiwang and Yangsan). The IFTs act as a processing centre for exports handling loading, unloading, classification, information processing, and packing of freight. These facilities house distribution centres, freight stations and container yards but not custom clearing bays. The Korean government plans to develop more of such terminals in other parts of the country.

Approximately 2,350 TEUs are transferred via rail to the facility on a daily basis, travelling just under 6hr from Busan. The Euiwang ICD is located on the Busan Seoul road and rail corridor which provides a rail capacity of 36 trains per day. The rail corridor provides a capacity of 750,000 TEUs but with a through put off about 1.8 million in 2010, the ICD still utilises the road network. As of 2010, the rail mode share of throughput handled by the ICD was about 25% (Regmi, 2012).

Furthermore, under the umbrella of its U-City Project, Busan city is pursuing an innovative strategy which applies ubiquitous technology to the city's main infrastructure and industries, including freight harbour and transportation. Specifically, Busan has completed the setup of Ubiquitous strategy plans for U-Port, U-Taffic and U-Convention. The U-traffic strategy is set to support a reduction in traffic congestion and logistic costs and involves a development in transport system automation, the implementation of smarter traffic management and the provision of transportation related information.

Linked with the Ministry of Maritime Affairs and the Port Authority, the city plans to set up an integrated community based system through which new generation and existing port facilities are able to grasp information on location and status of cargo in real time. These systems would apply technologies such as radio frequency identification (RFID) and include the use of traffic control systems and traffic information systems for Heavy Goods Vehicles and provision of automated toll system which enables instant electronic payments to be made, resulting in smoother traffic flows.

2.2.1.4 Effect of Dry Port Solution

The implementation of an ICD strategy allows for the distribution of container loads between small-sized trucks, large to mid-sized trucks and railways. The small sized trucks are generated at distribution centres and run to the neighbouring consumer communities, while large to medium sized trucks and railways service longer distances. This dry port solution supports a logistic system that realised environmental friendly cost effective economies of

scale by reducing logistics cost, including lead time and fuel costs (MLTM ROK, 2009).This dry port handled almost 1.9 million TEUs in 2008 and has been identified to contribute to the substantial reduction of congestion in and around the port of Busan (UN ESCAP, 2009b). The use of the rail has been suggested to ease road traffic congestion and reduce the environmental impact of vehicles. It is believed that an increase in rail mode share and a further expansion of the railway capacity should further enhance the environmental benefits of the dry ports (Regmi, 2012).

2.2.2 Auckland, New Zealand

2.2.2.1 The City Demographics

Auckland, the most populous city in New Zealand has a population of 1.4 million, accounting for a third of New Zealand's total population, and houses the largest seaport in the country. The Auckland region is the fastest growing and accounts for over 45% of New Zealand's total population growth. Auckland is divided into four main parts: Auckland city, Manukau, North shore and Waikatere. Auckland city is the main commercial centre of New Zealand with its central district housing its port and many financial and business service firms. The city also holds a number of manufacturing companies producing a range of perishable goods like sugar and brewing to a range of consumer durable goods like glass, paint, plastic and cement. However the majority of its industrial and commercial areas are located along the Manukau Harbour in south Auckland. While the Manukau Harbour is one of the largest water inlets on the west coast of New Zealand, navigation in this area is limited due to its narrow nature. Subsequently, the numbers of ship calls are limited.

2.2.2.2 Container Trade Structure

The Port authority in Auckland (Port of Auckland Limited) operates two ports, port of Auckland in Auckland Harbour side near Auckland's central business districts and the port of Onehunga on the Manukau Harbour in the west coast. The port of Auckland is the nation's largest container port occupying just-under 1km ^{2} of land. The port of Auckland has two main container terminals located less than 2km apart- Axis Fergusson and Axis Bledseo. Both terminals have plenty of cargo-handling equipment and state of the art container tracking systems. A small proportion of containerised cargo is also handled by other

conventional terminals. Although there is no competition between these terminals as they are both operated by the port of Auckland Limited, each has to compete with other ports for patronage. The port of Auckland is mainly owned by the Auckland Regional Council. It is located on the north island of New Zealand. It handles 51% of the New Zealand's North Island's Container trade, 45% of New Zealand's total container trade and provides links to 165 ports in 70 countries around the world. Empty containers account for 35% of the total export TEUs. As of 2011 import, export, empty and transhipment account for 55%, 39%, 20% and 6% of the throughput respectively (Ministry of Transport Te Manatu Waka, 2012).The port runs an on-site empty depot.

As of 2008, Auckland terminals remain the primary container port in the region handling more than 840,000TEUs (Port of Auckland, 2009). An economic impact assessment concluded that the port's economic activities generated 36% of New Zealand's GDP (Islam et al, 2010). However, container terminals in the Port of Tauranga located 200km away, are Port of Auckland's main competition, handling over 400,000 TEUs in the same year. In the past few years, Auckland has seen a decline in growth as it appears to be losing market share to Taranga which exhibits an increase in cargo volumes handled.

2.2.2.3 Dry Port Solution



Figure 2.122: Port of Auckland present inland terminal location (Source: Marinova, 2006)

To help stave off competition and reduce congestion, Auckland has plans to develop

five inland Terminals outside the city. At present, only two of these terminals are in operation - East Tamaki and the Wiri Inland terminal in the south of Auckland. East Tamaki is 18km from the port and was the first terminal developed. It is however served only by trucks. The Wiri Inland terminal is an intermodal terminal linked to the Port of Auckland by road and rail and can be classified as a dry port solution. With a capacity to handle up to 200,000 TEUs pa, this bimodal facility went into operation in 2010.

Driving forces

The port of Auckland container terminals are complemented by the Wiri Inland port to offers an alternative for customers to receive and deliver cargo. The dry port initiative was driven by two main motives. Firstly, it was hoped that such infrastructure would alleviate congestion on the city roads, as trucks are moved from road to rail, and at the same time increase the capacity of the port. Secondly, the implementation should stave off competition from the Port of Tauranga which handles about 23% of the nation's containers and has its own inland terminal, Metroport, located within Auckland city limits and developed to serve the Auckland region. Both Metroport and Wiri inland terminal are located adjacent to north island main trunk line and in close proximity to Auckland's biggest exporters. As of 2008, the volume handled at Metroport was 150,000TEU. The Wiri dry port solution is a strategic move to attract export cargo scattered around the north island that may currently use the Metroport through the Port of Tauranga or any others.

Since import and export cargoes will clear at the inland terminal as though it were at the dock, its location should increase Auckland's market share since the port is brought closer to the hinterland. It is said that "around 70% of containers passing through the port of Auckland originate in or are destined for surrounding areas of the Wiri inland port" (CONLINXX, 2010a).

Institutional framework and ownership structure

Regulatory responsibility for directing uses and activities relating to maritime development is under the Auckland Regional Council (ARC). The regulatory framework for how it does this is contained in its Regional Policy statement. Specifically, the frame work that governs the dry port implementations is outlined in the Auckland regional Freight Strategy. The policies set out have the objectives to: "Improve regional understanding of the importance of freight through information and communication, promote and advocate a supportive funding and regulatory framework for freight, support investment in the

strategic road network and TDM that will provide congestion relief for freight traffic, support the development of a strategic Freight Network, develop initiatives to improve local area freight management and promote a freight system that is clean quiet and safe" (ARC, 2006).

Wiri Inland terminal is owned on the basis of a Public-Private partnership. The Wiri Inland port is managed by CONLINXX limited, a subsidiary company set up and owned under a joint venture between the port of Auckland and the NZL group, a New Zealand owned cargo handling and logistics service provider, owning 70% and 30% respectively. The rail exchange is owned by KiwiRail.

Operational and functional strategies

The Wiri Inland port provides all the services and functions expected at a traditional port including a full customs service. Importers and exporters are expected to pick up and drop off cargo at this facility as if at the port. The inland port offers full security, stuffing and de-stuffing facilities and uninterrupted movement of containers to and from the port of Auckland. The facility provides cargo owners with long-term storage options and an empty container yard to optimize local delivery. The facility supports door-to-door delivery of cargo to south Auckland's warehousing and manufacturing core through its dedicated train and fleet of trucks.

The terminal operates as an intermodal hub providing bimodal (road and rail) connections to the port terminals. It acts as a load centre to South Auckland areas and a satellite terminal to the port of Auckland.

Physical strategy

The Wiri inland terminal is located 25km from Port Auckland in the south of Auckland. It is close to two major state Highways (1 & 20) and adjacent to a rail exchange that has three rail sidings each with a capacity for 22 wagons and 2,000m of rail track connected to the North Island Main Trunk Rail Line. The rail format means that a track can be used for repositioning locomotives while two trains work simultaneously. The freight hub covers about $1km^2$ (10 Hectares) of land while the intermodal rail exchanges covers $0.5km^2$(5 hectares) of land. The freight hub has further land for development if there is need to increase capacity. It has presently been developed to handle a total of 100,000 TEUs annually (CONLINXX, 2010b).

Logistic strategy

The terminal is connected to the port and its hinterland by two modes of transport – road and rail. The rail link came into operation in March 2010 and connects the inland port to the port of Auckland's intermodal rail exchange. Presently, the rail operator (KiwiRail) runs four services of 23 wagons a week in each direction. KiwiRail also owns the land where the rail exchange stands. The rail infrastructure includes 3 rail sidings and 2,000m of rail track.

The port of Auckland has applied a number of intangible logistics strategies in operating the inland terminal. A Vehicle Booking System (VBS) is used to even out truck trip generation and eliminate daily peaks and troughs of truck arrivals at terminal gates (Port of Auckland Limited, 2008). The port authority has applied an extra demurrage charge at the port and reduced it at the inland terminal as an incentive to encourage shippers to use the inland terminal. Uninterrupted transfer of containers between the port of Auckland and Wiri terminal is ensured.

2.2.2.4 Effect of Dry Port Solution

The solution is predicted to reduce road congestion and save up to 2.5million truck km per year, an estimated 100,000 truck movement per year, and so create significant environmental benefits (Port of Auckland Limited, 2008). The inland hub reduces dwell time on container terminals, increases the size of the ports effective hinterland and improves the efficiency of port operations (Auckland Regional Council, 2011).

2.2.3 New York, USA

2.2.3.1 The City Demographics

The New York metropolitan area is located on the north eastern Atlantic coast of the United States of America. The region has a population of close to 18 million people as of 2009 and occupies a total land area of 8,683km^2 (2,050 people per km^2). The region is one of the densest in the world and is home to one of the world's largest ports and the 3rd largest port in the US (after Los Angeles and Long Beach). A study conducted in 1963 by the transport commission showed that an average work day produced about 13.7 million auto trips and 2.8 million truck trips (Wood and Leighton, 1969; Wood, 1970). More recently,

Holguín-Veras and Thorson (2001) were able to prove that compared to other transportation modes, truck traffic accounted for over 90% of total freight movement in the region. The high volumes of passenger and freight trips through the city cause congestion, and as a result increase internal costs (e.g. travel time costs) and external costs (e.g. increased emissions) to the passenger and freight users.

2.2.3.2 Container Trade Structure

Over the last 40 years, the volume of containerized trade through the port of New York and New Jersey has steadily increased along with increase in global containerization. This growth can be attributed to a number of economic factors including a growth in global trade and a shift of trade routes from west coast port facilities to services via the Panama Canal, Mediterranean Sea and the Atlantic Ocean.

The container terminals handle approximately 14% of the total container traffic through the United States (U.S. Census Bureau, 2012). In 2009, the container volume through the Port of New York and New Jersey was 3.6 million TEUs which increased to 5.3million TEUs by 2010(Leach, 2011). Assuming a typical trailer carries the equivalent of two TEUs, this equates to nearly 1.8million one-way truck trips per year. Over 85% of all containers imported through the port of New York/New Jersey are destined to consumers within 360miles (600km) of the port.

2.2.3.3 Dry Port Solutions

The emerging dry port solution in New York constitutes of a network of intermodal rail terminals, each providing a direct link to the port and operating as extensions to the port of New York/New Jersey. This solution is referred to as the New York Port Inland Distribution Network (NY PIDN). Once completed, the transport system will comprise a barge, truck and rail system that provides services between the marine terminals and inland terminals located at or near 13 clusters of marine customers and distribution outlets. Over 82% of the port container market is believed to be located within 50 miles of the inland terminals. Figure 2.13 shows the Port Inland Distribution network in New York New Jersey. The system moves containers by barges to water accessible ports such as Albany, Rhode Island and Boston while the rail links move containers to inland terminal in Pittsburgh, Buffalo and Worcester. The inland terminal at Albany has been discontinued, while

terminals in Pittsburgh and Worcester are operating as intermodal facilities, other intermodal connections to terminals like Buffalo are still in development. The inland container terminals offer U.S customs and clearing services (NCHRP, 2003).



Figure 2.13: Port Inland Distribution Network (Source: PANYNJ, 2004)

Driving force of dry port

The dry port solution was motivated by a realization of the negative impacts of increasing truck congestion in the region on the cost competitiveness of the port of New York and New Jersey which became more obvious from the increasing number of truck trips and the extended waiting hours for pick-ups (NCHRP, 2007). The Goal was thus to increase port throughput capacity and market share, reduce congestion, reduce inland distribution costs, and improve air quality through the reduction of truck trips (Leitner and Harrison, 2001). Apart from congestion, it was hoped that the solution would reduce the need for container storage space within the already constrained marine port, improve air quality, generate new jobs and increase the competitive nature of the region.

Institutional frame work and ownership structure

In the USA, the implementation of dry port solution is heavily influenced by transport policies. These Policies are outlined on a state level rather than a national level. The majority of transport regulations are set out by some state transportation agencies (the New York State Department of Transportation (NYSDOT), the Port Authority of New York and New Jersey (PANYNJ), the Metropolitan Transportation Authority (MTA), the New York

City Department of Transportation (NYCDOT), the New York City Economic Development Corporation (NYC EDC), the New Jersey Department of Transportation (NJDOT) and New Jersey Transit (NJT) (Holguín-Veras, 2000) and the federally mandated local Metropolitan Planning Organizations (MPOs) - the New York Metropolitan Transportation Council (NYMTC) and the North Jersey Transportation Planning Authority (NJTPA).

The Port Inland Distribution Network was initiated by the Port Authority of New York and New Jersey but is owned and operated under a public-private partnership. The partners include the Port Authority of New York and New Jersey, port operators, and a number of state and government agencies, all of who have been unable to raise the estimated full funds necessary to complete the development of the entire proposal. For this reason, only a few terminals operate in the full extent for which they are assigned.

Operational and functional strategies

The inland terminals offer cargo handling, warehousing, empty storage, consolidation, distribution and intermodal logistic facilities to support movement of containers to and from the port of NY-NJ.

Physical strategy

The inland ports are located in or near the centres of 13 dense trade clusters of marine customer services and distribution activities located within 600km radius of the port. These clusters are locations were container demand exists and increased productivity can occur from the transfer of containers to the inland port. The Container traffic to these clusters account for 82% of the container market.

Logistical strategy

The PIDN involves the use of dedicated rail, barge, and truck shuttle services in moving containers between the marine port and inland intermodal terminals.

2.2.3.4 Effect of Dry Port Solution

The Port Inland Distribution Network is expected to reduce congestion, improve efficiency and reduce the cost of inland transport by 20 per cent (UNESCAP 2004). Projections of terminal productivity shows that with the PIDN system in place, vehicle travel times will reduce with freight being evenly distributed among more transport modes and container dwell time at the ports will be significantly reduced (Leitner and Harrison, 2001).

2.2.5 Sydney, Australia

2.2.5.1 The City Demographics

The city of Sydney is the capital of New South Wales in Australia and is located in Australia's south east coast. It is the most populous city in Australia housing 3,7million people in its metropolitan centre alone. While the extensive area of 12,145km^2 covered by Urban Sydney if formally divided into 40 local government areas, the city of Sydney itself covers a smaller area of 1,687km^2 and constitutes mainly the Central Business district and its neighbouring inner-city suburbs.

2.2.5.2 Container Trade Structure

The port of Botany is located at the entrance of the city harbour and in the city's central business district. The port of Botany consists of two container terminals and is Australia's second largest container port handling 1.9 million TEUs in 2010, after the Port of Melbourne which handled 2.1 million TEUs (Bureau of Transport and Regional Economics, 2011). It handles around a third of Australia's total containerised throughput. These Figures are expected to increase to 5.5 million TEUs by the end of 2030. However, with a current capacity limit of 3.2 million TEUs per annum, this can only be realised if currently planned expansions are approved and completed (NSW Government, 2011). Almost all containerised freight through New South Wales (NSW) is handled by the port of Botany in metropolitan Sydney. Analysis of the import statistics reveals that 85% of these containers are destined or originate from areas within 40km of the port. As of 2008-09 import, export, empty and transhipment account for 43%, 19%, 24% and 15% of the throughput respectively (PwC, 2011).

2.2.5.3 Dry Port Solutions

With most of its population commuting in private transportation and almost 90% of container throughput being transported by road, Sydney currently has a large market base for road transport (Sydney Airport Corporation Ltd, 2009). This has in the past lead to heavy congestion on major arterial corridors specifically those through its major population and employment centres in the west of Sydney. The high levels of congestion affect the city's

overall productivity, liveability and sustainability (NSW Government, 2011). Furthermore, while the volume of transport via rail increased from 225,0000 to 250 000 TEUs between the years 2001 and 2010, the growth rate is not in line with the increase in container throughput and so the proportion of movement by rail has declined from 22% to 14% between those years.

NSW has set out plans to relieve congestions in the road network. One of their specified targets was to do this by increasing the proportion of container freight movement by rail to 40% by the end of 2016 (NSW Government, 2010). This target is to be achieved through investments in intermodal developments within Sydney. Enfield Intermodal terminal is part of a planned network of intermodal facilities developed to increase the container handling capacity in the region and encourage the modal shift to rail. The intermodal facility was approved for construction in 2007, ten years after its conception. It is currently under development.

Institutional frame work and ownership structure

The rail line upgrade programme is funded by the Australian government. The terminal will be operated by Hutchison Port Holdings (HPH) a subsidiary of the multinational conglomerate Hutchison Whampoa Limited (HWL).

Operational and functional strategies

The Enfield Intermodal Terminal should be in operation by mid 2013. The dry port will provide all the services and functions expected at a traditional port including a full customs service, full security, stuffing and de-stuffing facilities and uninterrupted movement of containers to and from the port of Botany.

The available facilities should include an empty container storage facility, warehousing, Container freight station where containers can be stored and unpacked for distribution and cargo can be consolidated into containers for export. The intermodal terminal will act as a load centre to a light industrial logistic centre which is to be developed down the road from it.

Physical strategy

The Enfield intermodal terminal is a 60 hectare site located about 18km from the Port of Botany. The site is on the old Enfield marshalling yard located in an industrial and commercial area. The facility will have the capacity to handle 300,000 TEUs which would

almost double the current intermodal capacity in Sydney.

Logistical strategy

The Enfield intermodal terminal is connected to the port of Botany by a dedicated freight line and major road access. While the majority of the rail line is dual track, it has a single track along 3 km which limits the operational capacity. Like a seaport, the centre is to operate 24hours a day, 7 days a week.

2.2.6 Discussion

From Table 2.6 there are obvious similarities with ports and port cities that employ dry port solutions with the hope of mitigating congestion. Each case represents one of the largest cities or most populous cities in its regions. While in some cases the city's population is a small percentage of the national population (as with Busan and New York), the containers handled as a proportion of the national throughput remain high for all cases. Busan with a population accounting for only 7.5% of South Korea handles 66% of the nation's containerized traffic and New York with a population accounting for only 6% handles 13.2% of the national container traffic. The implication of this is that majority of the container traffic through these ports are destined for a number of other cities as is shown by the envelope of the port's customer bases as in the case of New York/ New Jersey, 82% of the container trips originate or are destined for area up to 600km from the port. On the other hand, Sydney and Auckland, each with a population accounting for over 30% of the national population have at least 70% of container trips destined or originating within 50km of the port. Wherever the destination or origin of the container trips, the issue remains that because the ports are located at the edge of these regions, access to the port's hinterlands must be through the port's surrounding network which happens to be the city network. In most cases, the container growth rate is at or above the global container growth rate of 6.6%, and so presents the growing problem (UN ESCAP, 2005b).

A key rationale for the development of a dry port facility connected to congested port cities is the need to reduce congestion in the surrounding areas of the port. However, as has been shown, the dry port solutions are often driven by a combination of other factors including:

- A need to enlarge the port's hinterland and improve the port's competitiveness. As in the case of the city of Auckland, the Wiri dry port was developed to encourage competitiveness of the port of Auckland against the Port of Tauranga.
- An opportunistic move to capture demand for value added services like empty container services and container stuffing/stripping.

Most dry port solutions are still in their early stages and the true effects on traffic are yet to the fully documented. However, there is a clear pattern in solutions used by cities suffering from similar problems. The main similarities of the dry port solutions exist in provision of similar operational function. In all cases the dry port is developed to function as a satellite terminal to the city's port and/or a load centres to the port's customer base. As satellite terminals, they exist within close proximity to the port, prove a means for buffering container flows and accommodate value added activities. As a load centre, the dry ports are located within an area of major production and consumption and so provide an interface between the shippers and the port. All cases locate the dry ports close to main consumption/production areas constituting of its customer base. In the case of Auckland, the dry port is located in Manukau, South Auckland which houses major industrial areas in New Zealand. This is also the case with Sydney which locates its dry port within 20km of the port since its customers exist within 40km of the port. In the case of Busan, Seoul Metropolitan region, located 350km from Busan, houses the port's main customer base and so, the dry port solution (Euiwang ICD) is located close to this region. The dry port provides a gateway to Seoul and its surrounding area. The case of New York is similar yet different. The port's customer base is scattered within 600km of the port. Thus, a dry port solution constituting a network of intermodal terminal acting as a load centres to an identified customer cluster is employed. In general, the proximity of the dry port to the port is related to the location of the port's customer base. In all cases, the cities appear to embrace the fundamental hope that locating the dry ports closer to the customers makes the option of rail more competitive than road.

In all cases, the dry ports offer the same added value services including empty storage, and warehousing for distribution and consolidation. However, the magnitude of provision varies between solutions. In all cases empty storage facilities are provided to aid container repositioning. The size of which is related to the ports export and empty container traffic. None of the facilities perform trans-loading, trans-modal or free trading functions.

This is logical since none of these services are available at the seaports.

The physical strategies relating to size and capacity of the facility is driven by the port's container throughputs and this constrains the dry port's container throughputs. For example the port of Busan handles over 11.8 TEUs million and its connecting dry port (Euiwang ICD) is developed with a capacity of 1.5million TEUs while the Port of Auckland handles under 1 million TEUs and it connecting dry port (Wiri inland terminal) is developed with a capacity of 100,000TEUs. In all cases, the dry ports are located within urban areas possibly because of the level of infrastructure development in the area. For instance, Enfield intermodal terminal in Sydney is being developed on the site of an existing marshalling yard located within a developed industrial and residential area. Generally, the physical strategy employed is related to the characteristics of the port's container trade structure as well as the characteristics of the city.

In relation to ownership structure and funding, private and public partnership exist in 3 out of the 4 cases. PIDN is the largest project and is the only project that is 100% funded by the public sector, suggesting that it is more challenging to secure private funding for large scale dry port solutions. The Enfield Terminal and PIPN are both still in development while the Euiwang and Wiri terminal are well into operation. Although no empirical analysis has been carried out to determine their true effectiveness in reducing congestion, the utilization in both cases has lived up to expectation. The Euiwang terminal for example was originally the only inland terminal providing customs services and was developed with a capacity of 1.5million and peaked it capacity by handling a total of 1.9 million TEUs in 2008. On the other hand, to assist with the problem of congestion within the port of Busan, the Korean government developed the port of Gwyagang and is presently in the process of building Busan New port. This is an indication that a dry port solution consisting of a single intermodal terminal may in the long run be insufficient and so dry port solutions consisting of a network of intermodal terminals should be considered.

In the case studies, all dry ports are connected to high capacity rail lines but are also connected by road. It is hoped in each case that the dry port would encourage the shift from truck to alternative modes (rail), thereby reducing congestion on access to and from port facilities. However, with no empirical data provided to support a true reduction in congestion by the dry port solutions, it is impossible to access the true effect of these strategies on traffic congestion based on the experiences of these cities. For example, The Enfield project was delayed because of bureaucracy that stemmed from the fear that its

operation would increase traffic in the areas surrounding the terminal. Issues relating to the true economic and environmental viability of locating such a facility so close to the existing port are being raised at conception. Issues with double handling and the impact of its operation on the communities in its immediate vicinity have also been questioned.

However, the advantage of an intermodal system has been accepted to be true and lends itself to a common knowledge that moving trips from road to rail increases unused capacity in the road network and so helps mitigate congestion. Furthermore, with majority (85%) of container trips destined for the immediate vicinity of the port Botany, it poses difficult to support a distant or midrange dry port solution. With that agreed, the exact location of the facility depends also on other factors like land availability and geology among others. The Enfield terminal was originally proposed to accommodate 500,000 TEUs however it was rejected by the state government because of questionable benefits of the added warehousing function. It was argued that the benefits from reduced container trips on roads would be counteracted by the addition of smaller trucks generated from the warehouse (Strathfield Council, 2009).

Table 2.6: Characteristics of port and port cities

Characteristics	**Port of Busan, Busan**	**Port of Auckland, Auckland**	**Port of New York/New jersey, New York**	**Port Botany, Sydney**
City size	Largest port city in south Korea	Most populous	3rd Most Populous	Most populous
Population of metropolitan area	3.6 million (7.5% of south Korean)	1.4 million (33% of New Zealand)	18 million (6% of US)	4.25 million (20% of Australia)
Population density of metropolitan area	4,666 per km^2	382 per km^2	2,030 per km^2	2,037 per km^2
Contribution to GDP	-	37%	-	25%
Relative Port Size	Busiest Port in south Korea	Busiest port in New Zealand	3rd largest port in the US	2nd largest container port
Cargo throughput	> 11.8 million TEUs (2010)	≈ 840,000TEUs (2008)	5.3 million TEUs (2010)	1.6 million TEUs (2009)
Port Throughput as a percentage of country's	66% (south Korea)	37% (New Zealand)	14% (US)	33% (Australia)
Average container growth rate	7.6% (2005 - 2010)	7% (1989 - 2007)	5% (2008 – 2010)	8%
Percent destined for immediate environment of port	-	70% (within 50km of port)	80% (within 600km of port)	85% (within 40km of the port)
Import- export ratio for laden containers	1:1	2:1	2:1	2:1
Transshipment as percentage of total traffic	44%	6%	-	15%
Empties handled as percentage of total traffic	18%	20%	28%	24%
No of containers generated by port per day	7000 TEUs	1200 TEUs	4000 TEUs	2900 TEUs
Intermodal terminals connected to port	1	1	13	6
Distance away from existing inland terminals	350km	25km	600km	18km – 45km
Major Industrial, commercial and economic Center	Yes	Yes	Yes	Yes

Table 2.7: Characteristics of dry port solutions

Strategies	**Euiwang ICD / Busan**	**Wiri Inland Terminal / Auckland**	**PIDP / New York New jersey**	**Enfield Intermodal Terminal/ Sydney**
Ownership/Funding				
Ownership structure/Funding	PPP (BOT)	PPP	Public	PPP
Investment	KNR, private companies	KiwiRail, POAL, NZL group	Federal/State Government	HPH, State Government
Physical strategies				
Distance from major market	Terminal is 25km from Seoul	Terminal within 10km of south Auckland's manufacturing area	Terminals within 50 miles of Consumer market	Consumers within 40km of Port Botany
Distance from port (classification)	350km form Busan (midrange)	25km from Port of Auckland (close)	Located within 360 miles from Port of NY/NJ (midrange)	18km from Port Botany (close)
Capacity (TEUs)	1.5 million TEUs	100,000 TEUs	-	300,000 TEUs
Container throughput (TEUs)	1.9 million TEUs (2008)	-	-	-
Equipments	Reach stackers, Forklifts, Cranes	Reach stackers, straddle carriers	-	gantry cranes, forklifts, Reach stackers
Site Area	74,520m^2/735,000m^2	100,000m^2		600,000m^2
Logistic Strategies				
Network of dry ports	No	No	Yes	Yes
Network of logistic centers	Yes	Yes	Yes	Yes
Transport modes to dry port	Road, Rail	Road, Rail	Road, Rail, Barge	Road, Rail
Information Communication technology	Yes	Yes	Yes	-
Vehicle booking system	Yes	Yes	-	-
Operational strategies				
Satellite terminal	To port of Busan	To Port of Auckland	To the port of NY/NJ	To port Botany
Load center	To the area of Seoul	To South Auckland area	For 13 consumer clusters	To Sydney urban area
Trans-modal	No	No	No	No
Cargo transformation	No	No	Yes	No
Trans-loading	No	No	No	No
Consolidation/deconsolidation	Yes	Yes	Yes	Yes
Warehousing	Yes	Yes	Yes	Yes
Empty depots	Yes	Yes	Yes	Yes
Free trade zone (FTZ)	No	No	No	No
Customs clearance	Yes	Yes	Yes	Yes

2.3 Summary

A number of port cities have employed dry port solutions, particularly as a measure for alleviating congestion. However, once the locations for these facilities are identified and allocated to terminal operators for development, it is often up to them to decide what capacities and facilities to introduce within these sites. These decisions constitute the characteristics and strategies of the dry port and may not always be favourable to road network conditions.

In the context of assessing the effect of the characteristics of a dry port on its ability to mitigate congestion, the comparative review undertaken in this chapter presents inconclusive quantitative evidence as there exists no empirical data to quantify the effect of dry port solutions on congestion in these cities. Assessing the effect of a dry port solution on congestion requires a before and after analysis run over the periods before and after the construction of dry ports. This empirical assessment requires a long period of observation. Unfortunately, such a study has not been done and is not possible under the limitations of resources and time associated with this research.

However, based on the case studies the following observations are made on the characteristics of dry port solutions employed by congested port cities:

- They are characterised by the inclusion of basic added value services. Most commonly empty depots and warehousing for distribution and consolidation. The size and capacity of the facilities are strongly related to the characteristics of the trade structure including the port's throughput and the volumes of transhipment and empty containers.
- The dry ports are located close to major consumption and production regions and so act as load centres to these areas which house the port's main customers.
- The dry ports are connected to the ports by at least two different modes.
- The size of the project influences its ability to attract private funding. The bigger the project, as with the New York Port Inland Distribution Network, the riskier and so less attractive.

A variation in a dry port's operational, logistical and physical characteristics may influence its ability to reduce congestion since these dictate the magnitude and location of

trucks generated in the network. The present research explores the impact of a close dry port solution on traffic congestion within the road network. It focuses on the effect of varying a number of common characteristics in a dry port solution. As found in this chapter, the most common characteristics relate to the location of the customers of the dry port and to the inclusion of basic added value services such as empty storage facilities and warehousing for distribution and consolidation. These characteristics are varied within a dry port case to derive the dry port scenarios explored in this study. The scenarios are outlined and discussed in Section 3.2 of this thesis.

The following chapter discusses the research methodology employed and provides a background to the port city selected for study in this thesis.

Chapter 3

Research Methodology and Background of Case Study

The term research methodology refers to the method used in collecting, analyzing and interpreting data useful for answering research questions. The method available for use depends on the type and purpose of the research. Thus, to determine the methods available for use in this research, it is important to first consider the categories under which this research may fall. Various scholars have proposed a range of classifications for types of research including Kothari (1990); Wacker (1998); Dawson (2002) and Kumar (2005). The most common classification by Kumar (2005) is discussed briefly below. However, the reader is referred to the references for detailed review of the various classifications proposed by these scholars.

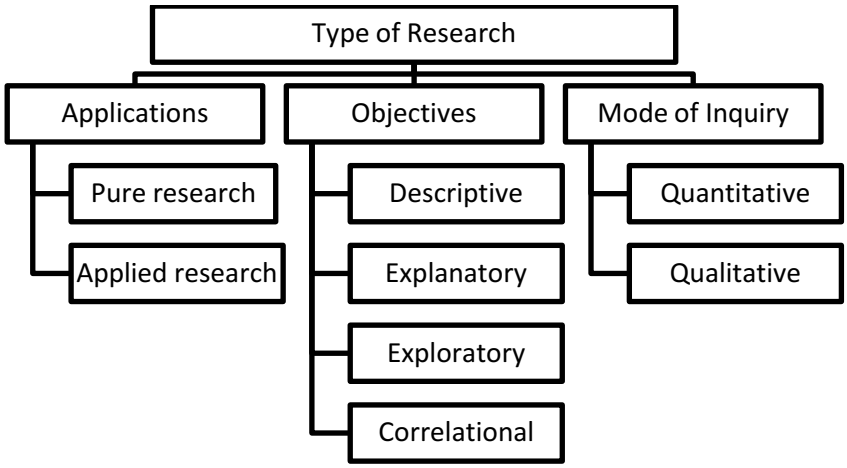


Figure 3.1: Classification of research types (adopted from Kumar, 2005)

Kumar (2005) provides a basic classification for research and does so under three main headings based on the application of the research study, the objectives in undertaking the research and the mode of inquiry. Each of these is further divided in sub-classes as outlined in Figure 3.1 above. Pure research refers to those that formulate and test theories and hypothesis that may or may not have practical applications in the present or future time. Applied research on the other hand refers to those that address specific and practical questions. Descriptive research attempts to describe a situation, problem phenomenon or observable fact. Explanatory research attempts to define the 'why' and 'how' aspects relating to the problem phenomenon. Correlation research attempts to establish relationships between aspects relating to the problem phenomenon. Exploratory research considers the research that explores objectives within areas of limited body of knowledge. Most studies are a combination of a descriptive, explanatory and correlation research (Kothari, 1990). A quantitative research, unlike a qualitative one, is structured and based on

the measurement of quantity or amount. Thus, results from a quantitative research are presented in terms of quantity. Qualitative research on the other hand relates to qualities of entities or processes that are not measured in terms of quantity and amount but relating to non-numerical data collection. Using this category and based on the objectives outlined in Section 1.3, the research can be categorized as an applied explanatory quantitative research and a methodology applicable to this type of research should be considered for use.

Saunders et al (2007) identifies the case study strategy as the most common approach for explanatory research as it is particularly good for examining "why" and "how" objective enquires. Yin (2003) defines a case study as an empirical inquiry that investigates a contemporary phenomenon within a real-life context. This approach exists in two forms: single and multiple cases (Voss et. al, 2002). The single case design aims to make generalizations and explore theories on the basis of a single case while the other uses a multiple number of cases for generalization. This research focuses on a single case - Lagos, Nigeria as it allows for greater depth for research within the time and resource limitations allocated to a PhD research. This method however limits the accuracy of generalized conclusions because of possible misrepresentation of the single case. Yet, it provides a deeper foundation on which other cases can be explored in the future to support or oppose the theories and observations spun out from the research. Yin (2003) postulates that a single case strategy may be used if a) the case study represent a critical case in testing a well formulated theory; b) the case study represent an extreme case or a unique case; c) the case study is the representative or typical case; d) the case is a revelatory one and e) the case study considers the case at two or more different points in time. The case of Lagos, Nigeria is revelatory and representative of coastal countries in west central Africa. Eisenhardt (1989) states that case studies can be used to provide description, test theories or generate theories. Thus, findings from this research can be generalized to cities within this region.

The research aim focuses on quantifying a reduction in network congestion by introducing a close dry port solution with varying characteristics. Therefore, it adopts the deductive research methodology (i.e. theory testing) as opposed to the inductive approach which is related to the generation of theory. The research involves the generation and analysis of quantitative data. The method for retrieving the data required for a quantitative analysis can be classified under Inferential, experimental and simulation approaches (Kothari, 1990). The inferential approach relates to the study of a sample from which

characteristics and relationships of a population can be inferred. The experimental approach involves the development of a controlled physical research environment through which the effect of variable can be explored. The simulation approach involves the development of an artificial environment through which the dynamic behaviour of a system can be explored. In this case, the movement of containers through transport network is considered the system. While the inferential approach cannot be applied to this study as it does not relate to a population, an experimental approach would require a large data collection process to be undertaken over a long period of time. Due to time restrictions this research employs a simulation based approach to evaluate the performance of dry port solutions within an artificial environment that simulates reality. The output of the simulation is then analyzed in a rigid fashion.

This chapter is divided into two sections. Section 3.1 puts the study in context by exploring the physical, economical and container related characteristics of the port city selected for study. Section 3.2 outlines the research method employed within the case study and discusses the method of analysis.

3.1 Background to the Case Study of Lagos, Nigeria

Global maritime freight transport has experienced strong growth and profound change over recent decades. This trend has affected transport logistics within and beyond the ports, and has made it necessary to reassess the institutional framework as well as the efficiency of the inland transport network in port cities. Southern California amongst other developed regions faces issues with its inland freight distribution system. The inability of the trucking industry to handle high cargo volumes because of congestion on roads leads to delay to containers at Los Angeles/Long Beach ports.

This issue of congestion on strategic routes within urban areas near ports, although common around the world, poses a greater problem to developing countries where poor inland transport services forces manufacturing and other key industries to locate to areas adjacent to the port. A typical example is China, where trade-induced growth appears to be limited to areas adjacent to the port. This is evident in the percentage (90%) of export-oriented industries located within China's four coastal provinces (Guangdong, Jiangsu, Fujian and Shangkai) (Asian Development Bank, 2005).

In Africa in particular, the issue of road congestion and growth in freight traffic

coupled with poor physical and institutional infrastructure is apparent in the high level of its freight transport costs. Road transport costs in Africa are generally high compared to other developing economies. For example, Rizet and Hine (1993) found, by comparing three African countries to Pakistan and France, that road transport costs in African countries were up to 6 times higher than in Pakistan and 40% more than in France – a country with much higher labour rates. The World Bank (2009) analyzed the freight transport system as being inefficient especially since the trucking industry is a labour-intensive one. Africa's low wage levels should mean its transport costs are much lower. The high costs are linked to various institutional and structural factors, including high seasonal demand for trucks, poor road infrastructure leading to high accident rates and high vehicle cost, poor management, congestion on roads, use of trucks requiring frequent repair, and general insecurities which make night driving undesirable (Pederson, 2001).

Most West and Central African (WCA) countries with ports located in major cities face problems with high transport costs and city congestion, for example Lagos, Abidjan, Dakar and Douala. The constant movement of containers and trucks through such cities results in congestion on strategic routes to the port. Lagos-Apapa port in particular is the busiest in the WCA region and accounts for almost 30% of the containerized traffic in the region. Based on the 2005 port statistics provided by the Nigerian Port Authority (NPA), 90% of containers arriving in Nigeria move through the Lagos area, and are then distributed around the country from these locations.

Over the past years, the volume of containerised cargo moving through Nigerian ports has increased tremendously, a trend which continued except in 2008 to 2009 when the world wide economic downturn implied a drop in growth rate between these years. With container traffic increasing faster than port traffic as a whole, a lack of appropriate container handling infrastructure and integrated transport systems may hinder the port's handling ability and may in the future limit the container traffic flowing through such countries. This lack of fluidity of the freight flow in urban areas has been pointed out as evidence of barriers to trade. Consequently, any steps taken to improve port access in congested areas around ports would have a positive impact on port efficiency and economic development in such countries (World Bank, 2007).

Nigeria is a typical case where the increase in freight volume, increase in population, and location of ports within close proximity to major GDP generators affect logistical efficiency. Using data from desk studies, physical interviews, and questionnaire handout,

the author accesses the current situation in Nigeria, specifically Lagos. This section provides the reader with the findings from this assessment and so sets the context for the case study. The author discusses the geography and structure of trade in Nigeria, the structure of the container industry, the current process of container movement, the geography and socio-demographics of Lagos city and the condition of the transport network at the time of this research.

3.1.1 Geography and Demographics of Nigeria

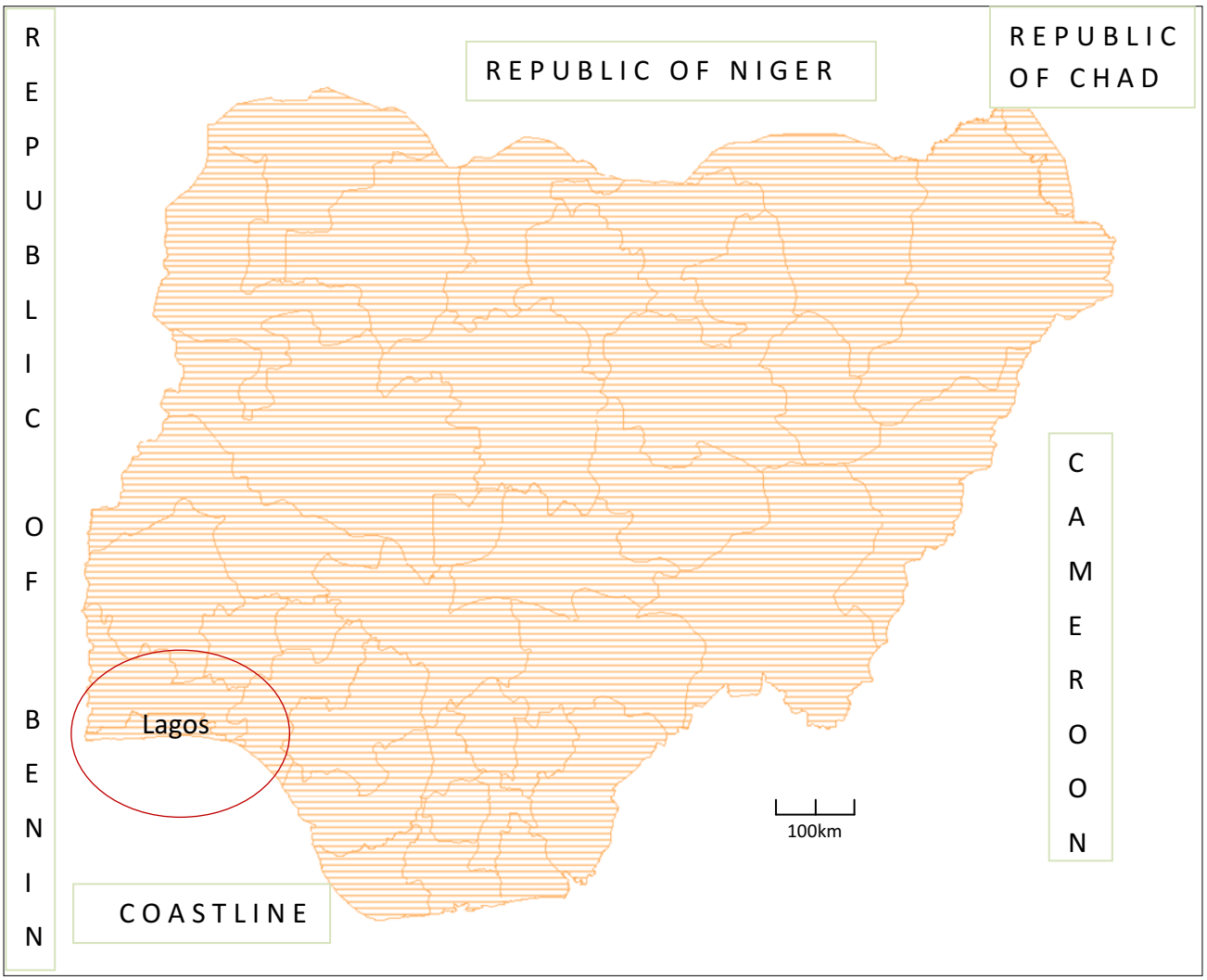


Figure 3.2: Geography of Lagos, Nigeria

Nigeria is located in West Africa and according to the definition of the World Bank, belongs to the group of low income countries. With over 150 million inhabitants, Nigeria is Africa's most populous country. It covers a land area of 911,000km^2 and is bordered by Republic of Benin to the west, Cameroon to the east, Niger to the North, Chad to the north

east and a coastline of 853km in the south. The country is divided into 36 states and Abuja (the Federal Capital Territory) which lies in the geographical centre of the country.

The city of Lagos, a state in the south-western corner of the country has a population of about 15 million people and is one of the most populous urban areas in the country. The city covers an area of only 738km^2 and has a population density of 18,150 persons per km^2 making it the smallest state in the country, the most populous city in Africa and the fourth most populous city in the world after Mumbai, Kolkata and Karachi (City mayor statistics, 2009). It is the commercial and economic centre of the country. Figure3.2 is a map of the country showing the location of Lagos in Nigeria.

3.1.2 Geography and Structure of Trade in Nigeria

3.1.2.1 Location of Ports in Nigeria

Nigeria's ports are located in the southern part of the country along the coastline of the Gulf of Guinea. There are five main commercial port complexes in the country namely; Lagos Port Complex, Rivers Port Complex, Delta Port Complex, Onne Port Complex and Calabar Port Complex. These port complexes receive vessels carrying general cargo, dry bulk cargo and liquid bulk cargo. Each of these complexes comprises a number of ports concentrated within the same area. Crude-oil is dispatched from crude-oil terminals located in Niger-delta region in the south- eastern part of the country. Figure 3.3 shows the location of these port complexes and Table 3.1 identifies their constituent ports.

Although this research centres on containerised cargo moving through Lagos ports, the reader will be presented with an overview of trade moving through Nigeria's commercial ports before focusing on containerized cargo and the Lagos ports. The following sub-sections give an overview of the trade structure in Nigeria and describe the structure and scale of trade in Lagos ports.

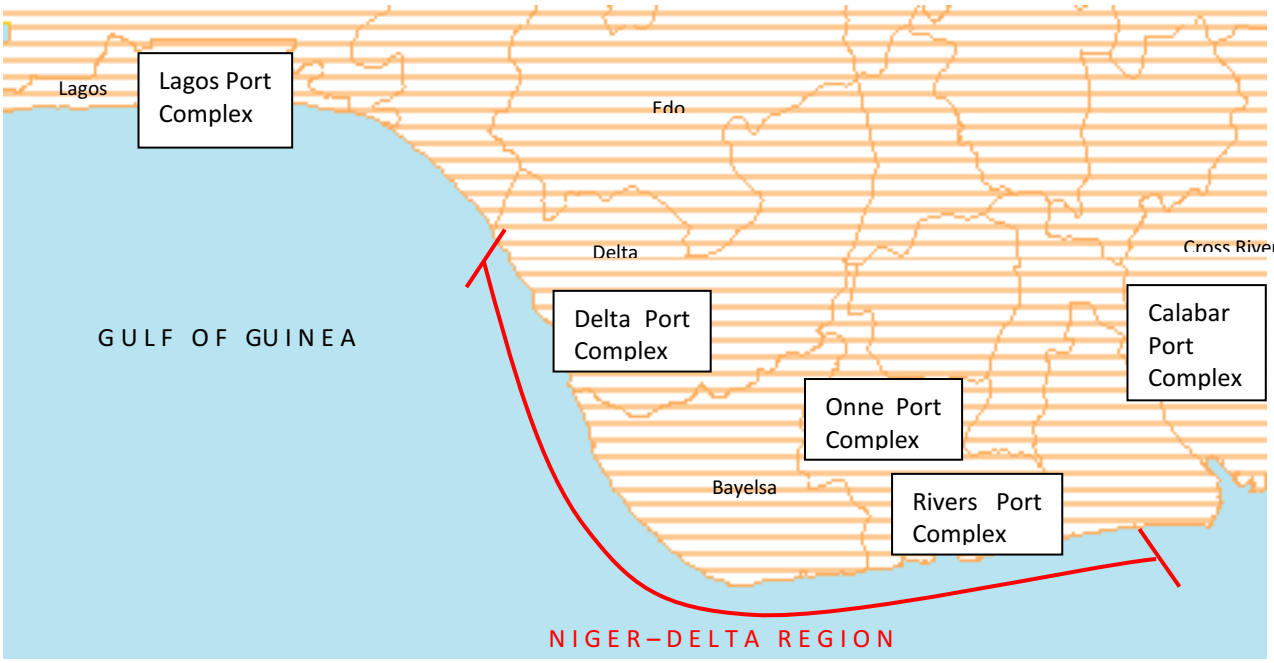


Figure 3.3: Map showing location of ports

Table 3.1: Nigeria's main ports and oil terminals

Lagos port complex	Rivers Port Complex	Onne port complex	Delta port complex	Calabar port complex	Crude-oil terminals
• Apapa • Tin Can Island	• Port Harcourt • Okrika	• Federal Light Terminal (FLT) • Federal Ocean Terminal (FOT) • Bonny LNG	• Warri • Koko • Sapele	• Calabar	• Escravos • Forcados • Qua-Iboe/ Eket • Bonny off/on shore • Brass • Pennington

3.1.2.2 Overview of Trade Through Nigerian Ports

Nigeria has witnessed a steady growth of trade through the years. Figure 3.4 illustrates the continuous increase in the total volume of import and export merchandise over the period (1999-2011). Between this periods, trade in Nigeria witnessed an average growth of 11% between the years 2000 and 2011.

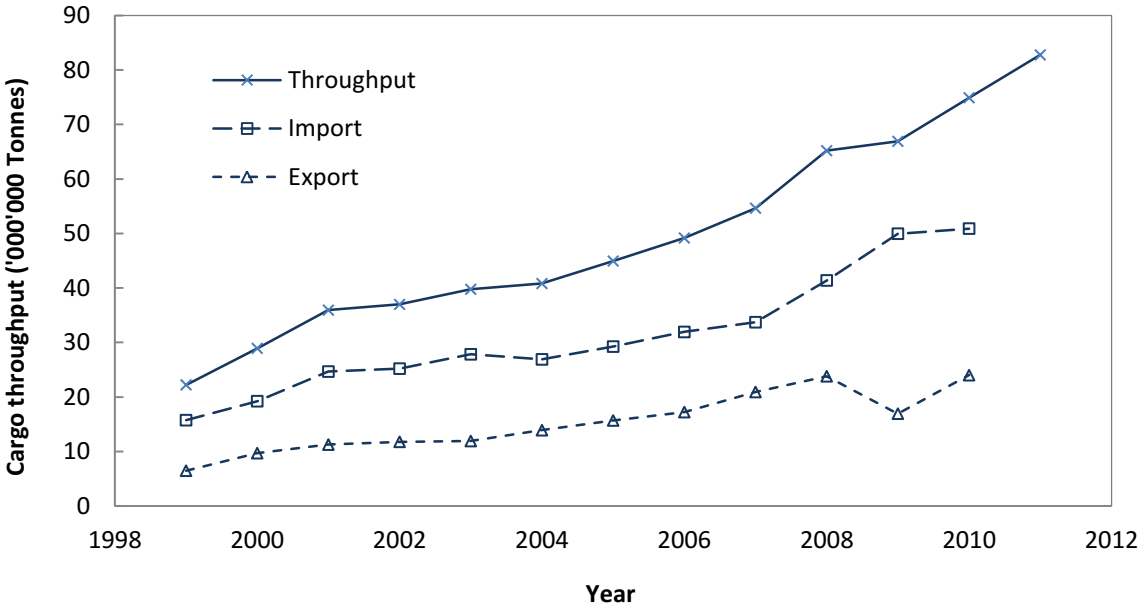


Figure 3.4: Cargo throughput at Nigeria ports in tonnes (excluding Crude-oil)

(Source: Corporate and Strategic Planning Division, Nigeria Ports Authority)

Nigeria's main exports include crude oil, Liquefied Natural Gas (LNG), cocoa, cotton and animal feed, among others. Crude oil export (through crude oil terminals in the Niger delta region) accounts for 74% of Nigeria's port throughput in tonnes while non crude oil exports and imports account for 29% of the throughput in tonnes. In 2005, the registered volume of crude oil shipped via the crude oil terminal was 112,872,821 tonnes, compared to a 14,579,897 tonnes of non crude oil related exports. Crude oil accounts for about 90% of total volume of merchandise exports, while Liquid Natural Gas export (through the Bonny LNG terminal in the delta region) accounts for 80% of the remaining 10%. On the other hand, Nigeria's import merchandise accounts for 17% of the port's throughput. However, not considering crude oil and LNG, import merchandise through Nigeria's ports account for 95% of the port throughputs. Figures 3.5 & 3.6 illustrate a clear distinction between Nigeria's export (excluding crude oil) and import trade pattern. Excluding crude oil, liquid bulk goods account for majority (93%) of Nigeria's export commodities, while dry bulk goods represent the higher percentage of import merchandise.

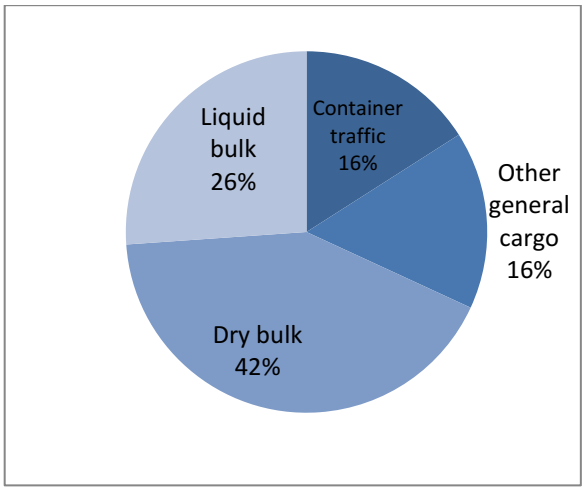


Figure 3.5: Breakdown of Nigeria's import volume by cargo type (2005). (Source: Nigerian Ports Authority)

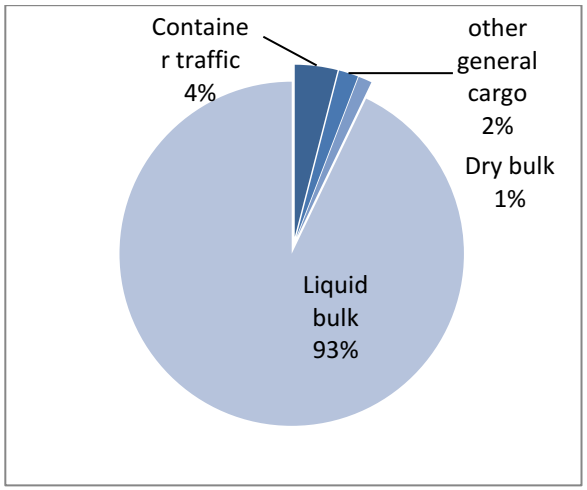


Figure 3.6: Breakdown Nigeria's export (excluding crude oil) volume by cargo type (2005). (Source: Nigerian Ports Authority)

Nigeria is basically an import economy once mineral products are excluded from trade volumes. Not considering oil exports, Nigeria's ratio of imports to export is 8.5/1 in volume terms. Although substantially better than other African oil producing countries, this ratio remains higher than most oil producing developing counties in other regions of the world (see Table 3.2 below).

Table 3.2: Import / export ratio (excluding crude oil)

Region	Countries	2007 Import/export ratio (calculated in value term)
Africa	Nigeria	8.5
	Algeria	28.3
	Angola	20.9
Middle east	Iran	3.2
	Saudi Arabia	3.2
Asia	China	0.7
South America	Mexico	1.2
	Ecuador	2.0

Source: International trade statistics 2008, World Trade Organization (WTO); Nigeria Foreign trade summary 2007, National Bureau of statistics (NBS)

The economies of African oil-producing countries like Nigeria appear to be one dimensional - Importing mostly finished goods, exporting mainly crude-oil and petroleum related products but with almost no manufactured or agricultural goods exports. As petroleum products are delivered via pipelines, it becomes clear that in linking non-oil trading to road traffic conditions; one must focus on the distribution of imports rather than the delivery of export goods to ports. One must also understand the manufacturing

potential of the country in forecasting developments in trade patterns. Whilst this research begins by focusing on imports alone, in future research, the import/export ratio may need to be adjusted to account for trends in the container traffic mix.

Figure 3.7 presents a breakdown of Nigeria's import commodities by cargo type. Dry bulk commodities account for 42% of import cargo. Dry bulk commodities include mainly wheat grain and construction cement which account for 56% and 25% respectively of the total dry bulk cargo. Liquid bulk commodities account for 26% of import merchandise. Such commodities include refined petroleum products and vegetable oil imports. Refined petroleum products alone accounts for 99% of Nigeria's total liquid bulk import merchandise in tonnes. Although Nigeria's four refineries (two in Port Harcourt, one each in Warri and Kaduna) have a total installed capacity of almost 440,000 bbl/d (equivalent to 22,161,000 tonnes per year), issues relating to sabotage, fire, poor management and low maintenance reduce their output capacity, leading to an inability to meet domestic demands and thus forcing the country to import refined petroleum products. Nigeria imports refined petroleum products from developed countries like the United States, United Kingdom, Belgium and France, and also from African countries like Cote D'ivoire, South Africa and Ghana.

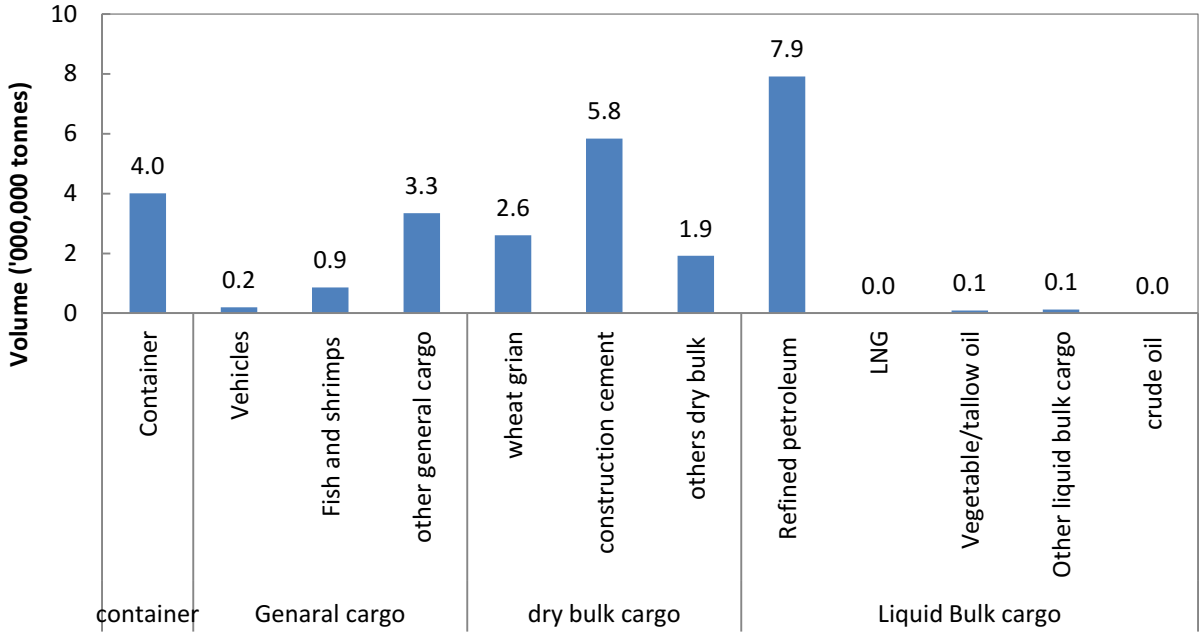


Figure 3.7: Import volume ('000,000 tonnes) of various cargo types

(source: Nigerian Port Statistics Report, 2005; Nigerian Ports Authority)

General cargo accounts for 32% of import merchandise. It is often referred to as break bulk and consists of a variety of merchandise transported in a variety of packages

including bags, boxes, cartons, crates, pallets and containers. General cargo through Nigerian ports can be grouped into containerised cargo, uncrated vehicles (Roll-on- Roll-off vehicles), Fish and shrimp goods and other commodities. Other commodities include merchandise like industrial machineries, rice, flour and sugar.

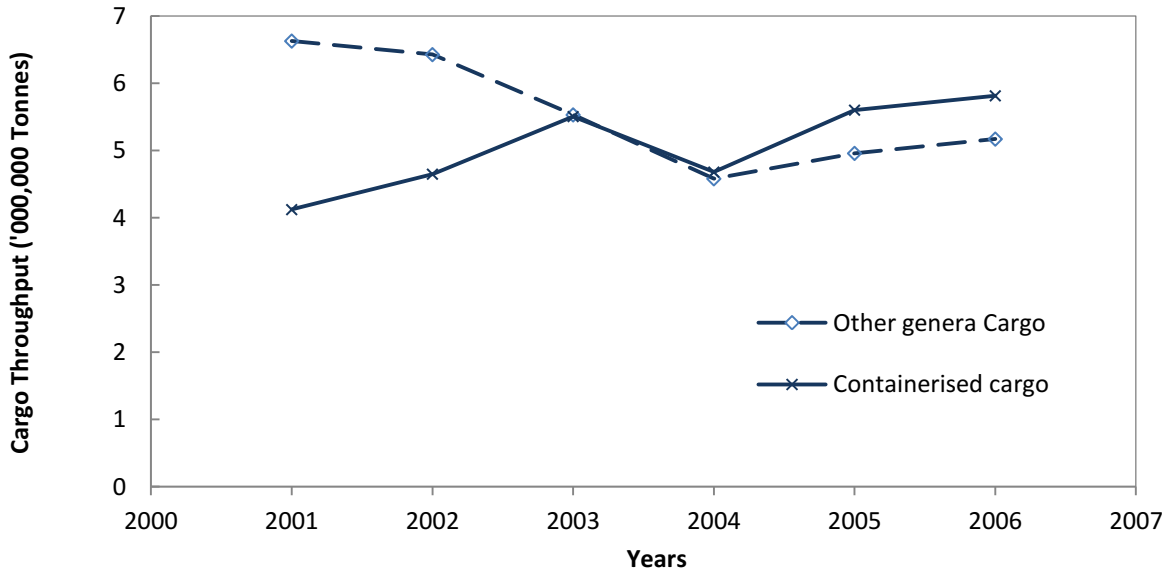


Figure 3.8: Trend in general cargo (Source: Nigerian Ports Authority)

Over the years, the volume of other general cargo has been declining while that of containerised cargo has increased. Figure 3.8 shows the growth of containerised cargo traffic compared to a decline in other general cargo (in tonnes) and Figure 3.9 shows a steady increase in container traffic through Nigerian ports (in TEUs). The advent of containerisation implies that less general cargo commodities are transported in loose packages such as those listed above as Importers are opting to transport goods in unitised volumes. This trend is expected to continue with a further increase in containerisation. In 2002, the Royal Haskoning report predicted that container traffic through Lagos port would grow at a rate of 5% between the years 2005 and 2010. However in reality growth rates between 8% and 29% occurred. This was above the average rate of economic growth of 8% which was observed between 1999 through to 2009 and 6.3% which was observed between 2004 and 2009 (JICA, 20011).

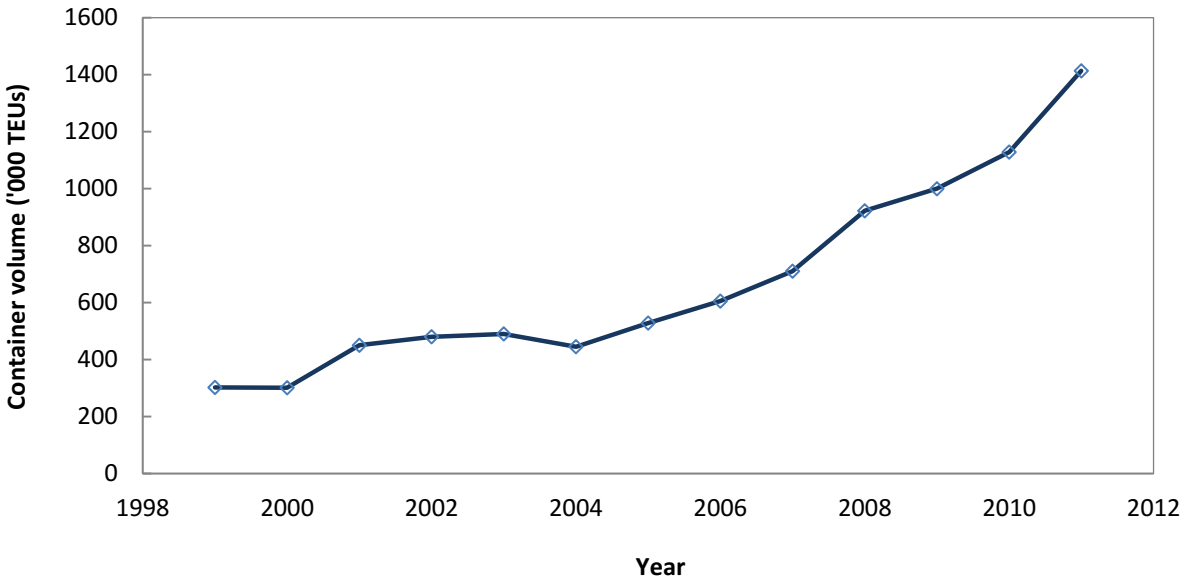


Figure 3.9: Trend in containerised cargo between 1999 and 2011

Figure 3.10 categorises imported container traffic by the type of commodity enclosed. This has been done using the standard international trade classification (SITC). Nigeria's main import products in order of percentage volume include manufactured goods (33%), food and animal products (18%), machinery and transport equipment (16%), chemicals (13%), mineral and related products (7%). Nigeria's total import "value" has increased by almost 630% within the last 10 years. Figure 3.11 illustrates this increase in import expenditure. The economy is spending more money on imports, especially on the categories abovementioned; manufactured goods, machinery & transport equipment, food and living animals and chemical related products which have increased by over 780%, 650%, 625% and 500% an 270% respectively, a trend which is likely to continue. The increase in demand for such goods can be linked to an increase in population, an increase in the number of construction projects and an inability to sustain domestic production.

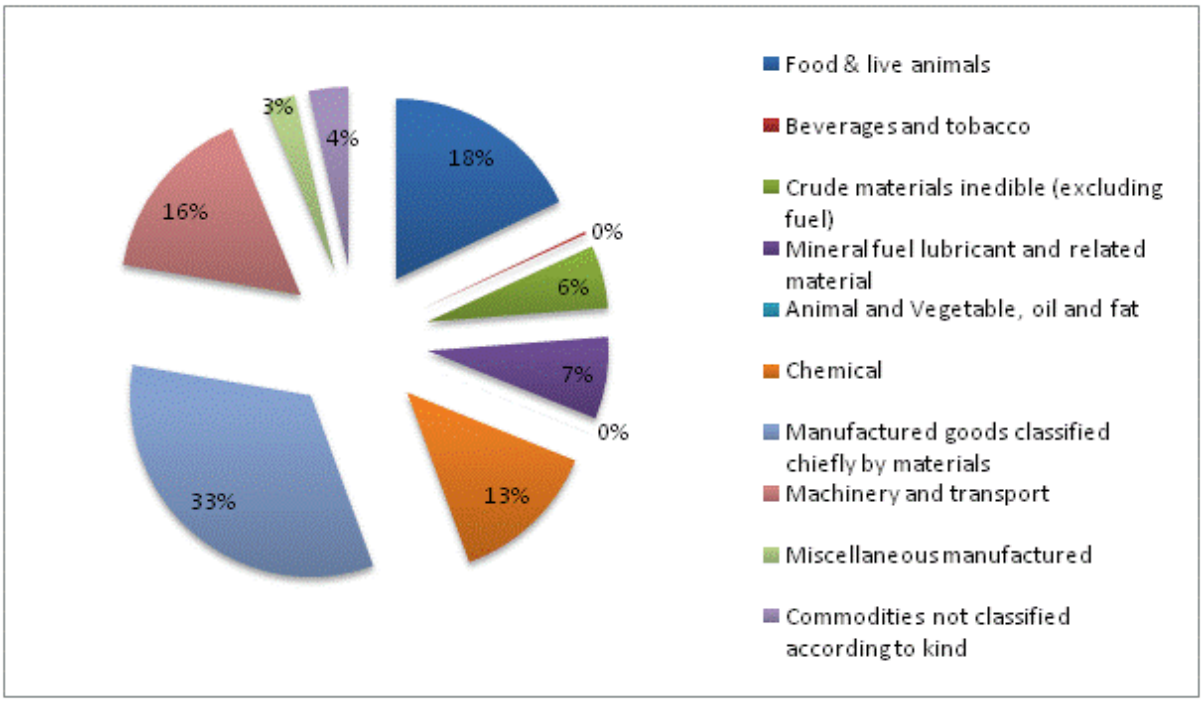


Figure 3.10: Containerised commodities in tonnes (Source: NPA 2009 statistics)

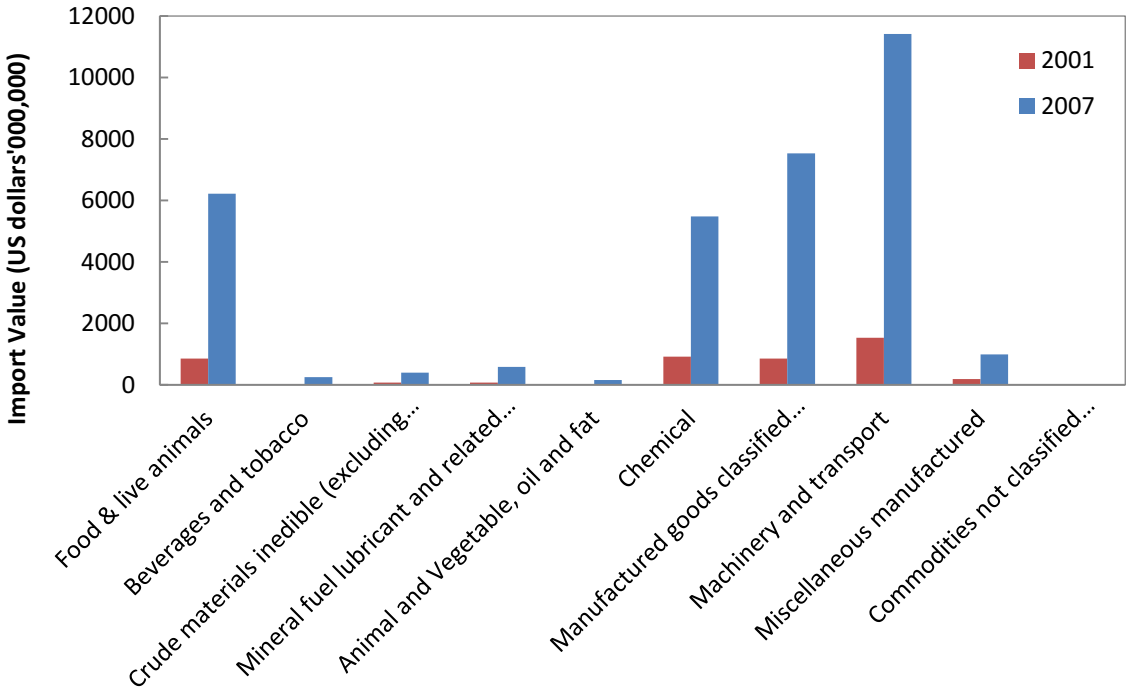


Figure 3.11: Growth in import value (Source: National Bureau of Statistics, Trade summary)

3.1.2.3 Distribution of Trade Through Nigerian Ports

In 2009 cargo throughput (excluding crude oil) totalled 66,908,322 metric tonnes. A breakdown of this shows that Apapa port handled 28%, Tin Can handled 19%, Rivers 10%, Onne port recorded 31%, Calabar recorded 2% and delta region recorded 10% of total merchandise in metric tonnes. The distribution of various cargo types between these ports is discussed below.

Liquid bulk commodities account for a large percentage of the throughput. Such commodities include refined petroleum products as imports, and crude oil and LNG as exports. 61% of Nigeria's imported refined petroleum products are shipped to Apapa port and then pumped to oil depots and distributed via road. The other 39% enter via Tin Can Island (15.4 %), Warri (9.8%), Okrika (7.1%), Calabar (4%), Federal Ocean Terminals (1%), Port Harcourt (1%), Koko (0.6%) and Federal Light Terminals (0.1%). No crude oil is reported to be exported via the Lagos Port Complex but rather through the crude oil terminals in the Niger-delta region. Liquefied Natural Gas which accounts for 83% of exports (not including crude-oil), is produced in the south-eastern part of the country and exported via the Bonny LNG terminal.

Dry bulk comprises mainly of cement and wheat grain which account for about 80% of this cargo type. While dry bulk accounts for a substantial amount of import cargo it accounts for a much lower proportion of export merchandise. 65% of dry bulk commodities move through the Lagos Ports (Apapa and Tin Can Island), another 19% moves through the rivers port (Port Harcourt), 10% move through the Onne ports (FOT) and the final 6% move through Calabar and Delta ports (Calabar, Sapele and Warri). Adjacent to these ports are facilities that process and bag the imported bulk commodities.

Excluding containerised cargo, the largest group of commodity types in the general cargo category are vehicle and Fish commodities. 92% of vehicle cargos are handled in the Ro-Ro terminal of the Tin Can Island port. The remaining 8% are handled by other ports in the country. Fish commodities and other general cargo (excluding containers) are distributed as follows: the Lagos ports (Apapa and Tin Can island) handle about 65% of this cargo type in tonnes, 15% is handled by the river port complex, 12% by Onne port complex, 7% by the Delta port complex and 1% by the Calabar port. Containerised cargo is handled mainly by the Lagos port complex which handles about 90% of the total containerised merchandise. The Rivers ports (FOT and FLT) handle about 8% and the remaining 2% are

handled by delta and Calabar ports (Warri and Calabar).

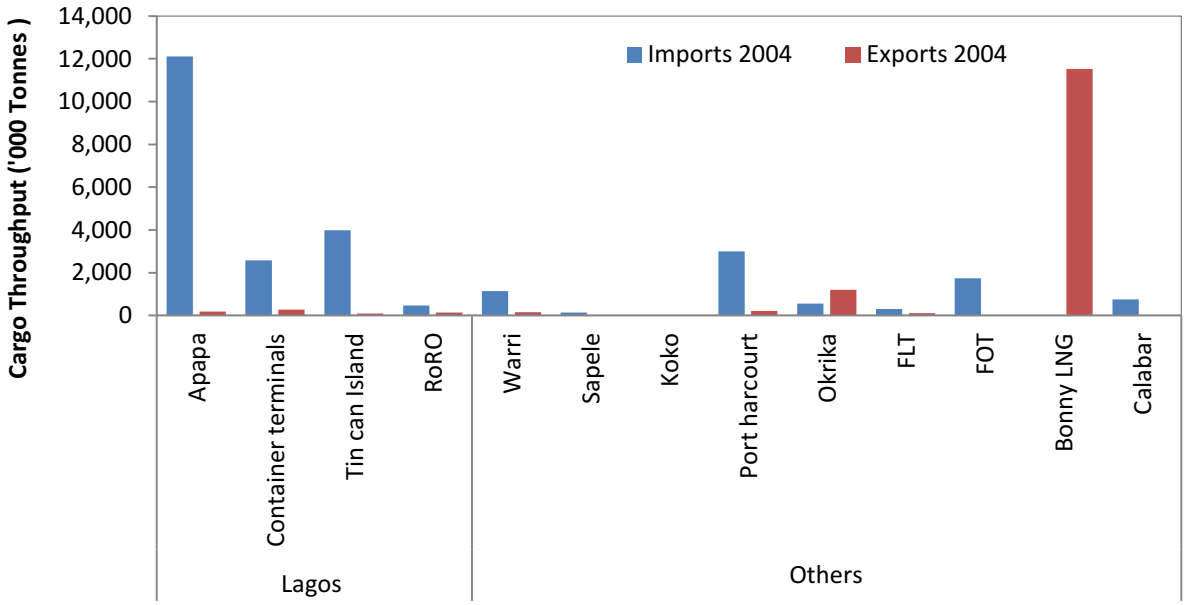


Figure 3.12: Distribution of trade through Nigerian ports (excluding crude oil)

(Source: NPA, 2005 statistics)

In general, import commodities enter the country mainly through the Lagos ports with Lagos handling just over 70% of total import merchandise in tonnes. On the other hand, export commodities exit the country mainly through the ports in the Niger-delta region. Figure 3.12 illustrates this point.

Figure 3.13 is a chart showing the distribution of import commodities, by commodity type, through the Nigerian ports. Including refined petroleum products, 51% of imports are consumer non-durable goods while another 43% are raw/ intermediate goods used as input in the production of goods consumed mainly by the Nigerian population. The other 6% are either consumer durable or capital goods. 57% of imports arriving in Lagos ports are consumer goods while 38% are intermediate goods. The situation is slightly different in the Delta and Port Harcourt ports where consumer durable and intermediate goods account for 40% and 55% respectively (Figure 3.13). Although intermediate goods account for majority of imports in the Niger-delta region, the Lagos complex receives over 67% of the country's total import intermediate goods.

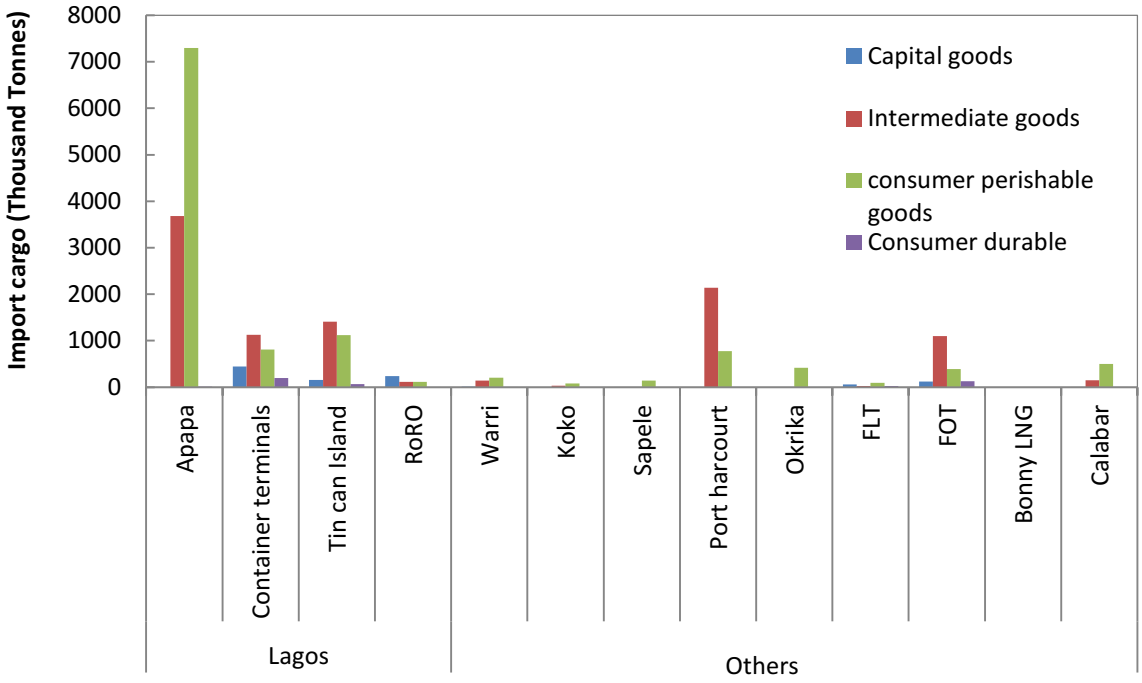


Figure 3.13: Economic analysis of import cargo (Source: NPA Annual Report, 2005)

The four biggest contributors to Nigeria's GDP are agriculture (38%), services (26%), crude petroleum (17%) and trade (11%). However, although trade and services account for 60% of the population's activities in Lagos, agriculture accounts for only 2%. This implies that a good proportion of food consumed in Lagos is imported or arrive from other parts of the country by road. Imports through Lagos are mainly consumer goods with over 78% of Nigeria's consumer goods arriving at the Lagos port complex. With Lagos state population accounting for only 10% of the country's total population, it is reminiscent that Lagos areas may not be the final destination for all non-durable goods arriving at its ports. A possible explanation might be that some of these goods are destined for distribution centres/warehouses in Lagos, and then dispersed to different parts of the country. Freight forwarders play a vital role in Nigeria's shipping process by providing distribution services and acting as middle men between shipping lines and consignees.

3.1.2.4 Scale and Structure of Trade Through the Lagos Ports

The Lagos ports comprise of two port complexes- Apapa port and Tin Can Island port complexes located about 5km apart. The Apapa port comprises of the Apapa port terminals and the container terminal. The Apapa port terminal handles mainly general cargo, liquid bulk and dry bulk cargo while the container terminal specialises in container handling. The

Tin Can Island complex comprises of the Tin Can Island terminals and the Ro-Ro (Roll-on-Roll-off) terminals. The Tin Can Island terminals handle container, general; cargo, liquid bulk and dry bulk cargo while the Ro-Ro terminal specialises in vehicle and containers.

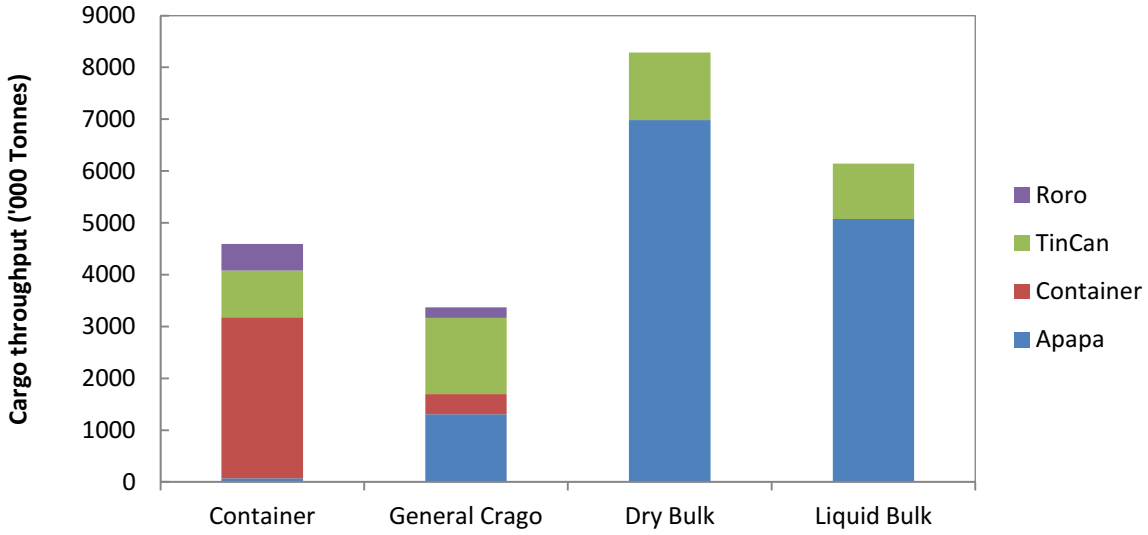


Figure 3.14: Cargo throughputs by type through Lagos ports (Source: Lagos Port Complex Annual Report, 2005)

Lagos ports receive over 70% of Nigeria's import commodities. However, they handle less than 6% of Nigeria's export commodities. Figure 3.14 gives a breakdown by type of cargo moving through Lagos ports in 2005.Dry bulk accounts for 37% of the total import volume arriving at Lagos ports. These accounts for 65% of dry bulk cargo imported to Nigeria. Such goods include cement, wheat grain and sugar which are intermediate goods used in manufacturing finished products. Import dry bulk accounts for over 97% of the dry bulk throughput. Liquid Bulk through the Tin Can and Apapa port accounts for 27% of total merchandise through the Lagos ports. It constitutes mainly of import refined petroleum products which represents over 99% of liquid bulk merchandise through the Lagos ports.

Container traffic and general cargo combined accounts for 36% of import traffic through Lagos ports. Excluding container traffic, general cargo in 2005 accounted for 15% of freight through the Lagos ports, with Apapa port and Tin Can Island port handling 7.6% and 7.4% respectively. Containers arriving at the Lagos ports represent 90% of Nigeria's container traffic. Classifying containers under laden and empty, it is observed that majority (100%) of the containers arriving at the Lagos ports are laden, while in comparison about 90% of export containers are empties (Figure 3.15). Import laden containers once unstuffed, are returned to the shipping lines' empty bays within the port or at specified empty depot facilities around Lagos. With a lack of manufactured goods for loading, the containers are

exported empty. This pattern influences the way Nigeria does trade and the overall transport costs to importers since shipping lines have to increase import tariffs in order to cover cost of their return trips.

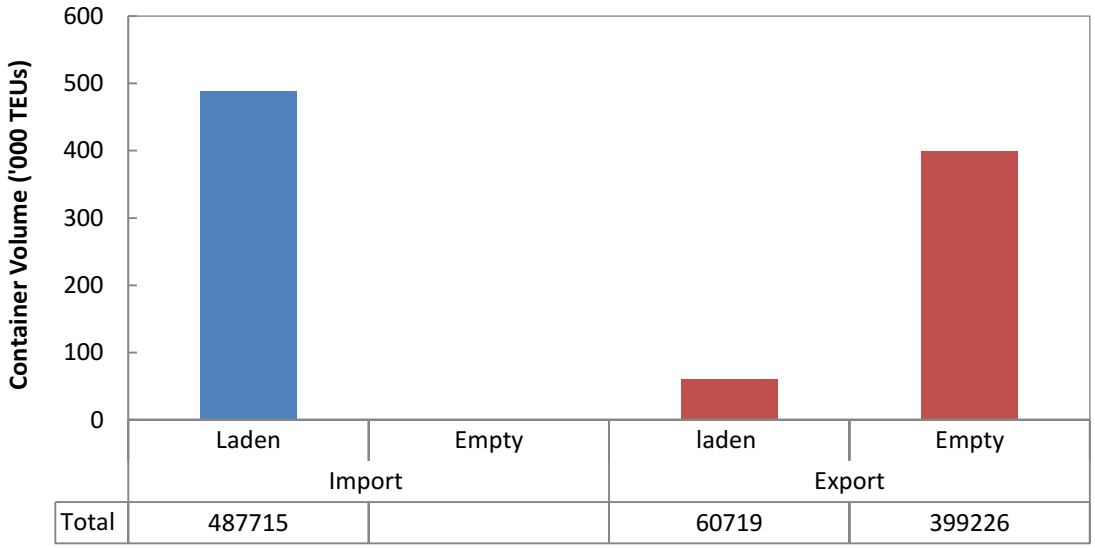


Figure 3.15: Lagos 2009 TEU throughput (Source: Corporate and Strategic Planning Division, Nigeria Ports Authority)

Containerised cargo can be disaggregated into intermediate/raw goods and consumer finished goods. Finished goods account for 65% of containerised cargo and include goods such as rice, frozen sea foods, household items, personal effects and other commodities that have completed their manufacturing processes but need to be distributed to the end users for consumption. The distribution of finished containerised commodities is highly dependent on the consumption pattern of the population and such containers are most likely to go through a distribution centre (such centres may be public or private container yards and so may vary between import transactions) before getting to the final consumers. Thus, it can be assumed that at least 60% of containers leaving the port terminals go through distribution centres before getting to the final user. Raw materials and intermediate goods, accounting for 35% of containerised goods are imported for use in the manufacturing of final-products in various industries. These goods on the other hand are required to arrive at the importers' manufacturing plants which are at fixed locations around the country. Clearly, the pattern of container traffic to some extent depends on the type of commodity enclosed in it.

In recent years the Lagos port complex has handled the highest overall cargo throughput, far ahead of other Nigerian ports. Figure 3.12 shows the imports through the various conventional ports. The locations of the ports in Lagos mean that all containers must

go through the city in order to access the final destinations. With 71% of Nigeria's non-oil import merchandise arriving at Lagos port complex, adding to its high population density and poor state of roads, it is no surprise that the roads suffer from a high level of congestion, specifically those on the approach to the ports. The dry port concept suggested as a method of mitigating congestion focuses on diverting containers from road to rail. The next section explores the existing structure of containerised freight distribution in Nigeria.

3.1.3 Structure of Containerized Freight Distribution in Nigeria

Trips to Lagos, Nigeria in 2009 - 2010 exposed the author to the issues surrounding traffic congestion on Lagos roads especially on the approach to/from the ports. The purpose of the trips was to get a feel for the situation in Lagos and to investigate the structure of the container industry. The author conferred with a number of officials in Nigeria's shipping business and key actors in the container industry through interviews and questionnaires. These interviews were unstructured and were carried out as informal discussions, in person, with terminal managers, managers of major hauling companies, freight forwarders and members of the Nigerian Shipping Council. The findings from each meeting were compared and the view of the majority was taken as true.

The visits provided the author with an insight into the processes involved in the container logistics chain, the issues surrounding container distribution and traffic conditions on the approaches to the ports. The pattern of container traffic depends on a number of factors including; the institutional framework, the available physical infrastructure, influence of key players, and the type of containerised commodity. These factors are discussed in the sections below. Laden export containers account for about 10% of container throughput which is insignificant and so not considered in the study.

3.1.3.1 Institutional Framework

Once containers are off-loaded from vessels on the terminal quay, one of two things may occur; 'stepping' or 'stemming'. Stemming as commonly termed in Nigeria, is the process of transferring containers to an off-dock terminal where the clearing process commences, while stepping refers to the instance where containers are off loaded and directed to stacking areas within the port facility. In the case of stemming, containers are

moved via the road network with custom escorts. Whether containers are stemmed or stepped depends solely on the storage capacity available within the port grounds. The clearing process is undertaken at the location to which the vessel offloads on berthing: stepping or stemming. The importer or agent has no say in whether stemming occurs or what off-dock facility to be used for clearing. The terminal operator decides which vessel's contents are to be sent to off-docks and the shipping line decides in what proportion containers are to be stemmed to their preferred off-dock terminals. However, the cost of transfer is incurred by the consignee.

Containers arriving at port terminal or off-dock terminals must undergo a clearing process. The process is complete once relevant documents are submitted (including Bill of Lading, Form M, etc.), all forms are completed, containers are scanned or physically examined and statutory charges including import duties are paid. In Nigeria, this process can take up to 21 days, a value which serves as a measure of the port's in-efficiency. After the clearing is completed, a release note is awarded to each consignment, allowing the container to leave the port or the off-dock terminals. At this point, consignees are given a fixed period of time in which to remove the consignment and return the emptied containers. The shipping line gives instructions on where to deliver empties. This could be at holding/collection bay within or outside the port facility. A demurrage charge is incurred if laden containers are not removed or empties returned on time. This fee is taken out of a deposit given to the shipping line and the excess refunded at return of the empty. If the containers are returned within the time frame specified a full refund is awarded. The deposit is in the range of $500 - $2000 per TEU depending on the shipping line and the size of the container. In order not to lose deposits and risk bad relationships with the shipping lines, importers, keen to minimise risks of delays, avoid long distance journeys. Thus, containerised commodities destined upcountry are sometimes deconsolidated at warehousing facilities within Lagos, and transported to their destinations using goods vans. This is most common with containerised finished goods.

3.1.3.2 Available Physical Infrastructure

These include the physical infrastructures which the containers move through or travel on. They include port terminals, off-dock terminals, existing Inland container depots, and the available transport network.

Port Terminals

In 2006, the federal government initiated the port privatisation programme. Under the chosen model, Nigerian Port Authority (NPA) owns the ports while the operations are provided by specific private sector operators. This section only discusses the terminals within the port city - the Lagos port complex. The port terminals are located within the grounds of Apapa and Tin Can Island ports and are managed by different terminal operators. Table 3.3 summarises lists the terminals that constitute the Lagos port complex and the type of cargo handled within them. A breakdown of the 2009 container statistics is included in Table A.1 of Appendix A.

Table 3.3: Terminals in Lagos port complex

Lagos port complex	**Terminal operator (concessionaire)**	**Berths**	**Cargo type handled**	**Container throughput 2009 ('000 TEUs)**
Apapa Port	Apapa Bulk Terminal Limited (ABTL)	1, 2, 3, 4, 5	Dry bulks (wheat, sugar, fertilizers, cement), oil	-
	ENL Consortium Ltd	6, 7, 8, 9, 10, 11, 12, 13	Break bulk, cement, gypsum, sugar	-
	Greenview Development Nigeria Ltd (GDN)	19, 19A, 20	Dry bulks(wheat, sugar)	-
	AP Moller Terminals Ltd (APMT)	15, 16, 16A, 17, 18, 18A	Containers	448
Tin Can Island Port	Joseph dam Ltd	1, 1A, 2	Dry bulks (wheat, sugar), steel	-
	Tin-Can Island Container Terminal (TICT)	3, 4, 5	Containers	220
	Port and Cargo Logistics (PCLT)	6, 7, 8	Containers, break bulk	132
	Five Star Logistics	9, 10	Containers, RORO, break bulk	44
	Ports & Terminal Multiservices Ltd (PTML)	11	RORO, Containers	63

(Source: Nigerian Ports Authority, 2009)

The concession of terminals in the Lagos port complex makes data collation quite complicated. For the purpose of this thesis, the main terminal in each port would be assumed to be representative of all terminals in the port and so would be the focus for information gathering. This is reasonable since the main terminals are expected to set the standard to which other terminals would try to keep up with so to remain competitive. Based on the 2009 port statistics, APMT terminal is the main container terminal in Apapa, while TICT and PCLT are the main terminals in Tin Can Island. Together these three terminals account for about 93% of containers through the Lagos ports. At the start of the concessions in 2006, APMT had a major market share of 74%. However, this has reduced to about 55% due to problems faced by the terminal in 2007. These problems relate to the concession agreement, lack of expertise in the African Market, overshoot of the port rehabilitation budget, non-exclusive access to concession site and mismanagement on the part of NPA in respect of its contractual obligations.

All terminals are equipped with a combination of mobile cranes, reach stackers, empty handlers, quay cranes and forklifts. APMT terminal has 5 Ship to Shore cranes (STSs), 3 of which were purchased at second hand value after the concession in 2006. It also has 6 new Mobile Harbor Cranes (MHCs) which at the moment are more efficient than the STSCs and will replace four of these. The MHCs have a handling rate of 15 moves per crane per hour, are cheaper, more flexible, lighter and do less damage to the quay. After all planned purchases are made; the terminal is expected to operate with as many as 10 MHCs. TICT berths are currently being serviced by 3 MHCs and in the near future may be serviced by STSCs. The terminal is considering investing in an empty container handler that stacks up to 7 tiers high.

The capacity of a terminal is determined as the minimum of the quay wall capacity, the quay crane capacity and the container yard capacity. At present overall terminal capacities are dictated by long dwell times within the container yards. The long dwell times are a function of the undue physical inspections undertaken within the terminal premises. Following the fire arms that were found in containers during a routine customs check in 2010, all containers are now subject to 100% inspection of which 70% is done physically. While all terminals have scanners for inspection, these are working at a rate of 80-100 trucks per day which is well below their capacity of 300-350 trucks per day. As of early 2011, the inefficient container checking procedure had increased dwell times from 19 days to an average of 27 days and up to 31 days in some terminals. Long dwell times are further

complicated by the excruciatingly long clearance process employed at the terminals. In Nigeria close to 80 forms and processes have to be signed off to complete the container clearing process. This is somewhat extreme compared to other African countries which employ fewer steps. For example, only 7-8 processes are completed in Benin and Ghana, which are also in West Africa.

Off-dock terminals

In 2001, the issue of port congestion in the Lagos port complex overwhelmed the port's operational systems. This led to a decrease in efficiency and underutilisation of the port system. Consequently, Nigeria bought into the concept of setting up off-dock terminals for logistics and distribution activities within the immediate vicinity of the ports. The off-dock terminals are used when container terminals are running at full capacity.

This option is more attractive to port authorities and terminal operators since all costs of double handling are transferred to the importer and it has a monetary advantage over increasing in-port capacity, since land outside the port is cheaper. However, their existence appears to have altered the pattern of container movement by adding an extra step to the logistics chain.

The off-dock terminals act as inland distribution centres having facilities with fixed installations offering the same administrative, custom and cargo handling functions as a seaport. They are secured areas where dutiable goods are manipulated, stored; customs inspections and examinations are carried out and statutory charges paid. They also act as distribution centre where commodities are loaded unto trucks, heavy goods vehicle or white vans for discharge to various other locations. The terminals are connected to the port via the road network and not to a high capacity rail link so do not classify as dry ports.

The functions of the off-dock terminals make them different to warehouses. Warehouses are simple storage facilities with handling equipment for the manipulation and deconsolidation of containers. Off-dock terminals on the other hand are terminals acting as mini-ports. In general, off-docks act as inland terminals connected to the ports by a road network. They are sometimes owned by terminal operators and logistics firms who are often in the same company group as container shipping lines.

There are two types of off-dock terminals; publicly and privately used depots. Public off-dock terminals are for the deposit of dutiable goods owned by the general public. The private terminals are owned by fast track importers who are often manufacturing

companies importing over 50 TEUs per month. This was an initiative set up by the government with the aim of providing a fast track delivery process for manufacturing companies while decongesting the ports. The company's containers are inspected on their private facility by Custom official and other relevant agents. In the case where a vessel is to be stemmed to off-dock terminals, containers belonging to fast track importers are retained in the container yard prior to collection. A list of such companies is included as Table B.1 of Appendix B.

There are presently over 30 active public off-dock terminals located within 35km of the Lagos ports. Their concentration within port regions is a typical case in which "polarisation in a limited number of centres is contributing to the saturation of the space and, at the same time, to the environmental impact deriving from the intense use of space and from the growing congestion of road traffic along the arteries that connect the main polarities" (Torbianelli, 2009). The Author carried out a survey to determine the flows of container between the ports and the off-dock terminal between the years 2007 and 2009. The survey involved handing out questionnaires to the managers of all identified off-dock terminals and collating the replies. Replies were received from 23 out of 33 off-docks. A summary of the result is included in Table B.2 of Appendix B. Figure B.1 of Appendix B is a map provided to show the location of the off-dock terminals in relation to the port terminals. Based on the data collected the main market share holders are the Lily Pond terminal and Hull Blyth terminal in Kiri-Kiri area and the Denca terminal in Amumo-Odofin area. Both of these are located within 5km to the north-west of the ports.

The establishment and growth of off-dock terminals in Nigeria aims to improve port capacity and originally assisted greatly in tackling port congestion problems arising from overloaded stacking areas. However, since the commercialisation of the ports, although port terminals have become more efficient and capacity has increased, growth in container throughputs and the increase in dwell times have ensured that terminals remain reliant on these off-dock terminals. It is believed that about 30% of containers discharged at APMT move through these off-dock terminals and just over 5% of containers discharged from TICT and PCLT move through them. The off-dock terminals are also used for empty container storage. The shipping lines specify the preferred off-dock terminal to which the consignees are to return empty containers prior to their transfer to the port terminal. The off-dock terminals used by the main shipping lines for storing empty containers are outlined in Table B.3 of Appendix B.

Inland container depots

The United Nations Conference on Trade and Development (UNCTAD) defines an ICD as "a common user facility with public authority status equipped with fixed installations and offering services for landing and temporary storage of export, laden and empty containers carried under Customs Control and with Customs and other agencies competent to clear goods for home use, warehousing, and export, temporary storage for onward transit and outright export"

In 2006, as part of the attempt to ensure a smooth delivery of consignments to the hinterland, the federal government of Nigeria approved the construction of 6 Inland Container Depots (ICDs) strategically positioned closer to the receivers of freight in each of the six geopolitical zones of the country. The ICDs are located in Aba (Abia), Ibadan (Oyo), Kano (Kano), Jos (Plateau), Maiduguri (Borno) and Funtua (Katsina), all with capacities between 10,000 and 50,000 TEUs pa. Figure B.2 of Appendix B is a map showing their location. The ICDs are located within a range of 150km and 1600 km by road from the port. The refurbishment of existing rail links was specified to begin with the link connecting Lagos to Kano (which is 1200 Km away by road). This development project is yet to be completed. The demise of the railways has led to the total dependence on road transport and has hindered the results expected from the introduction of ICDs in Nigeria. In general, these ICDs are not being used for the purpose for which they were created which is to ensure the transfer of freight from road to rail and reduce congestion within the port.

It is important not to confuse the facilities termed ICDs with those termed off-dock terminals. Although quite similar in that both act as extension to the port, their main difference is in their location and the roles they are designed to play. While ICDs are located outside the port cities, off-dock terminals are located within close proximity to the ports. Unlike off-dock terminals, the choice as to whether or not to use ICDs is in the hands of the importer. Off-dock terminals also have the added function of allowing importers to defer payment of duty to when the goods are required, thus acting as a free trade zone. In some ways, off-dock terminals in Nigeria are similar to close range dry ports while the ICDs resemble midrange dry ports although the lack of a functioning rail line disqualifies them from being classified as dry ports.

Transport infrastructure

Transportation network refers to the infrastructure through which goods and

persons move from one place to another. In general, a transport network may consist of various modes of transport including: road, rail, sea and air. This study is concerned with inland transportation specifically by road and rail as is discussed below.

In Nigeria, the government and public sector oversee the development of the inland transport infrastructure, yet road and rail transport has been used and developed at different rates, to different extents and within different time scales. Between the years 1950 and 1969, rail transportation was the predominant mode of transport, with significant amounts of goods and persons moving by rail to other regions in the country. By the 1970s, the length of roads developed began to increase substantially and the focus shifted from rail to road transportation. As of 2008, the total length of roads in Nigeria stood at about 194,000km of which only 30% are paved. In general, 15% of roads are classified as being in good condition, 25% in fair condition and 60% in poor condition (Agusto and Co, 2009). Roads are classified as federal, state, or local government roads depending on the level of government that owns, develops and maintains them. Table 3.4 below summarizes the characteristics of Nigeria's road network while Table 3.5 summarizes the characteristics of the road network in Lagos particularly.

Table 3.4: Summary of road statistics in Nigeria

	Ownership			
	Federal	State	Local	Total
Length of roads (km)	32,100	30,500	130,600	193,200
Percentage tarred	80%	34%	17%	58,252
Percentage un-tarred	20%	66%	83%	134,948

(Source: Federal Ministry of Works and Housing, 2008)

Table 3.5: Summary of road statistics in Lagos

	Ownership			
	Federal	State	Local	Total
Length of roads (km)	510	5817	3574	9,901
Percentage tarred	100%	51%	35%	4,728
Percentage un-tarred	0%	49%	65%	5,173

(Source: Road statistics, Lagos State Ministry of Works and Infrastructure, 2005)

Table 3.4 shows that 17% of roads in the country are owned by the federal government of which 80% are paved. While, local government roads are the majority,

constituting 67% of the road network, only 17% of these are tarred. From the table, it can be deduced that federal government roads account for almost 50% of paved roads suggesting that they are of higher standard that the other two segments. In Lagos specifically, all federal government roads are tarred, however only 50% of the total road network in Lagos is tarred. This is because Federal government roads account for only 5% of the road network in Lagos. The poor road conditions have been linked to inadequate maintenance, insufficient provision and mismanagement of investment, overuse and inadequate drainage system leading to a weakness in the road infrastructure.

More than any other mode of transport, the road has the greater use in the transportation of freight within the country. The country's 194,000km of road is maintained by the federal, state, and local government, with each overlooking 17%, 16% and 67% of the network respectively. Yet, the federal government roads carry 60% of the nation's total traffic. This may be due to the fact that while 11% and 33% of local and state government roads are paved 67% of federal government roads are paved. In Lagos especially, these federal government roads constitute the trunk routes and dual carriageways used by trucks in transporting freight.

Lagos is composed of several islands with very few bridges between them which act as major bottlenecks within the network. There are limited numbers of truck bans in operation in the Lagos Area that prevents trucks from accessing certain road ways. These can be found on the main bridges to and from the Lagos Island. The third mainland bridge and the carter bridge both have restrictions that prevent trucks from using them without permission or customs escort.

The rail transport network has been in disuse for many years but is presently being revamped for use by goods and persons. The rail network consists of about 3700km of railway track of which more than 95% are narrow gauge. However, the plan is to upgrade it to standard gauge. As of 2005, Nigerian railway operated only 527km of running line and sidings, carried about 94,000 metric tonnes of freight and had assets consisting of 8 diesel locomotives and 1,109 freight wagons. (Transport and communications quote from Nigerian Railway Corporation). In 2008, the volume of freight carried by the railway further reduced to 48,000 tonnes a Figure which is insignificant compared to the 3 million tonnes hauled by the railway at its peak in 1960. There is currently one major rail link connecting Lagos in the southwest to the north of the country comprising of 1,316km of 1,067mm narrow gauge-single track. The main rail line which runs from Lagos to Kano is currently being refurbished

by Costain. At present, no rail link exists from Tin Can Island, although rail access exists from the Apapa terminals. However this needs to be refurbished for use. The existing rail tracks are shown in Figure B.2 of Appendix B.

3.1.3.3 Stakeholders

The stakeholders are individuals or organisations that set policies and make decisions that influence the day to day running of the container supply and logistics chain in Nigeria. The key players in the shipping business include; the shippers and their agents, shipping lines and their agents, port terminal operators, off-dock terminal operators, transporters, and the Nigerian Port Authority (NPA).

It is common for importers to employ the services of a freight forwarder or an agent who helps with the clearing process or a logistics firm who on behalf of the client oversees the relevant stages in the supply chain. The logistics firm could play the role of shipping, freight forwarding and transporting. Depending on agreements, once the clearing process is completed, it is the responsibility of the importer, freight forwarder, or logistics firm to organise the delivery of the containerised cargo to the consignee's specified location. Very often, this job is subcontracted to major transporters who own fleets of trucks available for hiring.

The transporter collects the container after the clearing process at the port or the off-dock terminals and delivers it to the address specified by the consignee. This address could be a warehouse owned by the consignee/importer, a container yard or an area rented by the consignee/importer for container stripping. At these locations, the containers are opened and the commodities removed. The issue of ensuring safe and on-time delivery of containers is further complicated by the fact that each truck arrives with a driver assigned by the transporting firm which does not have complete control over what is done by its employees. Thus, it is often necessary to assign a third party at delivery, who oversees the drivers and ensures that no unnecessary detours are made to prevent delays enroute. The drivers themselves pose a risk to the transportation business. As it is impossible to track their every move, it is becoming difficult to ensure that they do not make unplanned stops or divert from their assigned course. Furthermore, it is becoming common for drivers to steal some/part of the commodities, or to tamper with parts of the trucks including withdrawing fuel from the tanks.

The major shipping lines in 2009 include MAERSK, CMA CGM and MSC carrying 28%, 23% and 11% of unloaded containers respectively. Table B.4 in Appendix B summarises the market share of the main shipping lines based on 2009 container throughput at Lagos container ports. Very commonly, shipping lines patronise specific terminals often having predefined agreements with their operators and sometimes partnership arrangements. For example, in 2008/2009, MSC vessels accounted for over 48% of the vessels arriving at Port and Cargo logistics terminal. Another example is the AP Moller- MAERSK partnership where over 70% of Maersk's vessels berth at the AP Moller terminal. The advent of conglomerates and business arrangements like MAERSK – AP Moller group and MSC – Port and Cargo/SIFAX group and their links to off-dock terminals has resulted in certain acts of favouritism during the container stemming process. The implication of this is that such lines have their containers stemmed to a limited number of off-dock terminals. The independent off-dock terminals, being the least favoured, are allocated fewer containers per year. In addition to this, future improvement in the efficiency of terminal operations may reduce the volume of containers stemmed to off-dock terminals and may force the less preferred off-dock terminals out of business.

Most shipping lines provide strings that call at both Apapa and TinCan Terminal or have alternative vessels calling at each terminal. This may be because the main customers prefer different terminals on the basis of tariffs judgements offered to them by Customs. In another case, based on an agreement with APMT, CMA-CGM may discharge containers consigned to the APMT terminal at TICT when APMT is full. MSC has a 30% equity stake in Port and Cargo Logistics Terminal and so all of its ships call at that terminal. On the other hand, although APMT is a sister company to Maersk, it handles a large number of container volumes for other lines and so not all of Maersk's ships call at APMT terminals for space constraint as well as Customs reasons. Table B.5 of Appendix B shows the shipping profile for the major shipping lines serving Lagos ports as of 2009.

3.1.3.4 Current Import Containerised Cargo Distribution Pattern

Following interviews with key players in the container industry including freight forwarders, shipping line agents and terminal operators, a general pattern for container distribution from the Lagos port terminals can be outlined. These patterns relate to the stemming and stepping processes discussed in Section 3.2.3.1.

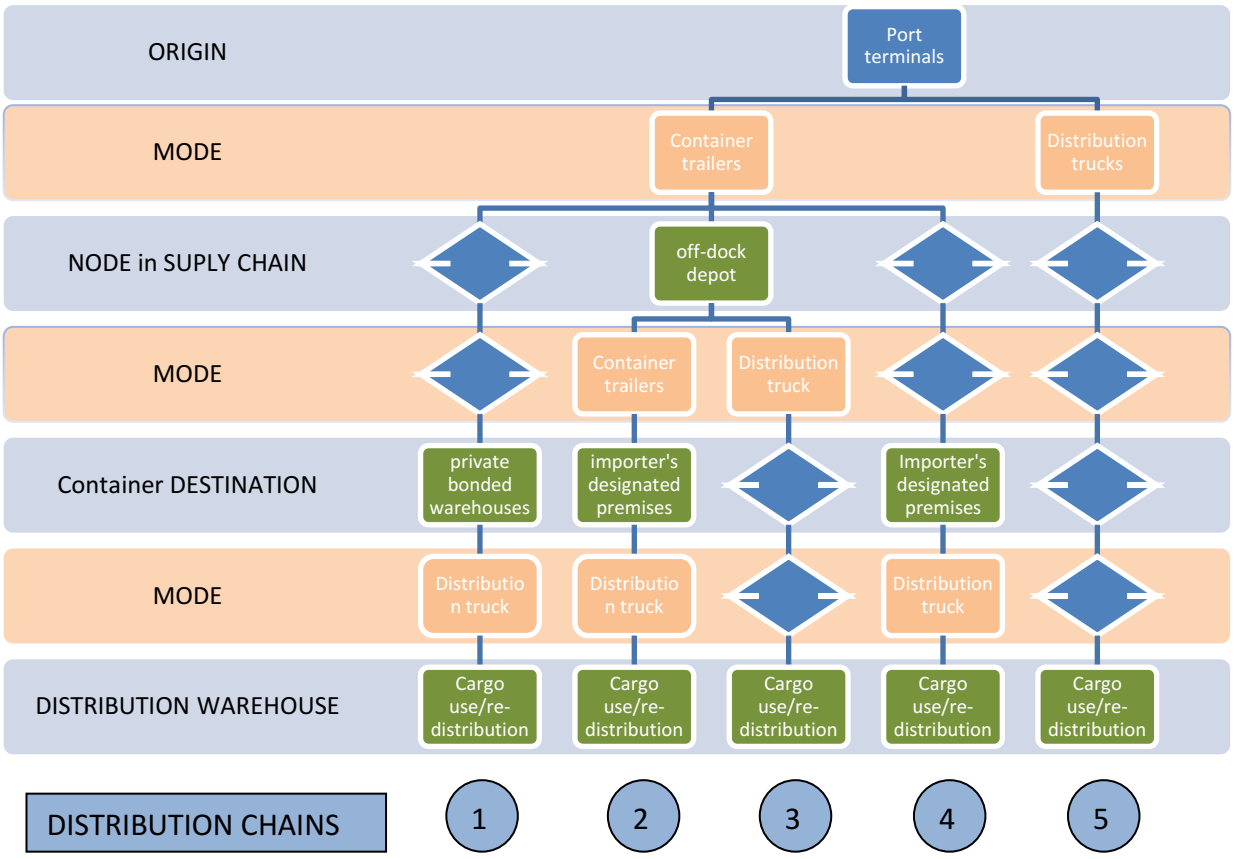


Figure 3.16: Container logistic chain[1]

There are several distribution chains through which containerized cargo reaches distribution warehouses (the first point in the supply chain where consumer goods are distributed for use and raw/intermediate goods are stored for use) in the country. These distribution chains constitute of a number of stages representing the move between the key nodal points (include port facilities, off-dock terminals, and private warehouses/distribution centres/delivery yards) in the container distribution chain. Each of these stages are characterised by the associated vehicle carrier (mode) and the containerised cargo destination (node in chain). Figure 3.16 describes the distribution pattern of containers through the container logistic chain and identifies the distribution chains that make up the container logistic chain.

In general, containerised cargo is transported within its original packaging

[1] In Figure 3.16, container trailers refer to container carriers transporting the containers, whilst distribution trucks are trucks carrying the contents of the containers.

(containers) by container trailers or in smaller distribution trucks and vans once removed from containers. The switch between container trailers to distribution trucks occurs at different points in each of the distribution chains. For example, containers cleared at port terminals are transported by container trailers via roads to importer's specified location where containers are stripped and the goods are used or distributed. Alternatively, after clearing at ports, containers are stripped and goods are transported in distribution trucks to specified locations where goods are used or distributed.

The research covers the movement of containers through all of the distribution chains outlined in Figure 3.16. Table 3.6 summarises the percentage of import laden containers associated with the distribution chains outlined in Figure 3.16. These Figures relate to the Lagos ports and are obtained from interviews with port and off-dock terminal operators. Also, it is found from interviews that 4 to 6 distribution truck movements are generated from a single container load.

Table 3.6: Import laden containers associated with each distribution chain

Ports	Distribution chains				
	1	2	3	4	5
Apapa	5%	25%	5%	60%	5%
Tin-Can	5%	8%	2%	80%	5%

Figure 3.16 is a representation of the logistic chain for laden containers and does not include empty export containers which have different distribution chain for their return to the port. To reduce congestion within the port, empty containers move from container yards to the empty depots specified by shipping lines before being transported to ports for export on a later date.

These findings form the basis for developing the transport model used in this research and are expanded on in Chapters 4 and 5 of this thesis. The transport model wil simulate the container moves at each stage in the logistic process.

3.1.4 Effect of Freight Movement on Traffic Conditions in Lagos

It is a common belief that 85% of all containers arriving in Lagos are destined for consignees within the Lagos area where they are stripped and distributed to different parts

of Nigeria. This container pattern poses a strain on the level of traffic in areas within the surrounding areas of the port.

The city's centre is characterised by a dense road network, located within 40km radius of the port complex. A 12hr manual traffic count was undertaken in January 2008 by Lagos Metropolitan Area Transport Authority (LAMATA) at various key road intersections within the city. The proportion of trucks in the average daily flow of vehicles with 2 or more axles was determined and is illustrated in Figure 3.17, using pie charts applicable to each survey point. It can be observed that trucks account for a substantial percentage of traffic; on average accounting for up to 20% of traffic. In general, routes carrying vehicles out of the city's centre, to the east and north of the country, and links in the immediate vicinity of the ports appear to have higher proportion of trucks using them. The size of the red dots represents the range of the percentage value of trucks travelling in various directions at the survey points, and suggests a variation in the pattern a truck travel. Ojota road survey point recorded the largest range, with one link carrying trucks accounting for over 70% traffic.

Figure B.3 of Appendix B highlights the potential congestion prone areas located within a 25km radius of the ports. It is a continuous raster grid produced by an interpolation of the over capacity at each survey point. These values were derived by subtracting the 12hr traffic count in PCUs from the practical capacity of the relevant section of roadway. The 12hr traffic count were obtained from traffic count survey provided by LAMATA while the practical roadway capacities were calculated using the Federal Republic of Nigeria's Highway Design manual. The grid map suggests that areas around the Ikorodu road, Ojota, Oworonsoki, Airport road, Alhaja Masha, New Festac bridge, Tin Can, Apapa Wharf road, and Mobil road survey station are the most prone to congestion.

Further analysis was carried out on the traffic count data, to understand the traffic configuration and so the role played by trucks in traffic congestion within various areas of the city. Comparing Figure 3.17 and 3.18 below with Figure B.3 of Appendix B, it can be seen that areas prone to congestion (those listed above) are also characterised by a high level of daily truck traffic and total traffic.

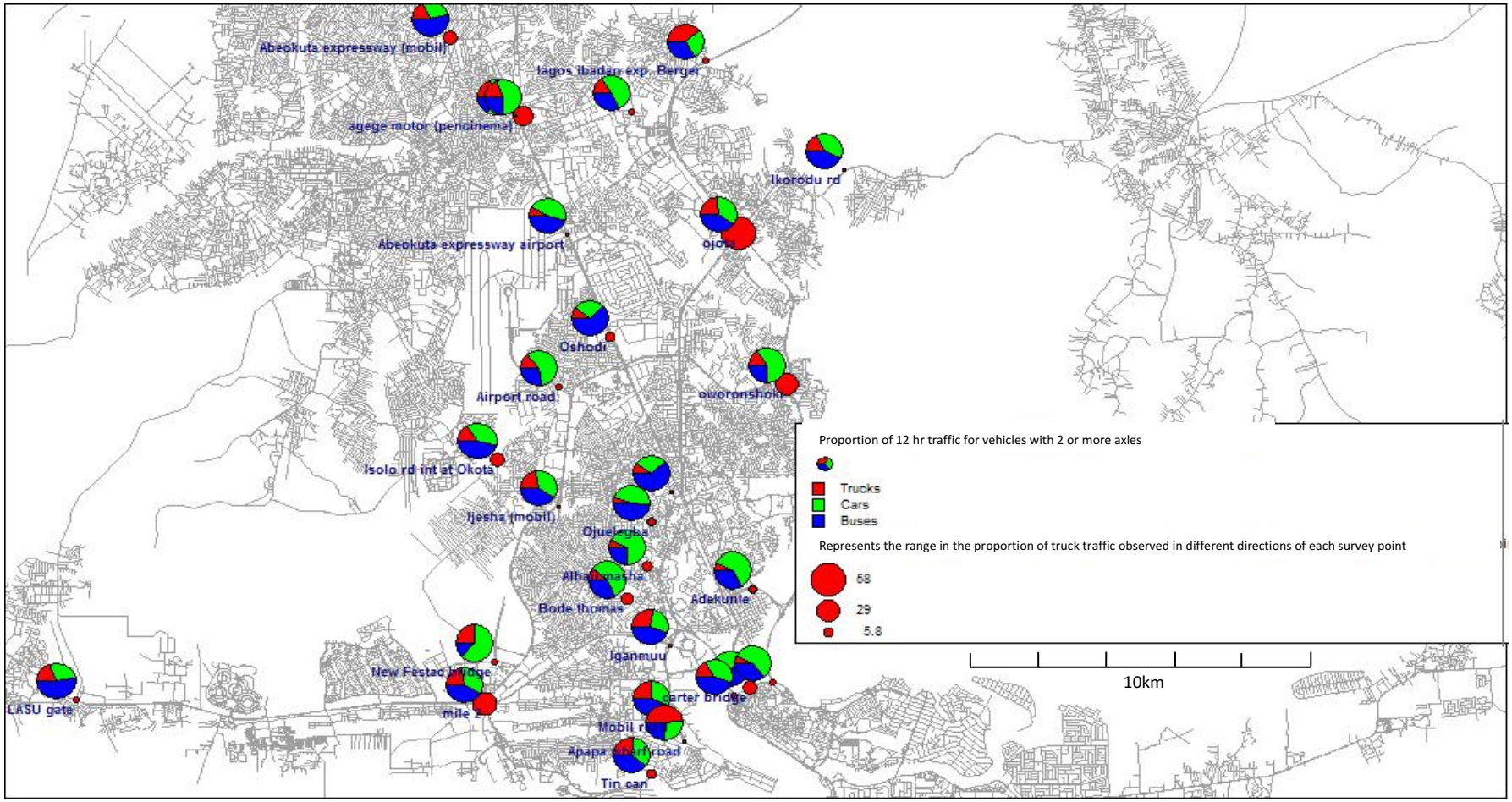


Figure 3.17: Schematic map showing the 12hr traffic in PCUs.

*The size of the red dot represents the range in the variation of the 12hr traffic at each of the survey point.

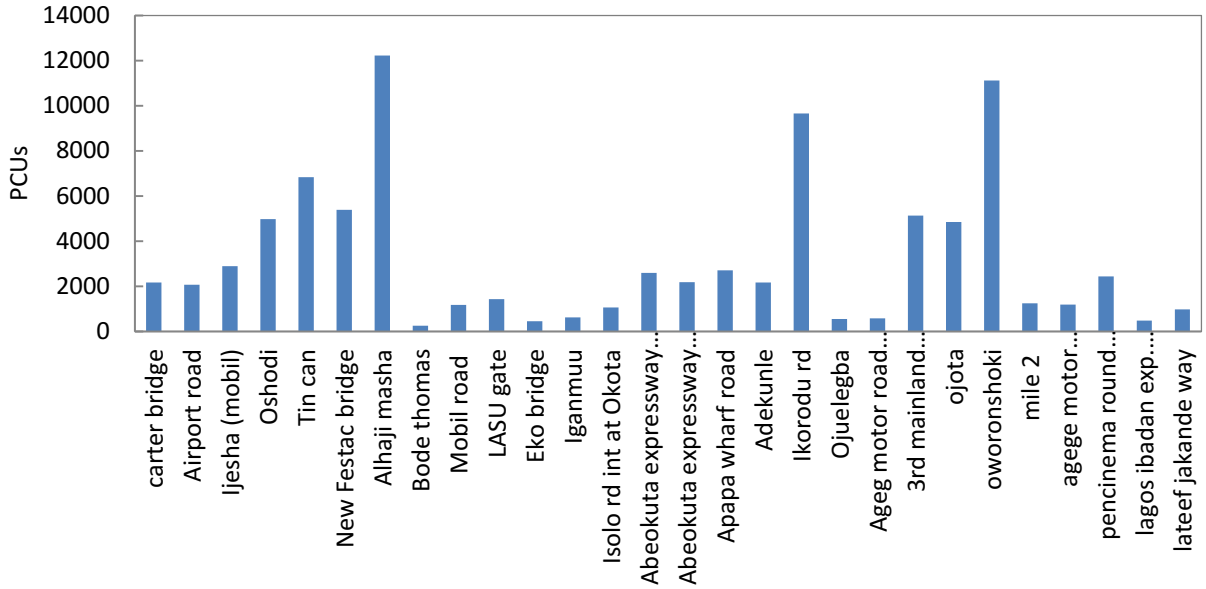


Figure 3.18: Truck traffic observed at each location during the 12hr time period (2008).

Figure 3.19 below suggests that within the 30km radius, there is a correlation between the level of freight traffic on links and the distance away from the port. On average, freight traffic accounts for just below 15% of traffic in PCUs. However, freight traffic accounts for above 20% of traffic in most areas within 5km of the port. Freight traffic concentration is at its lowest mid way through the city where it is dispersed over a large number of links on approach to different locations. However, it increases on the approach to the city rim as a limited number of exit links are available for use.

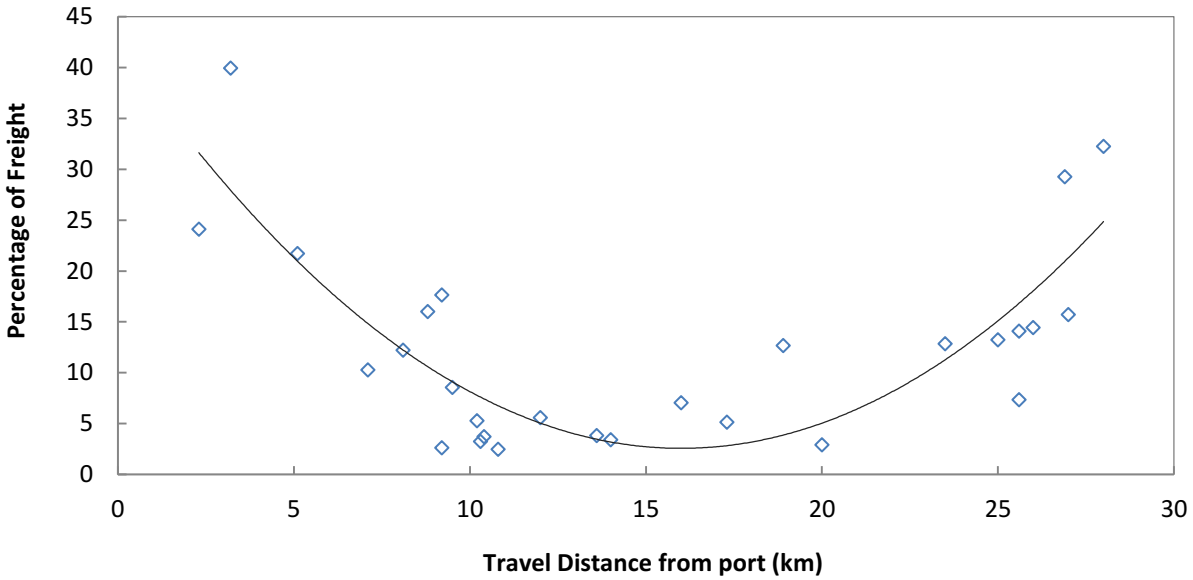


Figure 3.19: Percentage of trucks against distance away from ports

Roads within 5km of the Lagos ports are heavily congested with daily traffic often well above the design capacity. Figure 3.20 below compares the traffic and design capacity of a number of primary roads located within the port vicinity for the traffic analysis period of 12 hours. It can be observed from Figure 3.20 that most if not all the roads reach this maximum cap, with trucks accounting for a significant proportion of road traffic in the region.

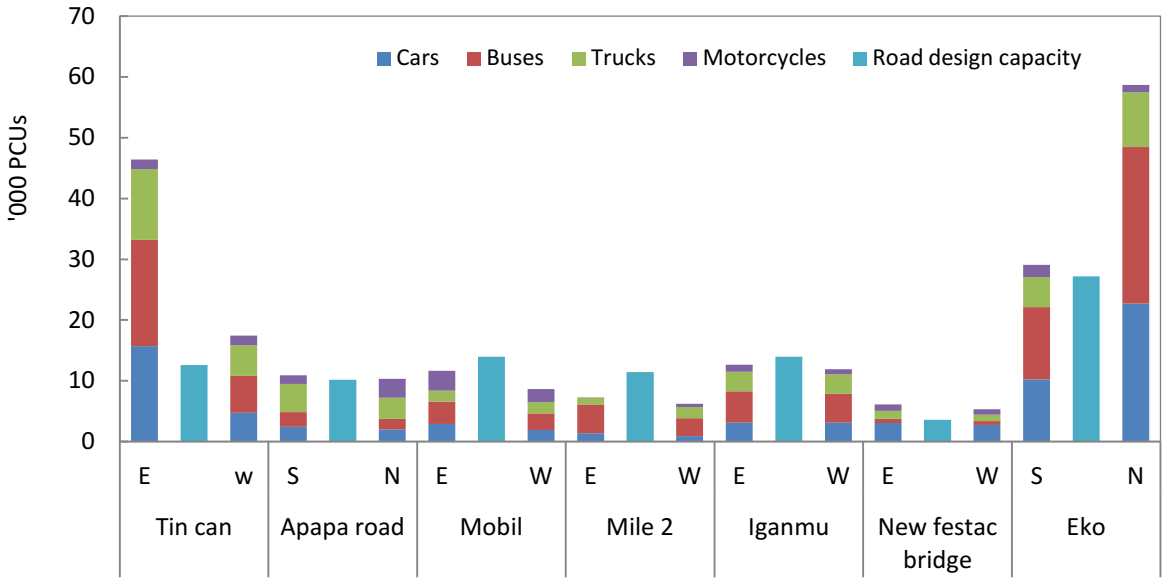


Figure 3.20: Average 12 hr traffic on some major roads leading to Lagos ports, in PCU (Source LAMATA, 2008).

Rodrigue (2008) claimed that congestion within a port region may also be attributed to the location of inland distribution centres. Notteboom and Roderigue (2005) suggested that although moving some port functions into the nearby hinterland, for example decentralising port distribution by creating inland distribution centres, increases the efficiency of port capacity use, it also brings about some disadvantages like heavier traffic on the roads within the port region.

Problems of congestion within the port vicinity are further worsened by the lack of parking spaces on the approach to the port gates. Parking spaces for trucks queuing to pick up or drop off containers are unavailable in the vicinity of the port and so trailers queue up on the main roads. This reduces the available space for transversing key access routes and fuels the congestion on routes in the vicinity of the ports. The issue is more crucial for the Apapa port terminals, which have only one access gate and much shorter internal access roads, than for the terminals at Tin Can Island. The short access roads from the main port

gate to the terminal gates means that vehicle queuing cannot be accommodated on internal port roads, and gets displaced to the public highway. While Apapa port terminals may increase capacity by reducing dwell times, improving the efficiency of crane moves or increasing storage space in yards, it is doubtful that the road network would handle the increase in traffic brought about by the capacity increase.

In general, the complex continuous flow of cargo throughput, added to poor efficiency within the ports, and poor state of the roads linking ports to hinterlands play a part in causing congestion on roads leading to the ports region and often on highway junctions away from the ports. With the level of containerization growing rapidly, the port's location may be detrimental to its sustainability and trade growth in the future. Consequently, any steps taken to improve port access in congested areas around ports would have a positive impact on port efficiency and economic development (World Bank, 2007).

3.1.5 Site for a Close Dry Port

As explored through case studies in Section 2.2 of this thesis, the dry ports employed by congested port cities, whether close or mid-range, are characterized by their close proximity to the port's main customer base. The trade pattern in Lagos is similar to that of Sydney and Auckland where the majority of containers entering the ports are destined for areas within close proximity to the port. In both cases (Sydney and Auckland), a close dry port is provided as a solution, thus supporting the proposed use of a close dry port to reduce road congestion in Lagos, Nigeria.

Techniques for determining the optimal location for a dry port have been proposed and applied by a number of researchers. Earlier research conducted by Ruthen (1998) relates location of the terminal to the number of available terminals, rail distance, and system performance of the rail services within a TERMINET model used to design an inland intermodal terminal in the Netherlands. Ng and Gujar (2009) undertook an analysis using a heuristic grid technique to determine the optimal location of a dry port based on the least cost centre. In their method, the optimal location is the place with the minimum transport costs. This concept is similar to the work done by Arnold and Thomas (2004) who use an integer programming model to minimise total transport costs in order to find optimal locations for intermodal terminal. Wand et al (2009) proposed the use of a robust

optimization model within a stochastic environment. A number of researchers have applied Data Envelopment Analysis (DEA) efficiency measures to obtain optimal facility locations (Narasimhana et al 2005, Klimberga et al 2008).

Multi-criteria analysis is also used to define the most appropriate location for intermodal terminals. In general these methods consider the factors and set criteria that may impact the efficiency of the facility. The importance of these criteria is compared with respect to stated interests and preferences. Kapros et al (2005) uses this method to examine the trade off between public and private interest. They use the Rembrandt method to weight criteria and rank location alternatives using additive aggregation functions. Analytic Network Process (ANP) and Analytic Hierarchy Process (AHP) have also been employed in multi-criteria evaluation to determining the optimal location of logistic centres (Promentilla et. al, 2007; Fariborz, 2006; Kahraman et. al, 2006). Both Yang et. al (2007) and Ou et. al (2009) employ a fuzzy optimization problem to solve the location problem.

The location of a dry port is important for ensuring efficient and effective movement of freight between the seaport and point of consumption or production (Ag et. al, 2009). Once such favourable location is found, the impact of such a facility on the road network is yet another point for research. This study does not concern itself with the optimal location of such a dry port facility but instead with the impact of such a facility on congestion in the road network.

In the context of Lagos, Nigeria, the characteristics of a close dry port is constrained by the issue of inadequate transport investment common to such developing regions. For this reason, the choice of potential dry port locations is limited by the location of existing rail lines and availability of land. A previous study carried out at Imperial College identified a potential location for a close range dry port connected to the Lagos ports (White et.al, 2009). By carrying out a multi-criteria analysis that considered factors including infrastructure costs, proximity to an existing rail line and road access, land cost, constructability, and the potential for expansion, the study identified a site located 50km north of the port as suitable for the location of a close dry port. The site selected is located at the rim of the Lagos city and close to the only rail line running from Lagos to Kano. The proposed site is an unoccupied land area of approximately 700,000m^2. The location of the dry port is illustrated in Figure 3.21. The thesis is taking this proposal further by examining the impact of such a dry port on traffic conditions. This is done by exploring the effect of the dry port solution on traffic conditions compared with a ‘no dry port’ scenario. The research

method is described in the sections following this paragraph.

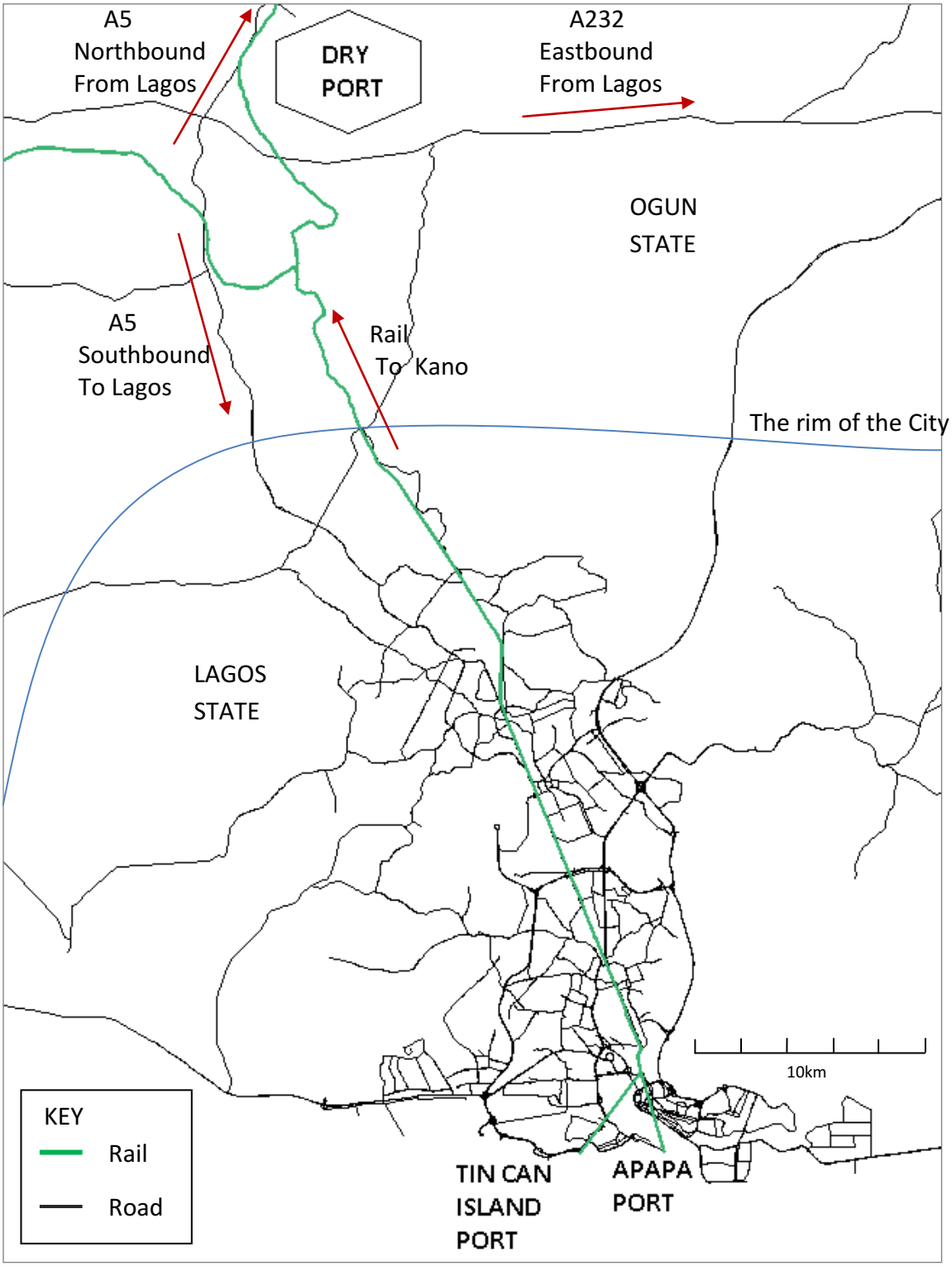


Figure 3.21: Location of close dry port.

3.2 Overview of Research Method

This research takes a case study approach to exploring the impact of a close range dry port on traffic congestion in a port city. The process involves developing a container freight traffic model to simulate current container traffic patterns as well as those caused by the introduction of selected close dry port cases. The current container traffic pattern is derived from the container flows through the nodes in the present supply chain as is described in Section 3.1.3.4. However, in the test scenarios, the dry port is an added node to the supply chain and provides an alternative mode (rail), to importers which produces an alternative container traffic pattern. This is outlined in Figure 3.22 below. The distribution of containers through the stages in the supply chain is modelled using the framework described in Section 4.2 of this thesis and is described in more detail in chapter 5. The current traffic pattern is referred to as the reference/baseline case while those related to the inclusion of the dry port are the test case scenarios. The reader should note that the purpose of the thesis is not to find the optimal geographical location for the dry port but rather to consider the effect of such facilities on traffic conditions in the city and the impact of some outlined characteristics on its ability to reduce congestion.

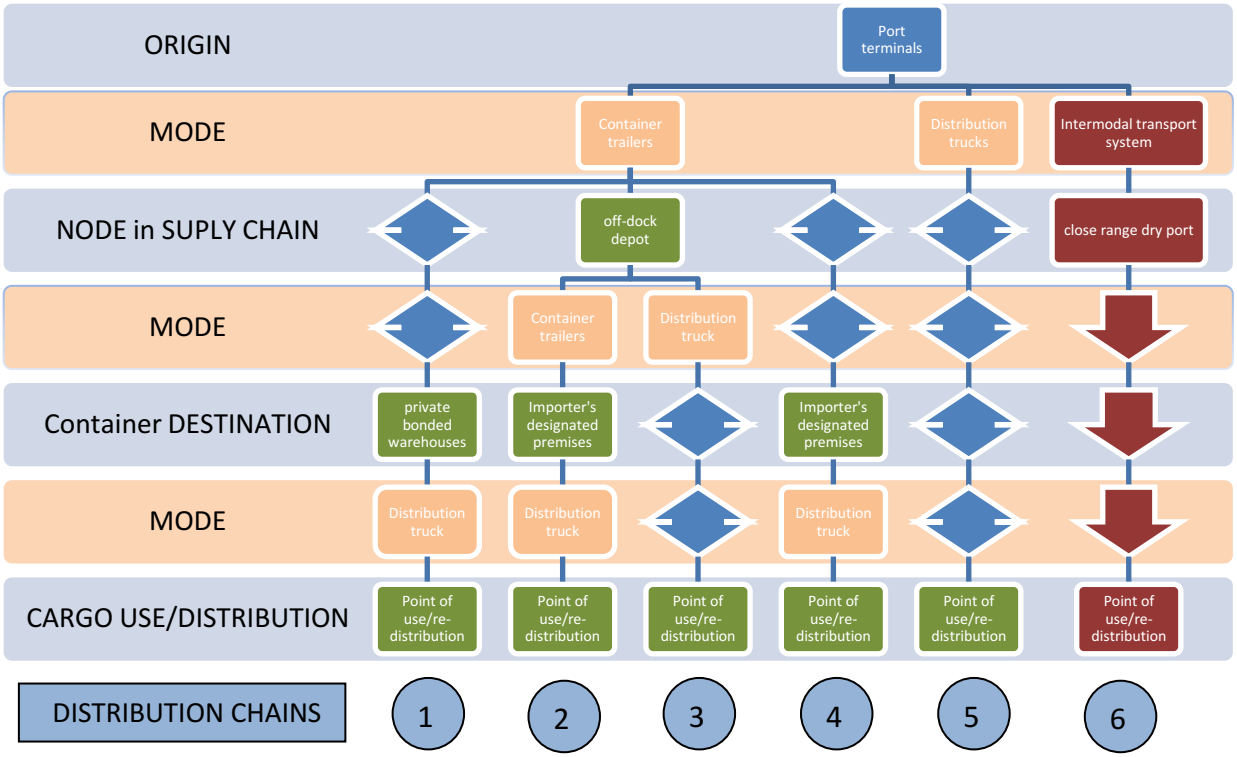


Figure 3.22: Container distribution in dry port case

In this case study, the reference and test case scenarios are modelled and their

impact on congestion in the transport network is measured and compared. The level of congestion relating to the traffic patterns obtained from each case represents the output of the model and is measured using selected performance measures. The output of the test scenario cases are compared to those from the reference case to obtain the relative benefit of each test scenario case. The relative benefits associated with each scenario case are then compared to identify the causes of any differences between them. The next two sub-sections discuss the test scenario cases explored in this study and outline the network impact measures selected for use in this study. Section 3.2.3 outlines the tasks that build up to the findings of this study. These tasks are discussed briefly in this section but expanded upon through the subsequent course of this thesis.

3.2.1 Outline of Dry Port Test Cases Scenario

The research aims to quantify the impact of a container close dry port solution on traffic congestion in a port city. Following the review in Section 2.2, the most common operational characteristics of dry ports connected to port cities are selected for focus in this research and include the provision of Empty Depot Service (EDS) and warehousing for container stripping and cargo distribution within the dry port. In this context warehousing is considered for distribution only since containerised trade in Nigeria, like other West African countries is found to be import oriented. Thus, the second operational characteristics (added value service) considered is termed a Freight Distribution Service (FDS). Scenarios for analysis explore the existence of the dry port solution with and without the identified characteristics. Their impacts are considered at different levels of dry port throughput.

Clearly, given a location, the operational characteristics of a dry port will dictate the volumes of trips exiting or entering the dry port facility. The research focuses on the inclusion of two operational characteristic variables - Empty Depot Service (EDS) and Freight Distribution Service (FDS) - in a dry port solution and so explores the impact of four dry port cases.

- Case A: Close dry Port with FDS
- Case B: Close dry Port without FDS
- Case C: Close dry port with EDS
- Case D: Close dry Ports without EDS

3.2.1.1 Case A or B: Close Dry Port With or Without Freight Distribution Service (FDS)

On arrival of containers via rail at the dry port, containers are transferred to the container yard to await clearing and collection. Upon collection, two scenarios may occur: 1) Laden containers are placed on a trailer and transferred to a consignee defined location; 2) laden containers are sent to the Freight Station to be stripped and the goods are transferred to trucks for transportation to a consignee defined location. While the first scenario can occur in a dry port with a container yard, the second requires the provision of a Container Freight Station as well.

For simplicity, this research considers the worst cases relating to the scenarios above and so considers only extreme conditions. Thus, the case of a dry port with FDS considers a container freight station that deconsolidates 100% of container volumes through the dry port. That is all containers arriving at the dry port are stripped. On the other hand, the case of a dry port without FDS considers a dry port that deconsolidates 0% of its container volumes. That is no containers through the dry port are stripped within the facility.

3.2.1.2 Case C or D: Close Dry Port With or Without an Empty Depot Service (EDS)

Following the delivery of a laden container to the consignee, the empty trips are generated from one of the following scenarios: 1) the empty containers are sent back to the dry port for transfer via rail to the seaport 2) the empties generated are sent to other existing empty depots in the container distribution chain. The first scenario supports the provision of an empty depot within the dry port facility and refers to a dry port that is set up to receive empties on behalf of the shipping lines. In the latter, consignees are encouraged to use other existing empty depots and so an empty depot service may not be provided within the dry port.

Relating to empty container handling, two extreme situations are considered. Firstly, for the case of a dry port with an empty depot, the facility handles 100% of empties generated from containers through dry port. All empties generated from the dry port are returned to the dry port. On the other hand, in the case of the dry port without empty depot, the facility handles 0% of empties generated from containers through the dry port. That is consignees do not send empties back to the dry port but rather are required to use other existing empty depots and so an empty depot service is not provided within the dry port.

The extreme case A and B like case C and D are mutually exclusive and cannot exist concurrently. That is to say that in the extreme case, a dry port cannot provide an empty depot service and at the same time not provide it. This is same with the case of the FDS. However, the provision of an empty depot and a FDS are independent and both characteristics can exist in an extreme solution. Thus, a factorial technique is used to allow the two independent events to be varied within this single study. The factorial design produces 4 revised combination cases for test:

- Test Case 1: Close dry port with FDS and with EDS
- Test Case 2: Close dry port without FDS and with EDS
- Test Case 3: Close dry port with FDS and without EDS
- Test Case 4: Close dry ports without FDS and without EDS

In the analysis, only one variable is considered at a time by comparing cases with the same alternative variable. That is excluding the variable that is being tested, like cases are compared with like cases. For example, case 1 is compared to case 2 and case 3 is compared with case 4 when exploring the FDS variable.

3.2.1.3 Level of Dry Port Utilization and the Allocation Mechanism

The dry port cases outlined above are tested under 7 scenarios representing 7 different levels of utilization. The level of utilization is the volume of import containers handled at the dry port and is given as a proportion of the total import container traffic through the seaport in the reference year.

The 7 usage levels are derived from two distinct allocation mechanisms relating to different transport chain functions of the dry port. Five of these are derived from the 'satellite' allocation mechanisms and the other two are derived from a 'load centre' allocation mechanism. The 7 usage level scenarios are discussed below.

<u>Usage level scenario 1 to 2</u>

Scenario 1 is the usage level obtained from a 'load centre' allocation mechanism where the dry port is patronized by consignees in all zones within closer proximity to the dry port than to the seaport. This includes zones within and beyond the city limits and is determined on the basis of shortest travel distances to and from the ports and dry port. Zones closer to the rim are serviced by the dry port while those closer to the port are

serviced by the port. On the other hand, Scenario 2 is the usage level obtained from a 'load centre' allocation mechanism where the dry port is patronized by consignees in zones beyond the Lagos city limits only.

The level of utilization in these cases depends on the concentration of consignees within the appropriate zones. Only containers destined for these zones are directed to the dry port facility the others move through the existing distribution chains. The proportion of containers moving between zones and dry port will therefore depend on the demand/ generation of container traffic in each zone.

Usage level scenario 3 to 7

Scenarios 3 to 7 represent usage levels obtained from a 'satellite' allocation mechanism where the dry port services all zones in the country. Fixed usage levels representing the percentage of port traffic are considered at an increment of 10%. The usage level scenarios 3, 4, 5, 6, 7, represent 10%, 20%, 30%, 40% and 50% of the port traffic respectively.

The 7 usage level scenarios and 4 test cases are combined to give 28 test scenario cases. The effects of the 28 test scenario cases on road network congestion are measured within the model and analyzed to retrieve conclusions relating to the impact of these dry port characteristics. The 28 test cases and reference case is modelled as discussed inChapter 4 and 5 of this thesis.

3.2.2 Selected Measures for Congestion

Traffic congestion is defined by FHWA (2004) as "the point at which the performance of the transport system is no longer acceptable due to traffic inference". While two types of traffic congestion exist-recurring and non-recurring -, the model focuses on the recurring congestion that may be brought on by routine traffic volumes transversing the network, specifically those relating to container freight.

The performance of a transport system can be evaluated in relation to traffic congestion using congestion indicators. These performance indicators are most commonly grouped under three main headings: time based measures, spatial measures and Highway Capacity Manual (HCM) measures. Time based measures express the duration of congestion experienced by network users. Such measures include travel delay, travel time, mean speed,

vehicle hours travelled (VHT) and probability of delay. Time-based measures are easier to understand and are flexible enough to describe traffic conditions at various levels in the network. Thus, these measures are appropriate for analyzing specific locations as well as entire routes in the network (Quiroga, 2000). Furthermore, time based measures translate easily into cost measures and are increasingly being used by a transport agencies to monitor congestion in road networks (Quiroga, 2000). Spatial measures on the other hand define the spatial performance of the system. Such measures include lane occupancy on roadways, queue length, queue density and vehicle miles travelled (Bertini, 2005). Although queue based measures reflect the users perception of congestion, they are more difficult to measure and analyze.

HCM measures generally define the performance of the system at localized points in the network. The most commonly used measures are outlined in the Highway Capacity Manual. They include the volume/ capacity ratio (V/C ratio) and level of service (LOS) which can be derived from the V/C value. The volume capacity ratio relates the volume transversing a roadway per unit of time to the volume it was designed to handle. The LOS is determined based on the volume to capacity ratio and other traffic flow characteristics such as vehicle density. Traffic conditions are allocated to one of six classes ranging from A to F, where 'A' represents free flow and F represents a complete breakdown in flow. While these measures provide an adequate platform for comparing the performance of multiple roadways, they do not reflect the road users' experience in the network which is better reflected by time based measures. FHWA (2005), suggests that time- based measures be considered as the main indicator of congestion as they are easier to determine and recommend that other measures be used in addition to these.

The performance measure for congestion used in this study relate to network savings from container related traffic only. This measure the lower bound solution as it considers the link capacity made available to the non-container traffic (all other traffic). Furthermore, the study concerns itself with relative savings as these measures will allow for a simpler interpretation of results. These performance indicators are measured at two aggregate levels - system level and route level - and a disaggregate link level. The levels and performance indicators are outlined below.

1. System Level: This measures the impact of the overall container freight system on the transport network.

- System Freight Vehicle Hours Travelled (VHT): calculated as the total number of containerised cargo vehicle hours travelled in the analysis period.
- System Freight Vehicle Kilometres Travelled (VKT): calculated as the as the total number of containerised cargo vehicle kilometres travelled in the analysis period.

2. Route Level: This measures impact on round trips along main corridors. The analysis focuses on routes to and from ports and trips to and from the port city.
    - Route Freight Vehicle Hours Travelled (VHT): calculated as total number of containerised cargo vehicle hours travelled on routes to and from fixed zones within the analysis period. This identifies improvement to round trips trucks from /to fixed origin.
    - Route Freight Vehicle Kilometres Travelled (VKT): calculated as the as the total number of containerised cargo vehicle kilometres travelled on routes to and from fixed zones within the analysis period.
3. Link Level: This measures impact to traffic on links to and from the port and dry port, in the same way as described for the system and route analysis. The analysis focuses on links on approach to and from ports.

The vehicle hour savings is calculated as the difference between the vehicle hours travelled in the reference case (with no dry port) and the vehicle hours travelled in the test scenario case. A negative value implies an increase from the reference case. The same applies to the Vehicle Kilometre savings.

3.2.3 Overview of Method Process and Tasks

So far, thesis has provided the reader with a background of the study area and the structure of analysis (the test scenarios and network impact indicators). This section discusses the processes and tasks involved in the research method beyond those documented earlier. The processes relate to developing the container traffic assignment model and undertaking the comparative analysis that forms the basis of the finding in this study. The tasks are a breakdown of the steps undertaken within the processes. Outlined below are the tasks involved in each of the processes.

Process 1: Develop a container freight traffic model for the study area

Task 1: Literature review

- Review literature on existing freight models
- Review literature on methods available for estimating freight O-D matrix
- Review of literature on demand modelling
- Review literature of existing assignment models
- Select appropriate modelling tools

Task 2: Data collection for model

- Identify model requirements
- Investigate and collate existing data
- Run of independent surveys to collect unavailable required data

Task 3: Develop traffic model

- Develop transport network model
- Develop the assignment model
- Estimate the container traffic demand matrix
- Determine the volume of non-container traffic on links in the network

Task 4: Model calibration and validation

- Carry out Independent traffic counts and road side surveys necessary to validate and calibrate model.
- Calibrate and validate freight traffic assignment model

Process 2: Traffic impact analysis

Task 5: Run of reference and test scenario cases to obtain output for analysis

- Obtain model output for reference and test scenario cases outlined in 3.2.1. As discussed two common variables (empty depot service and freight distribution service) were selected for study.

Task 6: Traffic Impact Analysis

- Obtain performance measure related to the reference and test scenario cases.
- Compare results of test scenario cases

The outcome of the tasks 1 – 4 is a container freight traffic model which is used for

task 5 and 6. In that sense, process 1 produces the inputs into the traffic model which is used to simulate container flows in the road network of the study area. The characteristics of the resulting simulated network condition are the output of the model and the input to process 2.

Figure 3.23 summarises these processes. The outputs of process 1 are obtained by assigning a container demand matrix to routes in the road network using VISUM transport modelling software. The container demand matrixes represent the movement of containerised cargo between the supply chain nodes within zones in the study area. The matrix is derived using a combination of methods including demand modelling and grossing up of survey data. The assignment procedure models the trucker's route choices (pattern of distribution) and is based on a shortest-route algorithm which determines low impedance routes. The impact of the distribution pattern on congestion is then deduced from the model outputs using the performance indicators outlined earlier.

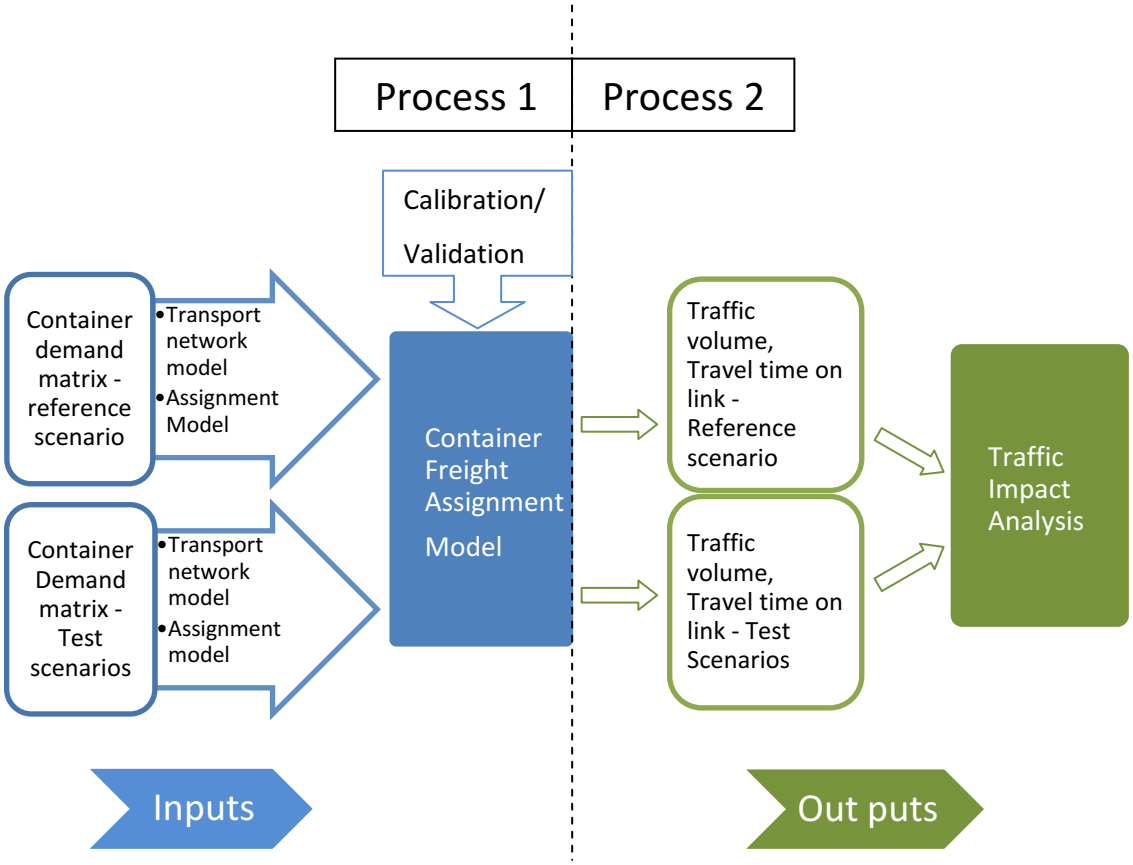


Figure 3.23: Method process

3.3 Summary

The first half of this chapter presents the reader with a background on the case surrounding the city selected for study (i.e. Lagos, Nigeria). It discusses the geography and demographics of the city, the structure of trade in Nigeria as a whole, the structure of container trade and the container industry and the current pattern of container distribution through the port city. The findings in this section forms the basis of the assumptions made in and structure of the container freight traffic model developed for use in this thesis.

The second section discusses the structure of the comparative analysis undertaken in the thesis, outlines the dry port scenarios to be investigated and presents the indicators employed to measure congestion in the road network. It ends by outlining the general method process and tasks involved in the research.

The remaining chapters in this thesis, reports on the tasks outlined in Section 3.2.3. The outcome of tasks 1- 4 is discussed in chapters 4 and 5 of this thesis while tasks 5 and 6 are tackled in chapters 6. In the next chapter (4), the literature review following task 1 is included in Section 4.1 and Section 4.2 details the framework under which the traffic model required for simulation is developed.

Chapter 4

Container Freight Traffic Modelling - Literature Review and Framework

Section 4.1 of this chapter presents a comprehensive review of the literature on existing transport models and techniques used in modelling freight movements. Section 4.2 builds on this review to develop the framework used for modelling the distribution of containerised cargo in Lagos, Nigeria.

4.1 Literature Review

A transport model can be used to predict the resultant pattern of the movement if people and freight. The movement of goods is the subject upon which this study is based. Many researchers including Pendyala and Shankar (2000), D'Este (2000) and Jong et.al (2004) support the use of a refined four-step transport modelling structure originally derived for passenger transport modelling in freight modelling. The four steps in the context of freight transports are identified as:

- Trip generation: this relates to the production and attraction of goods to zones. Specifically, in this step, the amounts of goods transported from the each origin zones to destination zones are determined.
- Trip Distribution: In this step, the distribution of goods generated at zones is determined as flows between origin destination pairs. The result of this are inputs into cells in the O-D matrix
- Modal split: this relates to the allocation of commodity flows to various modes of transport including road, rail, and inland water as relevant.
- Trip Assignment: Truck trips are assigned to the transport network to determine network link flows.

The differences between freight and passenger demand are believed to make freight modelling more complex than passenger modelling and suggest that freight transportation models should be developed uniquely. Researchers such as Ogden (1992), Holguín-Veras (2000a), Ortúzar and Willumsen (2001), and Friedrich et al. (2003) have identified the following points as key differences between the two types of demand (Freight and Passenger) and recommend that they are considered in the freight modelling process:

- Freight vehicles are often designed for specific commodity types which have various time constraints ranging from urgent unit parcels to non-urgent bulk shipments.
- Freight traffic unlike passenger traffic requires specific infrastructure and hubs for its loading and unloading.
- There are several actors in the freight industry (e.g. shipper, freight forwarder and haulier) that influence travel patterns in bulk (or batches) which is different to passenger travel where decisions are taken by individual travellers.
- The transport network carrying the freight traffic exists within a supply network which consists of nodes, links and terminal hubs which have specific constraints such as transfer delay times and capacity.
- The costs for shipment vary substantially between haulage service providers and are often defined only after a quote is requested by a potential shipper.
- Freight transport can includes many more trip chains than passenger freight. Holguín-Veras and Patil (2005) postulate that on average passengers make 1.2 stops per trip unlike freight which make up to 5.6 stops per trip.
- Freight transport is multidimensional and can be measured in a number of units such as truck weight (tonnes), truck volumes and number of truck trips.

Hensher and Figliozzi (2007) argued that changes in the supply chain procedures, freight systems and logistic structures are the primary cause of the obsoleteness of current freight models. They believe that the conventional four step modelling approach primarily designed for passenger transport cannot capture these complexities of freight movements. They advocate that in the application of this four-step model to freight, factors relating to the number of actors and type of commodity among others must be considered. Southworth (2003) supports this argument stating that a successful freight modelling tool considers supply chain logistics and may need to adopt entirely new modelling frameworks alongside the traditional methodologies.

Transport modelling in general can be done at two levels: macroscopic and micro-simulation. Micro-simulation refers to the dynamic modelling of individual vehicle movements within a transport system. Macroscopic models on the other hand simulate traffic flows as a cumulative traffic steam on a link-by -link basis rather than by considering individual vehicles.

These models are centred on the speed, flow and traffic density relationships and the conservation of flows. This research will focus on the macroscopic level of modelling.

4.1.1 Vehicle (trip) Based or Commodity Based Modelling

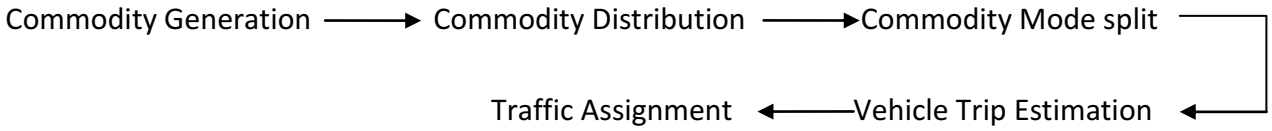
Based on such considerations as outlined on the previous page, freight transportation models can be classified under two major modelling platforms: commodity based and vehicle (Trip) based. The two approaches are characterised by the unit of analysis. While commodity based methods model freight typically by size and weight of commodity, Vehicle (Trip) based methods model freight by trip numbers.

Vehicle (Trip) based models focus on vehicle trips. This approach assumes that the mode selection has already been done and so eliminates the mode choice step in the four stage modelling process. Jacek Faucett Associates (1990) describe the trip based model as the approach where truck trips are generated directly and not converted from a quantity measure such as tonnes. These models are usually functions of land uses and trip data from traffic diaries and supply surveys. In general, the trip based modelling process can be considered under these three stages; Firstly, trips are generated using a number of methods for example, trips can be calculated as a function of socio-economic data or land uses data. Secondly, the generated trips are distributed to various zones to derive an O-D matrix which is then assigned to the transport network using appropriate traffic assignment methods.

Trip Generation ⟶ Trip Distribution ⟶ Traffic Assignment

The movement of freight can be related to different types of activities including; the movement of goods from producers to consumers, the movement of goods through a distribution chain, and the movement of goods from one mode to another (Pendyala, 2002). The modelling of freight under the commodity based approach deals directly with production and consumption at a commodity level. In particular, it relates to modelling freight movement by the weights of commodity usually in tonnes. In this approach, producers of a commodity are linked with consumers through knowledge of their economic relations. This characteristic makes this approach particularly suited for capturing economic and transport relationships in

freight demand estimation. Commodity based models generally start with known region-to-region table of commodity flow tonnage that is determined based on economic output forecasts and regional trade patterns. The Commodity based modelling process can be split into five stages:



Commodity generation relates to estimating the weight of commodities produced by each TAZ (Traffic analysis Zones). Commodity distribution relates to estimating the weight of commodity moving between each origin-destination pair which is most commonly done through spatial interaction models. Mode split relates to determining the weight of commodities using each mode of transportation. At the vehicle trip estimation stage, commodity weights are converted to vehicle trips. Finally, the traffic assignment is the process of assigning the vehicle trips to the road network.

The commodity based approach, unlike the trip based approach, focuses on the quantity or amount of certain types of goods. These models are most suited to economic input-output models for estimating freight demand and often require very detailed input-output data which are quite difficult to obtain. This approach is also often based on zonal level economic data which although relatively easy to collect often exist at highly aggregated levels, most commonly regional. The trip based approaches on the other hand are usually based on site level data which can be more resource constrained. Holguín-Veras and Thorson (2000b) discuss in detail the advantages and disadvantages of both types of models. They advocate that trip based models focus on measurable units for which a significant amount of data can easily be collected. These data exist as traffic counts, screen counts and very recently from intelligent transport systems which make data collection easier and more accurate.

The advantages offered by trip based approaches relate to the need for minimal data and less need for economic analysis. They however do not link economic patterns to freight flows. Furthermore, commodity based applications require more sub modelling compared to trip based approaches as they attempt to replicate the processes that take place at individual commodity levels. The commodity based approach is most suited to estimating freight

movements relating to manufacturers and movement to and from regions (Krishanan and Hancock, 1997).

The commodity based approach is most commonly used in practice because of data accessibility. However, it can underestimate truck trips because of its inability to capture some behaviour of freight flows such as empty truck trips, less than container loads and trip chaining (Fisher and Han, 2001). As argued by Stephan et al (2005), commodity based approaches model single trips rather than the round trips undertaken in reality. However, the trip based approach does not have this problem since it measures trips directly. Significant research effort has been dedicated to the role of trip chaining and empty trips in commodity based approaches. These include researches by Noortman and Van Es, 1978; Hautzinger, 1984 and Holguín-Veras and Thorson, 2000). Holguin-Veras and Thorson (2000) postulate that unlike commodity methods, trip based methods allow empty trip traffic to be accounted for more easily.

4.1.2 Classification of Freight Models

Other classifications for freight models have been proposed in a number of studies. The national Cooperative Highway Research Program (NCHRP, 2008), provides a comprehensive review of models used in the US. It classifies freight models under 5 main categories; (1) the direct flow factoring method (2) the Origin-Destination factoring methods (3) Trip-based truck models (4) Commodity-based truck models (5) Economic activity models.

The direct flow factoring method is a growth factor method which applies a growth rate to observed truck volumes on links. The growth factors applied to existing tables can be based on economic, employment and other indicators of growth at zonal level. The Fratar factoring method is an iterative proportional fitting technique often used to balance the production and attraction growth rates.

The O-D factoring method involves factoring an existing O-D table of freight flows and using this as input to the modal split and assignment stage process. The O-D tables are commonly obtained from existing freight databases such as the commercially maintained TRANSEARCH database in the US which provides data on the volumes of freight moving between origins and destinations at a county level by commodity type and mode. Where O-D

tables do not exist, they can be developed from surveys of freight shippers/receivers or carriers or by using an O-D matrix estimation technique often based on link observations such as truck counts. An example of such a model is the Interim Freight Model developed in Ohio.

Trip-based truck models use trip generation and trip distribution modelling techniques to produce a truck-trip O-D table. The O-D table is a direct input into the assignment step since it addresses only a single mode of transport (trucks). This is similar to the "3 – step" process akin to the Vehicle (Trip)-based model discussed above. Some examples are the Truck model developed by New Jersey and the Heavy Duty Truck Model developed by California governments. The commodity-based Truck Model better resembles the 4-step urban travel demand model. It uses the trip generation, trip distribution and modal split techniques to produce an O-D table that is input into the assignment. Economic activity models incorporate feedback mechanism with freight transport costs (Chow et al. 2010). The model uses the classic four steps of modelling but the inputs are modified as a result of the model's performance. These models use the Input-Output modelling approach to generate economic activity between the zones. These models are similar to the land use transport models used in urban passenger transportation. Some examples include the state-wide passenger and freight forecasting model developed in Oregon and the Cross-Cascades corridor Analysis tool developed in Washington using economic and land use patterns. Both models were developed to guide transportation investment and economic development in the region. The reader is referred to the publication for a more detailed review of these models.

De Jong et al (2004) present an exhaustive review of current freight models developed in Europe. Based on the techniques for deriving production and consumption, they classified freight models under four categories: (1) trend and time series models (2) zonal trip rate models (3) system dynamic models and (4) Input-output model. While this study classifies freight models under different names to those by NCHRP (2008), the categorisation is mostly similar. The factoring method category is equivalent to the trend and time series; the trip and commodity truck models are equivalent to the zonal trip rate category while the economic activity models relate to the system dynamic and input-output models.

Hensher and Figlozzi (2007) argue that a four step modelling approach is inadequate in dealing with the complexity of freight demand and emphasise the need for freight modelling

techniques to account for supply chain relationships and logistic constraints. Within the four step model, vehicle-based models fail to account for economic behaviour from which freight demand is actually derived while commodity-based models fail to account for all vehicle activities (Holguín-Veras and Thorson, 2003). Thus, new developments in freight models are moving towards more disaggregated approaches that incorporate supply chain patterns and truck chaining. While aggregate models focus on relationships on a zonal level, disaggregate model focus on that of individual decision makers.

Winston (1983) classifies freight models as "aggregate" and "disaggregate" models based on the level of data used. Aggregate models are based on zonal level data while disaggregate models relate to data on individual levels such as firms, shippers and decision makers. Winston (1983) and Regan and Garrido (2001) both postulate that disaggregate models can be further split into behavioural and Inventory models based on the modal split approach. They explained that behavioural models focus on the mode choice decision made by the shipper or customer and attempt to explore truck demand as a result of a process of utility maximization made by a decision maker while the inventory model attempts to integrate mode choice and production decision made at a firm level. Gray (1982) in his review of behavioural models highlighted the importance of understanding logistic processes and of identifying the institutional framework and decision makers in the freight demand modelling process. Regan and Garrido (2001) present a comprehensive literature survey on the potential of "disaggregate" models.

Following from the work of Winston (1983) and Regan and Garrido (2001), De Jong et al (2004) proposed a classification for freight models based on modal split approach. They classify freight models under seven categories based on the techniques used for modal split: Elasticity – based models, aggregate modal split models, Neoclassical economic models, Econometric direct demand models, disaggregate modal split models, Micro-simulation approach and multi-modal network models.

Elasticity-based models reflect the impact of changing a single given variable like cost of a transportation mode and is used for strategic evaluation. An example of this is the PACE-FORWARD model (Carillio, 1996). Aggregate modal split models are based on estimates of the market shares of modes at a zonal level. An example of this is the "aggregate-logit" model

which is based on a log-linear regression model that uses the ratio between the market shares of the modes as the dependent variable. In direct demand, the number of trips allocated to the mode is dependent directly on the attributes of a mode. A classic example is the "abstract mode" model proposed by Quandt and Baumol (1966). Smith (1974) analyses this model in good detail.

Neoclassical economic aggregate models consider freight transportation as an intermediate input in the production process of industries within a zone and consider the firm having an objective to minimize a cost function. The demand for each mode is derived by applying Shephard's lemma (Varian, 1978) to the cost function. Such a model was proposed by Friedlaender and Spady (1980). Multimodal Network models undertake modal split and assignment in one step. It identifies mode combinations that exist between two points in a network and choose the optimal combination based on a lowest cost algorithm. Cost functions vary from model to model and contain variables such as travel time and terminal costs.

Disaggregate modal split models focus on mode choice decisions made at the firm level. The models are most commonly based on multinomial logit and nested logit models. These use data from surveys of shippers and/or receiving firms. These models are based on the theory of profit maximization or cost minimization. Examples of such model include work done by Winston (1981), Nuzzolo and Russo (1995), Abdelwahab (1998) and Reynaud and Jiang (2000). Micro simulation models relate to models that derive vehicle flows from existing zone – zone flows (e.g. input-output models) using techniques such as Monte Carlo simulation.

Following on from the work done by Regan and Garrido (2001) on the need for more disaggregated types of models, Chow et al (2010) discuss freight models under two further categories: Logistic models and Vehicle Touring models. The author provides a general guideline for developing such models. Yang et al. (2000), advocate that both types of models are ideal for truck flow and bottleneck analysis. Vehicle Touring models are similar to the logistic models but focus on capturing the movement of the vehicle rather than units of commodity. Garrido and Mahmasssanis (2000) developed a space-time multimodal probit model which distributes freight flow by linking generation of service demand for each zone to different time periods. The model relates demand generation to socio-economic factors such as population and employment. Stephan et al (2005) and Hunt and Stefan (2007) use a Monte

Carlo simulation technique to construct tours by considering the time period, purpose of trip, vehicle type, next stop purpose, next stop location and next stop duration consecutively. The tours are selected from a list of tours generated from an exponential regression model that considers the land use of zones and the accessibility of each zone. This model is used to analyze truck policies in the city of Calgary in Canada and the state of Ohio. This method unlike the logistic model is very data consuming.

A logistic/supply chain model incorporates the movement of trucks through multiple intermediate stops to represent distribution channels. The model considers the behavioural peculiarity related to each actor in the distribution chain. These models generally focus on units of commodity rather than on vehicles (Chow et al, 2010) and can also be considered as commodity based tour models. Forms of Logistic models are covered by researchers who use aggregate zonal data along with logistic chain modelling to generate commodity flows through a supply chain (for example, Tavasszy et al, 1998; Liedtke and schepperle, 2004; and De Jong and ben Akiva, 2007) and those who use purely disaggregate firm level data within the logistic model (for example, Boerkamp et al 2000, Wisetjindawat and Sano, 2003; and Wisetjindawat et al, 2006).

Tavasszy et al (1998) developed the Strategic model for Integrated Logistic Evaluation (SMILE) to help determine how transport would be impacted by having a central European distribution. The model consisted of three levels: Production, Inventory and Transport. At the production level, the volumes of commodities produced and consumed are generated as a function of the demand, shipment and socio-economic factors. The inventory level comprises of obtaining and selecting optimal commodity destinations based on a multinomial logit model using inventory and transport costs. The final level involves a mode choice model that considers six modes based on the basis of a shortest route disutility.

A four-step modelling frame work for the supply chain stages in urban freight movement is developed by Boerkamps et al (2000) for the city of Groningen in the Netherlands. The model termed 'GoodTrip' considers the behaviour of all actors in the distribution channel. In this model, commodity production is related to land use of zones. The freight model developed by Liedtke and Schepperle (2004) emphasises the behavioural aspect of freight by modelling freight by order of an activity chain. It stems from the activity- based passenger

demand model. The production is obtained as a function of employment level in zones, various tour types are identified for each commodity using fuzzy clustering of trip samples and a gravity model is used to distribute the production to the tours types.

Wisetjindawat and Sano, (2003) developed a freight model to incorporate the fractional split distribution method developed by Sivakumar and Bhat (2002). In the model, production /consumption are obtained at a firm level from regression models relating to firm size, employee numbers and floor area. A mixed logit model is used to estimate the fraction of a commodity that is assigned to a customer j from shipper i. The commodity flows between zones are obtained by maximizing defined utility functions based on zonal attractiveness. Based on commodity flows in Tokyo, Raothanachonkun et al. (2007) estimated O-D matrices for truck trips by considering round trips and trip chain patterns for loaded and empty truck movements, attractiveness of zones and average payload. Donnelly (2007) proposes a hybrid micro-simulation model that uses the 1997 commodity flow survey to derive the commodity flow O-D matrix. The approach assigns discrete shipments from each O-D pair to shipper-receiver pairs using a Monte Carlo simulation process.

To overcome the inability of utilising vehicle based models to consider economic factors and commodity based models to account for realistic truck movements, Holguín-Veras and Thorson (2003) developed a model for empty truck movement that could be integrated with commodity flow models. The authors present a mathematical formulation for the flow of empty trips which are depicted as a function of a given commodity flow matrix. This model was incorporated into the work done by De jong and Ben-Akiva (2007). Building on from this, Holguín-Veras and Patil (2008) developed an O-D estimation method for freight that considers both loaded and empty truck trips.

Based on the travel cost on the network and the total number of commercial vehicles trips generated by and attracted to each zone, Wang and Holguín-Veras (2009) use entropy maximization technique (Section 4.1.5.1) to assign trucks to tours. The entropy maximization technique is used to find the most probable pair of locations (i-j) given the number of origins in location i and destinations in location j. The reader is referred to Section 4.1.5 for more detailed background on the entropy technique. Unlike the touring models discussed above, this model proposed by Wang and Holguín-Veras (2009) uses aggregate data and so requires less

data.

In general, freight demand models are characterised by a combination of different modelling approaches used within different stages of the four-step modelling process. In the following sections, the author presents a broad review of freight modelling approaches. The review does not aim to provide a new classification of the different models or modelling techniques currently used but rather to review a range of techniques used in freight models.

The process of developing a freight models for traffic impact assessment can be divided into two broad tasks; obtaining the freight origin-destination tables and allocating the table to the network. The latter is undertaken using traffic assignment models which assign trips to the network while the former is done through O-D matrix estimation approaches. The approach selected for O-D matrix estimation depends on whether information available is related to the magnitude of trip ends or links along the route of trips. The former scenario is linked with obtaining O-D matrices from the trip generation and trip distribution steps in the modelling process while the latter scenario relates to the synthetic O-D generation problem. Sections 4.1.3 to 4.1.5 discuss the techniques and approaches available for both methods. Section 4.1.6 discussed the methods available for the traffic assignment stage.

4.1.3 Trip Generation Models

Some of the techniques used to derive freight production and attractions are discussed below:

4.1.3.1 Trend and Time Series Analysis

Trend and Time series analysis involves the longitudinal exploration of past historical trends in freight activity (Pendyala, 2002). Time series methods range from simple growth factor models to complex regression models. Waliszewski et al (2004) estimate trips generated using growth rates that are commodity specific. The growth factors were based on the assumption that the land use patterns do not change much over time. Garrido (2000) employs a space time autoregressive moving average model to capture the autocorrelation between flows across the Texas-Mexico border. The model uses a data set consisting of monthly average truck

flows which presented good statistical fits and significant coefficients. The model estimates the probability that transport services are required at different time in a certain time period. This model was later developed into a multinomial probit model which uses a dynamic variance-covariance matrix.

Regression analysis measure the number of truck trips as a function of one or more independent variable such as land use, employment, population and other socio-economic variables (Slavin, 1974; Tadi & Balbach, 1994). Novak et al (2007) uses a linear regression modelling technique to predict freight generations at zonal levels. Such analyses have also been applied at site specific levels such as seaport terminals (Al-Deek et al, 2000; Holguín-Veras et. al, 2002). Al-Deek et al. (2000) derived the number of truck trips as a function of import and export containers at the port of Miami, Florida and then successfully transferred this to modelling other ports in Florida. Their results imply that a disaggregate truck trip generation model carried out at a site-specific level yields a more transferable model structure than spatially aggregated models. The methods used in past studies use observed data that measure only the freight activities as specific sites. Models that use spatially aggregated variable do not capture changes and characteristics at individual business levels.

4.1.3.2 Trip Rate Models

Zonal trip rate models relate the number of truck trips to the unit of variables such as the gross floor space, no of employees and land use classification. This method is straightforward and is accepted as a good measure for the short term planning of a small scale study area.

Cambridge Syntematics inc. (1996) developed a method of trip generation termed Quick Response Freight Manual. This model used data on the economic activities in each TAZ to estimate the number of commercial vehicle trips for each TAZ. The trip generation process involved; obtaining data on economic activities for TAZs, the use of trip generation rates to estimate the number of vehicle trips for each TAZs, and Estimating commercial vehicle volumes at external stations. Jack Faucett Associates (1991) describe a modelling approach which estimates trip generated at each TAZ from information on land use and trip data from trip diaries and shippers behaviour. The generated trips are then distributed using a form of gravity

model calibrated using the trip length distributions obtained from trip diaries.

Using traffic counts and based on Vehicle classes, Tadi and Balbach (1994) estimated trip generation rates for non-residential land use in California. Wegman et al. (1995) and Guha and Walton (1993) produced trip generation rates for container ports in the united states using vehicle counts and container related data.

4.1.3.3 Input-Output Models

Young, et al. (1981) and Zlatoper and Austain (1989) develop methods for estimating freight demand based on input-output models, using econometric techniques. These Input output models are an analytical formulation that outlines the relationship between the production output of an economic sector and the input utilized in its production process. Through this relationship, the required input volumes can be estimated from a given level of output in an economic sector. Input-output (IO) models are analytical formulations that represent the output of an economy as a function of the inputs used in the production process. These are presented as mathematical relationships which enable the level of output in a given economic sector to be estimated from the inputs. A classic example can be seen in the case of an automobile production line where a certain amount of energy, steel and other relevant inputs are required to produce a set number of cars. Given these proportions, it is possible to estimate the amount of a sector's input required to produce an asset level of output in the automobile sector. However, the relationship is somewhat complex since other inputs are required in the production of these inputs. For example the production of steel requires input from the energy and iron ore industry. In this way one sector's outputs are inputs into another economic sector. The IO model predicts these relationships that relate a unit output to its input. IO models are systematic analytical depiction of these intersectional relationships. This is used in commodity based modelling.

A basic IO model as outlined by Kanafani (1983) makes the following assumptions:

- Products in a sector are homogenous
- Within any sector, the technology and processes employed in production can be represented by the average and can be assumed to be constant
- An equilibrium exists between total demand and supply

The TEM-II Dutch model described by Tavasszy (1994) uses a monetary multi-sectoral input-output table for the country. The monetary units are converted to tonnes and the country level data is disaggregated to regional level on the basis of regional employment and population weights.

4.1.3.4 Behavioural Approach (Supply chain models)

Beyond the classic methods for trip generation, more recent works have tried to incorporate the peculiar relationship between freight demand and supply chain or logistic decisions. In this method, the demand matrices are derived by tracing the supply chain of industries/firms/business unit. This method aims to relate trip generation to the behavioural components of business activities. Iding et al. (2002) postulate that these methods embrace the fact that freight transport flows are influenced by various strategies employed within different industries and such strategies vary from firm to firm and may well be reflected in the supply chain of the business.

Some models that use this method estimate commodity generation at industrial level, and even production unit levels in other to mitigate the problems of spatial aggregation. An example of this is the work done by Wisetjindawat and Sano (2003) where trip generation is carried out on a firm-based modelling structure. Other recent researches have tried to relate freight movements to supply chains. Kawamura et al (2005) developed models of truck trip generation at the disaggregate level that incorporated the supply chain decisions made by individual businesses.

4.1.3.4 Summary of pros and cons of various trip generation modelling approaches

The pros and cons of modelling techniques used in deriving production and attraction are discussed below.

- Trend and time series models: The models are based on a period of historical or observed data. Although they generally produce good short term forecasts they can be inaccurate for long term forecasts as they assume that the under-lying economic conditions and trip-making pattern remains the same as today for which in reality may

not necessarily be the case. This assumption can be verified using data to confirm the steadiness of growth rates and trends over a time period. This exercise may however, require a long series of observed or historical data. On the hand, such methods require less time and fewer resources to develop.

- Trip rate models: One major limitation of this method is that the trip rates developed from trip generation data on similar land uses can vary significantly depending on the source of data, characteristics of the location selected for analysis and the time of day. The application of trip rates can therefore, present inconsistent between similar land uses. On the other hand, such methods are simple to implement. While developing such rates based on local economic activities has the advantage of better capturing the activity of the study area, the data required to estimate accurate trip generation models can be very extensive.
- Input-output model: these models link economic activities to commodity flows and allow for land use interactions to be explored. They are generally more reliable as they are derived from input-output tables which are commonly secondary data sources. On the other hand, to avoid biases when undertaking local level analysis, such tables should preferably be based on multi-regional level data and these more difficult to derive. Input-output models over simplify aspects such as trip chaining and empty hailing with regards to truck movement. The latter will especially be critical when modelling container trips in Nigeria since majority of export containers are empty.
- Supply chain model: Within the last decade, this technique has received widespread interest and forms the basis of a number existing freight models currently applied around North America and Europe. Such freight model includes the GoodTrip model and the SMILE model developed in the Netherlands. These models have been shown to account for the trip chaining characteristics associated with truck moves and allows for the analysis of how changes in the logistic patterns affect transport demand. These model are however, developed to incorporate one of the above mentioned techniques (time series, trip rates or input-output models).

The primary objective in this thesis is to develop a model to explore the impact of including a container dry port solution (altering the logistic organization) on the road traffic

conditions. Therefore, the model must be able to capture container moves within the existing and proposed container logistic chain. These containers are unitised cargoes that move in a single trip and generate empty trips. Thus a trip based unit is more suited to this thesis than a commodity-based unit as it focuses on movement from point to point. A supply chain modelling approach is most appropriate as it defines the container supply chain patterns by freight vehicle trips and so will allow the influence of changes to the logistic chain to be studied. Furthermore, historical data on container volumes through nodes in the supply chain are available and so a growth factor model is employed. As discussed, the drawback of the growth factor technique is that it assumes that underlying economic conditions and trip-making patterns remain the same. However, this assumption is accurate for short-term forecasting.

4.1.4 Models for Distribution

In developing a freight distribution model, one must consider the fact that individual commodities are attracted by not only the direct demand of consumers but also by the demand of industries involved in secondary manufacturing processes. The key approaches used in developing trip distribution model can be classified under four headings namely: microeconomic, macroeconomic, spatial interaction and simplistic proportional methods (Brogan et al. 2001).

The microeconomic analysis considers transport demand as an input to production and as being consumed at individual firm level. Thus, the level to which transportation is consumed and its influence on production output is considered as the attraction factor of the firm. Although such models are accurate in determining the attraction factors of firms handling a single type of commodity, they can be cumbersome when used in multi-commodity analysis.

The macroeconomic approach deals with the flows of goods and services between industries, and refers to the econometric approaches such as input-output models. The econometric approach comprises equations that relate inter-sector requirements to transport flows (Kanafani, 1983) and the input –output model specifically considers the relationship between the production outputs of sectors and the production input from other sectors in a region. As has been discussed in Section 4.1.3.4, these models attempts to quantify the relationship between industries and can be used for trip distribution as well as trip generation.

Spatial Interaction models refer to the category of models that describe distribution processes as a function of the space interaction. In this model, commodities are assumed to flow from surplus to deficit areas. The most common models under this family include gravity, intervening opportunities and direct demand models. The former two, unlike the latter, are used within the context of the four step urban transport modelling process – trip generation, trip distribution, modal split and traffic assignment. These models are used in both trip based and commodity based modelling.

The simplistic proportional methods involve the use of indicator variables in estimating freight attraction factors. For instance, Iowa's freight planning topology assumed the acreage of farmland to be proportional to the attraction of farm machinery and population Figures are used to estimate freight attraction to particular zones (Souleyrette et al. 1998).

The output of the trip distribution model is the origin destination matrix used in the assignment process. The following sections provide the reader with a description of the most common models and their use in freight transport model.

4.1.4.1 Input-Output Model

This modelling framework has been used by some for freight transport modelling (Sorratini and Smith, 2000; Jack Faucett and Associates, Inc. 1999). In both cases, the IO model relates the amount of commodity attracted to a given zone to the level of economic activity in the zone. Guilanio et al. (2007) combine a local regional input-output model with import/export commodity flow data to estimate intra-metropolitan freight flow matrices. Fisher et al (2000) used an Input-output model to estimate the inbound commodity flows by industry sectors in California. Sorratini (2000) estimated truck flows for the state of Wisconsin using input – output coefficients and data from a commodity flow survey. Other works include that from Hewings et al. (2002) and Zhao and Kockelman (2004) who formulated a regional commodity flow model using regional input-out coefficients. Holguín-Veras et al. (2001) provides detailed review on the input-output models and readers are referred to the literature.

While IO formulation has successfully been applied to freight modelling, it requires a significant amount of data on regional economic activity and regional flows. This method is most often used for developing O-D matrices in large scale systems and detailed regional or

national projects. IO models can be considered under two main types: single-regional and multiregional models. The single regional models consider a macroscopic analysis at a regional or national level. A multiregional model on the other hand applies to systems which could be divided into *n* sub-regions, and then it includes *n* regional IO tables for each sub-region, and also uses a system-wide IO table to control the total flows among all regions (Kanafani, 1983). Ham et al (2005) proposed a model that replaces the traditional 4 step transport model with a single step by linking regional input-output models and transport network flows. The model was developed using input-output coefficients, final demand and the commodity shipments for 13 sectors and 36 regions in the US.

4.1.4.2 Gravity Model

This model is derived as an analogy of the law of gravity. It is by far the most widely used form of trip distribution analysis. In the literature, various scholars have applied the gravity model to trip based modelling. Ogden (1978) applied the gravity model to various truck trip purposes Swan Wooster (1979) calibrated three gravity models for each truck type and Southwork (1982) incorporated a truck route chaining model in a commodity based gravity model formulation. Although gravity models are commonly used, issues relating to their accuracy in predicting truck distribution have been raised by some. Holguín-Veras et al. (2001) argues that the postulates of economic rationality embedded in the gravity model requiring it to possess a monotonically decreasing Trip length distribution is breached in some vehicle types which are shown not to exhibit the expected behavior.

The gravity model is a distribution model originally generated from an analogy with Newton's gravitational law. The model is based on the assumption that the attraction of trip from a zone i to a zone j is directly proportional to the attractive power of zone j and inversely proportional to the travel impedance between both zones (Sosslau, 1978). The simplest form of the gravity model is represented by the function outlined by Casey (1955) who applied the approach to relate shopping trips to town area. $T_{ij} = \alpha \frac{P_i P_j}{d_{ij}^2}$ Where P_i and P_j are the populations of the origin and destination towns, α is the proportional factor and d_{ij} is the separation between town i and j. This equation was later improved by including the use of total

trips rather than population and the use of a decreasing function in modelling the effect of distance on attraction. The revised function is written as $T_{ij} = \alpha O_i D_j f(c_{ij})$ where O_i and D_j represents total trip ends and $f(c_{ij})$ is a disutility function for travel costs representing a disincentive to travel. Popular versions of this disutility function are:

Logit's exponential function: $f(c_{ij}) = e^{-\beta C_{ij}}$ (4.1)

Kirchhoff's power Function: $f(c_{ij}) = c_{ij}^{-n}$ (4.2)

Combined Function: $f(c_{ij}) = c_{ij}^{n} e^{-\beta C_{ij}}$ (4.3)

Trips originating from a zone gravitate to another zone at a function that is proportional to its attractiveness and inversely proportional the separation between both zones. Depending on the information available, a number of gravity models can be formulated. These include:

Unconstrained Gravity Model- This model imposes no constraint on the total trips attracted or produced in a given Traffic analysis zone. This model is represented by the following:

$$T_{ij} = O_i D_{ij} F(C_{ij}) \quad (4.4)$$

Doubly constrained gravity Model – This model imposes constrains on both the number of trips produced and attracted to a given Traffic analysis zone.

$T_{ij} = A_i O_i B_j D_j F(C_{ij})$ Doubly Constrained Gravity Model (4.5)

Where O_i is the total trips originating from zone$i$, D_j is the total trips destined to zone j, $F(C_{ij})$ is an impedance function. The balancing factors A_i and B_j are the set of constants that the origin destination constraints are satisfied where $A_i = 1/\sum_j B_j D_j F(C_{ij});\ B_j = 1/\sum_i A_i O_i F(C_{ij})$

Singly Constrained Gravity Model- This model imposes constrains on either the trips produced or the trips generated to ensure that the model replicates the total trips produced or the total trips attracted to a given TAZ. The single constrained gravity models are derived by setting one of the balancing factors A_i and B_j equal to one. These can be considered as special cases derived from the doubly constrained models.

$$T_{ij} = O_i \frac{D_j F(C_{ij})}{\sum_j D_j F(C_{ij})}$$ Origin Constrained gravity Model (4.6)

$$T_{ij} = D_j \frac{O_i F(C_{ij})}{\sum_i O_i F(C_{ij})}$$ Destination Constrained gravity Model (4.7)

4.1.4.3 Intervening Opportunities Model

The formulation of the opportunity model originated with Stouffer (1940) who modified the gravity model by assuming the attraction between two points to be a function of not only the spatial attraction between two points but also function of the spatial environment of the between the two points. The method assumes a direct proportionality between the number of trips to a given destination and the number of opportunities at that destination, and an inverse relationship between the number of trips and the number of intervening opportunities. Following on from the gravity model, this model is formulated as:

$$A_{ij} = \frac{Z_j}{\sum(Z_k)T_{ij}} \quad (4.8)$$

where A_{ij} is the attraction of location j by residence of location i, Z_j is the attractiveness of zone j, Z_k is the attractiveness of all zones that are intermediate distances between i and$j$, T_{ij} is the trip distances between zones i and j.

Following on from this, the Intervening Opportunities model is based on a fundamental assumption that trip makers consider potential destinations sequentially, in order of their trip impedances from the origin point and so the probability of selecting a destination with lower trip impedance is a function of the probability of not selecting prior destinations with higher trip impedance. For trip destination arranged in ascending order with their trip impedances, the probability of selecting the nth destination depends on the probability of not selecting the consecutive destinations up to the (n-1)th destination. The mathematical formulation of the intervening opportunity model as defined by Ortúzar and Willumsen (2001) is shown below.

$$T_{ij} = O_i \frac{exp(-\beta x_{n-1})exp(-\beta x_n)}{1-exp(-\beta x_n)} \quad (4.9)$$

where: x_n is the cumulative attraction up to destination n and β is a calibration parameter. The

intervening opportunity model is considered a unique kind of the gravity model and can be calibrated as a gravity model.

Stopher and Meyburg (1975) suggest that the intervening opportunity model is a more satisfying formulation of trip distribution than gravity model as it provides a "stronger conceptual base, and attempts to address the problem of individual behavior." The Intervening opportunities model does not provide demand prediction much different to the Gravity model which also considers the attraction associated with each destination zone. Thus, this model is less commonly used because of the cumbersomeness related with estimating attraction for each origin destination pair (Ortúzar and Willumsen, 2001; Zhao et al, 2001).

Pyers (1966) reported a comparative analysis carried out by the US Bureau of Public roads to evaluate a number of trip distribution processes. The intervening opportunity was found to perform well and was calibrated with very little difficulty; it had the advantage that no socioeconomic adjustment factors were necessary. The Gravity model however proved slightly better in terms of accuracy with modelling the base year and forecasted simulation.

4.1.4.4 Fractional Split Distribution Model

Sivakumar and Bhat (2002) propose an alternative approach for distributing commodity flows. The motivation of the model is linked to the concept that freight demand is driven by consumption at the destination zones which is met by commodity flows from origin zones (Ogden 1978). Sivakumar (2001) argues that the fractional split distribution model considers the impact of the location patterns of zones on the amount of commodities generated at each zone.

In this model, fractions of commodity generated at zones are estimated to be consumed at each destination using a multinomial logit form. The fraction of freight consumed at a zone that is produced at each origin zone is represented as the dependent variable and is bounded between zero and one. For each consumption zone, the sum of the fractions across all production zones is equal to one. By this formulation, fractions of zero and one value represent the situation where zones may not serve a consumption zone, or the consumption at a destination zone is not entirely serviced by a single production node. The authors use a multinomial logit functional form as a pre-determined function (G_i)within the binary fractional

split model proposed by Papke and Woolbridge (1996) to formulate the model. This method was suggested by the authors to provide better results than the standard gravity model and has been applied by Wisetjindawat et al (2006) and Nuzzolo et al (2008).

4.1.4.5 Summary of pros and cons of various trip distribution modelling approaches

The gravity model is the most common form of trip distribution models used and can be readily found within software packages. Also, these models have limited data requirements and are simple to implement. On the other hand, the main disadvantage of this model lays in the lack of ability to explain all behavioural aspects of destination choice through its travel impedance and attraction factors.

The Intervening Opportunity model is a modified form of the gravity model that considers an additional factor (opportunities for trip purpose satisfaction at destination) for determining the trip interchange patterns. However, this technique is less used in practice because the lack of suitable software for application and calibration makes the theoretical basis much less understood and more difficult to handle in practice (Ortuzar and Willumsen, 2001) Furthermore, its theoretical advantage over the gravity model has been found to be insignificant compared to the added complexity of the technique (Easa, 1993; Zhao et al, 2004).

The gravity model is used in this thesis as it provides a good estimate for the distribution of freight as it can capture peaks in the trip distribution brought about by the production-consumption relationship related to freight (Holguín-Veras et al., 2001). It has also been argued to provide an accurate enough distribution for its complexity (Easa, 1993; Zhao et al, 2004). While the concept of the Frictional Split distribution model is simple and the method has been suggested to provide better estimates than the gravity model. However, it is not used because of its unavailability within the software accessible to this thesis.

4.1.5 Methods for Estimating O-D Matrices Using Link Data

According to Taylor et al. (2000) O-D matrices can be estimated through three different approaches: (1) Direct observation, (2) O-D Synthesis, and (3) generation and distribution modelling. So far, the methods for obtaining O-D matrices from trip generation and distribution

modelling have been explored. Many transport planners view the trip generation and distribution process as a well established approach for estimating O-D matrices, which has a long history and is hard to bring into question. In contrast, synthetic O-D generation is much less well used (Van Aerde et al. 2003).

O-D matrices are estimated using direct sampling (directly from surveys) or using modelling techniques. In the direct sampling method, O-D matrices are estimated from large scale surveys such as roadside interviews and licence plate surveys. These surveys are usually expensive and their results have expiry dates beyond which the matrix becomes more and more unreliable. Thus, methods that estimate and update O-D matrices from secondary information such as traffic counts on links, are most commonly used. This section discusses the most commonly used approaches for O-D matrix synthesizing. For more comprehensive reviews, the reader is referred to Nguyen (1984), Cascetta and Nguyen (1988) and Bera and Krishna Rao (2011).

4.1.5.1 Entropy Approach

The concept of applying entropy maximization to O-D estimation problem was initially proposed by Willumsen (1978), who demonstrated that by maximising the entropy the most likely matrix could be estimated subject to a number of constraints. On the other hand, the concept of Information minimization was first proposed by Van Zuylen (1978). More recent studies show that both methods are the same except for the unit of observation used in the approaches (Van Zuylen and Willumsen, 1980). While Willumsen's model uses trips as its units, Van Zuylen uses counted vehicles.

The O-D matrix chosen in the information minimization or entropy maximising approach is one that adds as little information as possible to the information in the target O-D matrix, while the equations relating the estimated O-D volume and the observed traffic count are taken into account. This matrix is obtained by minimising the function I :

$$I = \sum_{ij} g_{ij} \ln \frac{g_{ij}}{\hat{g}_{ij}} \tag{4.10}$$

Where $\hat{g}_{ij}$ is the target OD matrix and g_{ij} is the OD matrix representing the traffic between zones. The O-D matrix obtained from the minimization is derived as:

$$g_{ij} = \hat{g}_{ij} e^{\lambda_1 p_{ij}^1 + \lambda_2 p_{ij}^2 + \cdots + \lambda_{\hat{A}} p_{ij}^{\hat{A}}} \quad (4.11)$$

Where, each λ is a Lagrange multiplier associated with the constraint relating the link flow with the travel matrix. The obtained expression (g_{ij}) relies on the assumption of proportional assignment of the trips between zone i and zone j that use link a. This method is particularly useful since the information provided by traffic count surveys are often insufficient to determine a unique OD matrix. Unfortunately, both information minimization and entropy maximization approaches have the disadvantage of not considering the uncertainties in traffic counts and the prior matrix which can be erroneous and can influence the output (Bera and Krishna Rao, 2011).

4.1.5.2 Statistical Inference Approach

These estimation methods are based on the assumption that traffic volumes and the target O-D matrix are generated by some probability distribution. Cascetta and Nguyen (1988) presented a review of statistical methods for the estimation of OD matrices, including maximum likelihood, generalized least squares and Bayesian Inference approaches.

Maximum likelihood

The maximum Likelihood estimates are the set of parameters that generate the observed sample most often. In the case of O-D matrix estimation, the approach maximises the likelihood of observing the target matrix and the observed traffic counts on the basis of the true trip matrix. A model for estimating O-D matrices using a maximum likelihood technique was developed in Speiss (1987). It is assumed that the elements of the target trip matrix are obtained by sampling Poisson variables for all OD pairs (Spiess, 1987). Under the hypothesis that for each O-D pair t_i (no of trips) is obtained by observing an independent Poisson process with mean $p_i T_i$, the probability of observing t_i is:

$$Prob[Poisson\ (p_i T_i = t_i)] = \frac{(p_i T_i)^{t_i} e^{-p_i T_i}}{t_i!}, \quad i \in I \quad (4.12)$$

The Joint probability of observing the sample matrix $\{t_i\}$ is:

$$Prob[\{t_i\}] = \prod_{i\in I} Prob[t_i] = \prod_{i\in I} \frac{(p_i T_i)^{t_i} e^{-p_i T_i}}{t_i!} \quad (4.13)$$

Since the matrix $\{T_i\}$ satisfies:

$$\sum_{i\in I} n_{ia} T_i = V_a,\ a \in A$$
$$T_i \geq 0,\quad i \in I,$$

Where the coefficients n_{ai} correspond to the proportion of trips for O-D pair i that use link a, Va denotes the observed volume on link a and the matrix $\{t_i, i \in I\}$contains some a prior information on the O-D matrix $\{T_i\}$.

Then, applying the Maximum Likelihood Estimation technique (Wilks, 1962; Wilson 1976), a matrix$\{T_i^*\}$, that satisfies the constraints and yields the maximum probability for observing $\{t_i\}$, can be obtained in the form:

$$T_i^* = \frac{t_i}{p_i + \sum_{a\in A} n_{ia}\lambda_a},\ i \in I \quad (4.14)$$

Where λ_a is the Lagrangean multiplier associated with the constraints. The model can be formulated using trips or volumes as the basic unit of observation. This method is feasible while an entropy maximizing method might become infeasible because of zero-valued elements of g and the test problems are small, i.e. the networks with no more than 20 transportation links (Abrahamsson, 1996).

<u>Generalised least squares</u>

The Generalised Least Squares method has since been suggested by a number of researchers for use in estimating origin destination (Cascetta, 1984; Bell 1991). Bell (1991) discussed the use of constrained generalised least squares. This method is based on the well-known Gauss-Markov theory. The advantage of this method is that no assumptions are made about the distribution of the data and it allows the combination of the survey data relating to the origin-destination trip with link traffic count data, while considering the relative accuracy of the data (Bell, 1991).

In this method, the target O-D matrix $\hat{g}$ may be assumed as an estimated O-D matrix g with a probabilistic error term ε. This assumption leads to the linear specifications:

$$\hat{g} = g + \varepsilon \quad (4.15)$$

$$\hat{v} = v(g) + \eta \tag{4.16}$$

Where η is the error that relates the observed traffic counts $\hat{v}$ with $v(g)$. Both errors ε and η are often assumed to have zero means. If the target O-D matrix $\hat{g}$ has an error with a variance-covariance matrix Z and the dispersion matrix of the traffic counts is D, then the generalised least square estimator may be obtained by minimizing the function:

$$F(\hat{g}) = \frac{1}{2}(\hat{g} - g)'Z^{-1}(\hat{g} - g) + \frac{1}{2}\big(\hat{v} - v(g)\big)'D^{-1}\big(\hat{v} - v(g)\big) \tag{4.17}$$

Subject to the constraint $g_{ij} \geq 0$ which ensures that the O-D movement between zone i and j are non-negative. Bell (1991) presents an algorithm for solving this minimization problem that ensures that the non-negativity constraint is met. Both Bell (1991) and Cascetta (1984) assume proportional assignment.

Bell (1984) shows that the minimum information approach proposed by Van Zuylen and Willumsen (1980) can be estimated using this approach if the traffic counts are known to a high degree. It has also been shown that the estimator obtained from this method coincides with the maximum likelihood estimator in the case where the error terms of the traffic counts(η) and target OD matrix (ε) are assumed to follow the Multivariate normal distribution.

Equilibrium/optimization approach

These models are based on Wardrop's principle of the user optimization of traffic flow. This principle was originally applied to the traffic flow assignment process which requires that all routes with link flows between any O-D pair should have equal travel costs and the costs must be less than the cost of all other unused routes between the O-D pair. The equilibrium based O-D matrix estimation approach is obtained by inversing this problem. Thus, the O-D matrix estimation problem may be described with the aim to retrieve an O-D matrix that when user-optimally assigned to the network produces the observed O-D travel times and link flows. These methods consider congestion effects in the estimation problem.

Yang et al. (1995) extend the generalized least square methods by integrating the equilibrium assignment of the OD matrix into the model. The model is formulated as a bi-level (two level) programming problem. The upper level comprises of the generalized least square objective function while the equilibrium assignment is assumed at the lower level. This problem

is difficult to solve and so a heuristic algorithm is proposed where both levels are solved iteratively using proportional assignment from the lower level solution in the next upper level problem. The algorithm was shown to converge satisfactorily when applied to a small problem. Yang (1995) argues that the bi-level formulation has the advantage of always providing a feasible solution even if traffic counts are inconsistent and there exists only a subset of observed link flows. Similar bi-level problems have been proposed by LeBlanc and Farhangian (1982) and Jornsten and Nguyen (1979) who use the generalized least squares and the entropy maximum objective functions at the upper level respectively. In general, the bi-level programming approach involves an upper level trip matrix estimation problem and a lower level equilibrium assignment problem. Chen (1994) provides a detailed review on this technique.

More recently, path flow estimation based models have been developed to consider congestion effects. These models determine the O-D matrix according to the solution of path flows. At the core of the model is a logit based path choice model which interacts with link cost functions to produce a stochastic user equilibrium traffic pattern. Sherali et al (1994) proposed a linear path flow model while Bell and Shield (1995) developed a non-linear path flow model. In general, the procedure combines a shortest path network flow programming problem with a technique for generating the paths, from alternative paths, that will determine the optimal solution to the flow programming problem. Nie and lee (2002) and Nie et al (2005) further developed this work to eliminate the path enumeration required in the linear model proposed by Sherali et al (1994). This method still needs to be tested on large real-size networks to better assess its efficiency (Bera and Krishna Rao, 2011).

Another model based on the user optimal principle is the linear programming approach. List and Turniquist (1994) formulated a method for estimating multi class freight O-D matrices from classified traffic counts, partial O-D estimates, and cordon counts. This is based on a linear programming formulation which attempts to minimise the objective function which is the weighted sum of all deviations from the observed values. The technique is characterised by the assumption that zones in the study area are non-overlapping, with centroids where trips are destined or originate from. By relating commodities carried to the physical truck characteristics, the trip matrices were estimated for three vehicle classes -vans, medium and heavy trucks.

They showed that a relatively accurate truck trip generation estimate for a given zone can be derived if detailed data for trip matrices are available. Limitations in relation to the availability of freight data pose a significant challenge to this method as the size of the O-D matrix and computational burden increases as the aggregation level of data decreases.

4.1.5.3 Fuzzy Weight Based Approach

An important problem relating to estimating O-D matrices from link count data is the inconsistency of data that results from issues such as counting errors and the deriver's behaviour. The present fuzzy weight models aim to solve this problem by using a set of "fuzzy weights" for each piece of inconsistent data. In Xu and Chan (1993), link traffic counts are considered as imprecise values so, link counts are undertaken more than once and fuzzy weight are computed for each set of link counts.

4.1.5.4 Neural Network Based Approach

Neural network models synthesize O-D matrices from a set of traffic flow data through pattern recognition techniques that mimic the learning behaviour of the human brain. Yang et al. (1992), Chin et al. (1994) and Gong (1998) propose models for generating O-D information from link flows. While quite a number of researches have been carried out on Artificial Neural Networks, research still needs to be carried out on their applications in real size networks. The most obvious shortcoming of this type of model is the large amount of data needed to develop and validate it.

4.1.6 Traffic Assignment Models

At the assignment stage of modelling, the O-D matrix is assigned to the transport network. The process involves identifying optimal routes between each origin and destination pair and distributing the travel demand over them. In the context of traffic assignment, it is important to consider the supply and demand aspect of the transport system. Demand relates to the volume of trips moving between the O-D pairs as has been estimated. Supply on the other hand comprises of the road network $S(L, C)$ represented by Links L and their associated

costs C. This cost is referred to by different terms including; capacity function, link performance function, link impedance function and generalised costs.

The generalised costs express the impedance of independent links along the routes and indicate the relative reluctant of users to include a link on the chosen path. The cost is a function of factors that are believed to influence the choice of route when driving between two points in the network. Such factors may include the travel time, travel distance, monetary cost (fuel, toll charge), congestion and queues, type of road, scenery, and travel time reliability.

The most common approximation for generalised cost function is based on travel time on the link. These functions are based on traffic flow theory which relates speed to density and flows. Density is the number of vehicles occupying a given roadway, averaged over time and given in vehicles/km. It describes the closeness of vehicle to one another and is a measure of the freedom to manoeuvre. The relationship between speed, density and flow is illustrated in Figure 4.1 below and given by: $D = Q/S$ Where D is the density in vehicle/km, Q is the flow in vehicle/hrs and S is the speed in km/hr.

The curves suggest two extremes of traffic: 1) at max density (Jam), the speed is zero and flow is zero; 2) at zero flow, density is zero and a free flow speed applies to the roadway. Within these extremes traffic has a maximizing effect in that as the density increases, the flow also increases leading to a reduction in speeds and eventually a reduction in flow. The capacity (Q_{max}) is the maximum flow level on the speed flow curve and is the point where increased density and reduced speed result in a reduced flow (refer to Figure 4.1). Beyond this point, an unstable region is entered where low flows and low speeds are reached. Speed-flow relationships in particular have been established in many studies.

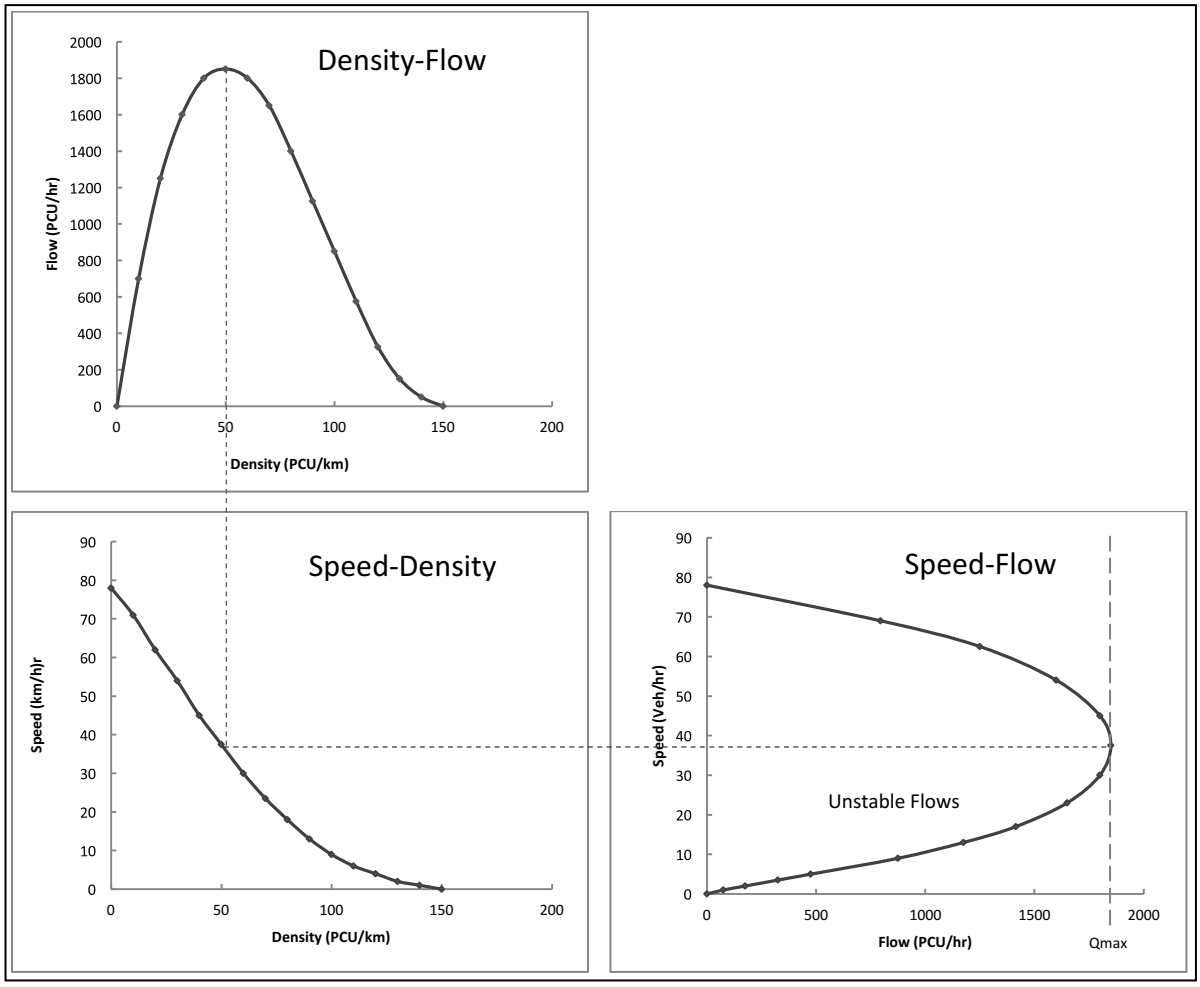


Figure 4.1: Characteristics of traffic flow

Since the speed on the link is a function of the link flows, the generalised cost function can simply be presented as relating the travel time cost on a link (a) to the flows (q) on the link and can be written in general terms as:

$$C_a = C_a(q) \tag{4.19}$$

These functions are commonly derived using hydrodynamic and queuing theories. A function that is very commonly used to relate flows to travel time was developed by the Bureau of Public roads (1964) and is defined as follows:

$$t = t_0 \left[1 + \alpha \frac{x^\beta}{C}\right] \tag{4.20}$$

Where: t is the travel time, t_0 is the free flow travel time, x is flow, C is the link capacity β and α are calibration parameters. Usual values for β and α are 4 and 0.15 respectively however,

they can and should be modified from link to link. A number of other functions have been formulated as an alternative to the BPR, for use in the traffic assignment problem. Some of such are reviewed in Ortúzar and Willumsen (2001).

The basic premise in traffic assignment is that travellers are rational and choose the shortest paths which are the routes that offer the least perceived generalised costs. The shortest path search is done using shortest tree building algorithms. These algorithms search sequentially for each origin node the shortest route to all other nodes. The two basic algorithms used for finding the shortest paths in a road network are the algorithms proposed by Moore (1957) and Dijskra (1959). Dijkstra's algorithm is known to be superior than Moore's in particular for larger networks but is more difficult to programme see Ortúzar and Willumsen (2001). Full details on the procedure can be found in Dijkstra (1959).

Traffic assignment models exist in two different forms; static and dynamic. Static models assume that the traffic demand and supply are not time dependent but rather constant during the period of analysis. Dynamic models on the other hand assume that demand and route characteristics are time dependent. These models are much more computationally and data demanding and due to time restrictions were not considered for use in this study. The following sub-section provides a background to the traffic assignment methods available for use in static models.

4.1.6.1 All or Nothing Assignment

The simplest assignment approach is an "all-or-nothing" assignment. In an all-or-nothing assignment, all traffic between an origin-destination pair is assigned to a single path (the shortest/cheapest path) between the origin and destination. Travel time is taken as fixed and does not vary with the volume of traffic on links (no congestion). All drivers are assumed to perceive the same costs and so all are assigned to the most attractive routes and none to lesser attractive routes. This model is unrealistic since only one path between each O-D pair is ever utilized. Although it does not generate very realistic outcomes, the "all-or-nothing assignment is an important building block for other assignment models.

This assignment problem is equivalent to solving an optimization problem, which can be formulated on a route or link basis. The route based formulation uses route-level variables

while the link based formulation used link-level formulation, both of which lead to a linear programming problem which minimizes an objective function Z. In both cases, the objective function expresses the total travel cost experienced by all travelers. Both formulations produce the exact same solution. The route based formulation is outline below:

$$\left.\begin{aligned} &\min_{T_{ijr}} Z = \sum_i \sum_j \sum_r t_{ijr} T_{ijr} \\ &\sum_r T_{ijr} = T_{ij} \quad \forall i,j \\ &T_{ijr} \geq 0 \quad \forall i,j,r \end{aligned}\right\} \tag{4.21}$$

Where T_{ij} is the number of trips moving from origin$i$ to destination j, t_{ijr} is the travel cost on route r when travelling between origin i and destination j.

The constraints ensure that all travelers are assigned to a route (flow conservation) and flows on a link are non-negative. Although this problem can be solved using linear programming techniques, a shortest path algorithm is used because of the computational feasibility of such techniques. For each origin–destination pair a shortest path is determined, resulting in the generation of a shortest path tree for all origins. The assignment algorithm loads the O-D matrix $\{T\}$ to the shortest path to determine the flows on the links. The basic all or nothing algorithm is summarized below:

1. Consider first origin $i = 1$ and find shortest paths to all destinations
2. Consider first destination $j = 1$, assign all trips T_{ij} to the shortest route from i to j
3. Consider destination $j = j + 1$, assign all trips T_{ij} to the shortest route from I to j
4. If shortest route to all destination j have been considered then return proceed to step (5) else, return to step (3)
5. If all origins have been considered then STOP, else, Consider origin $i = i + 1$ and find the shortest path to all destinations
6. Repeat step (2), (3) and (4)

4.1.6.2 User Equilibrium (UE) Assignment

In this method, travelers consider the shortest (cheapest) route depending on the link loads (congestion is considered). The formulation of the User-equilibrium is attributed to

Wardrop (1952) who suggested that:

"At user equilibrium conditions, traffic in a congested network is in such a way that no individual trip maker can reduce his path costs by unilaterally switching routes and the cost of all used routes between the an O-D pair are equal and no greater than the cost on all unused routes between the same O-D pair"

Beckman et al. (1956) formulates the equilibrium problem as a minimization problem with objective function Z:

$$\min_{q_a} Z = \sum_a \int_0^{q_a} t_a(x)dx \tag{4.22}$$

$$\sum_r T_{ijr} = T_{ij} \quad \forall i,j \tag{4.23}$$

$$T_{ijr} \geq 0 \quad \forall i,j,r \tag{4.24}$$

$$q_a = \sum_i \sum_j \sum_r \alpha_{ijr}^a T_{ijr} \quad \forall a \tag{4.25}$$

Where t_a is link travel cost, q_a is the link flows, T_{ij} is the number of trips from origin i to destination j, T_{ijr} is the number of trips from i to j on route r and α_{ijr}^a is the link-route-incidence which is 1 if link a is on route r from i to j and 0 otherwise.

The most common method used to solve this minimization problem is the convex combination algorithm formulated in Frank and Wolfe (1956). The algorithm commonly known as the Frank-Wolfe method is a procedure for solving quadratic programming problems with linear constraints. The Frank-Wolf algorithm for solving the UE assignment problem is:

1. Initialization: set the number of iteration $n = 1$, and perform an All-or-Nothing assignment based on $t_a = t_a(0)$ to obtain flows q_a^n
2. Update link travel costs: compute new travel cost using $t_a = t_a(q_a^n) \ \forall a$
3. Determine descent direction: Using the new link travel costs, perform an All-or-Nothing to yield auxiliary flows w_a^n
4. Determine step-size: Find $\alpha^{(n)}$ that solves $\min_{0 \leq \alpha \leq 1} \sum_a \int_0^{q_a^{(n)} + \alpha\left(w_a^{(n)} - q_a^{(n)}\right)} t_a(x)dx$
5. Move: set $q_a^{(n+1)} = q_a^{(n)} + \alpha^{(n)}\left(w_a^{(n)} - q_a^{(n)}\right) \ \forall a$

6. Convergence test: if a predetermined convergence criterion is met, stop. Else, set n= $n + 1$ and return to step 2. This starts the iteration loop.

Evans (1976) showed that, provided enough iteration is performed, the Frank-Wolfe algorithm converges to the equilibrium solution. This algorithm can be simplified by pre-determining the step size in Step 4 above. This approach is referred to as the Method of Successive Averages (MSA) and is a special case of the Frank-Wolf algorithm. This method was first suggested for use by Sheffi (1985) who shows that the method would converge to a unique solution if a number of conditions are satisfied. Firstly, the objective function to be minimised must be twice continuously differentiable and have a gradient that vanishes only once in the feasibility regions subjected by the conservation of flow and non-negative constraint. Secondly, the search direction has to be a descent vector and the move size set a priori has to satisfy two conditions:

$$\sum_{n=1}^{\infty} \alpha^{(n)} = \infty \quad \text{and} \quad \sum_{n=1}^{\alpha} \left(\alpha^{(n)}\right)^n < \infty \tag{4.26}$$

One of the simplest move-size that satisfies both search direction conditions is $\alpha^n = 1/n$ where the iteration counter is used to generate the weights. The advantage of this method is linked with its simplicity due to the predetermined step sizes. In this method, weights are assigned to the results obtained in each iteration. On the other hand, the method is very slow to converge and appropriate convergence criteria are difficult to identify. The slow speed of convergence is linked to the fact that the method utilises the estimates from all iterations and newer estimates are assigned lower weights while initial estimates are higher. Furthermore, if the MSA procedure is stopped at a prematurely determined number of iterations, a poor convergence solution may be achieved. This can happen because the results of MSA iteration asymptotically oscillate around the true solution value and do not approach convergence monotonically (Regueros et al, 1992).

The user-equilibrium problem can also be solved using heuristic approaches namely the capacity restraint and the incremental assignment technique. These methods are characterized by the mechanism of network loading associated with them. In the incremental assignment technique, a proportion of the O-D matrix is loaded to the network using an all-or-nothing assignment at each iteration while in the capacity restraint method the all-or–nothing

assignment is repeated at each current iteration using the link travel costs obtained from the previous iteration. Sheffi (1985) provides a detailed review of the processes and algorithms associated with these techniques. Sheffi (1985) argues that these methods may not converge to the equilibrium solution and supports the use of the convex combination method proposed by Frank and Wolfe (1956) in solving the user-equilibrium problem.

Assignment convergence criterion

In an iterative procedure, such as that outlined above, the convergence criterion determines the number of iterations required to reach convergence. This criterion may have a considerable impact on the solution obtained since the successive improvement becomes smaller with each iteration and in a real-world network it may take a large number of iterations to reach convergence. Thomas (1991) outlines stopping criterion under three basic types: (1) those that consider the difference between estimates of quantities (e.g. flows and costs) derived in successive iterations (2) those that measure the agreement between the latest assumed link costs, assigned flows and assumed cost-flow relationship (3) those that consider the improvements that may result with continued iteration.

Specifically, Rose et al (1985) outlines stopping criteria to include those considering:

1. A maximum number of iterations.

2. The change or percentage change in the objective function between iterations given by

$$\left[\frac{Z^n - Z^{n-1}}{Z^n}\right]$$

Where, Z^n is the objective function at iteration

3. The maximum change or percentage change in link flows between iterations

$$\min_a \left[\frac{|x_a^n - x_a^{n-1}|}{x_a^n}\right]$$

where x_a^n is the flow on link a at iteration n

4. A relative gap (duality gap)

$$RG = \frac{\sum_a (Z_a^n . x_a^n) - \sum_a (Z_a^n . Y_a^n)}{\sum_a (Z_a^n . x_a^n)}$$

where Z_a^n is the cost at the current flow on link a, Y_a^n is the all or nothing flow on link a and x_a^n is the current flow on link a.

5. An average excess cost which is the total additional cost of all routes in the network averaged over the total flow.

$$EC = \frac{\sum_a (Z_a^n . x_a^n) - \sum_a (Z_a^n . Y_a^n)}{\sum OD}$$

Where, $\sum(OD)$ is the demand.

Rose et al (1985) advocate the Relative Gap to be the most reliable measure of convergence as it represents an estimate of the distance between the current and optimal equilibrium solution. Boyce et al (2004) suggests that the relative gap (RG) should be at most 0.0001 for satisfactory convergence.

4.1.6.3 System Optimal (SO) Assignment

Unlike the user equilibrium assignment which tries to minimise the travel cost of individual travellers, this method aims to achieve a system state where the total travel cost on a network is minimized. At the equilibrium state in the SO assignment, no individual can change route without increasing the total travel costs on the system. In terms of travel time, this assignment method proposes a solution where system travel costs (congestion) is minimized when drivers are instructed to use certain routes. This is not a behaviourally realistic model but can be useful in analysing Intelligent Transport System (ITS) scenarios.

From the principle, the objective function to be minimized is:

$$\min_{q_a} Z(q_a) = \sum_a t_a(q_a) q_a \qquad (4.27)$$

It is interesting to note that the UE and SO methods produce identical results when congestion effects are ignored i.e. when travel time (cost) is not a function of link flows. The problem becomes finding the network flows that minimise the network total travel time (cost) given a fixed value for link travel costs. This resulting problem is also the all-or-nothing assignment.

4.1.6.4 Stochastic Assignment

A deterministic approach to traffic assignment assumes that road users have identical

and perfect information on the network costs and choose the least cost paths from their origin to destination. This assumption is central to the assignment methods that have been discussed earlier, specifically the UE method. The Stochastic method on the other hand assumes that driver perceptions of costs on any route are not identical and relaxes the assumption in the deterministic approach by including a random component in the traveller's perception of travel costs.

The two methods commonly used for stochastic assignment are outlined by Burrell (1968) and Dial (1971). Burrell's method is based on the Monte Carlo simulation to present the variation in the driver perception of link costs. The method used by Dial (1971) is a logit model based on reasonable paths. A path is deemed reasonable if every link in the path has its initial node closer to the origin than its final node. Sheffi (1985) identifies stochastic models as a special case of discrete choice models and specifies two route choice models namely the multinomial logit models and the multinomial probit model. The reader is referred to sheffi (1985) for details of these models.

Daganzo and Sheffi (1977) formulated a stochastic user equilibrium (SUE) solution that combined the basic assumptions of a stochastic model with that of a user-equilibrium model. The stochastic user equilibrium assignment leads to an equilibrium in which no traveller can improve his individually perceived travel time by unilaterally changing routes. Because of the underlying assumption that travellers perceive link costs differently, the SEU assignment results in a spread of each O-D flow over multiple routes. The route choice proportions depend on the travel time (costs) which in turn depends on the link flows which depend again on the route choice proportions. Unlike the classic UE assignment, less attractive routes do not have zero flows but rather lower utilisation. The SUE assignment produces more realistic results than the classic UE model because it permits the use of less and more attractive routes. Sheffi (1985) showed that the UE assignment is a good approximation for the SEU assignment in congested networks.

4.2 The Proposed Framework for Modelling Container Freight through Lagos, Nigeria

This section aims to develop a framework for modelling containerised freight transportation in Lagos, Nigeria, specifically with regards to containers entering the road network through the Lagos Port terminals. The model concerns itself only with containers generated at the port in order to explore the impact of diverting containers to a rail-connected dry port. The review of existing modelling techniques indicates that a supply chain /logistic chain model within a transport model is most appropriate since they are able to capture how changes to the container logistic chain influences vehicle traffic/volumes in a road network.

Regarding the unit of analysis, commodity based units are found to be most commonly used within supply chain models however, these units do not consider such trips that may arise from the commodities such as empty trips. Since containers are unitised cargoes that move in a single trip and generate empty trips, a trip based unit is more suited to this study as it focuses on movement from point to point. Furthermore, the study is not concerned with the exact commodity being carried but rather the type of packaging.

Container demand is generally linked with importers who are independent companies or the freight forwarding companies employed by importers. While the final destination (point of consumption) of containerised cargo is very difficult to trace, the movement of the container prior to stripping is much easier. This is because containers require certain handling equipment which is readily available at fixed locations and the importers' demands are steady and repetitive, the scale of which depends on the size of the firm. This model concerns itself with the movement of Full Container Loads (FCLs) to the places where they are stripped or in the case of Stripped Container Loads (SCLs) the movement of the containerised cargo to the first subsequent point of call. SCLs constitute of Less than Container Loads (LCLs) and Full Container Loads (FCLs) that are stripped at off-dock terminals, port terminals, consignee's designated container yard and the dry port.

This section presents an overview of the framework employed for modelling container related traffic for use in this study. It outlines how the supply chain of a typical type of freight (containerised cargo) can be traced to generate the O-D matrix integrated in a traffic model. It

also outlines how the World Bank's HDM IV model can be used in accounting for peculiar factors that influence a trucker's route choice in developing countries. A detailed report on the application of this framework and the development of the model is presented in Chapter 5 of this thesis.

4.2.1 Overview of Modelling Framework

The level of detailing of a model depends on the objectives of the model, its planned use, the time frame of analysis and constraints in terms of human resources and data availability. The most important factors are the objectives of the model and its planned use as these drive the assumptions upon which the model is built and the level of aggregation that is acceptable. In the case of this study, the objective of the model is to simulate the network impact of containerized cargo traffic before and after the introduction of dry port solutions. Thus, a macroscopic model that simulates traffic flows as a cumulative traffic steam on a link-by -link basis would be adequate. Due to time and resource restriction associated with a Doctorate research, a simplistic modelling approach that combines techniques adopted in existing transport software has been used.

The proposed model combines features of a logistic/supply chain model within the 3-step model discussed in Section 4.1.2. The core concept of the supply chain model is an understanding of how containerised cargo moves through the container logistic chain, that is from port terminals to final destinations which are defined in this study as the point of stripping for FCLs and the next point of delivery for SCLs. The structure and condition of the container logistic chain in Nigeria has been investigated and discussed in Section 3 of this thesis. At each step in the logistic chain, trip generation and distribution models are employed to obtain the O-D trip tables that are loaded onto the network. The model allows the author to examine how changes in the container logistics chain affect the transportation network.

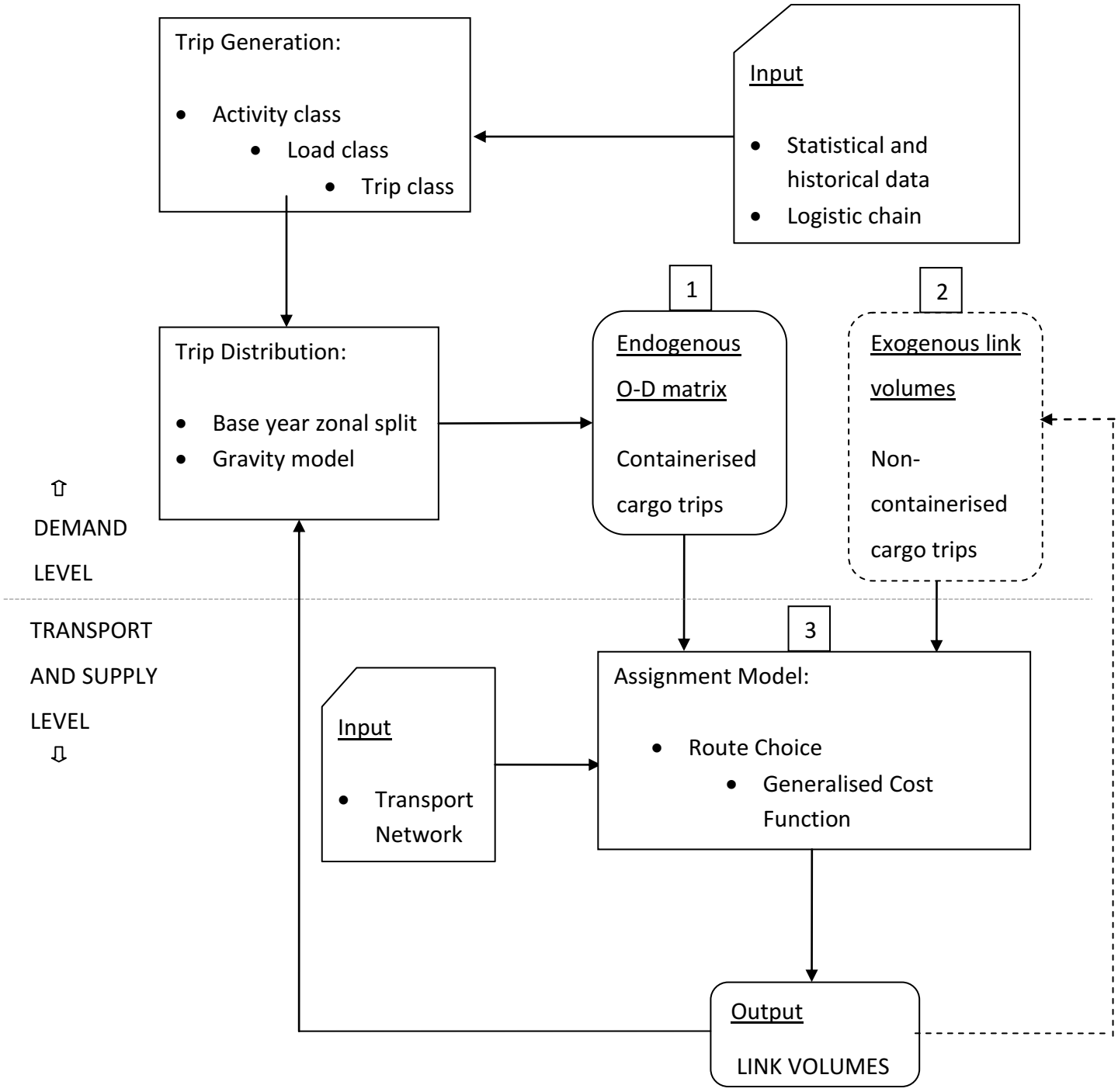


Figure 4.2: An overview of the modelling approach

The proposed modelling framework is summarised in Figure 4.2 and can be considered at two levels; the Demand level and the Transport/Supply level. The demand level relates to estimating trip matrices for two classes of traffic; the containerised cargo traffic and the non-container related traffic (all other traffic). The transport and supply level constitutes the link

generalised cost function and the algorithm associated with the traffic assignment model. These steps in the framework are discussed in Sections 4.2.2 to 4.2.6 and implemented in Chapter 5 of this thesis.

4.2.2 Containerised Cargo Trip Matrices

The containerised cargo trip matrix describes the movement of container-related traffic between zones in the network. This is estimated by considering the container logistic chain and the vehicle touring processes associated with containers. All trips originate from the port and are distributed through the relevant node in the supply chain before arriving at their destinations. The container O-D trips associated with this process are modelled at three levels:

Level 1 - The supply chain "Activity classes": Activity class represent the movement of containerised cargo from one node to another in the distribution chain. Nodes in the distribution chain refer to points where the container or its contents are manipulated. In the case of Nigeria activity classes includes; port to importer, port to off-dock terminals, off-dock to importer etc. Each activity class is handled by a different actor in the industry, for example container movement from port to importer is organised by the importer while the movement from port to off-dock terminals are organised by the shipping line and terminal operators. The reader is referred to Figure 3.15 of this thesis. For each activity type, container volumes (in TEUs) are obtained from historical data.

Level 2 - The container "Load Classes": "Load Classes" represent the type of container loads and their associated "Vehicle class". Container loads are classified under Full container Loads (FCLs) or Stripped Container Loads (SCLs). Container volumes associated with each load type are calculated as a proportion each of the activity classes identified at from level 1. The volumes in TEUs are converted to vehicle trips using appropriate trip conversion rates.

Level 3 - The cargo "Trip classes". The Trip class represent the stages (trips purposes) in the tour process associated with each load class (FCLs and SCLs). This includes laden trips and Empty trips. The tour process is based on the life cycle of a container. Trip classes in the same activity class are considered to be organised by the same actor. Figure 4.3 is an example of a tour process associated with FCL and SCL load types and an activity types (in this case port to importers). Trip volumes from level 2 are allocated to trip classes on the basis of a flow

conservation constraint which ensures that equivalent flows through each stage in the tour are the same. Within each tour, the attraction and production at zones are balanced.

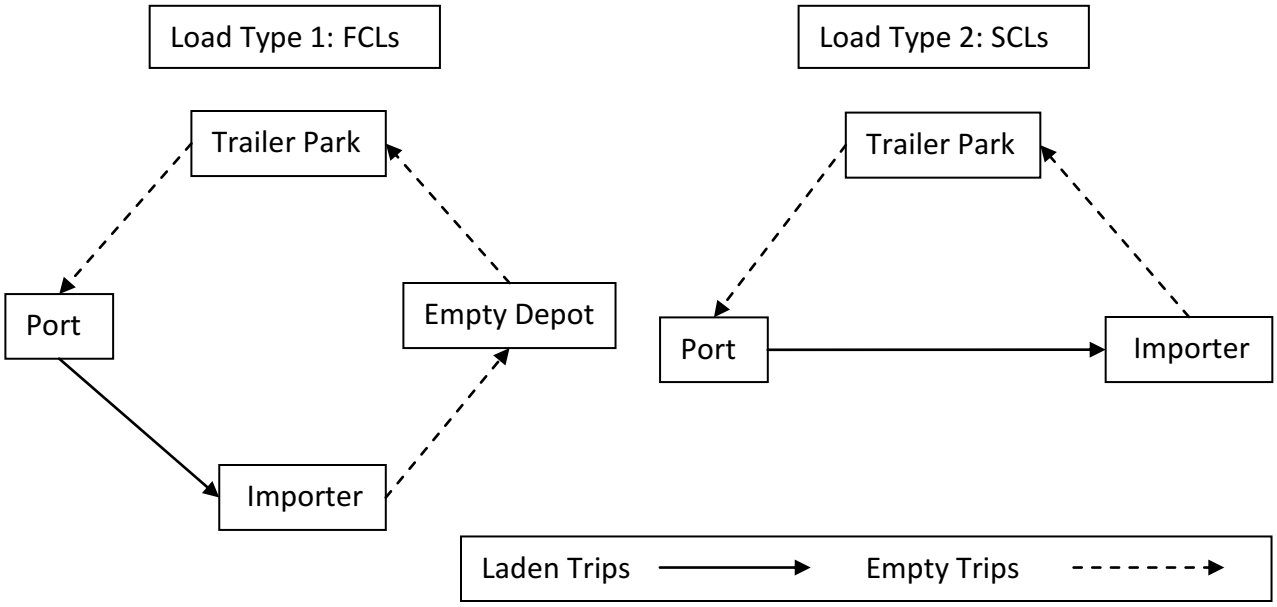


Figure 4.3: Example of vehicle tours[2]

O-D trips are estimated for FCLs and SCLs using two different methods. FCLs are split across zones according to container destination data obtained from surveys in a base year. This is logical since the demand for freight traffic is driven by the location of relevant actors in the logistics chain. In the study, the year 2009 has been selected as the base year and container volumes have been forecasted from the base year on the basis of past growth trends.

The literature review found the gravity model to be the most widely used trip distribution technique for freight and so the O-D trip matrices for SCLs have been obtained according to an origin constrained gravity model. Furthermore, this method unlike other methods considers trip impedance (Fratar model) and is less cumbersome to apply and calibrate (intervening opportunity model).

The outputs of this "3 level" trip matrix generation process are trip matrices for a chain

[2] Motor parks refers to the locations where HGVs are parked.

of trip classes that are associated with a combination of activity classes and load Classes. These matrices are summed up according to their load classes to obtain matrices for each load class and so vehicle type. The specific trip classes relating to this study are outlined in Section 5.2.1.

4.2.3 Exogenous Link Volumes for Non-container Related Trips

Non-container related traffic refers to all traffic in the network that is not container related. This includes vehicle types such as passenger cars, buses, and vehicles carrying other freight cargo. At the time of the model development, no such O-D trip matrices where available to the author for use. Yet, it is necessary to consider other traffic as the model is being developed to consider congestion on network links which cannot be achieved by loading container related traffic only. However, the size of data and resources (monetary and time) required to develop trip matrices for such vehicle classes were unavailable and so, traffic volumes for non-container related traffic are input as exogenous variables for each link (in PCU's).

In the case of modelling passenger transport with missing freight trip matrices, it has been widely accepted to approximate the freight link flows as a function of passenger flows on links or the capacity of links. The proposed model is based on a regression analysis where the independent variables are factors that may influence the volume of non-container related traffic. These factors relate to the features of the link and the characteristics of the zone in which the link exists. Some examples of the factors which could be used include:

- Proximity of link from trade hubs
- Proximity of link to city exit routes
- Level of public transport service on link
- Private car ownership/population of zone
- Level of commercial/industrial activity in zone
- Road Network density in zone

The decision on what factors to consider is directly related to data availability. In the present study, the proportion of non-container related traffic on links has been based on a regression analysis using the proximity of the link to the ports as the predictor variable. The

reader is referred to Section 5.3 for details of the regression model used to derive the non-container related traffic volumes on links in the network.

4.2.4 The Proposed Generalised Cost Function

The Generalised Cost Function or Link Performance Function is a measure of the resistance perceived by a road user as a hindrance to his journey through the network. In the context of container traffic, the Generalised Cost Function is a mathematical relationship that represents a measure of the cost or resistance encountered by truckers when moving from one node to another in a network. It represents the factors that are considered to influence the driver's route selection process.

4.2.4.1 Understanding Truckers Route Selection Process

Stepanedes et al (1989) in their study were able to show that in general drivers rarely consider more than two routes, even though numerous alternative routes exist. Looking at a road map, an individual may be able to identify a finite number of possible routes. Yet, for trucks and indeed large vehicles, not all routes are viable. It is often impossible without prior knowledge of the road conditions to identify these "motorable" routes. The driver's experience of the road network allows him to narrow down his route choices to one or two practical options from which he makes the perceived optimal selection. In developing countries where road conditions are vastly variable, favourable routes available when travelling between an origin destination pair are determined from past experiences. Truck operators informally pass on the knowledge to new drivers by giving directions on which roads to use, prior to commencing the journey.

A survey carried out by Nigeria Shippers' Council has shown that problems encountered in the course of transporting goods include; extortion by agents (41%), bad roads (35%), insecurities including armed robbery and accidents (12%), theft/pilferage (11%) and others (1%). This was based on the replies to a questionnaire sent out to haulage companies. Ubogu et al (2009) supported these findings showing that harassment from law enforcement officers, traffic delays and armed robbery were by far perceived as the most problematic operational

constraints confronting cargo haulage in Nigeria. The trucker would therefore be expected to consider such factor during a route selection process and where possible avoid routes with such problems.

In his report on trucking constraints in Nigeria, Ubogu et al (2009) showed that traffic delay in the city centre was the second most important freight operational constraint, while harassment from law enforcement agents such as Customs and the Police was suggested to be the most important constraint. It was however suggested that truck drivers who experience traffic delays in the city are not likely to encounter harassment from law enforcement officers or armed robbery attacks. Thus, passing through the metropolitan areas automatically reduces the chances of harassment or armed robbery as the traffic delays increase. Issues with harassment are sporadic, not completely legal and are at most times carried out to frustrate the drivers, who are then forced to hand out bribes so as to prevent undue delays. The poor road conditions in the country ensure that trucks are most often restricted to a limited number of routes between any O-D pair. The traffic volumes on such key arteries are above capacity and higher than they would be if the road conditions on other routes were of higher standards. The harassment points are located along such key freight arteries through which trucks are expected to pass. The behavioural pattern of the truckers thus dictates the location of such check points and not necessarily the reverse. For this reason, harassment by agents has not been considered in the model.

Previous works have identified a number of factors as influencing a driver's decision on route choice. These include travel time, risk of delays, real and perceived cost, toll charges, the road conditions, availability of backhaul cargo, scenery and services, and other attractions along the routes (LABC, 2002). A survey was undertaken by the author to verify the critical factors that influence the trucker's route choice in Nigeria, the results of which are summarised below.

Survey result and analysis

A survey was carried out by the author to verify the factors that influence the trucker's route selection process in Nigeria. It involved handing out questionnaires to a sample of cargo hauliers and road transport owners to explore the factors taken into consideration when selecting a preferred route between any two O-D points. It was assumed that the trucker's route choice would be influenced to various levels by factors such as those aforementioned. It

was necessary to explore the relevant factors - how they related to each other and how important they were in the route selection process. The questionnaire aimed to quantify the relative importance of the factors that influence the truckers' route selection patterns within the road network in question. The questionnaire presented truckers with a list of influencing factors on which to assign weights of importance and rank in order of relative importance. Based on an understanding of the container haulage industry in this third world country, factors such as attractions along the route and scenery were deemed as not relevant to influencing a trucker's route choice and so were excluded from the questionnaire. Factors like adverse weather conditions (e.g. rain seasons) are not controllable and so not considered in the model. A copy of the questionnaire circulated is included in Appendix C.

Whilst circulating the questionnaire to the truckers in Lagos, the level of illiteracy among them created a communication barrier, which often made it arduous to get the questionnaire filled in accurately. Furthermore, the challenges faced with moving around the city to conduct interviews meant that replies to the questionnaire were received from only 32 truck owners. Although the preferred sample size was not acquired at the time of the visit, the replies received expanded the authors understanding and allowed certain conclusions to be drawn.

Speaking to the truckers, it became clear that no formally outlined procedures are applied during the route selection process. The decision appears to rely on the driver's discretion which is based on his experiences and knowledge of the roads. It was clearly reiterated by most drivers, that there were often only one, and at the most two available routes between any O-D zones. With further investigation, it became obvious that this was the case simply because these routes were on many occasions, the most "motorable" ones for trucks towing container trailers.

To quantify the perceived importance of these factors to a trucker, a "weighted priority" is calculated for each factor and compared. The "weighted priority" is calculated by averaging the product of the weight (which represents a score of 1 to 5 for the importance of these factors in the route selection process) and the priority (which represents the ranking of these factors for the relative importance of each factor) assigned to each factor by the interviewee. The summary of the results are included in Table 4.1 below. It is important to mention that this weighted priority is not used within the generalised cost function but rather to give an idea of

the relative importance of each of these factors. Lower weighted priority values imply higher importance.

Table 4.1: Summary of weighted priorities

Factors	Weighted priority
Type of roadway used. i.e. whether it is an expressway, trunk road, or secondary	3
Road surface conditions of roadway on route and general structure of roadway	3
Journey time on roadways en- route, which is influenced by the level of traffic.	4
Urban congestion black spots or the existence of by-passes	5
Safety on route/roadway	7
Size of vehicle (height and width)	8
Drivers hours, and where the drivers like to take their rest breaks (including good	14
Cargo features e.g. Weight, perish ability, fragility	15
Availability of backhaul cargo.	19
Toll charged roadways and bridges on route	24

While the road surface conditions, type of road way and journey time are found to be the most critical factors in a trucker's route selection process, all factors are considered to play a part in the trucker route selection process and should be included in the generalised cost function.

- Road surface condition and general structure of roadway: This has a huge effect on the ride quality, the service life of the vehicle and the cost incurred in maintaining the vehicle. In Nigeria, most trucks used are fairly heavily used vehicles already in relatively bad condition, with mileages of up to 600,000 kilometres. Continuous use of dilapidated roads means that these vehicles are prone to tyre punctures and induced wear and tear of parts, leading to an increase in the number of tyre and part changes made per year. In an economy where no tyre rethreading is available, spare parts scarce and their costs relatively high, any route option that presents a lower chance of a tyre puncture or a vehicle break down occurring en route is well preferred. Also, dilapidated roads force vehicles to move at slower and less optimum speeds for fuel consumption. This

increases the volume of fuel consumed per kilometre, and adds to the overall operating cost of the particular vehicle.

There is a direct relationship between the road roughness/surface condition and the vehicle operating costs. Key costs in the operation of trucks include; part replacement, administrative costs which incorporate unknown charges imposed at police check points, cost of tire repairs and cost of fuel. Generally, in an effort to maximise profit margins, truckers endeavour to avoid routes that negatively influence their operating costs.

- Type of roadway: This factor addresses the classification of roads used by truckers. Drivers would, where available, use expressways and by-passes simply because they are most likely to accommodate the trucks, most often paved and less prone to poor physical conditions. The level of congestion on the road does not alter the choice made on this basis, simply because congestion is an issue on most of the roads in the country. Also, based on the effects that bad roads have on the vehicle condition, truckers find it more economical to spend time in traffic than to expose their vehicles to poor quality roads. Thus, when faced with the options of approaching a freer dilapidated road and a congested good road, the latter option may most likely be selected, especially on an upcountry trip where vehicles are exposed to bad conditions for longer stretches.
- Travel time on route: The time spent in journeying between two O-D points is crucial, especially in the container business where importers/consignees are given a fixed number of days within which to return the empty containers to the shipping lines. Completing the backwards and forwards journey within a fixed window frame becomes crucial in a competitive market where providing a high quality of service in quick time is vital to securing customers. The trucker continuously struggles to find a balance in these factors when making decisions.
- Vehicle size (width and height): The width of the road and number of lanes available determine whether or not a road can be used. For this reason, trucks may choose to stay clear of residential roads unless they are unavoidable. The headroom available on a road influences the route choice. High vehicles would be unable to use roads with height restrictions. Thus, a road may be classified as a no through route to a particular

vehicle type because of the vehicle's dimensions and the headroom available on the road.

- Other factors: As tolled roads are very few within the road network, this factor is ignored. Back haul of cargo is unpredictable and depends on whether the driver has cargo available for collection at the time of delivery. He may wish to earn some extra money by deviating en-route in order to make the collection and delivery. This act is not supported by the management of container companies, as the priority is to return the empty containers to selected bays within the time specified by the shipping lines. They however have no direct control over the decisions taken by the drivers once the truck is out of the yard.

  The characteristic of the cargo has little to do with route choice on the road network as the delivery of all cargo types is treated with the same level of urgency. Furthermore in cases where time constraint may apply, the route choice is still driven by the characteristics of the network, since vehicles go as fast as the network allows.

  The location of check-points en-route is a nuisance as emphasised by truck operators during the interviews. Such points are mobile, constantly changing and located on major truck routes. For these reasons, check-points are unpredictable and difficult to avoid. This problem could be linked to corruption within the Police Force in the country and could be eliminated by discontinuing check-points on roads and implementing a country level reform against corruption. This argument applies also to safety on roads.

The ideal generalised cost function is one that considers all these factors in the right proportions. However, determining this may be cumbersome. As this is not the main aim of this study, the author proposes to use a proxy that considers these factors indirectly.

4.2.4.2 Components of the Generalised Cost Function - Application of the World Bank VOC Function

In order to maximise profits, truck operators may aim to increase the vehicle utilisation within the service life of the vehicle, reduce the operating costs or increase the charge for every

km of utilisation. Consequently, to maximise vehicle utilisation, truck operators would minimise idle time by maximising the trips made within a given period of time. These trips can be maximised by avoiding traffic delays to keep the travel time per trip to a desired minimum.

Traffic delays are characterised by slower speeds, longer trips and increased queuing (Hook, 1995), all of which increase the costs to the truck operator. This cost consists of the cost of operating the truck and the opportunity cost forgone. The opportunity cost is characterised by the cost of lost time due to traffic congestion which is a function of the value of time. The exact value of this cost varies with the size of the operating firm and the market price of the service in monetary units per hour. Since the haulage sub-sector in Nigeria is dominated by a large number of small scale operators, the value of time cost to firms would be similar in magnitude for all firms.

Daniels (1974) splits the operating cost of vehicles into two categories - running costs and standing cost. The running cost includes components like the fuel consumption, tyre consumption, oil lubricant consumption, labour costs, and maintenance cost, all of which vary with the distance and speed of travel. The standing costs are not sensitive to the volume of traffic and include overhead costs, interest and insurance. These operating cost components are considered a function of the road characteristics, the vehicle characteristics and local factors like the speed limit, unit costs and driver attitude (Watantada, 1987). These factors, especially the vehicle and road, have been identified by Ademimila (1977) as key factors influencing congestion in the Lagos metropolitan area.

Assuming that a trucker would select a route that maximises profit, a function that defines the effect of traffic delays on the operator costs of a truck could be used as the generalised cost function in the assignment process. Such a function would relate the current allowable speed of a vehicle due to congestion to the costs incurred by the truck operator when using the route. Such a function must also consider the effect of the vehicle and road characteristics (including road surface, road structure and type) on the speed at which the vehicle travels along a route and so on its operating costs.

It is important to note that although truck drivers are often not the operator of such trucks, both parties perceive a cost which is influenced by the road conditions and speed of travel. While truck drivers relate to a measure of time, truck operators relate to cost measures,

yet the perceived cost effect is one and the same. Apart from keeping travel time en-route to a minimum, a truck driver, in order to protect his job, would try to avoid disruptions to the smooth running of the truck. Such hindrances include, breakdown of vehicle due to engine overheating and tyre punctures, all of which are influenced by the condition of the road surfaces and the level of traffic on the roads. The truck operator's cost function considers not only the driver's time costs but also the possibility of all such eventualities stated above.

The generalised cost function, otherwise referred to as the impedance function, is a function which prohibits the use of a network objects (Links) and varies between each object depending on its attributes/characteristics. It measures the effort put into using the network object within a traffic process or transport system in this model. The appropriate impedance function is one that best defines the trucker's perceived costs of the directly controllable operational constraints aforementioned and so influences the trucker's route choice. The model assumes that truckers are aware of the costs associated with such constraints and base their decisions on them.

The generalised cost $Za^{k}(x_a)$ function proposed is a function consisting of the Vehicle Operating Cost (VOC) and the Travel time (a function of speed, distance, road surface condition and traffic flow/congestion). The VOC is a function of the road characteristics, vehicle characteristics, tyre wear, vehicle utilisation, labour cost, maintenance cost, and fuel cost. In this model, the generalised cost function relates only to the containerised cargo traffic and not to other traffic.

$$\text{Generalised Cost} = \begin{bmatrix}\text{Travel Time Cost}\\ \text{Component}\end{bmatrix} + \begin{bmatrix}\text{Vehicle Operating Cost}\\ \text{Component}\end{bmatrix}$$

$$Za^{k}(x_a) = \left[Ta^{k}(x_a)\right] + \left[Ca^{k}(x_a)\right] \quad (4.28)$$

Where

$Za^{k}(x_a)$,the generalised cost is the impedance function on link 'a' related to a vehicle type 'k' travelling on it, and is a function of the volume of traffic using link 'a'.

$X_a = X_p + X_f$ (where x_a = traffic flow on link (a), X_p is the exogenous non-container related traffic flows and X_f is the container related traffic flows). X_p is constant for a given travel

demand in a transport system.

$\mathrm{Ta}^{\mathrm{k}}\ (\mathrm{x}_{\mathrm{a}})$, is the travel time cost incurred by road user driving a vehicle type 'k' on link 'a'.

$\mathrm{Ca}^{\mathrm{k}}\ (\mathrm{x}_{\mathrm{a}})$, is the Operating Cost incurred by road user driving a vehicle type 'k' on link 'a'. The type of vehicle used depends on the type of cargo being transported.

Vehicle operating cost component (VOC) $\{\mathrm{Ca}^{\mathrm{m}}\ (\mathrm{x}_{\mathrm{a}})\}$

The vehicle operating cost represents the cost to maintain and run the vehicle. This cost varies with the physical characteristics of the road, the vehicle characteristics, the cost of fuel, the cost of tyre repair or replacement, the cost of labour, the cost of spare parts, and other administrative costs involved with operating the vehicle.

The World Bank's Highway Design and Maintenance tool, HDM-VOC (HDM IV model) provides relationships for calculating VOC for roadways in developing countries. The relationships are part of a tool developed by the World Bank to support technical and economic appraisals of road projects in developing countries. The equations are based on mechanics and primary cost studies carried out in Kenya, the Caribbean, India and Brazil. It contains relationships that can be used to predict the consumption of resources as a function of road traffic conditions, road characteristics and vehicle characteristics in developing countries. It was originally developed to predict the various components of the vehicle operating costs in a "free-flow traffic environment" and was later adopted to vary with traffic flow levels on link (roadways). In this model, the relationships that vary with link flows form the basis of the link performance function referred to here. The operating cost is a sum of its components and is defined as a function of link flows as in equation 4.1 below.

$$Z(x_a) = \sum_{k\in K}\sum_{a\in A}\{ F_a^k(x_a) + O_a^k(x_a) + T_a^k(x_a) + I_a^k(x_a) + C_a^k(x_a) + E_a^k(x_a) + L_a^k + P_a^k\}D_a \qquad (4.29)$$

Where,

$F_a^k(x_a) =$ Fuel consumption cost

$O_a^k(x_a) =$ Oil consumption cost

$T_a^k(x_a) =$ Tyre wear cost

$I_a^k(x_a) =$ Interest cost

$C_a^k(x_a) =$ Crew time cost

$E_a^k(x_a) =$ Depreciation cost

$L_a^k =$Maintenance labour cost

$P_a^k =$ Maintenance parts cost

$D_a =$Length of link *a*

The relationships for each of these components are discussed in Appendix D. Basic traffic theory relates link flows to speeds. An increase in link flow leads to vehicle interactions which lead to a reduction in vehicle speeds. The equations suggest that a reduction in speed gives rise to an increase of the individual operating cost components and so the operating cost. Thus, it can be inferred that operating costs increase with increase in link flows. Figure 4.4 illustrates this point.

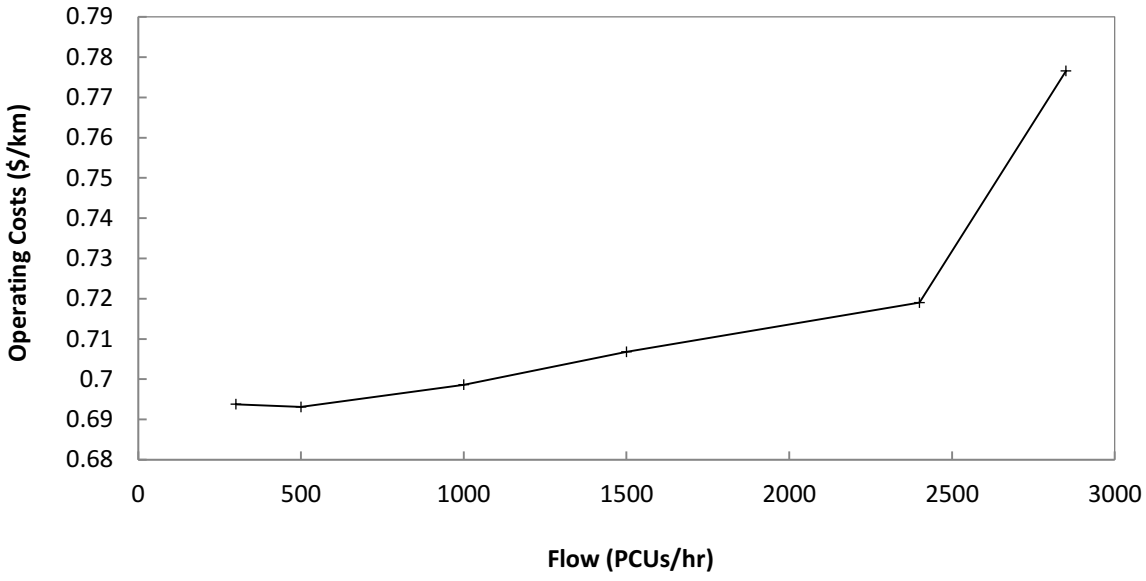


Figure 4.4: Truck Operators Cost Vs Flow (Source: The World Bank)

Apart from flows on links, other road characteristics affect the operating costs in

different ways. The operating cost of a vehicle on a road increases substantially with increase in length, surface roughness, horizontal curvature, and vertical gradient but decreases with increase in super elevation and altitude of terrain. Furthermore, the size, gross weight and engine power of a vehicle influences its speed of travel. Yet, unlike flow, speed and travel time these parameters do not change over time but rather vary from link to link or from vehicle class to vehicle class.

Travel time cost $\{\mathrm{Ta}^{\mathrm{m}}\ (\mathrm{x_a})\}$

Travel time cost comprises of the cargo time cost and is a measure of the opportunity cost forgone. This opportunity cost relates to the revenue forgone by the trucking company because of lost time due to traffic congestion and is based on the value of time. The exact value of this cost varies with the size of the operating firm (market share) and the market price of the service in monetary unit per time unit. Since the haulage sub-sector in Nigeria like most developing countries is dominated by a large number of small scale operators, the value of time cost to firms would be similar in magnitude and is assumed to relate to the market price of the service provided. The travel time cost is given by the formulae:

$$\mathrm{Ta}^{\mathrm{m}}\ (\mathrm{x_a}) = \alpha[\mathrm{t_{cur}}] \tag{4.30}$$

Where:

α = the total value of time given as the sum of the value of lost time in cost/unit time.

$X_a = X_p + X_f$ (where $\mathrm{x_a}$ = traffic flow on link (a), X_p is the exogenous non-container related traffic flows and X_f is the container related traffic flows). X_p is constant for a given travel demand in a transport system.

t_{cur} = the travel time on link (a) as a function of traffic flow on link ($\mathrm{x_a}$).

The travel time is determined from the saturation of roadways/links which is based on the volume of traffic on the link and the capacity of the link. At free flow, the travel time (t_0) of a link can be derived by dividing the link length (d) by the free-flow speed (v_0) on the link. The travel time on a loaded link is determined using a predefined speed-flow/ volume-delay curve. These curves/functions describe the correlation between the current traffic speed (vcur) and

the link flow (xa). At the time of model development, speed-flow relationships had not been developed for Nigerian local conditions and so the author assumes the basic "three –zone" speed –flow model used within the HDM tool from which the VOC equations were obtained. This speed-flow model as proposed by Hoban et al (1994) predicts that below a certain volume, denoted Q_0, there are no traffic interactions and each vehicle type (n) travel at an independent free speeds denoted S_n (S_1, S_2, and S_3 in Figure 4.5) Once beyond Q_0 traffic interaction commences and the speed of each vehicle begins to decrease until reaching the nominal capacity (Q_{nom}) where all vehicles travel at the speed of the slowest vehicle, denoted S_{nom}. Beyond this point, vehicle speeds decrease towards the speed S_{ult} which occurs at ultimate capacity (Q_{ult}). The "three zone" speed flow model is illustrated in Figure 4.5 below. The values of Q_0, Q_{nom} and Q_{ult} vary depending upon the road type and width. Hoban et al determined the speeds at free flow; the effect of congestion on speed is approximated using the "three zone" speed flow model. The vehicle free speeds are influenced by the road and vehicle characteristics. The values of the parameters (S_{ult}, Q_0, Q_{nom} and Q_{ult}) vary depending on the road type and width of the road. The values assumed for use in this study are based on those proposed by Hoban et al (1994) and are summarized in Table 4.2 below. As data relating to speed–flow relationships are unavailable for Nigeria, this simplified model is assumed acceptable for this study as it is used in the World Bank's HDM tools within the context of developing countries, of which Nigeria is one.

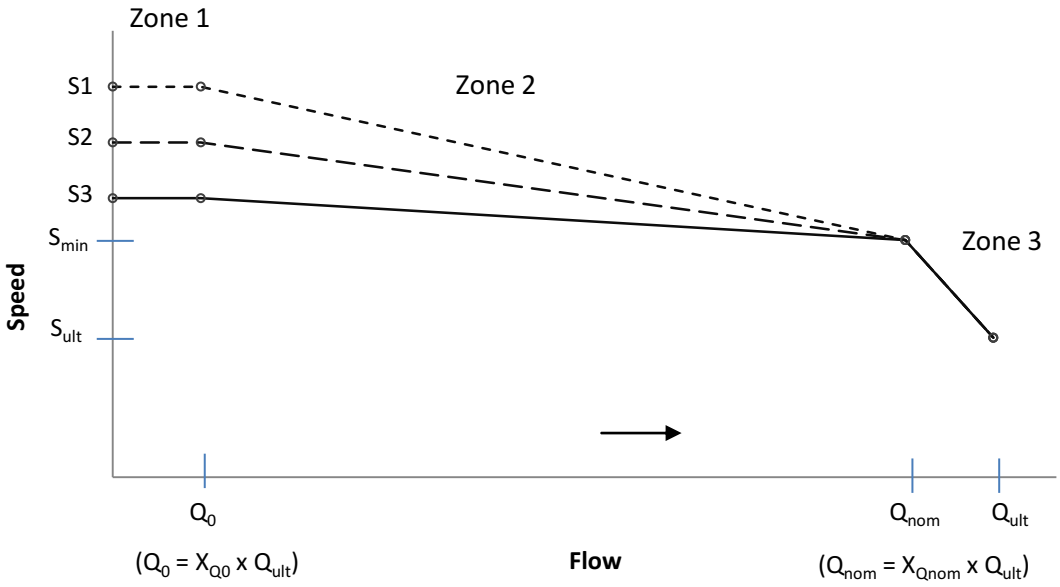


Figure 4.5: "Three-Zone" speed flow relationship

Table 4.2: Speed-flow parameters by road type

Road type	Road width (m)	X_{Q0}	X_{Qnom}	Q_{ult} (PCU/h)	S_{ult} (km/h)
Single Lane road	≤4m	0	0.7	600	10
Intermediate road	4 to 5.5m	0	0.7	1800	20
Two lane road	5.5m to 9m	0.1	0.9	2800	25
Wide Two lane road	9m to 12m	0.2	0.9	3200	30
Four lane road	≥ 12m	0.4	0.95	8000	40

4.2.5 Assignment Process and Algorithm

Traffic assignment presents the concept of how traffic is distributed within a network given its structure, capacity and spatial demand. The basic problem in traffic assignment is to find the link flows given the network, the link performance function and the Origin–Destination trips. The assignment process is based on a Dijkstra shortest–path algorithm which identifies low cost routes. This follows from a behavioural assumption that motorists choose to travel along paths that minimise general travel cost. A stable condition is reached where no traveller using the network can reduce their travel cost by unilaterally changing routes. At this condition, for each O-D pair, the travel cost on all used paths is equal and also less than or equal to the travel cost that would be experience by a trucker on any unused paths. This condition is referred to as **User-Equilibrium**. It assumes that all motorists (Truckers) have full information of the travel impedance on every possible route.

For container related traffic, the equilibrium has to be characterised and formulated mathematically. Containerised cargo link flow pattern can thus be obtained by solving a mathematical program with an objective function to minimise the cost function $\left(\mathrm{Za}^{k}\ (\mathrm{x_a})\right)$. Where $\left(\mathrm{Za}^{k}\ (\mathrm{x_a})\right)$varies with vehicle type.

$$\left(\mathrm{Za}^{k}\ (\mathrm{x_a})\right) = \mathrm{Za}^{1}\ (\mathrm{x_a}), \mathrm{Za}^{2}\ (\mathrm{x_a}), \mathrm{Za}^{3}\ (\mathrm{x_a}), \mathrm{Za}^{4}\ (\mathrm{x_a}), \mathrm{Za}^{5}\ (\mathrm{x_a}) \quad (4.31)$$

Consider a set of vehicle class K, travelling between a set of Origin-Destination (R-S) pairs W, using a transportation network G=(N,A) where N is a set of nodes and A is a set of links.

$$min_f \sum_{w \in W} \sum_{k \in K} \sum_{a \in A} \int_{x=0}^{x=x_a} Z_a^k(x)\, dx \quad subject\ to \tag{4.32}$$

$$\sum_{m \in P_{rs}} f_{rsm}^k = q_{rs}^k, r \in R, s \in S, k \in K \tag{4.33}$$

$$\mathrm{x_a} = \sum_{r \in R, s \in S, m \in p_{rs}, k \in K} PCU^k\, f_{rsm}^k\, \delta_{rsma}, a \in A \tag{4.34}$$

$$\mathrm{x_a} \leq K_a, a \in A \tag{4.35}$$

$$f_{rsm}^k \geq 0 \tag{4.36}$$

Where:

A = Set of links

W = set of origin-destination pairs

R = Set of origins

S = Set of destinations

P_{rs} = Set of paths connecting r to s

K = Set of Truck types (container carriers, distribution trucks)

PCU^k= PCU factor for truck of type k

q_{rs}^k = OD matrix for trucks of type k

f_{rsm}^k = Flow of vehicle type k from r to s on path m

$\mathrm{x_a}$ = Flow on link in PCUs

K_a= Capacity of link *a* in PCUs

$Z_a^k(x_a)$ = Truck Operator's Cost of using link *a* by mode *k* expressed as a function of flow

The assignment process is based on a shortest-path algorithm which identifies the lowest cost routes. This follows from a behavioural assumption that truckers have previous knowledge of the road conditions and so choose to travel along paths that minimise the operating cost associated with travel. This cost considers the road conditions, the

characteristics of the vehicle class and the effect of other vehicles on travel time. A user-equilibrium is sought, where a stable condition is reached when no traveller using the network can reduce their costs by unilaterally changing routes.

Sheffi (1985) establishes two conditions that are required for the user-equilibrium problem to have a unique solution. The link cost functions are non-decreasing with respect to flow on a link and the functions are separable such that the flow on one link exerts more influence on the cost on this link than the flow on any other link does. Since these conditions are met in this formulation, there should be a unique user equilibrium solution.

4.2.5.1 Algorithm

The method of successive averages (MSA), known also as a simplified transformation of the Frank-Wolfe algorithm, (Sheffi, 1985) is used to solve the model. The MSA is based on a predetermined move size along the descent direction, and the detailed steps of the algorithm are described as follows:

- Step 1 Initialization. Based on road condition on link (a) and characteristics of vehicle class (k), calculate the generalised cost $Z_a^k(x_a^n)$ at free-flow. Using $Z_a^k(x_a^n)$ as Link impedance, assign the travel demand of each class traveller to the network, according to all or nothing method. This generates a set of initial link flows $x_a^{(0)k}$ the iteration counter to n=1.

- Step 2 Update. According to the current link flows; calculate the new generalised Costs $Z_a^k(x_a^n)$.

- Step 3 Direction Finding. Based on the current set of Link Costs, assign the demand to the network according to an all or nothing method. This yields the auxiliary link flows $\left\{ y_a^{(n)k}, \forall k, a \in A. \right\}$.

- Step 4 Averaging: Based on the current auxiliary flows, using a move size sequence of

1/n, calculate the link flow by setting.

$$x_a^{(n+1)k} = \propto y_a^{(n+1)k} + (1-\propto)x_a^{(n)k}, \forall k, a \in A \quad (4.37)$$

- Step 5 Convergence check: If convergence criterion is met, stop iterating and obtain solution. Otherwise, set n = n+1 and return to step 2. The following convergence criterion is used here; examine the similarity of network flows of successive iterations, G1 $\rightarrow$ 0

$$G1 = \sum_a \sum_k Z_a^k (x_{a+})(x_a^k - y_a^k) \quad (4.38)$$

Where, $x_{a+} = \sum_k x_{ik}$

For a predetermined precision parameter, $\varepsilon = 1.0\mathrm{E}-05$

$$G2 = \frac{\sqrt{\sum_a \sum_k \left(x_a^{(n+1)k} - x_a^{(n)k}\right)^2}}{\sum_a \sum_k x_a^{(n)k}} < \varepsilon \quad (4.39)$$

4.2.5.2 Software and Programming

This Assignment stage consists of two levels: transport planning software - VISUM is used to structure the multi-class assignment problem while the process for calculating the generalised cost and the Method of successive average is programmed in Visual Basics. Both interfaces communicate through VISUM's Component Object Model (COM) interface. Generally, information on link attributes (road characteristics) is stored in VISUM while the vehicle characteristics are stored in Excel. VISUM exports the link attributes to the Visual Basic programme which computes the link Generalised costs for each vehicle class on each link. The calculated generalised cost is imported into VISUM to represents the impedance function used in the assignment process.

The shortest path between any one O–D pair is derived using this generalised cost functions. VISUM assigns the O-D matrices to the route with minimum impedance. VISUM exports the new link flows to Visual Basic for use in calculating a new set of generalised costs. The Visual Basic programme then computes a new set of generalised costs and exports it into VISUM. The process continues in a loop until the user–equilibrium is achieved. This process is mapped out in Figure 4.6.

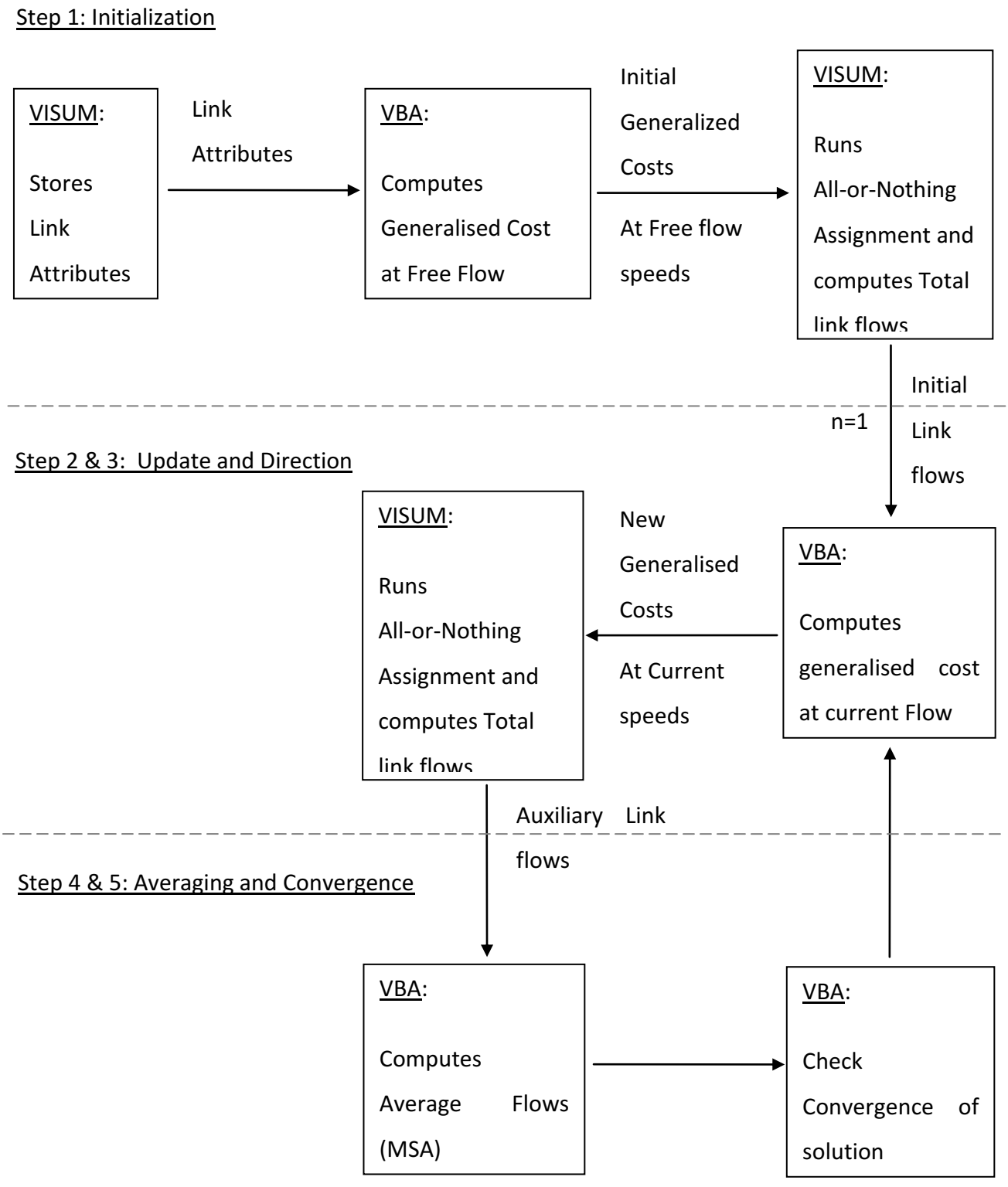


Figure 4.6: The assignment process

4.2.6 Assumptions

The proposed framework is based on the following assumptions:

- All vehicles in an activity class make round trips carrying empty containers on return trip. This assumption ignores potential backhauling of cargo and is justified since backhauling is a task not commonly undertaken in Nigeria because of its logistic complexity. The assumption slightly overestimates total trip lengths and travel times.
- Flows through stages in the supply chain are assumed to be continuous, directional and occurring at the same time. Thus, the O-D flows for the different trip classes are applied to the network simultaneously and represent the worst case network loading.
- Volumes of containerised export cargo are equivalent to 7% of total throughput and so are ignored. However, this does not affect the validity of the model because export moves are assumed to be a substitute for empty moves. This is done because no information is available of the movement from point of drop off for imports to point of collection for export. Also, while port statistics give a geographical distribution for imports they do not do so for exports. The impact of this assumption is that the model does not capture multiple trip legs associated with export laden containers. However, since laden export containers account for a minute proportion of export container trips, total trip length and travel times are only slightly underestimated. This could however be considered in future research.
- The assignment model is based on the assumption that drivers are aware of the available routes for travel and define the best routes based on experience. The route chosen is therefore one that minimises the perceived generalised cost of travelling between any one origin-destination pair.
- The port is the only entry point for containerised cargo into the transport system and all containers are assumed to have entered the network through a port terminal.

The effects of the overestimating assumptions are expected to balance the effect of the underestimating assumptions and so, the output of the model should be close enough to reality.

4.2.7 A Simplified Numerical Example

This example is provided to illustrate the characteristics of such results obtained from the traffic assignment model outlined in Section 4.2.5 using the cost function proposed in Section 4.2.4. In this example, the catchment area is split into 4 zones connected by a network consisting of 11 links. All links are open to traffic approaching from both directions. The centre of zones 1,2,3,4 are accessed directly by nodes 1,6,4,2 respectively.

For simplicity, only 3 stages in the container distribution chain (activity classes) are considered to exist in this example. These are port to importers, port to off-dock terminal and off-dock terminal to importers. Containerised cargo is transported on trailers and in trucks depending on the load type (FCLs and SCLs). A combination of vehicle type (trailer and truck) and the 3 stages in the distribution chain generates 6 sets of demand matrices. These matrices are introduced simultaneously onto the network. In this example, the total demand for O-D pairs w_{12}, w_{13}, w_{14}, w_{21}, w_{23}, w_{24}, w_{31}, w_{32}, w_{34}, w_{41}, w_{42} and w_{43} are 550, 950, 650, 200, 200, 200, 600, 900, 550, 560, 500, and 500 respectively. Non container traffic on links is calculated exogenously as a proportion of container traffic on each link.

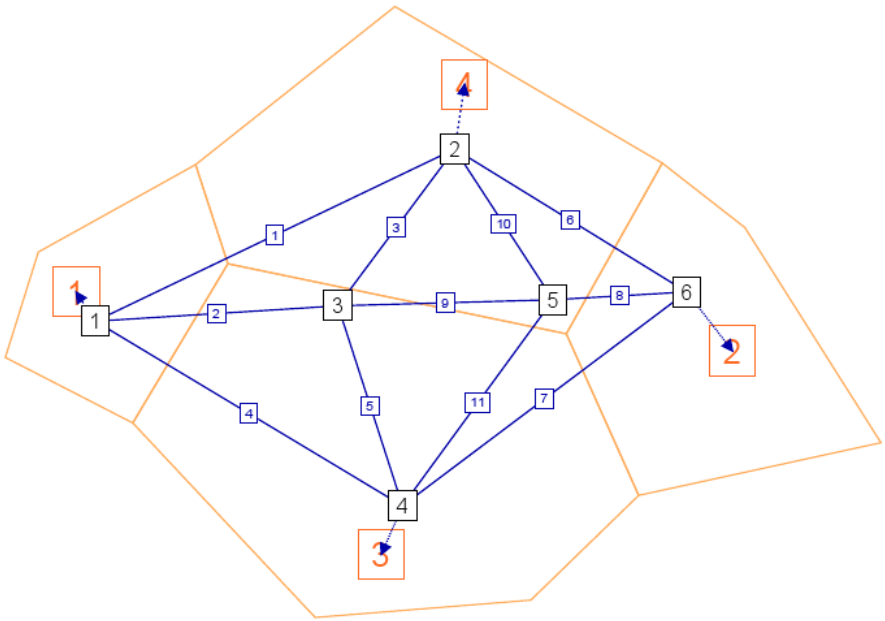


Figure 4.7: Test network

To illustrate how the traffic assignment model behaves in predicting the container flow

pattern, two scenarios are considered. Scenario 1 represents a situation where road conditions vary significantly from link to link (as can be found in developing countries). The varying characteristics of links assumed in scenario 1 are shown in Table 4.3. The width and capacity of all links are fixed at 7.5m and 2800veh/hr. The demand is assigned to the network using the solution algorithm described in Section 4.2.5 and the flow patterns are derived. Figure 4.8 shows the pattern of container flows.

Table 4.3: Link characteristics

No	**Length (km)**	**Road type**	**Average rough (IRI – m/km)**	**Horizontal curvature (deg/km)**	**Vertical gradient (m/km)**	**Super elevation (%)**	**No of rise + falls**	**Link TOC Trailer**	**Link TOC Truck**
1	11	Bendy + severely undulating	15	150	25	5	3	14.5	10.2
2	10	Straight + Level	3	3	1	2	1	7.1	5.0
3	6	Bendy + level	7	50	3	2.5	2	5.1	3.6
4	13	Bendy + severely undulating	15	150	25	5	3	17.1	12.1
5	8	Bendy + level	7	50	3	2.5	2	6.7	4.8
6	8	Bendy+ gently undulating	15	75	15	3	2	10.3	7.3
7	11	Bendy + slightly undulating	12	50	3	2.5	2	11.7	8.4
8	6	Bendy + level	7	50	3	2.5	2	5.1	3.6
9	13	Bendy + gently undulating	10	150	25	5	3	13.7	9.6

10	7	Mostly straight	4	15	10	2.5	2	5.2	3.7
11	10	Straight +Level	3	3	1	2	1	7.1	5.0

Link 9 or a combination of link 10 and 3 are the most likely routes available when travelling between nodes 5 and 3. All drivers journeying between these nodes choose to combine links 10 and 3 even though the total lengths of both routes are exactly the same. No driver travels of link 9 as no costs can be saved by using this route. This is the case because, while links 9 is bendy and undulating, the conditions on 10 and 3 are generally level. This translates to a lower combined TOC of 10.3 for trailers on links 10 and 3 compared to 13.7 for trailers on link 9. Likewise, when travelling between zones 1 and 2, drivers opt to use the longer route combining links 3 and 2 because the combined cost of travel on the level roads (links 3, 2) is less than on the bendy and severely undulating link 1. This situation is the same for a shorter link 1 which is unfavourable compared to a combination of links 3 and 2, as well as link 4 which is less preferred to link 2 and 5. The truck operating cost to each vehicle on each link at free flow is listed in Table 4.4 above.

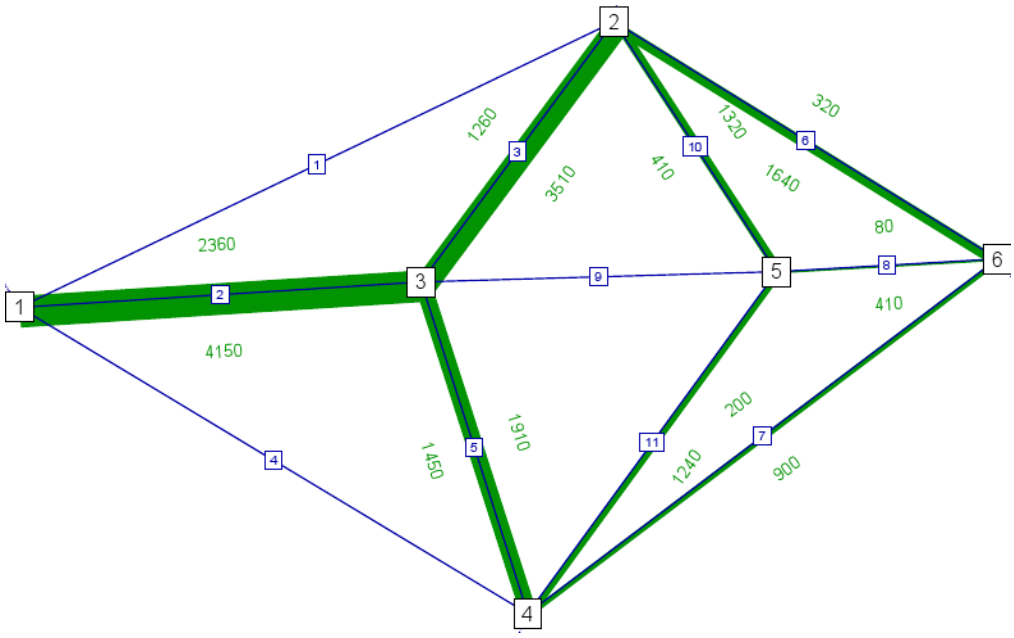


Figure 4.8: Link flows in vehicle numbers

Alternatively, Scenario 2 represents a situation where the road conditions are consistent

through the network and all links have the same characteristics. Of course link length varies. In this case, since all roads have the same conditions, then the fastest route would be the shortest route. The drivers take the fastest/shortest route and switch between paths until no more time can be saved by unilaterally changing routes.

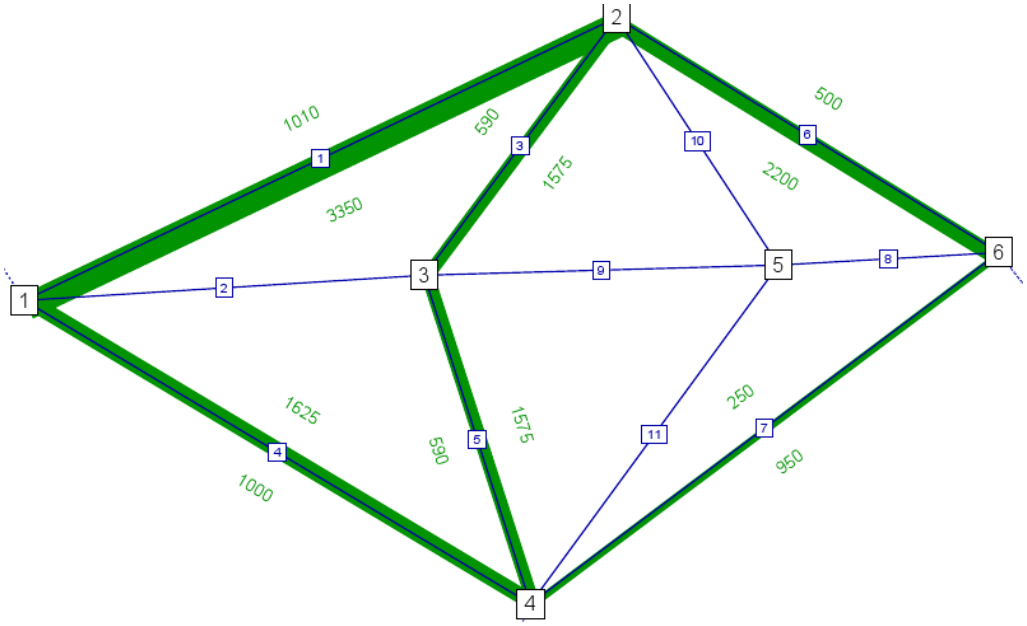


Figure 4.9: Link flows in vehicle numbers

Figure 4.9 shows the pattern of container flows obtained when the demand is assigned to the network using the solution algorithm. A similar pattern would be obtained if a traditional volume-delay function were employed, one that considers only the relationship between flow, speed and travel time only. The underlying assumption of such a function is that road conditions have little or no influence on the speed at which a vehicle travels and so can be ignored. This assumption is valid in developed countries where there are little or no variations in the road conditions.

Figure 4.10 and 4.11 verify the convergence of the proposed solution algorithm. As shown in the Figures, the G values declines rapidly to zero after a few iterations, from which point, it becomes stable. The specified convergence requirements are achieved after 300 iterations. Figure 4.12 shows that the average flow of links with fluctuating flows converge to a single value. These results support that, on approach to equilibrium, truckers do not benefit much by shifting to an alternative route and so, solution is close to the solution. The convergence criteria are obviously sensitive to variations in the road network conditions. The

smaller the variations, the longer it takes to converge. Furthermore, convergence will be slower if the TOC of the alternative routes are close in value.

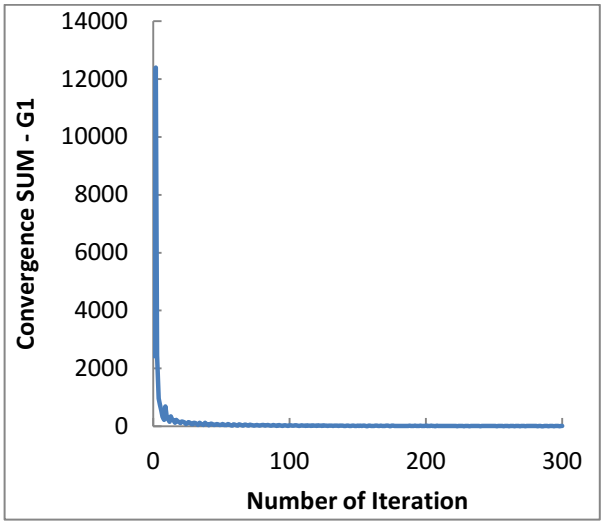


Figure 4.10: Convergence of proposed algorithm

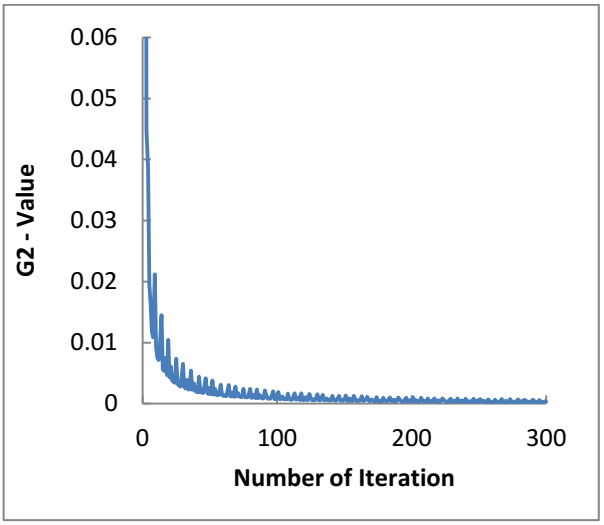


Figure 4.11: Convergence of proposed algorithm

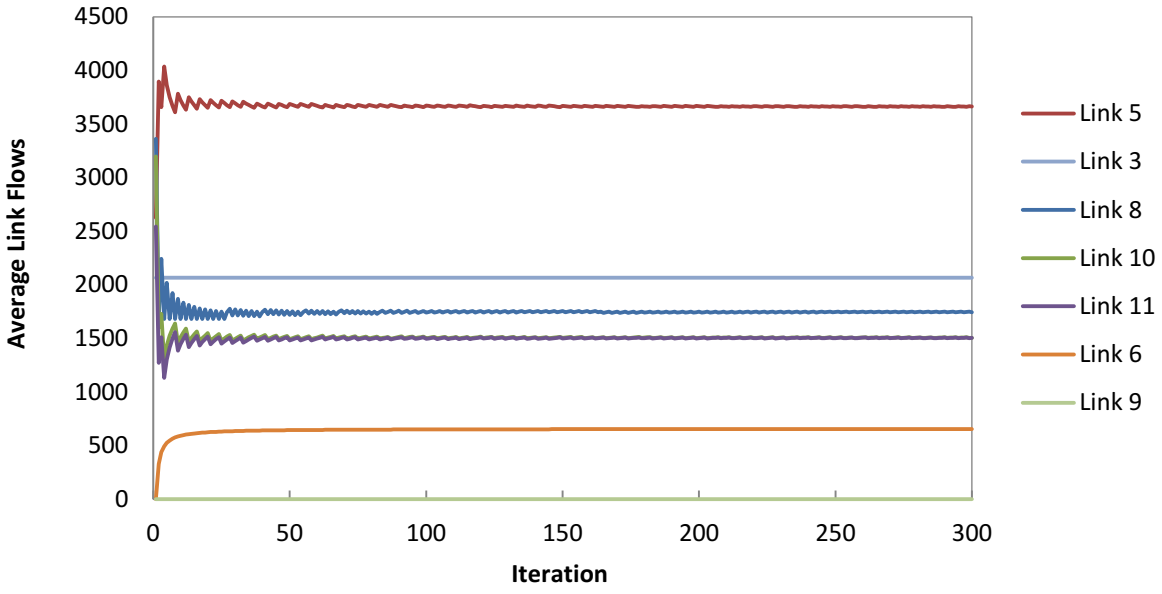


Figure 4.12: Convergence of link flows

The findings support the bases of the model in terms of the factors identified as important in the route selection process. Like Nigeria, the road network in developing countries is often characterised by an inconsistency in the standard of the road conditions. The

links in the network vary from bituminous paved, to concrete, to unpaved roads. These are further broken down to roads in good or bad condition often with cracks and potholes. This characteristic of the road network makes it difficult to use a traditional Volume Delay Function in the assignment process, as these often consider only the relationship between flow, speed and travel time, and does not consider the effect of road characteristics, like surface roughness, on vehicle speeds and so travel time.

Generally, in the assignment model, truck drivers when faced with alternative routes of identical length will choose to travel along the route with the lowest truck operating and travel time cost. Also, truck driver would prefer to travel along a longer route as long as they can avoid poor roads to avoid damage to their vehicles and so reduce the operating cost. Given the condition of the road network, the proposed model identifies the routes that would most likely be used by truckers when travelling between any one O-D pair. The assignment model is applied to the case of Lagos, Nigeria.

4.3 Summary

The first half of this Chapter includes a review of literature on freight models and modelling techniques, while the second half presents a brief discussion of the approach taken to model the distribution of container – related freight through a road network in a developing country, particularly Nigeria. The modelling framework proposed in Section 4.2 integrates freight supply chain modelling within an urban transport model by deriving the container-related O-D matrices from an understanding of the container logistic chain. This allows for an analysis of the impact of a container logistic pattern on freight demand within a transport system.

Section 4.2.2 provides an overview of the process for obtaining the container related O-D matrices required for input to the assignment stage. Section 4.2.3 introduces how the volumes of non-container related traffic on links are obtained. Section 4.2.4 discusses the generalised cost function which is employed within the assignment model to account for some factors which are considered to influence a trucker's route choice in developing country. Section 4.2.5 describes the algorithm, software and programming technique used in the

assignment. The chapter concludes by working through an example network to illustrate the output of such an assignment approach.

Although this work is based on a study of Lagos, Nigeria, the framework can be adapted to the individual nature of the road network and structure of the container industry in other developing countries. The approach can also be employed when studying the distribution pattern of other types of cargo originating from the ports.

Following this framework outlined in Section 4.2, the model used in this study is developed and validated in the next chapter (5).

Chapter 5

Container Freight Traffic Modelling - Implementation of Modelling Framework

As outlined in Section 3.2 of this thesis, the transport model is being developed to simulate the resulting pattern of port related containerized cargo movement through the Lagos area with and without the proposed dry port facility. The model is developed within the framework proposed in Section 4.2.

This chapter discusses the development of the model used in this study including the data collection process and the assumptions made. It begins by discussing the graphical representation of the transport network employed before discussing the process for the derivation of the container related demand and non-container related link flows. It then moves on to discuss the process for calibration and validation of the base model (the current/without the dry port scenario) before expanding on the extra steps included to model the scenarios with the proposed dry port facility. It considers some physical implications of the dry port scenarios and finishes by exploring the limitation of the model.

5.1 Transport Network Representation: Assembling and Data Source

The graphical representation of the transport network refers to a representation of the geometry, spatial structure and physical characteristics of the transport network in Nigeria. At the stage of data collection, this representation was unavailable and so was developed for the purpose of the research.

The development process concerns itself with defining the network objects which constitute the graphical network and includes the links, nodes, and zones that make up the transport network. Links represent segments of roadway or railways while nodes represent junctions in the road and rail network and are the starting and terminating element of links. All movements are assumed to start or finish at the centre of zones which are connected to nearby nodes by 'connector' links. In the network representation, each of the network objects is assigned attributes based on physical characteristics, which are determined from available information.

Detailed data on network junctions (nodes) were unavailable at the data collection stage and so junction modelling was excluded from this study; however turn arrangement at nodes in the network are specified. Following on from this, it is assumed in the model that all nodes (junctions) have the same impedance and so, route choice is made on a link to link basis. This is adequate for this study since the research concerns itself with link and route

based analysis. Thus, for the purpose of this research, the transport network comprises the Traffic Analysis Zones (TAZs), the road and rail network orientation and the attributes of these specified network objects.

The network orientation was obtained from an independent GIS company source in Lagos who provided the author with raw shape files containing a road and rail map of Nigeria. This provided information on the physical separators (rivers, bridges and railways) and the road network presented as polylines and nodes. This raw representation was provided in WGS84 coordinates and the required area of study was extracted and developed using the Geographic Information Systems – MapInfo and the transport analysis software-VISUM. GIS Database on road conditions and road characteristics did not exist and so the required information was collected in paper format and manually transferred into the system. Where data were missing, an approximation was made from Google Earth.

5.1.1 Freight Traffic Analysis Zones

Freight Traffic Analysis Zones (FTAZ) are regions representing the origins and destinations of freight trips within the network. The model considers nodes in the container distribution/supply chain within zones thus; physical areas are clustered based on their network connectivity, their function in the supply chain process and their socio-demographics characteristics. Each FTAZ represents aggregated supply chain nodes in the network and contains various location possibilities. For example; a zone may contain a number of off-dock terminals, a number of industries or firms and a number of retail outlets or markets. Port terminals are however isolated within their own FTAZs.

If Freight traffic analysis zones are too big, the trip distribution characteristics would not be presented clearly as there may be loss of traffic volume on network due to the gain of intra-zonal trips. However, a large number of FTAZs would require a large amount of disaggregated data. As the data used in this research was collated by the author within limited time and funding, a sensible size for the FTAZ was derived on the basis of the level of aggregated data available for the areas and the network density, calculated as the total road length within the zone over the area of the zone. Where the road network is sparse, larger zones are specified. The area of the zone is calculated in Arc GIS using the polygon shapefile.

In this process, the hierarchical matching technique that nests the information on smaller zones within a larger zone is used. Various layers of data available are over lapped in

the geographic information system, including land use data and, socio-economic information of the study area such as population, the location of industries and commercial areas, city boundaries and the road network of the study area. The zoning classification begins with the 22 administrative areas (local government areas) in Lagos and 35 other states in Nigeria. However, to minimize the loss of inter-zonal trips and accommodate the high network density in the Lagos area; the administrative areas and states are split into smaller zones according to the accessibility of areas. This is done by grouping together smaller regions within the administrative areas on the basis of existing physical separators, network connections, and available disaggregated socio demographic data.

The zoning system employed consists of 46 FTAZs in the Lagos Area, 2 seaport FTAZs, 1 dry port FTAZ and 37 FTAZs representing the rest of the country. These zones are used only for the purpose of trade and do not accommodate habitation. The other zones include areas of combined habitation and commercialisation, and can be split into zones within Lagos and zones outside Lagos. The zonal system adopted is summarised in Table E.1 and Figure E.1 of Appendix E. The main data sources used in specifying the characteristics of zones are listed in Table E.2 of Appendix E.

In the model, trips are generated or attracted to the centre point of the zone which is defined as the location distribution grid for commercial and industrial facilities within the zones and is estimated in ArcGIS and MapInfo. The centroid connectors represent local access points onto the road network.

5.1.2 Links

Roadways such as streets, highways and expressways are modelled as arcs in VISUM. A bi-directional roadway is represented by two links corresponding to each direction, so that they represent separate network objects and are assigned different attributes where necessary. One-way road ways are represented as a link in a particular direction, Single carriage ways are modelled by a single arc in two directions while dual carriages as double arcs with each arc representing a one way right-hand traffic.

Links in the network represent road stretches with similar roadway and traffic characteristics. This ensures that a reasonable consistency is achieved and assumptions/ approximations are more accurate. Each link is associated with a list of attributes that are used in the traffic assignment process. The link attributes include but are not limited to;

length, width and number of lanes, headroom clearance and restrictions, link capacity, free-flow speed and speed limits, road surface conditions, and link orientation. At the time of network development, no collated database for the road network in Nigeria was available and so to the author compiled one from raw data collected from various sources.

The road links in Nigeria can be considered under five major classes: expressways, highways, primary roads, secondary roads and minor roads. To reduce compilation time, the database is compiled for only express, highways, primary and secondary roads in the network. This is logical since the model concerns itself with freight and minor roads in Lagos are considered as no-truck routes. For zones outside Lagos, only expressways are included in the model. The road network deployed for this study consists of a total of 4,600 unidirectional links, classified by ownership (state, local or federal) by type (expressway, highway, primary and secondary) and by structure (dual or single carriageway).

The road characteristic database collated for this study was created by a manually inputting data associated with roadways in a network. Data on road condition was incredibly difficult to obtain and collate. Were data did not exist, logical assumptions were made. The sections below explore how link characteristics are identified or approximated from available data. The main data sources used in developing the road and rail network employed in this study are listed in Table E.2 of Appendix E.

5.1.2.1 Length, Width and Number of Lanes

The length of the polylines in the geographical system shape file represents the length of physical transport links in the network. The calculation is based on the spherical distance method that keeps the measurement on the curved surface of the earth by converting the data to Latitude/Longitude before calculations. The link lengths are calculated on the basis of a WGS 84 coordinate system.

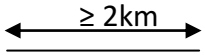
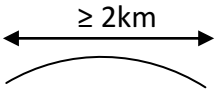
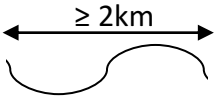
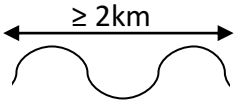
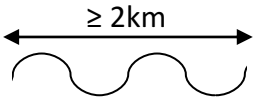
The carriage widths of links were derived from a number of publications that specify the length, carriage width and surface conditions of all roads in Lagos and classify them based on the ownership and their administrative areas. A list of the publications is included in Table E.2 of Appendix E. The specified lengths are checked against the calculated length to ensure consistency. The widths of carriageways specified are randomly checked by comparing to width measurement made in Google Earth. The sheer size of the network made it impossible to compare the length and carriage width of every single object. Thus, only random checks were carried out.

The number of lanes on links are approximated from Google Earth and extrapolated from the carriage width data where available. To ensure that only effective lanes are considered, the number of lanes is assumed to be the number of non-stationary working lanes which are shown as lanes with mixed traffic in Google Earth. This aspect of the work was time consuming and monotonous as it involved assigning all relevant variable to individual links by referring to and compiling data from a number of sources including paper and electronic forms.

5.1.2.2 Link Orientation and Environment

There are no data available on the vertical and horizontal alignment of roads and so, vertical gradient is assumed to be fixed at 15m/km for all links while horizontal alignments vary. A road's horizontal alignment is specified for each link depending on the trajectory of the arc represented in the GIS shapefile. Depending on the number of peaks and troughs associated with an arc, the road it represents is relatively classified according to Table 5.1 below. The link's altitude of terrain (m) is extrapolated from spot height data superimposed unto the network.

Table 5.1: Definition of alignment categories

Alignment category	**Relative definition**	**Description**	**Horizontal curvature (deg/km)**	**Super elevation (%)**
1-Straight	No peak over at least 2km		3	2
2-Mostly straight	up to 1 peak over at least 2km		15	3
3-Bendy	up to 2 peak over at least 2km		65	3
4- Severely Bendy	up to 3 peak over at least 2km		115	4
5-Winding	More than 4 peak over at least 2km		400	6

5.1.2.3 Link Capacity

Capacity is the maximum hourly flow rate at which vehicles can transverse a roadway under specified prevailing conditions. The link capacity data was nonexistent and so a simplification of the Nigeria highway manual was employed in approximating the link capacity. The Highway Manual states that links with the following conditions may attain the highest possible capacity outlined in Table E.3 of Appendix E.

- Lanes should be 3.65m wide
- The hard shoulder should be wide enough for cars to be clear of the pavement when parked
- The lateral clearance from pavement edge to roadside installation or permanent obstruction such as poles, bridge abutments and retaining walls should be at least 1.8m.
- Traffic consists of only passenger vehicles and does not conflict with commercial vehicles. The model allows for a percentage reduction according to the proportion of trucks in the mix.
- Road alignment (bends and hills) does not affect passing sight distances.

Where physical restrictions limit these conditions, the highest capacity should be reduced according to some specified reduction factors. Only the limiting factors relating to the physical condition of roads for which data is available are considered, for example, data on directional imbalance of traffic was unavailable and so this limiting factor was ignored. This is acceptable since an upper bound capacity is compared with an upper bound traffic volume in the analysis. The limiting factors considered are outlined in the paragraphs following this.

<u>Restricted capacity due to lateral obstructions</u>

As there are minimal rules enforced on parking on most roads in Nigeria, it is assumed that frequent obstructions may occur on either side of the pavement especially in commercial industrial and port areas. In such areas, the frequency of obstructions is assumed to be highest and the effective lane width lowest in such areas. Thus, a reduction in lane capacity is applied to areas where parking along hard shoulder exists. It is also assumed that the hard shoulders are not wide enough for parked vehicles and also, all

available parts of the road infrastructure are occupied by moving vehicles. Furthermore, on routes to and from trade hubs, the Queuing of vehicles including trucks, trailers and tankers, restrict capacities. Thus, where no loading bays or hard shoulders appear to be available, it is assumed that physical obstructions are generally next to the pavement edge and occur on one side of the lane. The restrictions in Table E.4 of Appendix E are applied to the capacity.

Sight distance on 2 lane two-way (single carriageways)

This considers restrictions to the distance in which a driver can see down the road to seek the opportunity to pass. For this to have no impact on the capacity of a link, the design manual suggests a minimum sight distance of about 0.45km on all lanes through the length of the road. Although achievable on straight and levelled roads, this is not the case with curved roads where the line of sight is restricted on approaching the curve or with undulating roads where the line of sight is restricted at the peak of the rise. In both cases, the sight distance is reduced as the driver approaches the obstruction and increases as he passes the obstruction.

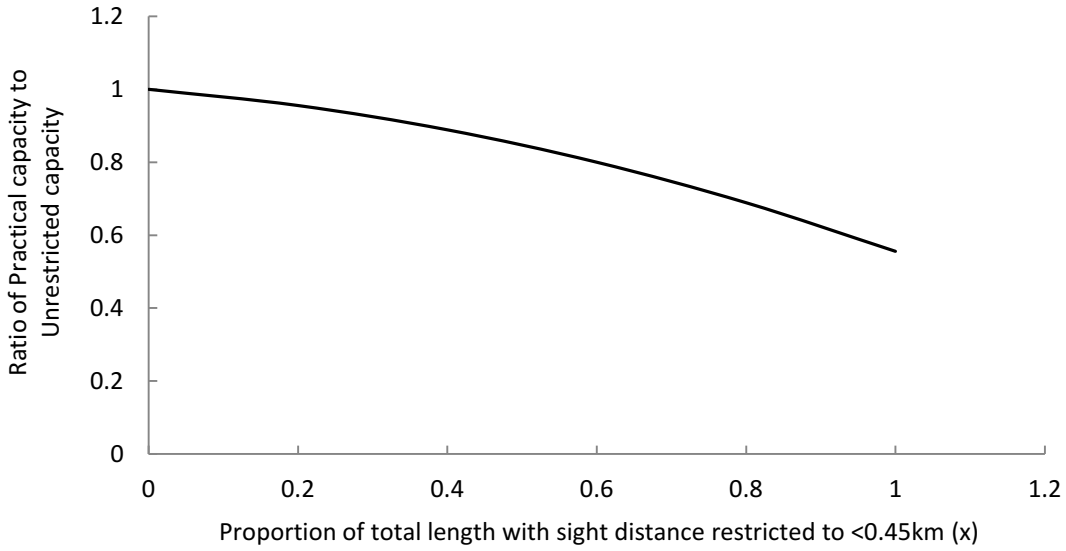


Figure 5.1: Practical capacity against proportion of sight distance

The applied restrictions are based on road alignment allocated in Section 5.1.2.2. The effect of sight obstructions on capacity is derived based on the link alignment category and link length using equation below and Figure 5.1 above.

$$x = \frac{y \times 0.9km}{L} \tag{5.1}$$

Where x is the proportion of total length on which sight distance is restricted to less

than 0.45km, y is the number of horizontal curve peaks along the link, and L is the total length of the Link.

Restricted capacity due to volume of commercial vehicle

The Highway Manual for Nigeria provides an equation for calculating the effect of truck proportions on road segment capacity and this is also defined in equation 20-4 of the Highway Capacity Manual and is given below:

$$F_{HV} = \frac{1}{1+P_T(E_T-1)} \quad (5.2)$$

Where: P_T is the proportion of truck traffic and E_T is the Passenger Car Equivalence for Trucks. An average truck equivalence of 1.5 is assumed to exist on a multilane roadway and 2.2 for a two lane two way road.

5.1.2.4 Speed-Flow Model, Speed Limits, Headroom Clearance and Vehicle Restrictions

The speed model adopted for use here is the "three-zone" model proposed by the Hoban (1987) and is used within Highway Design and Maintenance (HDM) tools developed by the World Bank. These tools are developed by the World Bank transport department for use in evaluating policies and programs for construction and maintenance of roads in developing countries. The "three-zone" model has been discussed in Section 4.2.4 of this thesis. It is developed around five key parameters that describe the traffic condition on a link. These parameters vary between links depending on the link type and width of road according to Table 4.3 in Section 4.

- Q_{ult} which is the ultimate capacity of the link
- Q_{nom} which is the nominal capacity at which all vehicles travel at the same speed
- Q_0 which is the flow on link at which vehicle interaction occurs and vehicle speed begin to decrease
- S_{nom} which is the speed at nominal capacity
- S_{ult} which is the speed at ultimate capacity

The speed limits vary from link to link depending on the link type. Expressways, highways, primary and two-way roads are assigned speed limits of 120, 100, 80 and

60km/hr respectively. However, trucks are assumed to travel at a maximum speed of 100km/hr which is based on speed restrictions applied by the independent haulageing firms. Roadways with Heavy Goods Vehicle restrictions do not allow trucks to transverse across and are thus modelled as links closed to the truck transport system.

5.1.2.5 Road Surface Conditions

Irregularities in the road surface are expressed in roughness specifically the International Roughness index (IRI). This index was developed by the World Bank and is based on the average rectified slope (ARS), which is a ratio of a vehicle's accumulated suspension motion as it transverses a roadway and the distance travelled by the vehicle at motion. An open ended IRI scale re-plotted from Sayers et al, 1986 is shown in Figure 5.2 below.

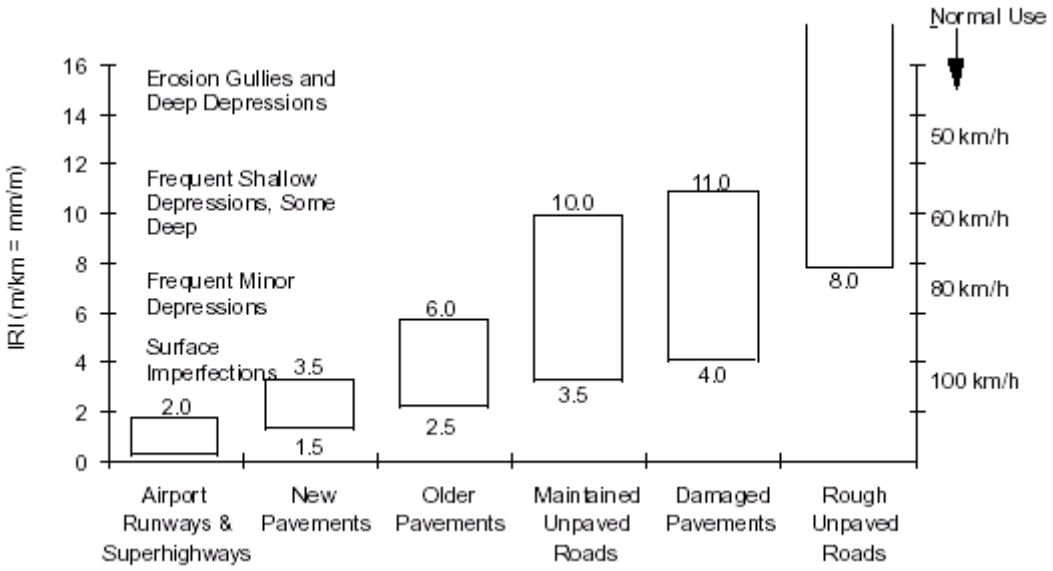


Figure 5.2: An open-ended IRI scale (source: Sayers et al, 1986)

The Roughness index data and indeed any other quantitative measure of surface condition were not readily available at the data collection stage. So, for the purpose of this research it is inferred from known variables assumed to drive road improvement and from observations on Google Earth. The key variable identified is the frequency of maintenance associated with a roadway, which is driven by the design speed and the available maintenance budget. Road conditions on main roads like expressways and highways are assumed to be better than on secondary roads. This is supported by the fact that there is a higher proportion of paved expressway compared to paved highway roads and this can be observed in Google Earth. Secondly, infrastructures owned and maintained by the higher

tier of government (federal government in the case of Nigeria) are more regularly maintained because the infrastructure-management institutions are usually provided with larger operational budgets. These assumptions are supported by the results of an analysis of historical transport budgets associated with a sample of roads owned by the different levels of institution (FMWH, 1999). This assumption is also supported by the statistics on the percentage of paved roads as discussed in Section 3.1.3.2. The results are summarised in the Table 5.2 below.

Table 5.2: Summary of road statistics in Nigeria (FMWH, 1999)

Ownership	**Total (Km)**	**Average annual budget per unit length (million Naira/km)**	**% Paved roads**
Federal	281.2	1.21	80
State	150.8	.94	34
Local	23.7	.66	17

Based on these assumptions a relative IRI matrix for the link is developed for use in this study. The matrix assumes that the road conditions deteriorate as one moves away from ownership by federal institutions and from roads associated with high speeds and limited accessibility (i.e. expressways). The applied matrix is shown in Table 5.3 below.

Table 5.3: The IRI Roughness Matrix [3]

	Paved / unpaved road roughness (IRI, m/km) per road class and category							
Road Category	**Express (5) Paved**	**Express (5) Unpaved**	**Highway (4) Paved**	**Highway (4) Unpaved**	**Primary (3) Paved**	**Primary (3) Unpaved**	**Secondary (2) Paved**	**Secondary (2) Unpaved**
Federal	2	6	4	8	6	10	8	12
State	6	10	8	12	10	14	12	16
Local	10	14	12	16	14	18	16	20

[3] Author's estimate based on HDM IV characteristics and info on road characteristics derived from FMWH (1999).

5.1.3 Assumptions

Specific to the case of Nigeria, the following assumptions were made:

- It is assumed that residential roads are no-truck routes and so truckers use mainly express, primary and secondary roads in the network.
- For simplicity, route choice is based solely on link impedance and not impedance at junction.
- Links represent homogeneous road segments.
- As there are no rules enforced on parking around the ports. It is assumed that frequent obstructions occur on either side of the pavement especially in commercial and port areas.
- In deriving capacities, it is assumed that the hard shoulders are not wide enough for parked vehicles and also all available part of the infrastructure are occupied by moving vehicles.

These assumptions present a potential over-estimation of truck volumes on links and a potential underestimation of capacity, implying that the modelled network may approach saturation. Thus, the findings relate to the case of a network that is saturated.

5.2 Containerised Cargo Trip Matrices: Assembling and Data Source

As outlined in Section 4.2 the trip classes represent the trip purposes associated with each activity class. These activity classes represent segments in the container logistic chain which when linked together describe the logistic chain flows of containerised cargo. Demand matrices associated with each trip class are applied to the network simultaneously during the assignment. The matrices are derived from 2009 data on container movement and for the purpose of calibration/validation are translated to 2011 demand matrices using a growth factor. The growth factor represents the increase in container traffic between the years. It is assumed that no changes occurred in the supply chain process between the two years.

This step in the modelling framework is concerned with deriving O-D trip matrices

for the trip classes. Since the port is the only entry point in the container inland logistic chain, all containers are set to begin their journeys at the ports and move through the distribution chain to their destinations. Thus, all demands are extrapolated from the annual container flows through the ports. An annual trip matrix is derived for the trip classes and then converted to an hourly matrix. The trips are approximated for worst case (95th percentile) and most likely (60th percentile) hourly scenarios, from the known total traffic flows. The process for obtaining the trip matrices used in this study is outlined as follows:

1. For each activity class, derive TEU production in zones based on annual import volumes. This refers to the total number of TEUs going from port to importer, port to private terminals, port to off-dock terminals and off-dock terminals to importer. This is derived from container statistics in the base year of the two container generating nodes - port terminals and off-dock terminals. The year 2009 is selected for deriving the base year O-D trip matrices. This decision is linked to the availability of data at the time of the study.
2. Consider proportion of Full Container Loads (FCLs) and Stripped Container Loads (SCLs) generated at each laden trip generating nodes (port and off-docks) and split TEU production into Load classes (FCLs and SCLs). Stripped Container Loads (SCLs) consist of cargo off-loaded from Full Container Loads (FCLs)or Less than Container Loads (LCLs) once stripped. They are transported as general cargo in trucks and can be generated at ports, off-dock terminals and consignee's premises.
3. Using results from step 1 to 2 derive the number of TEUs for each trip class. This represents the trips purposes (stages) associated with each load class. For example, the trip classes associated with the activity class, port to off-dock terminal include Port to off-dock terminal, off-dock terminal to trailer park and trailer park to port. This is based on the assumption that all trip purposes (trip classes) associated with an activity class generate the same number of TEUs.
4. Convert unit of packaging (number of TEUs) into vehicle trips.
5. Distribute Full Container Loads (FCL) trips between zones on the basis of known Location of supply chain nodes and the number of TEUs handled in the base year.
6. Distribute Stripped container loads (SCL) trips on the basis of an origin constrained gravity model

7. Convert annual trip matrix to hourly trip matrix. The outcome is a combination of matrices associated with each activity class and within a one hour analysis period.

The assumptions made and processes associated with these steps are discussed in the sections following this. Data collected by the author is provided for future use by readers except where the data is sensitive and was given in confidence.

5.2.1 The Trip Classes

Based on the knowledge of the container distribution chain as discussed in Section 3 and following the '3- level' process outlined in Section 4.2, five activity classes and twenty-three trip classes are defined. Table 5.4 outlines the trip classes and their associated activity class and load class. The trip classes are derived based on the assumption discussed in section 4.2.6 and the following assumptions:

- No backhauling exists, so trucks run complete tours serving only one destination at a time and returning to where they started from after delivery.

- Trip classes are obtained from a single vehicle tour associated with an activity class and load class. Each vehicle tour is associated with a unique actor and so, all trip classes under the same activity class are organised by the same actor. Containers moves organised by different actors are considered as independent activities and so are represented as independent activity classes. For example, although activity class 4 is a follow on from activity class 3 (see Table 5.4), the associated vehicle tours are independent since the activities are organised by two different actors. Trips between port and off-dock terminals (class 3) are organised by port terminal operators/shipping lines while trips between off-dock terminal and importers (class 4) are organised by the importers. Thus, the activities are considered as discontinuous and are associated with independent vehicle tours and so trip classes.

- In the case of the freight distribution to minimise monetary and time cost, only the necessary trips are made so, it is logical to assume that laden container move only forward along the distribution chain and no one trip is ever repeated. Thus, the number of trips produced per unit time is 1.

Table 5.4: Containerised cargo trip classes

No	Activity class	Load class	Trip class	Laden trip	Empty trip
1	Port to Importer	FCLs	Port to Importer	x	
			Importer to Empty depot		x
			Empty depot to Trailer park		x
			Trailer park to Port		x
		SCLs	Port to Importer	x	
			Importer to Trailer park		x
			Trailer park to port		x
2	Port to Private terminal	FCLs	Port to Private terminal	x	
			Private terminal to Empty depot		x
			Empty depot to Trailer park		x
			Trailer park to port		x
3	Port to Off-dock terminal	FCLs	Port to off-dock terminal	x	
			Off-dock terminal to Trailer park		x
			Trailer park to Port		x
4	Off-dock terminal to importer	FCLs	Off-dock to Importer	x	
			Importer to Empty depot		x
			Empty depot to Trailer park		x
			Trailer park to off-dock terminal		x
		SCLs	Off-dock terminal to Importer	x	
			Importer to Trailer park		x
			Trailer park to off-dock terminal		x
5	Importer to Distribution	SCLs	Importers to Distribution warehouse	x	
			Distribution warehouse to Importers		x

5.2.2 Container TEU Generation at Port and Off-dock Terminal Zones

The first stage of the process approximates annual container volumes through activity classes 1 to 4 from container annual throughput at Lagos ports according to behavioural patterns specific to the case of Nigeria. The activity classes 1 and 2 are derived from the process of stepping while activity class 3 and 4 are derived from the stemming process. The concept of stemming and stepping is discussed in Section 3.2.3 of this thesis. The annual volume of containers moved in activity class 1, 2, 3 and 4 are calculated as a proportion of total annual volume of container handled at the port terminals in the base year.

The volume of containers handled at ports is influenced by their level of attractiveness to shipping lines. In the past years, a lot of researches have focused on

understanding port choice from a shipping line's perspective. The major influencing factors put forward include oceanic and inland distances, port efficiency measured by certain key indicators, geographical location, service quality, volume of cargo and port costs (Tongzon and Sawant, 2007;Ng, 2006). As the Lagos ports – Apapa and Tin Can Island – have almost the same geographical characteristics, the factors that would most influence each port's competiveness in relation to the other are its performance indicators (e.g. The ship turn-around time, the dwelling time of cargo, cargo handling rate), and the port costs. Nigeria's port statistics suggest that shipping lines have their preferred terminals and most often berth at the same terminals. Their choice of what terminal to berth at depends on their relationship with the terminal operators, the availability of berthing facilities at terminal, terminal handling charge and on the terminal's perceived efficiency level. Modelling the process by which shipping lines select the port terminal to berth at is not included in the scope of this work as the study focuses on the movement of containers from port gates to inland destinations. In this study, annual container volumes are simply obtained from historical data. An arbitrary year 2009 is selected for analysis and all required data are collected for this year. The outputs of this step are container volumes generated for each activity class.

The data used in this stage is collated from physical interviews and questionnaires sent out to all port terminals and operating off-dock terminals to collate container statistics. The findings and data obtained for are outlined below:

- Annual Laden/empty container import for year 2007, 2008, 2009. The container throughput was collected from individual port terminals and compiled by the author. The data was retrieved from the corporate and strategic planning division of Nigerian Ports Authority and has been included in Table A.1 to A.5 of Appendix A for reference purposes.

- The annual proportion of import containers stemmed to Off-dock terminals was found to be an average of 10% of import volume for Tin Can Island terminals and 30% for Apapa port terminals. This is based on replies during interviews with port terminal managers. The terminal managers were unwilling to provide actual container volumes to support this. However, these values were checked against calculated port capacities and rough estimates of total containers received at off-dock terminal and were found to be good approximations.

- The containers handled by off-dock terminals in 2007, 2008, 2009. This data has been included in Table B.2 of Appendix B for future reference. This showed an imbalance in container distribution between off-dock terminals. For example, while some off-dock terminals may be operational, the volumes they handle are negligible compared to other competitors.

- The location and number of the containers handled by private terminals in 2009 and 2010. This data is retrieved from Nigerian Customs services and a shipping line database made available by Nigerian Ports Authority.

- Location of consignees and the containers imported in 2009, 2010. This is data is retrieved for a shipping line database made available by Nigerian Ports Authority.

5.2.3 FCL and SCL ratio

The volumes of FCL and SCL loads are calculated as a proportion of container volumes generated through each activity class. The proportion of containerised cargo leaving port and off-dock terminals as Full Container Loads (FCLs) or Stripped Container Loads (SCLs) is aggregated and is based on interview replies from terminal managers. The following parameters were found:

- The annual proportion of import containers stripped at port represents an average of 5% of import containers. FCLs represent the remaining 95%.

- The annual proportion of import containers stripped at off-dock terminals represents an average of 10% of the off-dock terminals' outbound flow. FCLs represent the remaining 90%.

5.2.4 Converting Number of TEUs to Vehicle Trips

Full container loads are further split into 20 foot (20F) and 40 foot (40F) unit loads. Based on port statistics, 40F containers account for 45% of container traffic (in TEUs). FCLs are associated with articulated trucks which may carry one of three container arrangements; a single 20F load, two 20F loads, and a single 40F load. Thus, FCL vehicle trips constitute of a combination of 20F and 40F loads. In translating FCL loads to trips, it is

assumed that all 40 foot units generate a single trip and three 20 foot units generate 2 trips. The assumption was based on a survey carried out by the author that showed that approximately 67% of sample of twenty foot units were transported in pairs and 100% of a sample of 40F containers were carried singly. The survey involved a 12hr roadside count of trailers carrying two 20F, one 20F, two 40F and a single 40F and was carried out over two days.

Stripped Container Loads comprise two types of container loads: less than container loads which are deconsolidated at ports or off-dock terminals and full container loads that are stripped and distributed in smaller consignments. The latter occurs when a single consignees uses the stripping location as a distribution centre. The vehicle trips generated from LCLs depend on the average number of consignments grouped within each container. An interview with the Nigerian Ports Authority revealed that on average 5 van trips are generated from a single TEU. Thus, a ratio of 1TEU to 5 vehicle trips is assumed for SCLs.

The stripped container loads generated at ports and off-dock terminals are derived as a proportion of the annual import traffic. The assumed proportions are outlined in section 5.2.3. On the other hand, stripped container loads generated at the importers' designated premises are derived from the container volumes attracted to each zone (as derived in Section 5.2.5.3). These are expected to be fixed irrespective of the logistic distribution process since an importer is considered to import a fixed (known) number of containers in a year.

5.2.5 Deriving Trip Matrices for FCLs

This section discusses the processes involved in defining the trip matrices for trip classes associated with the FCL load class. The matrices are based on container moves through the container logistic chain in the base year.

Trip classes are obtained from a single vehicle tour associated with an activity class and load class. In deriving the matrices for each trip class, the attraction and production of zones within a single tour are balanced. The volume of trips generated at zones is equal to the number of trips attracted to the zone. The attraction to zones for one trip class (e.g. port to Importer) is the production of the zone for the succeeding trip class (e.g. importer to empty depot) and so on. A trip matrix associated with the trip classes are derived through the following simple process described below.

5.2.5.1 To Off-dock Terminals in Zones

As discussed in Section 3.2.3, the choice of the off-dock terminal used, is made by the terminal operators in conjunction with the shipping lines. Very often, the operators have set agreements and are sometimes part of the same mother company as the shipping line and so patronise one another. This step reinstates the fact that the choice of off-dock terminals is generally fixed and repetitive. Thus, the move of containers from port zones to off-dock terminal zones is derived from the known locations of off-dock terminals and the container throughput handled by the terminals in the base year.

The author approached the management of 33 off-dock terminals requesting the terminal container statistics for the years 2006, 2007, 2008 and 2009. They were also requested to specify the proportion of TEUs directed from each port in each year. Of the 33 off-dock terminals approached, replies were received from 25. The outcome of the survey is summarised in Table B.2 of Appendix B. Each terminal is assigned to a zone on the basis of the zonal system defined for this study. The number of TEUs handled at terminals in the same zone is summed up to give the TEUs attracted to off-dock terminals in the zone from each port in the base year. The relative proportion of TEUs obtained from this is used to split the annual container volumes generated at ports between the zones. The relative proportion of TEUS attracted to zones in the base year is compared to the other available years (2006, 2007, and 2008). The pattern is found to remain the same. This supports the assumption that allocations are generally fixed and repetitive.

5.2.5.2 To Private Terminals in Zones

The private terminal management comprises importers with rights to express port clearance by the Nigerian Customs Service. Their containers are often cleared within their designated yards. This is the case for major manufacturing companies and importers. A list of these companies was obtained from Nigerian Ports Authority and the Nigerian Customs Service. The list is provided in Table B.1 of Appendix B. The locations of these companies and the number of the containers imported by each in 2009 and 2010 are obtained from a shipping line database provided by the Nigeria Ports Authority.

Each private terminal is allocated a zone within the zonal system defined in this study. The number of TEUs imported by PBWs in the same zone is summed up to give the total TEUs handled by PBWs in the zone and a relative weight is calculated for each zone.

The number of TEUs attracted to PBWs in each zone is calculated as a product of the relative weight and the container volume generated from the activity class (Port to PBW).

5.2.5.3 To Importer in Zones

Containers that are not deconsolidated within the port facility or sent to off dock terminals are assumed to be transported directly to the hinterlands. The distribution is based on the assumption that container flows are repetitive and are attracted to zones depending on the concentration of consignees in each zone. Information on the destination of consignments is provided in documents like the manifests and waybills. The location of consignees along with the number of TEUs imported in 2009 has been collated by the Nigerian Ports Authority and made available to the author. This database was compiled from freight shippers and shipping line records. The database provided destinations of container TEUs and their related freight carrier (shipping line).

Based on the consignee's location, the 2009 consignments are aggregated by zones according to the zonal system defined in the study. The relative proportion of TEUs between zones is used to split the annual container volumes generated at ports and off-dock terminals in 2009 between the zones. The outcome of this is the attraction to importers in zones from ports and off-dock terminals.

5.2.5.4 To Empty Depot in Zones

Trips to empty depots are distributed on the basis of the market share of shipping lines and the known location of facilities to which shipping lines request empties to be delivered. The empty depots are located within 15kms of the port and lie predominantly to the North and North West of the port because of the physical barriers imposed by the coastline and the Lagos lagoon. The main empty depots are listed in Table B.3 of Appendix B and their market shares are included in Table B.4 of Appendix B. This distribution is ideal since the location to which to return the empty containers are specified by the shipping lines and consignees are not free to select one.

Based on the ratio of laden import to empty export containers consistent with each year, it is assumed that an empty trip is generated from the delivery of laden containers. Thus, empty container are generated at zones were SCLs are generated or at importer and private terminal zones where containers are unstuffed.

5.2.5.5 To Trailer Park in Zones

Vehicle trips to and from trailer parks (where vehicles are parked) are driven by the demand for trailer transport. This demand is equal to the container trips generated at the port terminals. The volume of trips produced at Trailer parks in zone i and attracted to port terminal/off-dock terminal in zone j is the inverse of the volume of trips produced in port zones j and attracted to Trailer parks in zone i. Originally, the gravity model was selected for this distribution as the volumes of trips moving from zone i to j is expected to be proportional to the number of trailers available in the zone i and inversely proportion to disutility between zones i and j. However, the trip length distribution required for calibrating such a model was unavailable and because of time and monetary limitations, could not be derived by the author.

Thus, two different methods are used to decide which zones the empty freight vehicles originate in: one which applies to movements of containerised cargo from ports and off-dock terminals, and the other to movements of containerised cargo from importers' yards to distribution warehouses. For the former, trips to and from trailer parks in zones are allocated based only on the availability of trailer in a zone which is indicated by the number of trailers parked in each zone. For the latter on the other hand, it is assumed that trucks which serve the activity class “importer to distribution warehouse” are either owned by the importer and so kept within the facility or leased from trailer parks within their zone.

This is acceptable since the Lagos area is within short distances from the ports and trailer parks are not located in all zones in the area. It is assumed that upon request for a trailer, customers are unaware of the exact location of the trailer. Furthermore, issues with delays at port makes the time of travel to port negligible to the overall time associated with the job. The outcome of this step is container volumes produced/attracted to trailer parks in zones.

Field survey was carried out to identify the location and capacity of various trailer parks in the Lagos area. The survey covered 164 trailer parks where the operators were required to specify the number of vehicles (by classification) parked on site. The field work was carried out in conjunction with the National Bureau of statistics, Nigeria. The result from this survey is included in Table F.7 of Appendix F.

5.2.6 Gravity Model for SCLs

Split Container Loads (SCLs) represent containerised cargo that has been removed from containers and is transported as general cargo in vans or trucks. Each zone in the network contains various location possibilities for the destination of commodities generated from SCLs. For example a zone may contain distribution centres, a number of industries or firms and a number of retail outlets or markets. Since a commodity may be associated with a specific location, the attraction of that commodity to a zone depends on the existence of the relevant location in a zone. The gravity model for SCLs is developed to capture this.

The trips generated at ports, off-dock terminals and the importers designated container yards are distributed based on the classification of commodities enclosed within the containers. Based on import statistics obtained in Nigeria, containerised commodities can be categorised into three broad classes: Intermediate/raw material, consumer durable and consumer perishable goods. Each commodity class is associated with a type of destination and activity level. Thus, a separate gravity model is developed for each commodity class and is used to derive trip distribution of SCL commodities transported from the ports and off-dock terminals to the destination zones. For example, raw materials are expected to be destined directly for industries while consumer goods for retail distribution centres. Within each gravity model, the attractiveness of a commodity type to a zone is indirectly driven by a set of socio-economic data associated with the locations. For example, intermediate and raw materials are linked to industries or firms and thus zonal employment level data is used. The model is singly constrained and assumes that the generations (p_i) at zones are known.

SCLs volumes are split into these commodity classes according to the classification of containerised import in the year 2009. The proportion of raw/intermediate goods, consumer durable goods and consumer perishable goods was found to be 0.35, 0.53 and 0.12 respectively. This raw data was obtained from the Nigerian Ports Authority and is included in Table A.6 of Appendix A. The classifications are also provided. A gravity model is generated for each commodity class, which is similar to the work done by Swan Wooster (1979), where a gravity model is calibrated for a number of truck types. In this gravity model analysis, the variable used to express flow is the number of “Distribution Truck Trips” generated per container TEU. An approximate equivalent number of distribution trucks for a single TEU is defined in Section 5.2.3.

The gravity model proposed thus constitutes of three sub-tiers of gravity models, each tier relating to a class of commodity. The model makes the assumption that each commodity class has an associated type of destination and so, each commodity class has a different distribution between zones, based on the use of different attraction variables. The model assumes a negative exponential deterrence function of the generalized cost. The structure of the three tier model is illustrated in Figure 4.3 below.

Gravity Models	Commodity Classes	Attraction variables
Tier 1	Intermediate / Raw Material	Zone Employment
Tier 2	Consumer Durable Goods	Zone wealth distribution Data
Tier 3	Consumer Perishable	Zone population Data

Figure 5.3: Three tier gravity model

5.2.6.1 Gravity Model for the Commodity Classes

Ogden (1977) suggests that while passengers at an origin seek out destinations, it is meaningful to conceive of a consumer or importer at a destination, examining alternative origins or supply points (e.g port, off-dock terminal) for his goods and so generating freight movement based on the demand for the commodities at the attraction end of the trip. Thus, a truck trip distribution can be modelled by rewriting the urban trip distribution model as follows

$$T_{ij} = \frac{A_j P_i F(x_{ij})}{\sum_j \lceil A_j F(x_{ij}) \rceil} \tag{5.3}$$

Where T_{ij} is the flow from zone i to zone j, P_i is the production activity at zone i, A_j is the attraction of zone j and $F(x_{ij})$ is the trip cost disutility function between zones i and j. Wells (1975) supports the use of an exponential disutility function for urban cases and so, a logit function with a single parameter is assumed. In this case, $F(x_{ij})$ is the Logit's exponential function:

$$F(x_{ij}) = e^{-\beta x_{ij}} \quad \text{Where, } \beta \text{ is the calibration factor.} \tag{5.4}$$

The production (P_i) refers to the number of distribution trucks generated at zone (i). This is estimated for each commodity according to the following formulas:

$$\text{For Trip from off-dock terminal zone: } P_i^w = \propto_1^w \propto_2^w \propto_3^w \propto_4^w \propto_5^w T_0 \tag{5.5}$$

$$\text{For Trip from port: } P_i^w = \propto_1^w \propto_2^w \propto_3^w \propto_6^w T_0 \tag{5.6}$$

Where; w is the commodity class, $\propto_1$ is the ratio of the volume of commodity type to the total containerised import volume (this is based on 2009 classification containerised import cargo), $\propto_2$ is the coefficient transforming a single TEU to the equivalent number of distribution trucks, $\propto_3$ represents the proportion of SCLs at off-dock terminals, $\propto_4$ represents the combined weight of off-dock terminals in zone i, $\propto_5$ represents the proportion of total import stemmed, $\propto_6$ represents the proportion of total import stepping, and T_0 is the inward container flow (TEUs) through port terminals, derived from historical data.

The attraction of a zone j is dependent on demographical indicators describing the intensity of the demand for its production. For example, raw and intermediate cargos are generally purchased for consumption by manufacturing/production firms or firms that provide services for example construction companies. Such commodities are inputs into the manufacturing/production process. Thus, the demand for such commodities in a traffic analysis zone would be directly proportional to the concentration of industrial activities. Employment level in zones is a proxy for this measure.

The attraction of consumer durable goods to a traffic analysis zone is driven by their demand and so proportional to the population and combined capital/disposable income of the TAZ. Data on disposable income and wealth distribution were available at local government level and were used for the traffic analysis zones within each local government area. The attraction is calculated as a relative distribution of total wealth (per capita income

multiplied by zonal population). The attraction of perishable consumer goods on the other hand is proportional to the concentration of trade zones (markets) and the population of the TAZ is an acceptable proxy for this.

The outcome of data assembling in this stage is zonal attractiveness for each zone under each gravity model tier. The gravity models are applied to obtain the attraction of each commodity to each zone. The model is origin constrained since information is only available for trip originating in zones. The Socioeconomic data used for zonal attractiveness were obtained from the Nigeria Bureau of statistics. The process undertaken to calibrate this gravity model and derive the β factor is discussed in Section 5.5.

5.2.7 Converting Annual Matrices to Hourly Matrices

The annual matrices associated with each activity class are converted to monthly, daily and then hourly flows, while accounting for the effects of seasonality in the year and the stemming and stepping of containers from ports. The annual matrices are multiplied by proportions (in percentages) that account for these effects. The proportions for each effect are derived from assumptions and surveys carried out. These are discussed as follows.

5.2.7.1 Seasonality in Converting to Monthly Volume (all activity classes)

The effect of various seasons in the year is accounted for in the distribution of monthly container traffic as a proportion of the annual container volumes in the base year. Assuming a normal distribution which is supported graphically by the box plot (Figure 5.4), approximately 10% and 12% of the annual imports through Apapa and Tin Can Island port respectively represent the busiest case month (95th percentile) while 9% represents the median case month (60th percentile). This Figure 5.4 is based on the monthly volume of containers through Apapa and Tin Can island port terminals. The shaded boxes represent the 25th percentile and the 75th percentile which are symmetrically placed with only a few outliers.

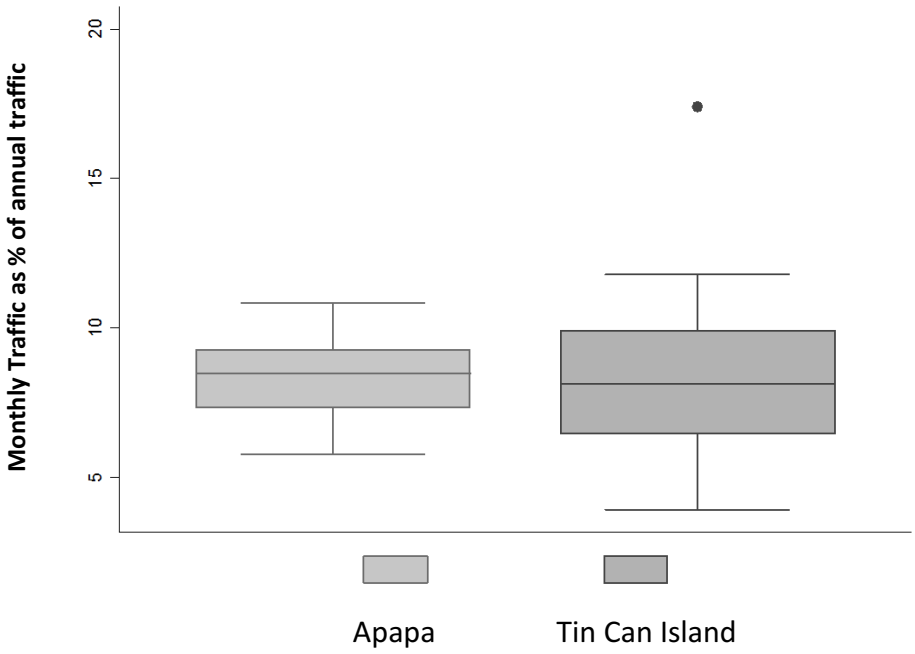


Figure 5.4: Box plot of monthly distribution through ports

5.2.7.2 Stemming and Stepping in Converting to Daily Volume (activity classes 1- 4)

Trips directed to off-dock terminals from ports (activity class 3 and 4) are generated from the stemming process while the stepping process generates trips directed to importers from ports (activity class 1 and 2).

Assuming it takes an equal amount of time to clear each consignment and each consignment remains within the facility for the same amount of time (the dwell time), then the daily flows through the port gate are governed by the number of consignments received on the exit day less the dwell time and the volume of stemmed vessels can be assumed to vary with the level of berth occupancy in terminals. The higher the number of berths occupied at any one time, the higher the demand for storage and the higher the chance of stemming. Thus, the daily distribution of stemmed containers can be assumed to be a function of the volume of vessels stemmed annually and the distribution of berth occupancy levels.

The number of containers stepped is also a function of the berth occupancy ratio, however, unlike stemming, containers that arrive at the berth stay within the facility over a period (dwell time) to undergo clearing before removal. Thus, the daily distribution of stepped container is assumed to be a function of the distribution of berth occupancy level in a month (reflecting peak period of container arrivals at berth) and the turnaround time of

vessels. All Laden containers off loaded from vessels are assumed to exit the port within 1.5 day after the average dwell time. The 1.5 days represent the average vessels idle time within which storage spaces are freed to allow room for new container arrivals. Figure 5.5 shows a distribution of berth occupancy level over the base year. This distribution is based on vessel operations data collected from a port terminal in Tin Can Island port. Daily distribution of stemmed containers is assumed to be directly proportional to this distribution. The daily number of containers stemmed is assumed to be uniformly distributed over the number of days in the month with similar berth occupancy levels. The worst and most likely case will occur at 95th and 60th percentile.

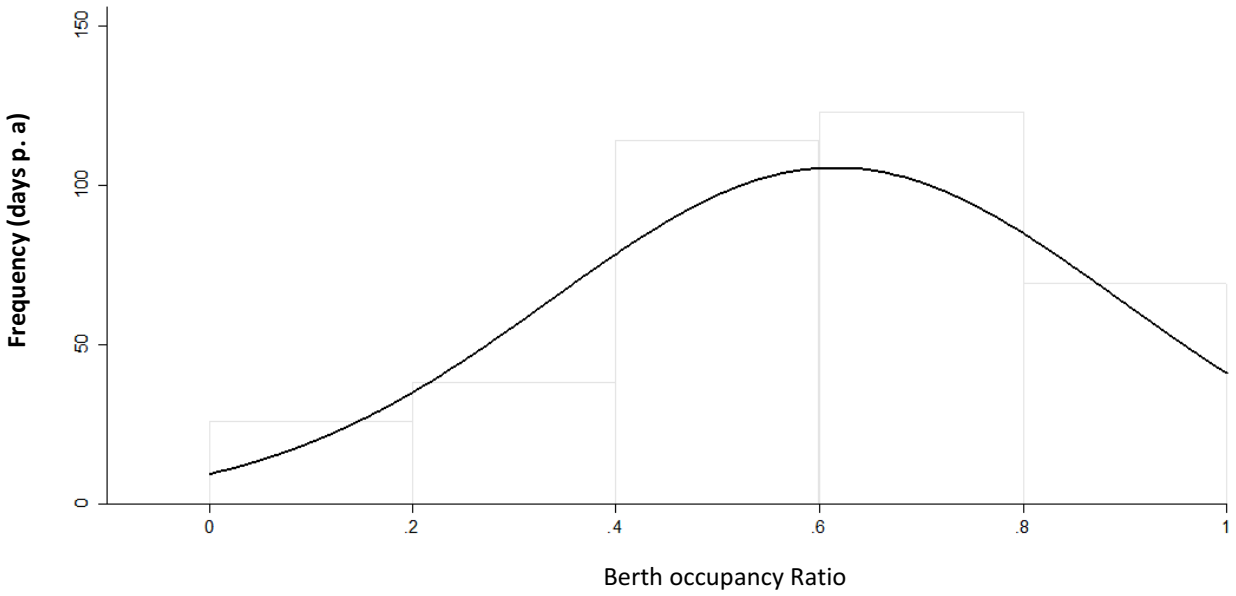


Figure 5.5: Daily distribution for stemming

5.2.7.3 Hourly Generation at Port (activity classes 1 - 3)

The assumed hourly distribution is based on a 12hr gate flow count survey carried out over three consecutive days. The results from the survey are included in Table F.1 - F.2 in Appendix F. The three day survey data is used to plot the graph of percent of hours in a day (probability) against hourly trailer traffic as a proportion of daily trailer traffic (see Figures 5.6). The worst case hour occurs when 12% and 14% of the daily traffic exit Apapa and Tin-can Island ports respectively. Data was collected only between the hours of 7am to 7pm and so the volume distribution outside these hours is unknown. However, it would be wrong to assume that all daily truck traffic occurs within the period surveyed. So, for the purpose of this research, it is assumed that only 60% of daily traffic stepped occurs within

the survey period while 40% of daily traffic stemmed occurs within the survey period.

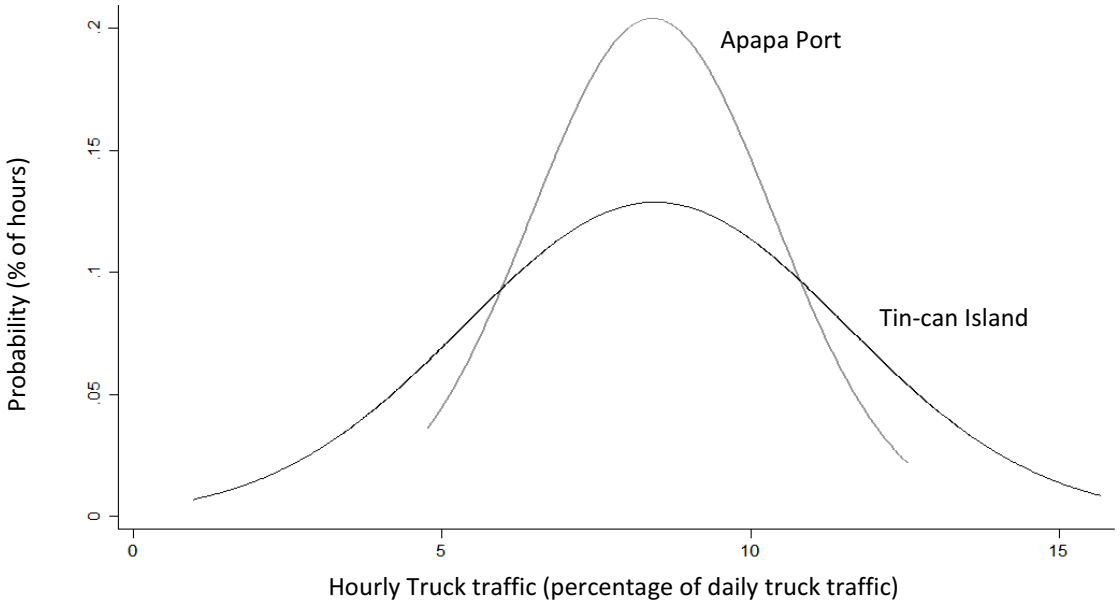


Figure 5.6: Daily probability distribution of trucks exiting port gates

5.2.7.4 Hourly Generation at Off-dock Terminals (activity class 4)

The hourly generation based on the assumption that off-dock terminals operate between 9am -6pm on Mondays to Saturdays and the clearing process and container collection take up to an average of 12 days. Thus, on a typical day, the container trips generated by off-dock terminals reflect the containers received at the facility 12 days previously and are distributed within the hours of 9am-6pm. The hourly distribution is derived from a 12hr gate flow count survey carried out at a select number of off-dock terminals. The results from the survey are included in Table F.3 - F.6 of Appendix F. As can be seen from Figure 5.7, in the busiest hour 19% of the daily container traffic exits the off-dock terminal.

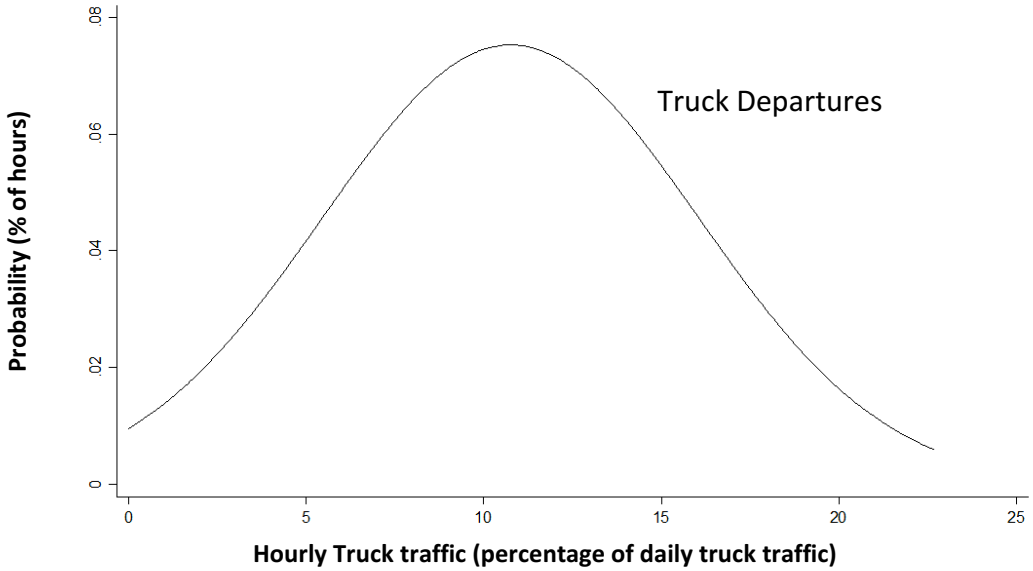


Figure 5.7: Daily probability distribution of trucks exiting off-dock terminal gates

5.2.7.5 Hourly Generation at Importers Designated Yard (activity class 5)

The hourly distribution of SCL trips at importer location may vary from importer to importer and is dependent on the type of facility whether manufacturing plant or distribution outlets, and on the number of working hours in the month. However, this information was unavailable at the time of study and so, in converting the monthly volumes to hourly volumes, it is assumed that the importer facilities are open 5.5 days a week and for 10 hours a day. The peak hour is assumed to account for 12% of the total daily containerised cargo traffic.

5.2.8 Deriving Demand Matrices for Validation - Growth Factor

Data from the year 2009 is used to develop the O-D matrices in the model. However, at the time of calibration and validation, there were no existing traffic counts or trip length data available to validate or calibrate the model for the selected year. Thus, a field survey was undertaken by the author in the current year 2011, to obtain the traffic count and trip lengths required to do this. Then, in order to standardise the model against the data collected, a growth factor is applied to the 2009 trip matrices to estimate 2011 trip matrices.

The application of a growth factor in relation to traffic forecasting is subject to a port's future capacity which is a function of the length of container space, number of

stacking rows, the stacking height and capacity of handling equipments amongst others. Container traffic forecasting has been addressed by a number of consultants and scholars, most of whom employ the relationship between growth in container trade and economic growth in forecasting container trade growth. Such analyses are most commonly based on a regression model between container volumes and GDP, and begin with forecasting future economic growth. This issue has been addressed by consultants and government bodies in Nigeria and so, is not dealt with in this study. In its place, an annual growth factor of 14.2% proposed by the Nigerian Ports Authority is applied to the 2009 container throughputs to obtain the 2011 throughputs. This growth factor represents the growth between the years 2009/2011 and is based on the container statistics for both years. The import Figures for the year 2011 have not been officially released as yet and cannot be included.

The demand matrices developed for use in validating the model are based on proportions related to the month in which the traffic count survey is undertaken. In deriving the 2011 demand matrix for use in the model, it is assumed that container related activities like the location of consignee warehouses and the logistic chain process remained the same between the year 2009 and 2011. The process of city expansion/development which is likely to generate new importers or force old importers to relocate is assumed to be insignificant over such a short time period.

The model is validated against traffic counts carried out in December, 2011. This month is a festive season and container volumes are one of the highest. Thus, the model parameters are set for a highest month. Also, the modelled trailer trips generated at the ports are compared to the gate flow counts outlined in Section 5.2.7 and adjustments are made to the daily distribution parameter to ensure that the modelled trip generation rates at port gates are close to those observed.

5.3 Non-container Related Link Volumes: Assembling and Data Source

To account for vehicle interaction in the traffic stream, it is important to consider for other traffic flows in the network. These are categorised as non-container related traffic and comprise of all traffic other than containerized freight including cars, buses, tankers etc. As outlined in Section 4.2, this traffic class is estimated exogenously, so the total flows on each link comprise containerized and non-container related traffic.

The non-container related traffic on links is derived as a function of the absolute volumes of containerised traffic and the estimated proportion of containerised traffic on each link. The proportion of containerized traffic on links is predicted from a simple regression model. The model relates the proportion of total link traffic that is containerised cargo traffic to a factor that influences the level of containerized and non-containerised traffic on roadways in a given traffic analysis zone. Based on data available to the author, the factors considered for use as the dependent variables in the regression analysis include:

- Private car ownership level /population density of the traffic analysis zone
- Concentration of available alternative links/network density.
- Concentration of industries in the traffic analysis zone
- Concentration of markets in the traffic analysis zone
- Distance of link from port
- Proximity to a city's exit route.
- Proximity to warehouses

Each of the factors is considered for use as the predictor variable. The regression model is based on traffic count data provided by LAMATA (Lagos Metropolitan Area Transport Authority). The data are available for 28 stop points scattered around the Lagos metropolitan area. The LAMATA traffic count data show total freight vehicle numbers. However this study distinguishes container freight from all other types of freight and groups all other freight with non freight traffic as non-container related traffic. Thus, the freight traffic counts are disaggregated by multiplying the total freight volumes by a coefficient that represents the proportion of total freight traffic that is expected to be containerised. While this coefficient may vary between links, the lack of data makes it impossible to confirm this. Considering the amounts of port traffic that are not containerised, and the general level of industrial and commercial activity in Lagos, it is assumed that 15% of freight traffic represents container-related cargoes. The data set compiled for use in the analysis includes:

- Population and population density of traffic analysis zones
- Total length of roads and land area of traffic analysis zones. This is used in calculating the network density of zones
- Employment levels are assumed as proxy variables for the concentration of industries and markets in the traffic analysis zones.

- Distance between links and ports
- Distance between links and city exit points.

5.3.1 The Regression Analysis

In the simplest form, regression relates to the best fit line that explains the relationship between a dependent variable (Y) and an independent predictor variable (x). The most basic form is a linear regression formulated: $Y = \beta_0 + \beta_1 X + \varepsilon$. This type of relationships is useful if most of the variation in the outcome of the dependent variable is linked to the particular predictor variable. In most situations, the outcome of the variable is dependent on more than one predictor variable. This situation leads to a multiple regression where the dependent variable is predicted by a combination of a number of explanatory variables. Regression analysis can also be considered as linear or nonlinear, linear being the most basic form. The definition of non-linear relates to the unknown parameters and not to the relationship between the covariates and the outcome.

Due to the limited data observation available, a simple regression analysis using a single predictor variable is developed. The explanatory variables in the data set are considered one at a time. Variables that are found to have a correlation with the level of freight on links include the population of zone, proximity to ports and proximity to the city exit points. The results of this analysis are summarised in Table 5.5 below and full details of the analysis are included in Section E.3 of Appendix E.

Table 5.5: Summary of Regression Analysis

Variables	Coefficient	Standard error	R-Squared	t-statistics	P-value	Statistically significant
Dist. from port	-0.010057	0.009881	0.6801	-6.90	0.0000	Yes
Dist. From city exit	-0.007638	0.007545	0.4960	-4.86	0.0003	Yes
Population	-1.46e-07	5.54e-08	0.2179	-2.64	0.0141	Yes
Population density	-4.64e-07	3.21e-07	0.0771	-1.44	0.1609	No
Network density	-0.000145	0.000360	0.0065	-0.40	0.6890	No
Employment level	0.000023	0.000052	0.0078	0.44	0.6615	No

The effect of population (p = 0.014) is statistically significant and its coefficient is negative indicating that the higher the population, the lower the proportion of freight traffic. The population is related to the level of private cars used and functions as a proxy for this. The distance of the link from ports and city exits (p = 0.000) are more correlated to freight on link than population is. However, the model for distance from port provides an R-

Squared value of 0.68 which is higher than that the 0.49 obtained for the distance from city exits. The R-squared values of 0.68 and 0.49 implies that approximately 70% and 50% of the variance of the distance of link from port and city exits respectively are accounted for by the model. Furthermore, looking to the p-value of the F-test, the overall model for the proximity to port is more significant than that for the proximity to exit points. Employment level, network density and population density of zones are not statistically significant with each related to a p-value of greater than 0.05. While the overall polynomial regression model is most significant for proximity to port and the proximity to city exit points, the proximity to port is selected for use in this model since it presents the most statistically significant simple regression model.

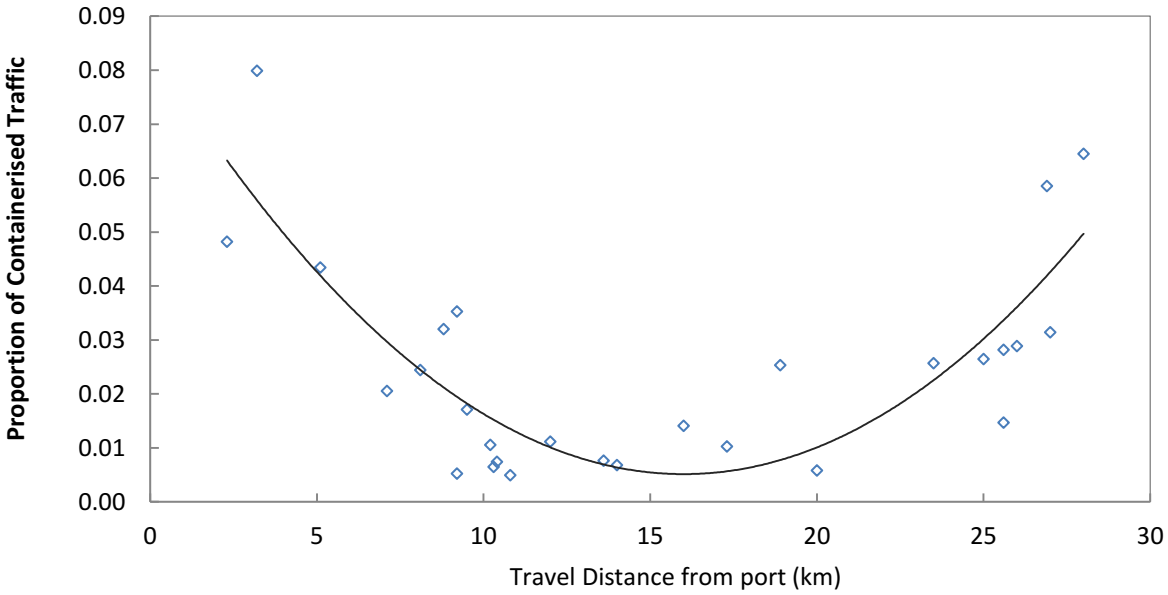


Figure 5.8: The Regression Model

The second order polynomial regression model employed for use is shown in Figure 5.8 and takes the form:

$$Y = \beta_0 + \beta_1 x + \beta_2 x^2 + \varepsilon \tag{5.7}$$

Given the proximity of a link to the closest port, the model predicts the proportion of the traffic on the link that is container freight. The non-container related traffic composition is modelled using the following relationship:

$$V_t^i + V_{nt}^i = V_t^i + \left(1 - \hat{Y}\right)\left(V_t^i + V_{nt}^i\right) \tag{5.8}$$

Where V_t^i is the Volume of containerized traffic on link (i); V_{nt}^i is the volume of non-

container related traffic; Y is the proportion of container traffic; β_0, β_1 andβ_2 are the regression coefficients of the prediction model and x is the shortest travel distance from a port to the centre of link (i).

By making V_{nt} the subject of the formulae:

$$V_{nt}^{i} = \frac{1-\beta_0-\beta_1 x-\beta_2 x^2}{\beta_0+\beta_1 x+\beta_2 x^2}\left(V_t^i\right) \quad (5.9)$$

The data used in this analysis relate to points within 30kms from the port. Thus, the model cannot be used to predict the proportion of trucks on links beyond 30kms form the port. In this study, container traffic is assumed to account for 5% of traffic on any link beyond this point.

The level of traffic on a link influences the speed of travel, the travel time, the generalized cost of a link and so the route choice in the assignment process. The generalized cost used as impedance in the all or nothing assignment is based on the total flows consisting of container related and non-container related traffic. The non-container related traffic is represented as a base flow and is assumed to be fixed and to co-exist with the containerised traffic volumes. This produces a worst case total container-related trip distance and travel time. This is because only container-related trips are forced to re-route to otherwise longer routes since all other traffic on links cannot be re-routed.

5.4 Model Calibration

Calibration in this context involves enhancing the accuracy of the representation of local conditions by checking and adjusting aspects of the model. The section relates to the process of calibrating the link performance function in the traffic assignment model and the gravity model for generating the demand matrices for the SCLs.

For the purpose of this research, adjustments were made to model parameters using the best available data to derive a result close enough to reality and this is verified using traffic count data collected on strategic links in the network and results from road side interviews on exit from the ports. Detailed calibration is a limitation to the project because of the time restrictions and size of data required and has been left for further research. However, a basic calibration has been undertaken and is discussed in this section.

5.4.1 Calibrating the Link Performance Function

The link performance function as discussed in Section 4.2 comprises travel time and operating cost components. The travel time and operating cost component are based on equations derived from the World Bank HDM-4 programme which relates speed and operating costs to a number of parameter that depend on the road conditions (link characteristics), Traffic conditions (congestion), vehicle characteristics and unit costs are specific to the study area - Nigeria. The network characteristics vary from link to link, the vehicle parameters are specific for each individual class and the traffic conditions vary with the level of traffic on a link.

The equations were developed from four major field studies conducted in Kenya, the Caribbean, Brazil and India and the validity has been demonstrated on independent field data from eight different countries (Paterson, 1987). Yet, a need for some local calibration has been emphasised. Lea (1988) shows that without calibration the actual and predicted VOC can be significantly different. Particularly, large differences occur due to different economic environments. For example, countries with high labour cost generally replace parts rather than repair them. The research shows the importance of calibrating the economic factors, particularly, in the VOC relationships.

Bennett and Paterson (2000) postulate that the degree of local calibration appropriate for this is a choice which depends on the type of application and on the resources available to the user. Calibration is considered within three levels termed – Basic application (level 1), calibration (level 2) and adaptation (level 3) which involves low, moderate and major effort respectively. Bennett and Paterson (2000) point out that in planning applications, the absolute magnitude of the Vehicle Operating Cost is not crucial because alternative policies are evaluated on the basis of comparison and so a basic application may suffice. This argument applies in this study since the input data are associated with links which are selected based on a relative preference in the assignment. Based on the intended use of the model, carrying out a level 2 or 3 calibration of the performance function is unjustified since the study is concerned with relative changes and not absolute. Furthermore, these tasks are enormous and due to restriction on time and funds were not embarked on in this study.

In this study, the level 1 calibration of the link performance function involves applying the values of important basic inputs derived from desk studies and minimal field

survey. The basic input data adjusted for this level of calibration include: characteristics of representative vehicles and unit costs and economic data for operating cost components. The vehicle characteristics are fixed between iterations and influence the absolute value of the link performance costs to specific vehicle classes. The basic input data are discussed in Section 5.4.1.1 below. Where basic inputs cannot be determined for local conditions, from desk studies and minimal field surveys, default values are adopted in this application.

5.4.1.1 Representative Vehicle Classes and Input Values

The link performance function in the assignment comprises the Vehicle Operating Cost (VOC) and the travel time costs and is dependent on the link characteristics (discussed in Section 5.1.2), and the vehicle characteristics. As it is impossible to calculate VOCs for independent vehicles in a traffic stream, representative vehicles are used for calculating VOCs. The characteristics of these vehicles are considered to be representatives of vehicles within the relevant vehicle classes. In this study, the vehicle classes are associated with each load class (FCLs and SCLs).

It is found that in Nigeria, haulage companies purchase 40F container single semi trailer as these allow for maximum utilisation since it can carry both single 20F and double 20F containers. In the model, truck tractors with 40F container semi-trailers are linked to FCLs while SCLs are linked to single unit trucks. At the port gates single unit trucks with 8 or more tyres account for 95% of goods vehicle while vans and unit trucks with fewer than 8 tyres account for the remaining 5%.

In the context of this study, trucks pulling containers would be termed trailers while single unit truck carrying stripped container loads (general cargo generated from containers) will be termed as trucks/unit-trucks. Figure 5.9 provides a description of the vehicle types associated with containerised cargo in the model. For simplicity, it is restricted to two classes.

The primary source of this data was obtained from structured questionnaires administered to haulage companies in Nigeria, the purpose of which was to identify the characteristic of vehicles commonly used to move containerised cargo loads. The size of the sample was limited to 15 companies by resource and time constraints. Once the replies were collated, the vehicle parameters and unit costs applied to the model were taken to be the mode or mean values of the sample data. The vehicle classes applied are illustrated above and the characteristics obtained from the field survey have been included in Table

D.1 of Appendix D. When certain characteristics were unidentified, the vehicle characteristics associated with the Brazil representative vehicle characteristics or default values specified in the World Bank HDM-VOC were used. Information on unit cost specific to the container industry was also determined through interviews and has also been included in Table D.1 of Appendix D.

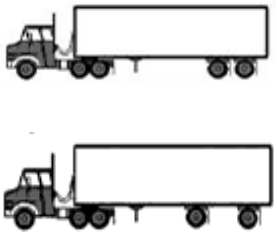
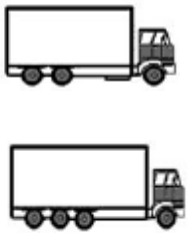
Load Class	Vehicle Class	Description
FCLs	Truck Tractor and 40F container single semi-trailer (5 axle)	
SCLs	Single unit Trucks (3-4 axle)	

Figure 5.9: Container-related vehicle classes

Since the haulage sub-sector in Nigeria, like most developing countries, is dominated by a large number of small scale operators, the value of time cost to firms would be similar in magnitude and is assumed to be related to the market price of the service provided. Ogwude (1993) in his research to estimate the value of transit time in industrial freight transportation in Nigeria, derived the value of time for two commodity groups - capital/intermediate and consumer goods by interviewing shippers. This value is calculated as the ratio of freight charges and the measure of transport service provided as perceived by the shipping firms over the duration of shipment. The values correspond to the opportunity cost which represents the amount of money the shipping firm is willing to pay to forgo in order to save a unit of transit time (Ogwude, 1993). His finding show that in 1993, a shipping firm in Nigeria will be prepared to forgo 2.1 Naira and 60 Kobo in order to save one tonne hour of a consumer good and capital/intermediate good shipment respectively (250 kobo = 1 Cent = 2.5 Naira). The naira has devalued since that period and the absolute value of freight charges has gone up. To account for this, the value of time with the same buying

power in 2011 is derived by applying an average increase of 22% to the value of time postulated in 1993. This gives an equivalent value of time of approximately 75.3 Naira (30.1 Cents) and 21.5 Naira (8.6 Cents) per tonne hour, for a consumer good and capital/intermediate good shipment respectively, in 2011. These represent the value of time per unit tone hour for stripped container loads (consumer goods and intermediate goods). The value of time per unit tonne hour for full container loads is calculated as a weighted average of the total tonnes of each commodity group in containers.

In the assignment, each vehicle class is associated with a value of time derived from the value of time per unit tonne hour for each load type (SCL/FCLs). For example, the value of time for trailers which carry FCLs are based on the average vehicle trip equivalent net weight (gross less tare weight) in tonnes. This is derived as the average ratio of total throughput in TEUs to the total throughput in tones for the years 2003 - 2008. 1 trailer trip is set as equivalent to 20 tonnes.

5.4.2 Demand Calibration – Calibrating the Gravity Model

The calibration process ensure that the demand estimates given by the model closely fit the observed demand. This process refers specifically to the gravity model used to derive the SCL matrix. This gravity model is associated with a single calibration parameter (β) within the disutility function (see Section 5.2.6). The calibration parameter (β) is adjusted to produce a trip length distribution or average trip length close enough to the observed. The basic approach to calibrating this parameter starts with guesstimating a value for β. In practice, 1/C has been found to be a good initial approximation for β, where C is the observed mean trip cost (Williams, 1975). Using this β value, the model is run to obtain a modeled trip length distribution (MTLD). This is then compared to the observed trip length distribution (OTLD). In the case where the both distribution are dissimilar or insufficiently close, then the process is repeated for a new guess until the MTLD is satisfactorily close to the OTLD. It is generally accepted that the gravity model is a good fit when the calibrated trip distribution is statistically close to the observed trip distribution for the base trips.

However, there are other more structured techniques for calibrating the gravity model. The most common ones were developed by Hyman (1969), Hathaway (1973) and Evans (1971) all of which have structured algorithms through which to determine β. Evans proposed to approximate β by differentiating an approximated polynomial function.

However, this method is dependent on the ability to evaluate the function $F_i(\beta)$ and it derivatives. The actual procedure suggested by Evans is too complex to document here and the reader is referred to Evans (1971) for details. The Hathaway method is based on a maximum likelihood approach involving the approximation of a relative likelihood curve by a normal curve with the independent variable representing the deterrence parameter β. Hyman(1960) suggests an iterative method that deduces an approximate value for β using the equation $\beta_m = \beta_o\ c_o/C$ and a rapidly converging formula to generate improved β approximations within each m iteration (where c_o is the mean modeled trip cost, C is the observed mean trip costs and β_o is the initial estimate). The modeled mean trip costs obtained from running the model using the new β are compared to the observed mean trip costs and the iteration is stopped once an acceptable level of accuracy is obtained. These methods were compared by Williams (1975) who suggested Hymans methods to be the most robust and accurate as it converges to arbitrarily small errors in generally faster time. The reader is referred to Hyman(1969) for more details on the algorithm.

The US Bureau of Public roads developed one of the most widely used methods for calibrating the gravity model (Stopher & Meyburg 1975). The procedure involves establishing the disutility function for the base year that produces a trip distribution close enough to the observed. After this function has been estimated, an adjustment factor is introduced at the zone to zone level to account for the remaining discrepancies between the observed and estimated trips, which is then used for future forecasting. This adjustment factor is usually computed as the ratio of the observed trips to the estimated trips for each Origin-Destination pair. However, the accuracy of this adjustment factor in making future predictions has been questioned by planners because of its inability to model complex socio-economic relationships between zones (Stopher and Meyburg , 1975). As Duffus et.al (1987) suggests, the use of such adjustment factors is sometimes not justified as it can result in large errors being introduced into the predictions and so this step is often omitted by planners.

The gravity model is calibrated to reflect trip distributions patterns of vehicles carrying stripped container loads within and beyond the city of Lagos. At the time of data collection, actual trip length distribution for each commodity class was unavailable and so a road side survey was carried out to determine this. The aim of the survey was to approximate the mean trip lengths and trip length distribution for vehicles carrying each defined commodity class (intermediate/raw goods, consumer durable and consumer

perishable goods), within the limitation of time and resources. An overview of the survey process and questionnaire used for the road side survey is included in Section G.1 of Appendix G. A summary of the interview responses is provided in Table G.1 - G.3 of Appendix G. Because of the scale of the survey, it was impossible to repeat the survey for trips exiting off-dock terminals so, trip distribution associated with trucks leaving the port was assumed also for trucks exiting off-dock terminals. Following this, a basic calibration process was carried out on the gravity model. This process is described in the following sections.

For simplicity, the sub gravity models associated with each commodity can be calibrated individually (one at a time) if the changes to the single calibration parameter (β) of a commodity class does not significantly influence the calibration variable-mean trip length of alternative commodity classes. Thus, the calibration process involved three stages: 1) sensitivity analysis to test if and how sensitive the mean trip lengths are to changes to the calibration parameter of the alternative commodity classes and 2) calibrating the three gravity models using observed mean trip length corresponding to each commodity class and 3) comparing the modelled trip distribution pattern with the observed trip distribution pattern.

5.4.2.1 Sensitivity Analysis

The main objective of this process is to explore how sensitive the model variable – the mean trip length for each commodity class is to changes to the calibration parameter of alternative commodity classes. Further objectives include exploring how the outputs of the model depend on the coefficient of the gravity model and how sensitive the traffic model is to inaccuracies in the gravity model. The exercise identifies variables that contribute mostly to the variability of the demand matrix corresponding to each commodity class and so emphasizes the parameters that must be determined most accurately in the future to reduce output uncertainty.

The analysis considers 3 independent variables β = (β1, β2, β3), and two dependent variables Y=(Y1, Y2, Y3)and Z = (Z1, Z2, Z3), where β1, β2, β3 is the coefficient of the exponential deterrent function $f(c_{ij})$ for commodity classes IG, PG and FG respectively, Y1, Y2, Y3 is the mean trip length for commodity type IG, PG, FG respectively and Z1, Z2, Z3 is the total vehicle distance travelled for commodity type IG, PG, FG respectively.

The “Factorial experimental design” method applied by Box et al (1983) and Rose

(1983) is employed in this sensitivity analysis. This method of analysis involves selecting an arbitrary number of samples for each model parameter and the model is run for all combinations of the sample. In this case, 3 β values are sampled for two extreme values determined rather arbitrarily. This experimental design requires 2^3 = 8 model runs. In reality, more values for β can be sampled but would require a rather tremendous number of model runs (in the order of factorial) depending on the number of samples selected. This method however only addresses the sensitivity relative to the samples chosen and not the entire parameter. Thus, it was ensured that the samples consider extreme values of the β parameter. The results from this experiment present a good enough representation of the behaviour of these variables since the two values sampled are extremes. In essence, the test considers scenarios that lead to extreme levels of demand.

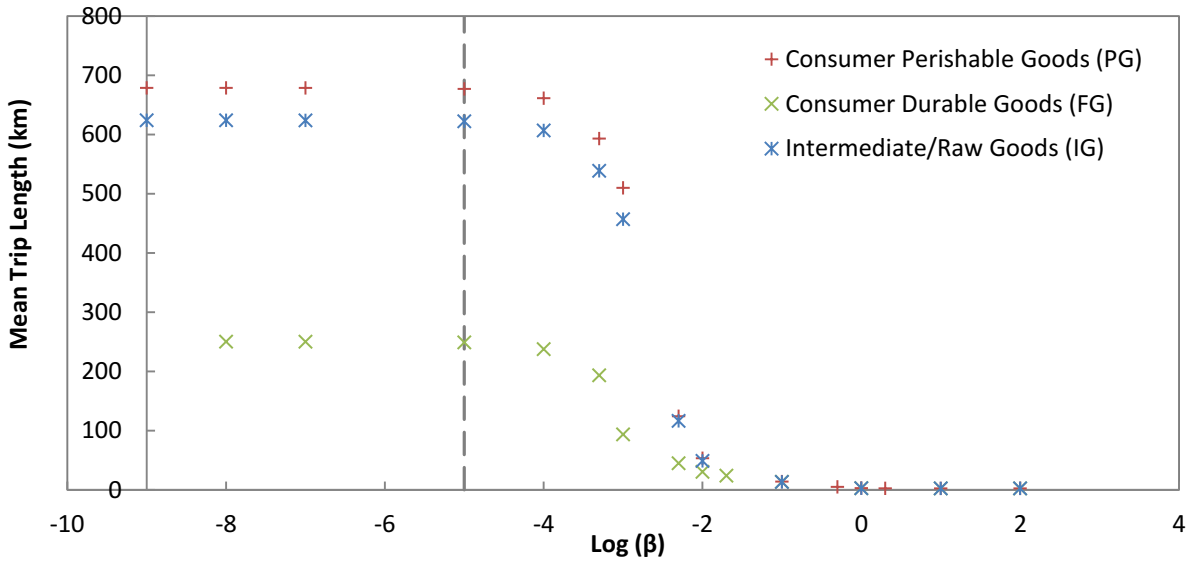


Figure 5.10: Mean trip length against Log (β) values for each commodity class.

The extreme β values for each sub gravity model are considered as values at or beyond which, changes to the modelled mean trip lengths are not substantial. The extreme β values for each commodity class are considered as β values corresponding to the lowest and highest possible mean trip length for each sub gravity model. The extreme β values applied in the sensitivity test is taken as the β values that envelope the extreme β values for each commodity classes, Figure 5.10 illustrates this point. The extreme β values are 1 and 0.00001. The high β value of 1 represents the scenario where fewer trips are attracted to zones further away compared to the distribution resulting from a low β value of 0.00001.

As discussed, the thesis considered eight combinations of two extreme parameters in the gravity model deterrence function. The first two scenarios consider the effect of

replicating two extreme values for the β coefficient in the disutility functions for each gravity model. These extremes are termed low and high. The remaining scenarios explore the response of the output values to a variation from these two extreme scenarios. These middle scenarios are obtained by varying one input β at a time. A list of these scenarios is given in Table 5.6 below. The extreme cases are scenario 1 and 8 with low and high beta values.

Table 5.6: Outline of scenario cases

Calibration factor	**Test scenarios**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
β_1	0.00001	0.00001	0.00001	0.00001	1	1	1	1
β_2	0.00001	0.00001	1	1	0.00001	0.00001	1	1
β_3	0.00001	1	0.00001	1	0.00001	1	0.00001	1

The sensitivity index, advocated by Hoffman and Gardner (1983), is employed as the measure of the parameter sensitivity and qualitatively exploring the combined variability of other β parameters resulting from altering individual β parameters. These measures are obtained for each parameter by increasing each parameter to an extreme value while leaving all others constant. The change in the output is then quantified and compared to the base case. The base case is considered to be the scenarios where all β values are sampled as extremes (scenario 1 and 8 in this case). The sensitivity Index (SI) is calculated as $SI = \left|(\mathrm{Dmax} - \mathrm{Dmin})/\mathrm{Dmax}\right|$ where, Dmax and Dmin represent the maximum and minimum output values respectively, resulting from varying input parameter over two extremes (Hamby, 1994). The sensitivity index describes how the model outputs are influenced by changes to the input variable. Values close to one implies that output variable is correlated to individual variables.

Table 5.7 shows the result from the sensitivity analysis. The calibration parameters $\beta_1, \beta 2, \beta_3$ corresponds to mean trip lengths M_1, M_2, M_3 of commodity class IG, PG, FG respectively. Clearly, changes to the calibration parameter (β) of any sub model have insignificant effects on the mean trip length and so demand matrix of other sub gravity models. Also, it is plausible to suggest that if the model is calibrated to alternative sets of observed mean trip lengths and β values, the results from the assignment procedure might no longer hold. Consequently, the sensitivity analysis explores the effect that changes to the β values have on the model output. The output variables that are likely to be affected by the gravity model coefficient include the total vehicle km travelled, the total vehicle hours

spent, and the total road user costs. These output variables are obtained from the run of each scenario (1 to 8) and compared. The sensitivity indices relating to these models outputs are also included in Table 5.6 above. Clearly, calibration parameter relating to commodity class FG presents the greatest impact on the network impact. This is logical since deconsolidated trips are generated mainly from Commodity class FG (Consumer durable goods). The same applies to Class IG (intermediate/raw goods) and PG (consumer perishable goods) whose impacts correspond also with their presence in the network. Evidently, in applying this method in modelling alternative networks specific focus must be given to selecting appropriate disutility functions and calibration parameters specifically for commodity classes that are main generators of trips.

Table 5.7: Sensitivity index for scenario cases

Scenarios		**Sensitivity Index =(Dmax-Dmin)/Dmax**					
No	**Description**	**Mean Trip Length (M_1)**	**Mean Trip Length (M_2)**	**Mean trip Length (M_3)**	**Freight Veh-km**	**Freight Veh-hrs**	**RUC**
1	Base case	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	$\Delta\beta_3$	0.000002	0.000001	0.987795	0.253847	0.247197	0.139408
3	$\Delta\beta_2$	0.000002	0.995391	0.000005	0.104319	0.104600	0.058411
4	$\Delta\beta_1$	0.995336	0.000000	0.000000	0.248673	0.252912	0.190791
5	$\Delta\beta_1$	0.995336	0.000001	0.000002	0.159511	0.164354	0.232716
6	$\Delta\beta_2$	0.000000	0.995391	0.000000	0.177932	0.178467	0.082941
7	$\Delta\beta_3$	0.000000	0.000000	0.987795	0.344883	0.337344	0.176593
8	Base case	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

5.4.2.2 Calibration

This process involves calibrating the sub-gravity models associated with each SCL commodity class. Each sub-gravity model is singly constrained and employs an exponential deterrence function. The function has a single calibration parameter (β) and so, one statistical variable is adequate for calibration. The mean trip length has been selected.

As described in Section 5.2.6, the demand model for SCL trips consists of three sub-gravity models each attached to the type of commodity carried by a specific vehicle class (m) between origin (i) and destination (j). The deterrence function is in the form: $f(x_{ij}^m) = e^{-\beta_m x_{ij}^m}$ where x_{ij}^m is the travel distance of vehicle carrying commodity class (m) between zone (i) and zone (j). It has been shown that the β parameters associated with

each sub-gravity model (commodity class) are not significantly sensitive to one another and so varying the β value of the deterrence function in one sub-gravity model does not force significant change to the mean trip length of another. Thus each function is calibrated on the basis of the standard gravity model calibration techniques outlined by Hutchinson (1974) where the accepted β value is one that causes the simulated mean trip length to match the observed mean trip length. Other calibration techniques based on matching trip interchanges rather than trip lengths are often used however, problems relating to the reliability of samples and available sample sizes as outlined by Ogden (1978) prevents its use in this application.

The Initial values for β are assumed to be 1 and the model is run to obtain a mean trip length for iteration (M_i^m). The difference between the observed trip length (M_{obs}^m) and calculated trip length (M_i^m) is compared against the convergence criterion. A margin of error for a 95% confidence of 10%, 12%, 15% is associated with the sample of consumer durable goods, Intermediate/raw goods and consumer perishable goods respectively and so a convergence criterion where the difference between the observed mean trip length and calculated mean trip length is less than 5% is deemed acceptable in this study. If it passes, the iteration is considered to have converged. Else, the β parameter is adjusted using the equation:

$$\beta_{i+1}^m = \beta_i^m \frac{M_i^m}{M_{obs}^m} \tag{5.10}$$

For each commodity class, the observed trip lengths are only available for the trips from port and this was assumed to apply also to trips generated at off-dock terminals. The model is calibrated using the observed mean trip lengths for the relevant commodity class. The modelled trip length distribution and mean trip lengths for the relevant vehicle classes are obtained by cumulating the flows between all O-D pairs against the distance travelled by the each vehicle class. From which, the proportion of trips in each travel distance increment is obtained. The mean trip length is the weight mean value of trip distance using the flow as weight. The accepted mean trip lengths and error margin from the calibration of each sub-gravity model is summarised in Table 5.8 below. While the average trip length is used in the calibration process, it is also interesting to compare the resulting trip length distribution with those observed.

Table 5.8: Summary of average trip lengths

		Mean trip length (km)		
	Commodity Class	**Observed**	**Modelled**	**Error (%)**
x_1 (β_1)	IG	144.1	144.3	0.138
x_2 (β_2)	PG	63.4	63.6	0.315
x_3 (β_3)	FG	187	186.8	0.107

The quality of the calibrated model can be measured by the accuracy with which it simulates the observed trip length distribution, thus, two tests are carried out to explore how the model captures elements of the observed distribution. These tests are conducted by comparing the simulated trip length distribution patterns to the observed pattern for each commodity class. The first test involves a simple graphical comparison of the trip distribution while the other is a goodness of fit test and measures of the similarity of the shape and position of the trip length distribution. Figure H.1 to H.3 in Appendix H shows the observed and modelled trip length distributions related to each commodity class. It can be observed, graphically, that while the errors in the mean trip length are insignificant, the discrepancies between the modelled and observed trip distribution are somewhat larger. A non-graphical comparison of the observed and modelled trip length distribution can be done using a chi-squared formulation or a Kolmogorov–Smirnov (K-S) test. In this case, the chi-square test cannot be used because of the large number of origin-destination pairs with zero counts and because the test assumes the distribution to be relatively normal which it is not as can deduced from Figures H.1 to H.3, the distributions are highly skewed. Consequently, the Kolmogorov–Smirnov equality of distribution test is used.

The Kolmogorov–Smirnov is a non parametric test that determines whether two data sets differ significantly. In this application, the modelled trip distribution is compared to the observed trip distribution with an aim to test if they are similar. Thus the null hypothesis H0: P1 = P2 is that the modelled trip distribution for each commodity class (P1) and the observed trip distribution (P2) both come from the same distribution. The test is carried out for 5% level of significance and so, the null hypothesis is accepted if the p-value obtained is greater than a significance level of 0.01 or 0.05. The results of this is summarised in Table 5.9 below. At significance level of 0.01, the null hypothesis is accepted for all classes

Table 5.9: Result of Kolmogorov–Smirnov (K-S) test

Commodity Class	No of Observations	P-value	Test at significance level	
			0.05	0.01
IG	67	0.039	Reject	Accept
PG	38	0.042	Reject	Accept
FG	91	0.094	Accept	Accept

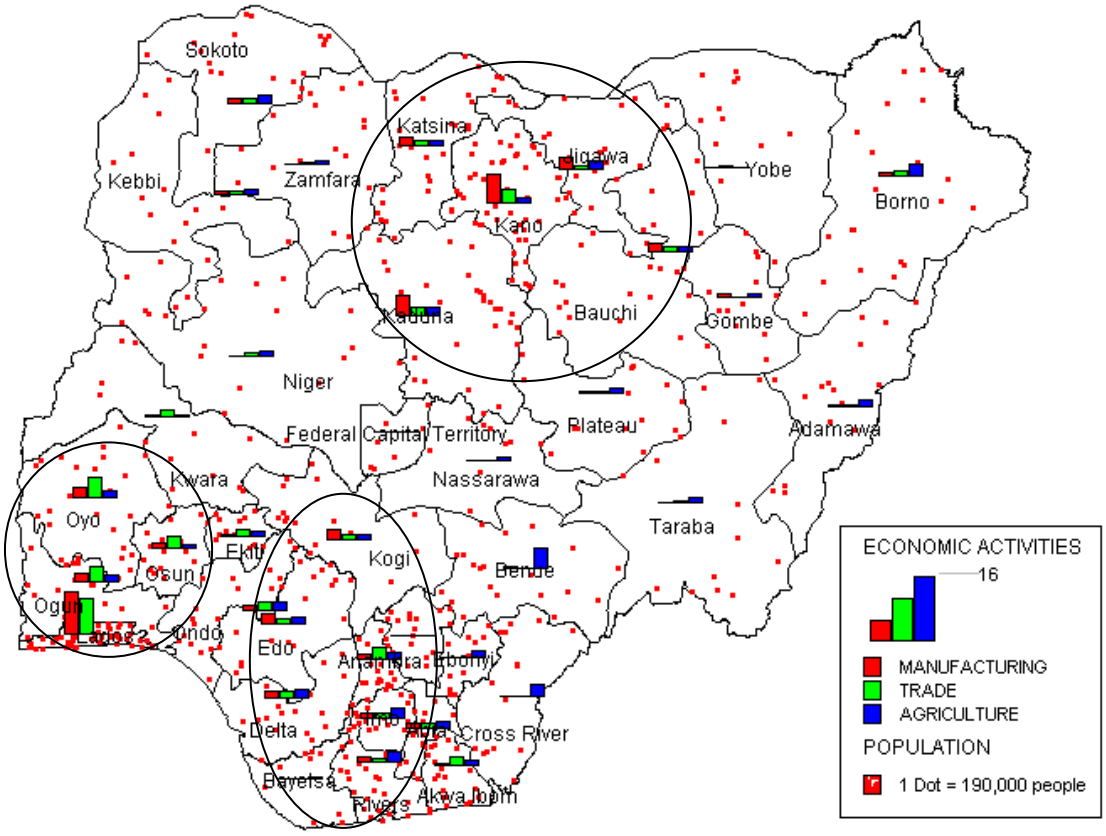


Figure 5.11: Map of Nigeria showing distribution of population and economic activity (adopted from FMT, 2002)

Figure H.1 illustrates the trip length distribution for raw/ intermediate commodity class as a cumulative density function and a probability density function. The cumulative density function suggests good fit with both function coinciding at most points. The modelled and observed cumulative curves both show that raw/ intermediate commodity travel as far as 1000km and over 80% of trips occurs within 200km of the port. The probability density curves expose a considerable overlap of the modelled and observed distribution. The probability density functions appear to taper exponentially with trip distances. However, the observed distribution shows that beyond 200km of the port, gaps occur between the histogram bars suggesting that intermediate/raw goods are attracted to

certain areas particularly those within 400-500km, 700-800km and 900-1000km from the port. Cluster in the observed distribution pattern represent clusters of the major industrial regions in Nigeria. Figure 5.11 illustrates the distribution of economic activities through regions in Nigeria and emphasis the manufacturing clusters. However, the model appears to distribute trips to areas surrounding these regional manufacturing blocks.

This is not surprising since the model is a simple analogue using the total employment level as the proxy for concentration of manufacturing industries within zones. This discrepancy can be corrected by applying a factor (during the calibration) to reduce the attractiveness to zones unrelated to manufacturing activities. This is not applied in this study as it required further data collection. Furthermore, the p-value of 0.039 from the K-S test suggests that there is no significant statistical difference between the modelled and observed trip lengths and so the null hypothesis that the modelled distribution is a good enough representation of the observed distribution can be accepted. Employment is accepted as a good measure of zonal attraction and the Logit function is a good enough representative of trip disutility as it predicts a trip length distribution similar to the observed.

Figure H.2 shows a cumulative and probability distribution for consumer perishable goods. Just under 80% of perishable commodities trips exiting the port are destined for areas within 100km of the ports, a figure also predicted by the model. These goods have their demand driven mainly by population needs and not population wants. They include finished food products, pharmaceutical products, cosmetic products and personal effect goods. Clearly, both observed and modeled distributions are not normal. The observed distribution suggests that such goods are distributed over much shorter distances from the ports (compared to intermediate/raw goods). Particularly, these perishable goods appear to serve only areas within 250km of the port. The distribution is based on a sample size of 38 responses so, a large number of zones have no trips attracted to them. For this reason, there are a number of gaps between the bar representing the uncovered trip ranges. However, the graph suggests a bimodal distribution which is reproduced by the model. The p-value of 0.042 from the k-S test suggests that at a significant level of 0.01, there is no statistical difference between the modeled and observed trip length distribution.

Figure H.3 is a cumulative and probability density distribution for consumer durable goods. The observed and modelled distributions are clearly not normal. Both distributions are highly skewed to the left of the graph with over 60% of trips destined to areas within

30km of the port. Furthermore, the observed distribution appears to be bimodal, a pattern which is predicted by the model.The p-value of 0.094 from the k-S test suggests that at a significant level of 0.05, there is no statistical difference between the modeled and observed trip length distribution and so the null hypothesis that the modelled distribution is a good enough representation of the observed distribution can be accepted.

Considering that such trips are destined to warehouses and markets for further distribution, it is not surprising that the model does not provide a perfect result as it is a simple analogue using a number of indicators as a measure of attractiveness of each commodity type to zones. While factors like market or warehouse concentration in each zone could provide a better measure of attraction for such commodities, resource and time restriction meant data collection was kept to a minimum and existing data was used whenever possible. Hence, existing socio-economic data is used.

The model has been shown to be calibrated to produces a good enough estimation of trips distributed to zones within 100km of the port which envelopes Lagos and the surrounding area and captures a distribution pattern close enough to the observed. Employment, per capita income and population are accepted as a good measure of zonal attraction and the Logit function is a good enough representative of trip disutility within the gravity model as they predicts trip length distribution for each commodity that is similar to the observed.

5.5 Model Validation

The final exercise in the transport model development is the model validation. Ortuzar (2001) outlines a general strategy for validation to be able to check whether the model can reproduce a known state of the system with sufficient accuracy; this could include confirming that trip volumes along key roads are well reproduced in the model. The model is validated by comparing the predicted link volumes (numbers of FCL and SCL vehicle movements per link) with the observed link volumes along key link in the network. The observed link volumes are derived from road traffic counts, and road side interviews. Within this process, data used for validation are kept separate from those used within the model.

The model was validated using results from a manual traffic count survey that was embarked on in December, 2011. This survey was carried out with an aim to derive freight flows at 13 independent locations in the network. The sites for comparison were selected

to include key exit routes from the ports and the port city. The selected locations are included in Table I.1 and Figure I.1 of Appendix I. The result of the count is summarised in Table 1.2 and I.3 of Appendix I.

In the context of Nigeria, containerised commodities can either move in the container in which they arrived pulled by a trailer or move in unit trucks (trucks) to which they are transferred. Container trailers carry containers only and all containers arrive through the ports thus, all trailers on roads are assumed to be moving within the existing container logistic chain. Trailer trips including empties and laden all sum up to the total trailer trips generated in the system. On the other hand, trucks carrying stripped containerised cargo are more difficult to identify. This is because other types of cargo are transported in similar forms of trucks and so, trucks on links carry a range of cargo types. Furthermore, the model estimates trips associated with stripped container loads that originate at the ports and off-dock terminals only but, trucks may originate from other points including retail or distribution outlets within the zones. While the numbers of trucks on links are known from the traffic count, it is necessary to translate the truck traffic counts on links to biased counts from container hubs.

A bias factor is derived from roadside interviews carried out with the aim to determine the proportion of truck counts that are carrying stripped container loads in particular. The magnitude of the field work meant that the survey was carried out at 5 out of 13 locations selected for link validation. The questionnaire used in this survey and details of the survey are included in Appendix J. Given the origin and destination of a sample of trucks, a proportion of port related truck trips was derived. Port-related trips are defined as trips originating from or destined to ports or off-dock terminals. Table J.2 of Appendix J shows a breakdown of journey purpose for each surveyed location. The results show that locations closer to the ports have a higher proportion of port related trips. Finally, the bias factor applied to estimate trips associated with stripped container loads is derived as a product of the proportion of port related trips on links and the proportion of port originating truck trips that constitute stripped container loads. This was taken to be 0.13 and was derived from the road side interview refered to in Section 5.4.2. The number of trucks (vans) on links is multiplied by the bias factors to derive the number of trucks on links carrying stripped container cargo which is used in the validation process.

Prior to validation, the network was checked and coding errors were removed. For completion, the validation is carried out at two time periods- the busiest and median

observed hour corresponding to the 95th and 60th percentile of the sample. Tables 5.9 to 5.12 give a comparison between the results from the model and the traffic count survey. They summarize the validation results for the two container trip classes: trailer trips pulling container loads and truck trips carrying stripped container contents. The variations between them are given in absolute, percentage and relative differences. A GEH (Geoffrey E. Havers) statistical test for these differences is also undertaken and the results are presented. According to the Design Manual for Roads and Bridges (DMRB) Volume 12, Section 2, Part 1, Chapter 4, 85% of volumes in a traffic model should have a GEH statistic of less than 5.0 which presents a good match between the modelled and observed volumes. On the other hand, values between 5 and 10 may require further investigation and those above 10 may not be considered as a good match. The GEH statistic is calculated using the formula:

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}$$ Where M is the modeled flows and C is the observed flows

Furthermore, the results are checked against the DMRB flow criteria for model validation which outlines that for link flows of less than 700 vehicle per hour, the absolute difference should be within 100 vehicle per hour.

Trailer volumes on links comprises laden and empty container trips. The model passes the 85% critical level outlined by DMRB with over 92% of volumes in the case of the 60th percentile hour and 96% in the case of the 95th percentile hour having a GEH statistic of less than 5 (Table 5.10 and 5.11). However, two locations present a GEH value of above 5. Both locations are on exit routes from the city. Locations 1a to 2b which are on routes to/from ports have GEH values well below 5 and absolute differences below 100 and so comfortably pass the GEH and flow criteria. In terms of trailer flows, the base model exceeds the DMRB validation requirements, implying that the model provides an accurate enough representation of the observed data.

Table 5.10: Trailers volumes on Link (vehicle per 60th percentile hour)

ID	Location	Observed counts	Modelled flows	Absolute difference	% difference	GEH
1a	Creek road bridge from Apapa	92	85	-8	-8%	0.80
1b	Creek road bridge to Apapa	91	70	-21	-23%	2.43
2a	Wharf road from Apapa	66	65	-1	-2%	0.15
2b	Wharf road to Apapa	100	93	-7	-7%	1.00
3a	KiriKiri road to Mobil	30	26	-5	-13%	0.86
3b	KiriKiri road from Mobil	46	38	-8	-17%	1.20
4a	Eko Bridge to Apongbon	19	21	2	11%	0.52
4b	Apongbon to Eko Bridge	11	12	1	9%	0.15

5a	Lagos Badagry Exp. to Mile 2	43	16	-28	-64%	5.09
5b	Lagos Badagry Exp. from Mile 2	21	17	-5	-19%	1.09
6a	Apapa-Oshodi Exp. from Mile 2	60	53	-7	-12%	0.95
6b	Apapa-Oshodi Exp. to Mile 3	66	60	-6	-9%	0.77
7a	Agege motor road from Mushin	11	11	1	0%	0.18
7b	Agege motor road to Mushin	24	21	-3	-13%	0.59
8a	Isolo road to Isolo	7	8	1	14%	0.15
8b	Isolo road from Isolo	4	4	0	0%	0.00
9a	Ikorodu/Mobolaji bank Anthony	56	65	9	16%	1.15
9b	Ikorodu/Mobolaji bank Anthony to	61	51	-10	-16%	1.34
10a	Agege motor road to Agege	15	17	2	13%	0.53
10b	Agege motor road from Agege	20	17	-3	-15%	0.78
11a	Lagos-Ikorodu Exp. to Ikorodu	4	3	-1	-25%	0.30
11b	Lagos-Ikorodu Exp. from Ikorodu	4	4	0	0%	0.08
12a	Lagos-Ibadan Exp. from Ibadan	48	19	-30	-60%	5.13
12b	Lagos-Ibadan Exp. to Ibadan	30	18	-12	-40%	2.53
13a	Abeokuta Exp. from Oshodi	12	11	-1	-8%	0.36
13b	Abeokuta Exp. to Oshodi	12	11	-1	-8%	0.43

Table 5.11: Trailers volumes on Link (vehicle per 95th percentile hour)

ID	Location	Observed counts	Modelled flows	Absolute difference	% difference	GEH
1a	Creek road bridge from Apapa	145	141	-4	-3%	0.35
1b	Creek road bridge to Apapa	102	116	14	14%	1.29
2a	Wharf road from Apapa	90	109	18	20%	1.82
2b	Wharf road to Apapa	131	156	24	19%	2.04
3a	KiriKiri road to Mobil	50	44	-6	-12%	1.78
3b	KiriKiri road from Mobil	65	63	-2	-3%	0.30
4a	Eko Bridge to Apongbon	42	35	-7	-17%	1.15
4b	Apongbon to Eko Bridge	21	20	-1	-5%	0.32
5a	Lagos Badagry Exp. to Mile 2	51	27	-25	-48%	3.95
5b	Lagos Badagry Exp. from Mile 2	26	28	2	8%	0.40
6a	Apapa-Oshodi Exp. from Mile 2	90	92	2	2%	0.18
6b	Apapa-Oshodi Exp. to Mile 3	87	101	14	16%	1.46
7a	Agege motor road from Mushin	22	19	-3	-14%	0.73
7b	Agege motor road to Mushin	32	36	4	13%	0.62
8a	Isolo road to Isolo	11	13	2	18%	0.77
8b	Isolo road from Isolo	5	6	1	20%	0.23
9a	Ikorodu/Mobolaji bank Anthony	103	108	5	5%	0.48
9b	Ikorodu/Mobolaji bank anthony to	77	80	3	4%	0.33
10a	Agege motor road to Agege	26	29	3	12%	0.57
10b	Agege motor road from Agege	23	29	6	26%	1.17
11a	Lagos-Ikorodu Exp. to Ikorodu	6	5	-1	-17%	0.13
11b	Lagos-Ikorodu Exp. from Ikorodu	7	6	-1	-14%	0.35
12a	Lagos-Ibadan Exp. from Ibadan	53	32	-21	-40%	3.28
12b	Lagos-Ibadan Exp. to Ibadan	40	32	-8	-20%	1.41
13a	Abeokuta Exp. from Oshodi	16	18	2	13%	0.40
13b	Abeokuta Expressway to Oshodi	17	18	1	6%	0.19

The modelled and observed volumes at the 95th percentile hour are plotted for different locations in the graph below (Figure 5.12). The graph illustrates the relative volume on links at different locations. The modelled flows peak at the same locations as the observed flows except in three cases. Yet, the model quite well predicts the relative patterns with only a few discrepancies.

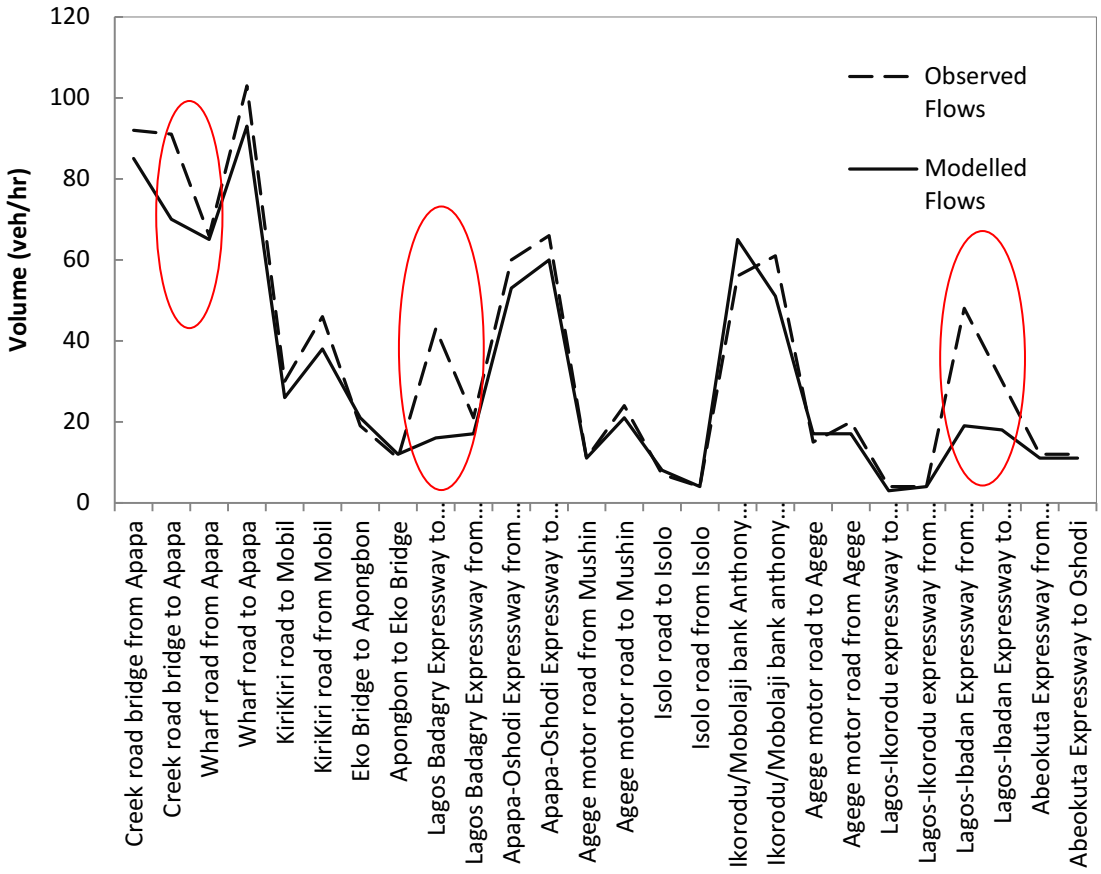


Figure 5.12: Plot of modelled and observed volumes

With regards to truck flows, the model passes the 85% critical level outlined by DMRB with 100% of links in the case of the both the 60th and 90% percentile hour having a GEH statistic of less than 5 (Table 5.12 and 5.13). The hourly truck volumes are relatively lower and so present high percentage differences. Yet, the GEH values for 100% of links are well below 5 and so indicate that the model provides an accurate representation of the observed data.

Table 5.12: Truck 60th percentile

ID	Location	Observed counts	Modelled flows	Absolute difference	% difference	GEH
2a	Wharf road from Apapa	5	5	0	-4%	0.09
2b	Wharf road to Apapa	11	14	3	25%	0.79
3a	KiriKiri road to Mobil	7	5	-2	-24%	0.67
3b	KiriKiri road from Mobil	3	5	2	81%	1.13
5a	Lagos Badagry Exp. to Mile 2	2	4	2	140%	1.36
5b	Lagos Badagry Exp. from Mile 2	5	7	2	43%	0.87
11a	Lagos-Ikorodu Exp. to Ikorodu	2	4	2	69%	0.92
11b	Lagos-Ikorodu Exp. from Ikorodu	2	2	0	9%	0.12
12a	Lagos-Ibadan Exp. from Ibadan	0	0	0	0%	0.00
12b	Lagos-Ibadan Exp. to Ibadan	7	9	2	31%	0.74

Table 5.13: Truck 95th percentile

ID	Location	Observed counts	Modelled flows	Absolute difference	% difference	GEH
2a	Wharf road from Apapa	7	9	1	20%	0.50
2b	Wharf road to Apapa	17	22	5	28%	1.07
3a	KiriKiri road to Mobil	9	9	0	0%	0.00
3b	KiriKiri road from Mobil	4	9	5	147%	2.10
5a	Lagos Badagry Exp. to Mile 2	2	6	4	188%	1.95
5b	Lagos Badagry Exp.from Mile 2	6	10	4	69%	1.44
11a	Lagos-Ikorodu Exp. to Ikorodu	5	8	3	50%	1.02
11b	Lagos-Ikorodu Exp. from Ikorodu	3	4	0	11%	0.20
12a	Lagos-Ibadan Exp. from Ibadan	0	0	0	0%	0.00
12b	Lagos-Ibadan Exp. to Ibadan	11	14	4	34%	1.04

5.6 Modelling the Test Scenarios

The aims of the study are to quantify the potential effect of a container close dry port on traffic congestion in a road network of a port city and to explore the effect of the characteristics of a close dry port, specifically the inclusion of an Empty Depot Service (EDS) and Freight Distribution Service (FDS), on its ability to reduce congestion. The research questions are addressed through a comparative analysis between a number of dry port scenarios with varying characteristics and a do-nothing reference scenario. This section will discuss how the dry port and reference scenarios are modelled.

The do-nothing reference scenario represents the current situation without a dry port solution which is modelled following the steps outlined in the previous sections. The year 2014 is selected as the reference year for analysis and so as with developing the model

for validation (Section 5.2.8), the 2009 O-D matrices are translated to 2014 demand matrices using the growth factor of 14.2%.

The dry port scenarios are modelled following the same framework outlined in Section 4.2. The non-container related traffic are modelled as base flows on links and are fixed between the do-nothing reference case and the dry port scenarios. The volumes of containerised traffic on links, on the other hand, vary between the dry port scenarios. This variation depends on the changes to the supply chain pattern of containers and so the origin-destination matrices at demand level and on the traffic assignment at supply level.

This section outlines the assumptions made and the developments specific to the transport network representation and deriving the containerised cargo trip matrices for each dry port scenario. It begins by outlining the dry port scenarios to be tested and defining some key terms used.

5.6.1 The Dry Port Test Scenarios

The reader is directed to Section 3.2 of this thesis, where the scenario cases for testing were first introduced. The inclusion of an empty depot and FDS are the selected characteristics and thus, the test cases represent close dry port solution with and without these characteristics. The close dry port solution being explored is one located on the outskirts of the urban area and connected to the seaport by rail - the site for which is discussed in Section 3.1.5. The 28 dry port scenarios outlined in Section 3.2 constitutes a combination of 4 test cases, and 7 levels of dry port usage derived from 2 allocation mechanisms.

5.6.1.1 Dry Port Test Cases

The four test cases outlined and explored in Section 3.2 include:

- Test Case 1: Close dry port with empty depot service and with FDS
- Test Case 2: Close dry port with empty depot service and without FDS
- Test Case 3: Close dry port without empty depot service and with FDS
- Test Case 4: Close dry port without empty depot service and without FDS

The Freight Distribution Service allows for container to be stripped within the facility and goods loaded onto vans /trucks for distribution to the relevant points of use/ sale or

redistribution. The goods off-loaded from containers can also be stored within warehouses provided prior to loading. Upon arrival of containers from the seaport, such services allow empty containers to be returned directly by rail to port without exiting the dry port gates.

The empty depot service allows for consignees to return empty containers to the dry port facility. It includes a yard where empty containers can be received and stacked in wait for export. The empty depot service relates specifically to the availability of the service to consignees. For example, in test case 3 (dry port without EDS and with FDS), consignees are not allowed to return empty containers to the dry port, however, empty containers generated from the stripping of containers are stacked in the empty depot facility in wait for export. Empty containers received or stored through this service are transferred to the seaport via rail only. The following sections outline how the scenarios relating to the test cases are modelled.

5.6.1.2 Level of Dry Port Utilization

The usage/utilization level of the dry port represents the volume of cargo (containers) moving through the dry port and is calculated as a proportion of container traffic that moves through the seaport in the do-nothing scenario (the case without the dry port). As the analysis is carried out on an hourly basis, it is calculated as a proportion of the annual traffic. The test cases are explored at 7 levels of dry port utilization derived from 2 container allocation mechanisms – Load centre mechanism and satellite mechanism.

The satellite mechanism represents the allocation mechanism where the dry port serves all zones in the country. In the satellite scenario container traffic using the dry port is distributed to consignees throughout Nigeria in the same proportions as imported containers as a whole. In this analysis, fixed utilization levels representing the percentage of container import traffic are considered at an increment of 10% and range from 10% to 50% (Scenarios 3 to 7 described in Sections 3.2 of the thesis).

On the other hand, the load centre mechanism represents the allocation mechanism where the dry port handles only containers destined for zones which are closer to the dry port than a port. Two alternative load centre mechanisms (LCM) have been considered. In the first (LCM 1) the dry port handles all containers imported through the port that are destined for zones beyond the city limits. This results in a utilisation level (throughput) for the dry port which is equivalent to 20% of the containers imported through the ports. In the second load centre mechanism (LSM 2) the dry port handles all container imports which are

destined for zones which are closer to the dry port than to the ports (including some zones within the city limit). This results in a utilisation level equivalent to 30% of all containers imported through the ports. In this mechanism, the zones contributing to the traffic through the dry port vary accordingly to the utilization level. Both mechanisms are illustrated in Figure 5.13 above. For the load centre mechanism, the rings enclose the zones that use the dry port. In this illustration, zone 5 and 6 represent the zones located beyond the port city limits, zone 4 represents zones that within the city limits but are closer to the dry port than the port while zones 1 to 3 represent zones that are closer to the port than the dry port.

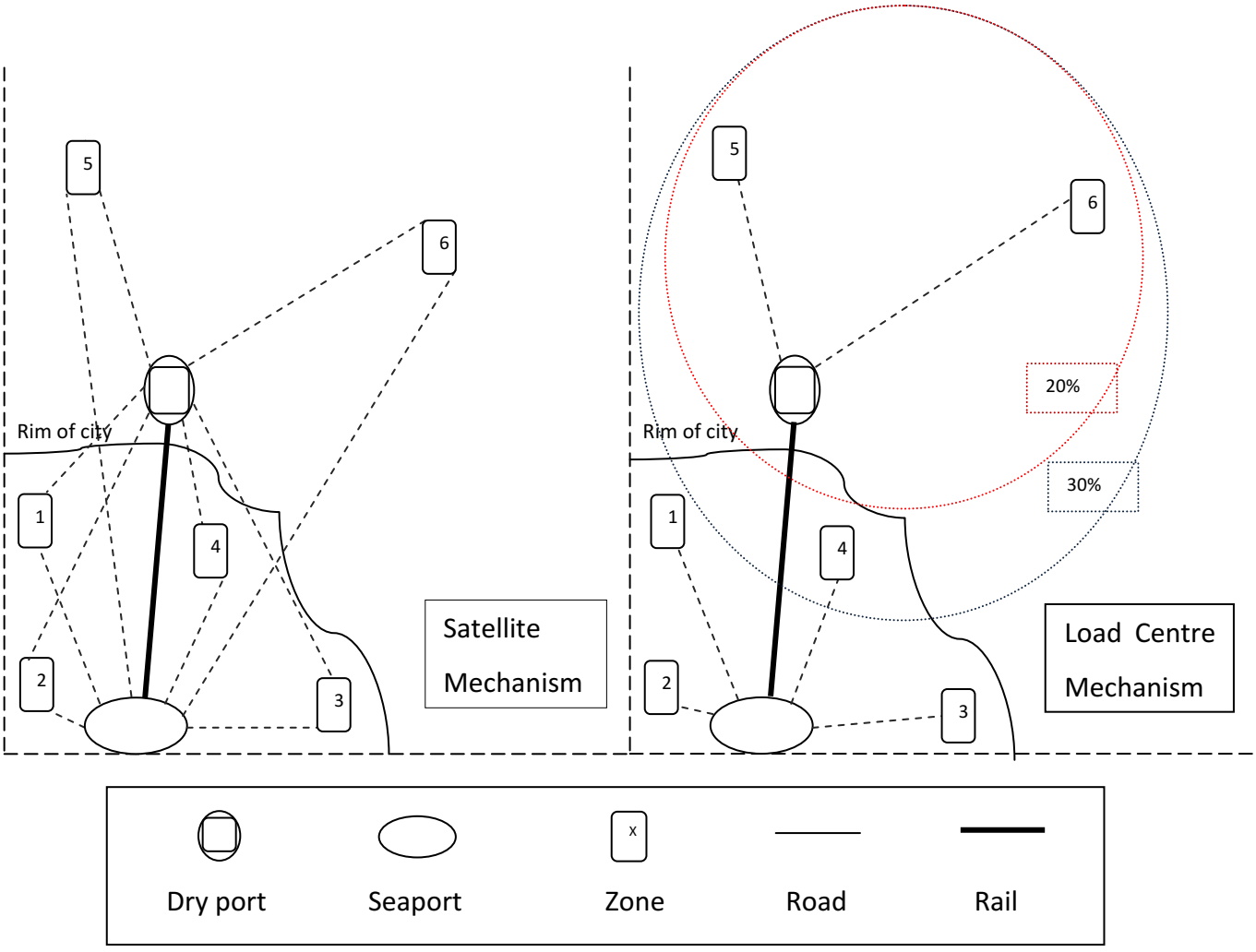


Figure 5.13: illustration of dry port container allocation mechanisms

The dry port and rail service is not considered to have a fixed capacity rather; the capacity varies with the level of dry port utilization. In each scenario, the dry port is assumed to have enough capacity to handle the level of usage.

5.6.2 Transport Network Representation

The proposed close dry port is introduced into the network as a zone and containers are diverted to the zone via a railway line modelled as a link in the network. While a number of factors such as equipment productivity, tariff levels, service quality, number of employees, size of dry port and location of dry port are expected to influence the utilization of dry ports, the study focuses on the effect of different levels of dry port utilisation on the road network rather than the cause of utilisation.

The railway lines connecting the ports to the dry ports are modelled as links in the transport system within VISUM. The railway line is modelled as a two-way link providing services to and from the port and dry port. In VISUM, links can be closed or open to certain traffic thus, rail links are open to rail bound traffic to and from the dry ports only. In this study, the dry port is connected to the port by a single railway line and there are no alternative routes to and from the port. Thus, all containers diverted to the dry port have to use the rail link which is also the shortest route.

5.6.3 Containerised Cargo Trip Matrices

This step in the modelling framework is concerned with deriving O-D trip matrices for the trip classes in each dry port scenario. These trip classes are derived from the logistic chain activities as is discussed in Section 4.2. The port is the only entry point into the system however, in the dry port scenarios, the containers enter the system through an additional point – the dry port. As with the do-nothing scenario, all demands are extrapolated from the annual container flows through the ports. An annual trip matrix is derived for the trip classes and then converted to an hourly matrix. A process similar to that used to derive the do-nothing trip matrices (discussed in Section 5.2) is used in deriving the trip matrices for the dry port scenarios.

All FCL and SCL traffic is assumed to be destined to the same TAZs as in the do-nothing reference case; the only difference is that a proportion of the containerised imports - derived from the utilisation level moves through a new intermediate node in the network called the dry port.

5.6.3.1 The Trip Classes

In the dry port scenarios, the dry port is an extra node introduced in the container logistic chain and so a new chain of activity classes associated with the dry port is added to the existing activity classes associated with the do-nothing scenario as outlined in Section 5.2.1. As discussed in Section 4.2, each activity class is associated with a set of trip classes and load classes. The dry port scenario constitutes of the previously identified trip classes associated with the do-nothing scenario and some newly introduced trip classes. These new trip classes are identified based on the assumptions listed in Section 5.2.1. Table 5.14 outlines the newly introduced activity classes and their associated trip and load classes.

Table 5.14: Newly introduced containerised cargo trip classes

No	**Activity class**	**Load class**	**Trip class**	**Laden trip**	**Empty trip**
1	Dry port to Importer	FCLs	Dry port to Importer	x	
			Importer to Empty depot		x
			Empty depot to Trailer park		x
			Trailer park to dry port		x
		SCLs	Dry port to Importer	x	
			Importer to Trailer park		x
			Trailer park to dry port		x
2	Port to dry port	FCLs	Port to dry port	x	
			Dry port to port		x
3	Importer to Distribution	SCLs	Importers to Distribution warehouse	x	
			Distribution warehouse to Importers		x

5.6.3.2 Container TEU Generation from Dry Port

Containers are considered to move through two alternative logistic processes representing the move from port to off-dock terminals, private terminals and importers by road, or the move from port to dry port via rail. All fast track importers with private terminals are expected to receive directly from the port since they have the clearing service available on site and so do not add to the volumes through the dry port. Thus, in the modelled year 2014 the volumes through the dry port is considered as a proportion of the annual import containers arriving at the port (947,300 TEUs) less those sent directly to the private terminals (56,838 TEUs). The annual volume of container traffic diverted to the dry port via rail and exiting the port via road varies between the dry port scenarios (utilization levels) as is included in Table 5.15. The relevant proportions represent the set utilization

levels selected for study. Some possible implication of such levels of usage is discussed in Section 5.7.

Table 5.15: Container volumes at each utilization level

Defined utilization levels	**Annual traffic exiting dry port (TEUs)**	**Annual traffic exiting port by road (TEUs)**	**Total traffic arriving at high sea (TEUs)**
0.1	94,730	852,570	947,300
0.2	189,460	757,840	947,300
0.3	284,190	663,110	947,300
0.4	378,920	568,380	947,300
0.5	473,650	473,650	947,300

The split of container traffic from Apapa and Tin Can (the two points of entry) is 47% and 53% respectively. The annual traffic exiting Apapa port by road (Table 5.14) is made up of traffic going to private terminals (5%), off-dock terminals (30%) and directly to importers (65%). The annual traffic exiting Tin Can Island port by road is made up of traffic going to private terminals (5%), off-dock terminals (10%) and directly to importers (85%).

For utilization levels associated with test case 2 and 4 (the dry port cases without FDS), the volume of stripped container loads generated at importers premises within the zones is the same as in the do-nothing scenario. However, for utilization levels associated with test case 1 and 3 (the dry port cases with FDS), where containers through the dry port are stripped within the facility rather than at the importers premises, the volume of stripped container loads generated at importers premises within the zones is calculated as a function of the total volume of import containers less the volume of containers diverted to the dry port.

5.6.3.3 Deriving Trip Matrices for FCLs and SCLs

The derived matrices are based on the following general assumptions;

1) The locations of importers remain the same over the near future and the location and market share of the ports remain the same. This is logical since no significant change is expected to occur in land use patterns and all port terminals are expected to have similar development to encourage market shift in their favour. At present, the APMT Apapa terminal is expected to make the largest investment towards capacity expansion by 2014 which may lead to some shifts in the market shares in their favour. However, as all terminals have some level of planned development, this shift is most likely to be minimal and is ignored.

2) It is assumed that containers distributed to private terminals are routed directly to their designated premises.
3) The volume of container loads imported by consignees within each zones remain constant between the do-nothing scenario and the various dry port test scenarios.
4) The roles of the off-dock terminals are assumed to remain the same and the stemming process still occurs. That is, a fraction of container volumes arriving on the high sea are diverted to off-dock terminals while another fraction is diverted to the dry port. The difference between the dry port and the off-dock terminals lies within the rail connection provided between the dry port facility and the port. However, as the role of the existing off-dock terminals may overlap with that of the close range dry port, it is important to explore how this adopted role impacts the benefit of the dry port strategy. Thus, two alternative realistic off-dock scenarios are explored in the analysis; the case where the off-docks retain their stemming functions and the case where the stemming functions are eradicated. The former is considered in Section 6.1 and 6.2 and the latter in Section 6.3

The following paragraphs detail the processes specific to developing the containerised cargo trip matrices associated with each dry port case.

<u>To importers</u>

For scenarios associated with test case 2 and 4 (the dry port cases without FDS), no containers are stripped within the dry port. The distribution of containers between zones in the network depends on the allocation mechanism associated with the dry port scenarios. For the satellite case, containers exiting the dry port and port for the importers designated premises are distributed to all zones in the same proportion as in the do-nothing scenario (described in Section 5.2.5.3). In the load centre case however, containers exiting the dry port are distributed only between zones beyond the port city or zones closer to the dry port than the port in the same proportion as in the do-nothing scenario. While containers exiting the port are distributed only between zones within the port city or zones closer to the port than the dry port, in the same proportion as in the do-nothing scenario.

For scenarios associated with test case 1 and 3 (the dry port cases with FDS), all containers diverted to the dry port are stripped within the facility. The stripped container loads generated at the dry port are distributed to points of use/distribution on the basis on the classification of commodities enclosed within the containers. This is done following the

framework of the three tier gravity model described in Section 5.2.6. However, the gravity model applied is doubly constrained where the attraction to zones is given by the column sum of the matrices for trips from ports/off-docks to distribution warehouse and importer premises to distribution warehouses in the baseline scenario. The average trip length used in calibrating this gravity model is assumed to be the same as in the do-nothing/ current scenario.

To empty depot

For scenario associated with test case 1 and 2 (the dry port cases with EDS), all empties generate from containers exiting the dry port are returned to the dry port facility. Other empties generated from containers exiting the port by road are returned to the existing empty depots in the port city and so are distributed between zones in the same proportion as in the do-nothing scenarios (described in 5.2.5.4). Empty containers received at the dry port are returned to the seaport via rail only.

For scenarios associated with test case 3 and 4 (the cases without EDS), all empties are returned to existing empty depot facilities only in the port city and are distributed between zones in the same proportion as in the do-nothing scenario (described in 5.2.5.4).

To trailer park

For all test cases, trips to trailer parks in zones are derived following the process outlined in Section 5.2.5.5. However, information on the location and size of existing trailer parks in zones outside the port city was unavailable and so it is assumed that 40% of importers using the dry port own vehicles or lease vehicle from within their zones while 60% lease from trailer parks in other zones within the port city. The impact of this assumption on the results is explored within the analysis reported in Section 6.

To distribution warehouse

For all dry port test cases, stripped container loads generated within importers designated premises are also distributed to points of use/distribution on the basis of the classification of commodities enclosed within the containers as described in Section 5.2.6. As information on the average trip length for SCL trips originating at consignees' premises within zones was unavailable, the average trip length is assumed to be the same as that for trips originating from the ports in the do-nothing scenario. The impact of this assumption on the results is explored within the analysis reported in Section 6.

5.7 Requirements for Rail Service at Set levels of Dry Port Usage

The characteristics of the rail shuttle service provided within a dry port solution is driven by the expected level of dry port utilization. The characteristics include the single train capacity defined as the number of TEUs carried by the train in a single direction, the number of train services available per day per direction of travel, the speed of travel, train loading whether single or double container stacking, and the container handling capacity at the ports and dry ports. The following paragraphs explore such characteristics of the rail service required for each level of dry port utilization considered in this study. The configurations outlined here are not necessarily optimal to achieve maximum reliability and minimise cost of development. However, it is presented to show the levels of services that may be required.

Table 5.16: Hypothetical characteristics of rail services for each utilization level

Utilization Level	Average Daily Laden Containers (TEUs)	Speed of Train (km/hr)	Single Train Capacity (TEUs)	No of Train Services per Day	No of Wagon Sets Available	No of Wagons in a Set	Multiple Rail Sidings at Port and Dry Port	No of Cranes	Crane Handling Rate (moves per crane hour)
0.1	265	60	68	4	2	17	No	2	20
0.2	530	60	76	7	3	19	Yes	3	20
0.3	795	70	100	8	3	25	Yes	3	25
0.4	1,060	80	120	9	3	30	Yes	3	25
0.5	1,325	100	136	10	3	34	Yes	3	30

The rail service provided must be capable of supporting the utilization levels of the dry port. Thus, the worst case throughput of the railway service is given as the sum of the laden and empty containers to be handled at the dry port. Table 5.16 includes an example of such characteristics necessary to achieve the marked utilization level assuming a single container stacking on trains. These requirements are the output of analysis carried out on the basis of the following reference assumptions:

1) A single track standard gauge railway line is available for use,
2) A distance of 56km by rail between port and dry port
3) The use of 25.75m long bogie container flat wagons capable of carrying 4 TEU single stacked.

4) Where necessary, multiple rail siding are installed at port and dry port for receiving empty containers and laden containers independently. This allows loading and off-loading of laden and empty containers to occur independently.

The single train capacity and the total number of trips possible in either direction of the rail line during the running period of a day determine the daily capacity of the rail service, which in turn is driven by the train turnaround time. As only a single track is available; the analysis is based on turnaround time associated with laden moves since these represent the worst case. It is based on the assumption that all return train trips carry a number of empty containers which is a fraction of the number of laden containers delivered. The train turnaround time associated with the laden trip is calculated as a round trip. That is the time taken for the train to deliver the laden container to the dry port and return to pick up more laden containers. The turnaround time of a single train trip is a function of the loading and unloading time at ports, the loading and unloading time at the dry port and the travel time of the train en-route. The former is dependent on the terminal efficiency which is driven by the labour and equipment capacity specifically, the container handling capacity in crane lifts per hour. The latter is dependent on the speed of travel, distance of travel and traffic interruptions such as due to signals and crossings.

The rail facilities available to the dry port influence the turnaround time associated with the train's round trip. For example, providing more than one set of container wagons (a set of container wagon refers to a number of wagons available to the port or the dry port at any one time) and additional rail sidings implies that empty containers can be loaded onto a set of wagon prior to the arrival of laden containers from the port. Specifically, with a single set of wagons allocated to the whole service, the train turnaround time is dependent on the travel time en-route and the loading and unloading times at the port and the dry port. In this case, the wagon must be unloaded and reloaded at each hub before the train can pull off. With two sets of wagons allocated to the service and multiple rail sidings provided at terminals, empty containers are preloaded unto a set of wagon which is pulled off by a locomotive upon arrival of the laden container train. The train turnaround time is then dependent on the travel time en-route and the loading and unloading time at port only. With three set of wagons allocated to the service, the turnaround time is only dependent on the travel time or the loading and unloading time whichever is more. However, shorter trains can be employed to reduce the loading and unloading times at terminals or the no of cranes and crane handling rates can be increased.

Beyond three wagon sets, the turnaround time for the train is dependent on the travel time and so, providing more than three wagon sets will not necessarily provide added value to single track rail line and the investment may not be justified. The train turnaround times and capacity of the rail service are restricted by the capacity of the single rail track. To increase capacity, a double track should be provided or passing siding is installed and used within strict logistic systems. Otherwise, increasing the speed of travel will only marginally reduce travel time and so train turnaround times.

In general, to maximise use of a single rail line at high utilization levels, the facilities provided must be such as to minimise train turnaround time. This can be achieved by overlapping the loading and off-loading activities undertaken at the ports and the dry port with the train journey. If this can be achieved, then train turnaround time is driven by the travel time which can be minimised by increasing the speed of transit.

The number of wagons in a set refers to the number of wagon pulled by the locomotive in any one direction. This value is restricted by the allowable length of a freight train and is dependent on the number of containers that has to be carried so as to achieve the required level of daily container moves at each level of dry port utilization. The average daily values for each utilization level are included in column 2 of Table 5.15. The maximum allowable length of train that can operate on the rail track depends on physical limits such as the length of rail sidings at terminals, allowable axle load and maximum trailing tonnage for single locomotives in use. The crane handling rate required influences the type of equipment required for the facility to function at a specified level of utilization. More effective and expensive cranes are required at higher levels of utilization.

In reality, any one of these factors can be adjusted for example, one may prefer to reduce the train capacity (train length) in other to reduce loading and off-loading time and meet cost requirements for equipments. Lower train loads will minimise the probability of delays and ensure higher levels of reliability. As these factors influence one another, they can be adjusted within certain constraining factors such as the maximum permissible speeds on existing rail lines and maximum allowable length of train.

The choice of what configurations to employ will depend on the cost of the options. For example, the cost of investing in sets of wagons has to be weighed against the cost of upgrading the rail line to a double track over the short distance and the long term benefits of each would be considered. The service capacity can also be increased by double stacking containers. However, the practicality of this depends on the headroom allowance and the

presence of physical obstruction along the route. Double stacking allows for less trips to be made but leads to increased loading and unloading times at the dry ports and ports. This is not always ideal if the train turnaround times are not driven by the time of transit (as is common with short distances rail services), as it may lead to a substantial increase in turnaround times. This in turn requires higher container handling capacity to reduce train turnaround time by increasing the number of cranes or the efficiency of crane hours by investing in faster systems. In this case, an optimum solution is one that maximises the single train capacity and minimising the container handling capacity at the dry ports and port.

5.8 Model Limitations

While this traffic model has been shown to provide a good prediction of the containerised cargo traffic on links, the model developed has some limitations, most of which are discussed below.

Need for large database

The demand model is based on probabilities and information of previous container destinations which require historical data. Thus, the accuracy of the demand matrices is based on the accuracy of the data. For example, the validation process suggests that the model underestimates container trips on exit routes to/from the city of Lagos. As the containers are split between zones on the basis of the location of importers and their volume of imports in the past, this error could be linked to an error in the data provided. It is plausible that while containers are registered to a company's address in Lagos, it may be destined for a branch outside the city. This does not deflect from the validity of the model; as has been shown, it passes the DMRB criteria.

The assignment procedure requires a large input of road characteristics. The exact values in some cases were unavailable and so were approximated from indirect variables. These approximations are acceptable since the assignment process is based on relative selections .i.e. the route/link selected for travel is the relatively better one.

A crude estimation of non-container related traffic

The model considers other freight volumes and non-freight volumes under a single

class (non-container related traffic) and approximates it as a function of container-related freight traffic on a link. This method accounts for the fact that the proportion of traffic that is freight on a link varies between links. Using a regression analysis, it relates this proportion to the travel distance from the port. The issue with this is that the individual vehicle trips (cars, buses, tankers, etc) are generated from independent supply chains and the volumes of each are influenced by different factors. For example, while passenger cars on links are expected to be proportional to the residential population of zones, freight traffic is more likely to be inversely proportional. The level of bus trips are driven by the existence of bus routes and the level of services associated with each line. However, this is acceptable as the purpose for which this model is built is concerned with only container movements. Non-container related traffic is introduced to induce congestion on routes during the assignment process. The task involved with modelling all traffic within the model used in this study would have been impossible to accomplish within the time, personnel and monetary resources available to the research.

In modelling the non-container related traffic, the traffic count data available for use was highly aggregated, so to determine the proportion of container traffic on links, an approximation of the proportion of containerised freight was made. This proportion is assumed to be equal to the proportion of import freight volumes (in tonnes) that are containerised. The problem with this assumption is that it disregards the direct impact of intra-zonal and inter-zonal freight trips. The volumes of such trips are expected to vary from link to link and one would expect that the proportion of such trips, unlike port related freight trips, would be lowest on links closest to the ports. However the model does not consider this.

While developing a complete port related freight model would have strengthened the transport model, the task would be impossible to complete for use in this study.

<u>Insensitive to changes within the container industry</u>

The model assumes that the location and import capacity of consignees remains the same and assumes a constant split of containers between the zones. This assumption while fine for short term forecasting is inaccurate for long term forecasting as it fails to capture potential changes that may occur over years. For example, importers may relocate to new zones and expansion of the city could cause new importers to locate in zones on the outer ring of the city.

The model assumes that the structure of the container industry remains the same and so is not sensitive to changes in the structure of the container industry. For example the model considers all export containers to be empty and ignores laden export containers as they do not presently account for a substantial proportion of exports. While this may be accurate over a short term, development in the economy may alter this pattern in the distant future. Also, future port expansion and development (such as those discussed in Section 3.2.3) is expected to minimise the need for off-dock terminals as these were introduced to increase port capacities without physically expanding the ports.

The model assumes that the location and market share of trade hubs remain the same. However, the development of new ports in the region would force a redistribution of containers volumes through existing ports. Also, the facility improvement and expansion of existing port terminal is expected to improve the competitiveness of a port and so force a redistribution of container volumes.

This method of modelling is ideal for short term analysis because changes such as those mentioned earlier are less likely to occur over short periods. However the modelling framework outlined can be used in the future to develop container models that encompass these potential changes. Furthermore, the model can be used for predicting link volumes associated with a known level of port throughput.

5.9 Summary

This chapter has outlined how the baseline scenario and dry port test cases are modelled. The matrices derived are assigned to the network to obtain the pattern of containerised freight movement associated with each dry port test scenario and base line/current scenario. The container-related vehicle-kms and vehicle-hrs[4] associated with containerised freight traffic is derived from each modelled scenarios. The output of each dry port test scenario is compared with that from the equivalent baseline scenario (the case without dry port) to derive the container-related vehicle-km and vehicles-hrs savings at

[4] In the following chapter, this is referred to as ‘freight vehicle-km’ and ‘freight vehicle-hrs’.

system level and route levels. The following chapter (6) outlines and discusses the results from this comparison.

Chapter 6

Empirical Results and Analysis

So far, research relating to the road network benefit of dry ports has been studied through case studies in which the dry ports are explored with fixed characteristics (layout and services provided). However, it is plausible that the layout and services adopted could influence the observed benefits and so should be explored. This thesis moves a step further to consider the potential impact of the dry port characteristics on its benefit within a traffic network and explores the transferability of the dry port concept to a developing port city in Africa. The thesis addresses the issue as to whether such a dry port solution can reduce congestion using data from a developing country in Africa. Furthermore, unlike previous literature, this thesis explores the benefit of the dry port within different parts of the road network.

As outlined in Section 1.3, the thesis aims to quantify the effectiveness of a close range dry port in mitigating congestion within port cities and approaches this by considering the impact of the dry port characteristics on its ability to do so. Specifically, it considers the functioning of two characteristic variables in the dry port solution namely, an Empty Depot Service (EDS) and a Freight Distribution Service (FDS). As outlined in Section 3, this is carried out within a case study approach, through a comparative analysis of results obtained from the simulation of dry port scenarios with a combination of these characteristics. The dry port scenarios outlined for test are discussed in Section 3.2 and the development of the transport model used to simulate the impact of the dry port scenarios has been discussed in Section 5 of this thesis. The four test cases outlined in Section 3 include:

- Test Case 1: Close dry port with EDS and with FDS
- Test Case 2: Close dry port with EDS and without FDS
- Test Case 3: Close dry port without EDS and with FDS
- Test Case 4: Close dry port without EDS and without FDS

As explained in Section 3.2 and 5.8, each dry port test case is linked to two container allocation mechanisms which are together associated with 7 utilization levels (5 associated with the satellite and 2 with the load center). The allocation mechanisms relate only to the inclusion of the dry port and not to do-nothing reference case. Figure 5.13 illustrates both of these allocation mechanisms and the reader is referred to Sections 5.6 of this thesis where the utilization levels derived from the load centre mechanism and the utilization levels selected for test under the satellite mechanism is described. A combination of 7

utilization level scenarios and 4 test cases presents 28 dry port test case scenarios. Figure 6.1 illustrates how the 28 test case scenarios are derived from a combination of the dry port test cases, the alternative allocation mechanisms and the levels of dry port utilization selected for test. The utilization levels (the proportion of base year container imports passing through the dry port) in both mechanisms are derived as a percentage of import traffic through the sea ports in the reference year 2014. As discussed in Section 5.6.3 the values (in TEUs) are extrapolated from the 2009 import traffic using a growth factor of 14.2% and are included in Table 5.14 of this thesis.

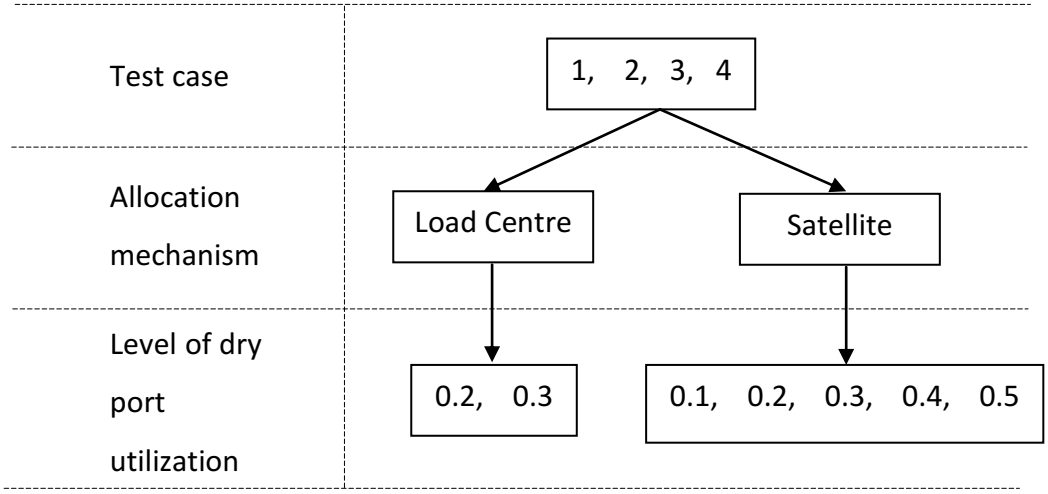


Figure 6.1: Combination of dry port test case scenarios

The comparative analysis involves evaluating performance measures associated with each dry port test case scenario against a do-nothing reference scenario that represents the case without a dry port under current conditions in the container logistic chain. The performance measures used in this study have been outlined in Sections 3.2. The impact on the network condition is gauged by the calculated freight vehicle-kms and freight vehicle-hrs savings from container-related cargo vehicles in the network.

As outlined, the impact of the dry port is explored at an aggregated system and route level, and a disaggregated link level. The system level analysis quantifies the impact on trips in the overall containerised cargo distribution system. The modelling approach makes it possible to consider the impact of the dry port on individual routes in the network. For this study, the route level analysis considers the impact to trips on four sets of routes

namely; routes to and from ports and routes to and from zones in the port city (within the rim of the port city). Routes to and from port refer to the routes used by container-related vehicles originating from or destined to ports, while routes to and from port city refers to the routes used by container-related vehicles originating from or destined to all zones in the port city (Lagos). These routes include long distance arterial and short distance routes between consignee location in zones and port or other zones. There are too many of such routes to be shown graphically however, in terms of proportionality, the length of the total routes to and from ports and the total routes to and from the port city accounts for 4% and 33% of the total routes to and from all zones in the network respectively. The link level considers impact on individual links to and from ports and dry port.

The following parts of this chapter analyses and discusses the results from the model runs. It draws conclusions about the impact of the inclusion of a Freight Distribution Service (FDS) and an Empty Depot Service within a close dry port solution and explores the overall network savings presented by the close dry port solutions. The results from the 28 combination of cases and scenarios outlined in Sections 3.2 are compared with the results from the do-nothing reference scenario to obtain the relative savings (benefits) of each combination. Table K.1 of Appendix K summarizes the results (the performance measures) relating to the do-nothing reference scenarios modeled while the relative savings from the dry port test scenarios are documented in Tables K.2 to K.6 of Appendix K. The benefits relate to the impact on the network and are measured as freight vehicle-kms savings and freight vehicle- hrs savings. The study focuses only on network benefits and does not consider port operations benefits or benefits relating to other aspects of supply chain economics such as faster Customs clearance times.

For each variable, whether Freight Distribution Service (FDS) or Empty Depot Service, the relative benefits of scenarios under opposing test cases are compared to explore patterns and deduce findings. For example, test case 1 (Close dry port with FDS and with EDS) and test case 2 (Close dry port without FDS and with EDS) are opposing cases used to explore the impact of the FDS variable. However, as explained in Section 3.2, the dry port cases considered in this study represent a combination of extreme scenarios of these variables (FDS and EDS) and so, not all sets provide alternative results. For example, test case 1 and test case 3 would produce the same results since the extreme (100% deconsolidation) implies that no empties are generated at the consignee's premises as all

containers are stripped within the dry port, the goods split into unit-trucks and no containers leave the premises. Thus, only the results from opposing cases that presents distinct results are compared. While these extreme cases may be unlikely scenarios (for example, it is unlikely that all containers arriving at the dry ports will be stripped within the facility), they allow for extreme case impacts to be considered. This chapter forms the basis for the answers to the main questions relating to the study:

- How effective are close dry port solutions in reducing congestion?
- How does the characteristics of the dry port solution affect its ability to reduce congestion, in particular what are the effects of including a Freight Distribution Service and an Empty Depot Service in the dry port?

The performance measures are also evaluated against variations in some key assumptions made including; changes to the function of the off-dock terminals in the container logistic chain, the location of trailer parks that service the dry port and the average trip length of Split Container Loads (SCLs) generated at the importer's facilities. The former explores the impact of the role of the off-dock terminals on the dry port performance and considers the network benefit[5] of the off-dock terminals. This is explored in Section 6.3. To some extent, the average trip lengths of SCLs exiting importers facilities may affect this result and so the impact of the assumed trip lengths is explored. This analysis is undertaken to explore how robust the results are to changes in average trip length. The analysis is undertaken in Section 6.4 of this chapter. Sections 6.1 and 6.2 explore the impact of the variables (EDS and FDS) on the network benefit of the dry port based on the assumptions outlined in Section 5.7.3.

6.1 The Impact of an Empty Depot Service (EDS) on the Network Benefit of the Dry Port

[5] Only the logistical benefits are considered

An empty depot service in the dry port provides a storage service which allows empty containers to be returned to the port by rail. Without the EDS, containers moving through the dry port, once emptied by consignees, would be returned to existing empty depot facilities by road. These existing empty depots are also used by containers moving through the port by road and are located within and around the port. The implication of not having an empty depot service in the dry port is that all empty containers including those belonging to consignees outside the city would be returned via road to areas close to and within the port. This pattern is expected to worsen the road network conditions since more trips would be introduced to the road network. This theory is investigated in the analysis.

The impact of including or excluding empty depot services within a close dry port solution in Lagos is explored by comparing a set of opposing dry port test cases (case 2 and case 4) relating to when all or no empty containers generated from traffic through the dry port are returned to the dry port. These test cases are explored under the alternative allocation mechanisms (the satellite and load centre concept). The set of opposing cases that exist with no Freight Distribution Services (FDS) is selected for analysis as this represents the situation where all containers leave the facility; this illustrates the maximum achievable benefits of the dry port solution.

6.1.1 System Level Analysis

The system level analysis considers the impact of the dry port cases on the overall network. This is gauged by the calculated freight vehicle-kms and freight vehicle-hrs savings for all vehicles carrying container-related cargo in the network. The freight vehicle-hrs and kms savings from each test case is calculated by subtracting the freight vehicle-kms and freight vehicle-hrs associated with the test case from the corresponding values from the do-nothing reference case (case without dry port). Test cases associated with a negative saving imply that the congestion in the network is made worse by the test case whilst positive values implies a reduction in congestion. The detailed result of this is included in Table K.2 of Appendix K and summarized in Figure 6.2 and 6.3.

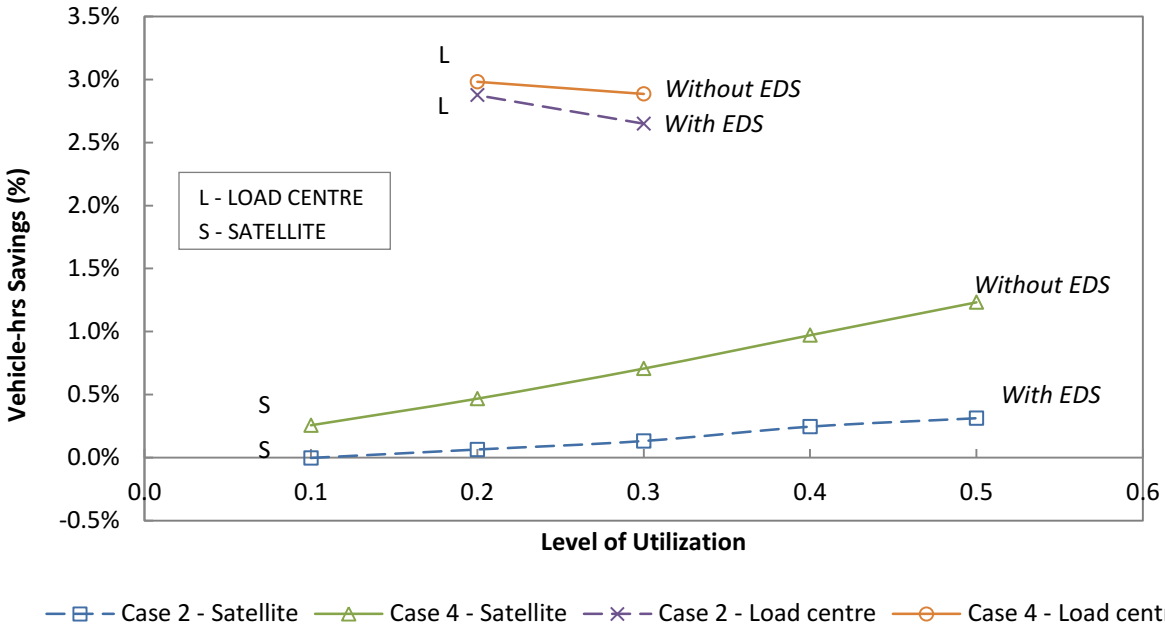


Figure 6.2: Freight vehicle-hrs savings to the system against the level of dry port utilization[6]

Figure 6.2 is a graph of the percentage freight vehicle-hrs saving from case 2 (dry port with EDS) and case 4 (dry port without EDS) obtained from two distinct allocation mechanisms (load centre and satellite terminal) - when all of these cases are compared with the do-nothing reference situation. It can be observed that all dry port cases present positive savings (up to 3%) to the system at all levels of utilization considered, yet, it can be seen that some cases present higher benefit than others. The savings are due not only to the substitution of rail for road traffic but also due to the rerouting of traffic brought about by the location of the dry port and the services provided within the facility.

Comparing the dry port case with EDS (Case 2) against the dry port case without EDS (Case 4), it can be observed that case 4 presents a higher freight vehicle-hrs savings than case 2 at all levels of utilization and for both allocation mechanisms. Beyond utilization level of 0.1, as dry port throughput increases, the difference between the freight vehicle-hrs savings obtained from both cases (with or without EDS) increases. The reduction in benefits associated with the empty depot service can be explained by the distance of consignees in

[6] The level of utilisation is derived as a proportion of the traffic which originally was cleared at the port or off-dock terminals.

the Lagos area from the dry port compared to their distance from the existing empty depots (as shown in Figure K.1 of Appendix K). In the case of a dry port without an empty depot, containers are sent to existing depots in the port city. For consignees in zones within the port city, the existing facilities are within close proximity and so, savings are made to their travel times and distance. However, in the case where consignees use the empty depot in dry port, empty container make longer return trips northbound to the dry port facility.

Further comparison between case 2 (with EDS)and case 4 (without EDS) shows the load centre cases to provide a higher freight vehicle-hrs savings of up to 3 times that of the equivalent satellite case. For example, at a utilization level of 0.3, case 2-load centre produces a vehicle-hrs savings of 2.6% compared to the vehicle-hrs saving of 0.3% obtained from case 2-satellite terminal. Likewise, case 4-load centre produces a vehicle-hrs savings of 2.8% compared to a vehicle-hrs savings of 0.7% obtained from case 4-satellite terminal. The high savings in the load centre case is due to the elimination of road trips moving from the port, north-bound, across the city to zones outside Lagos. With the dry port, a part of these journeys are made by rail. At 0.2 utilization for example, all containers located outside the port city are returned to the dry port which reduces their otherwise longer road travel distances.

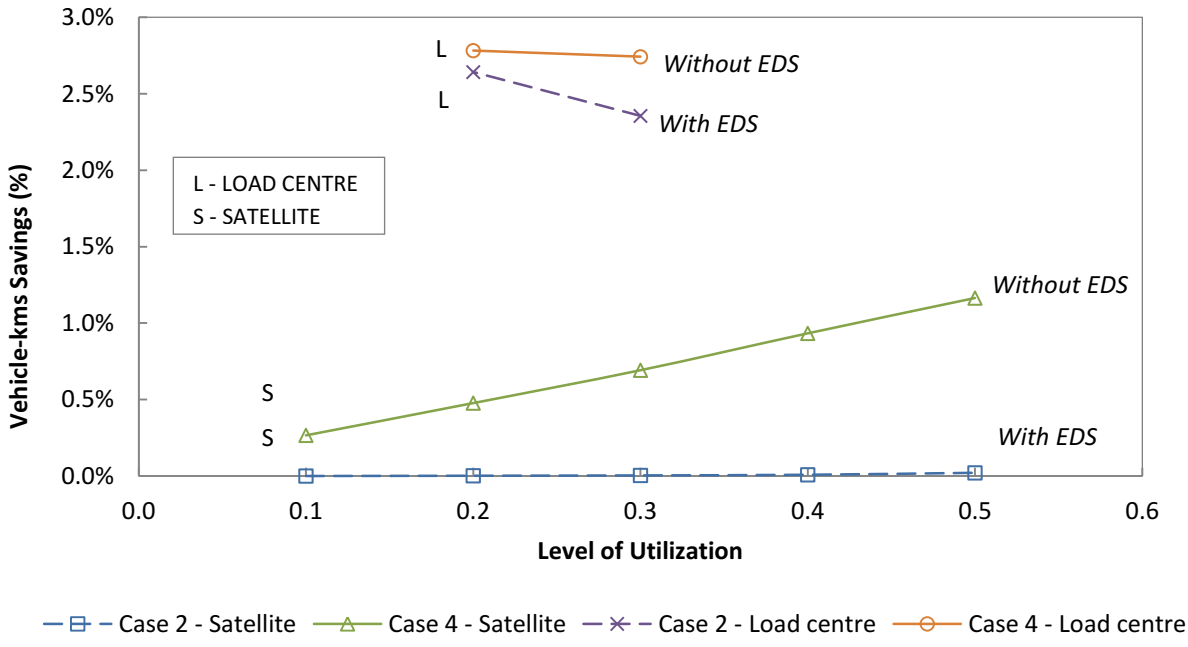


Figure 6.3: Freight vehicle-kms savings to the system against the level of dry port utilization

On the other hand, it can be noted that while the savings obtained from the satellite mechanism increases with utilization of the dry port, with the load centre mechanism, the

savings decrease with utilization. This pattern can be explained by the distance of the consignees to the dry port compared to their distance from the existing empty depots. At utilization level of 0.2 in the load centre case, only consignees in zones outside Lagos use the dry port. On the other hand, at utilization level 0.3, the dry port is used by consignees in zones closer to the dry port than the port (which includes some zones in Lagos). If the dry port does not provide empty depot services, empty containers are sent to existing depots in the port city. Thus, for consignees in zones within the port city, while the existing empty depots are within their vicinity and savings can be made to their road travel times and distances, these savings are off-set by the longer distances travelled by containers from zones outside the port city (Lagos). On the other hand, when an empty service is provided at 0.3 utilization (obtained from the load centre mechanism) containers located in zones within Lagos travel north-bound to return empty containers to the dry port facility, a distance which is further away from the existing empty depots.

The patterns discussed in respect of vehicle hrs savings are similar to those observed in the plot of the freight vehicle-kms savings (Figure 6.3).

6.1.2 Routes to and from the Ports

This section considers the impact of the dry port cases on routes to and from the ports. The freight vehicle-kms and freight vehicle-hrs associated with each dry port case is calculated as the total container-related vehicle travel distance and travel time on links along all routes to and from ports. The saving associated with each test case is derived by subtracting the freight vehicle-kms and freight vehicle-hrs associated with the test case from the corresponding values from the do-nothing reference case. The freight vehicle-kms and freight vehicle-hrs savings obtained from each case is included in Table K.3 of appendix K and summarised in Figure 6.4.

The first column of Figure 6.4 is a graph of the percentage freight vehicle-kms savings from container related traffic on routes from ports. It is observed that a minimum savings of about 10% is obtained at 0.1 utilization level and this increases up to 84% depending on the level of dry port utilization and the allocation mechanism implemented. Also, it can be observed that both cases of the dry port with and without an EDS present positive benefits to routes from the ports. However, the case 4 (without EDS) provides a

minimally higher freight vehicle-km savings than case 2 (with EDS). Suggesting that providing or not providing an EDS within the dry port has almost no effect on the savings, presented by the dry port, to routes from the port.

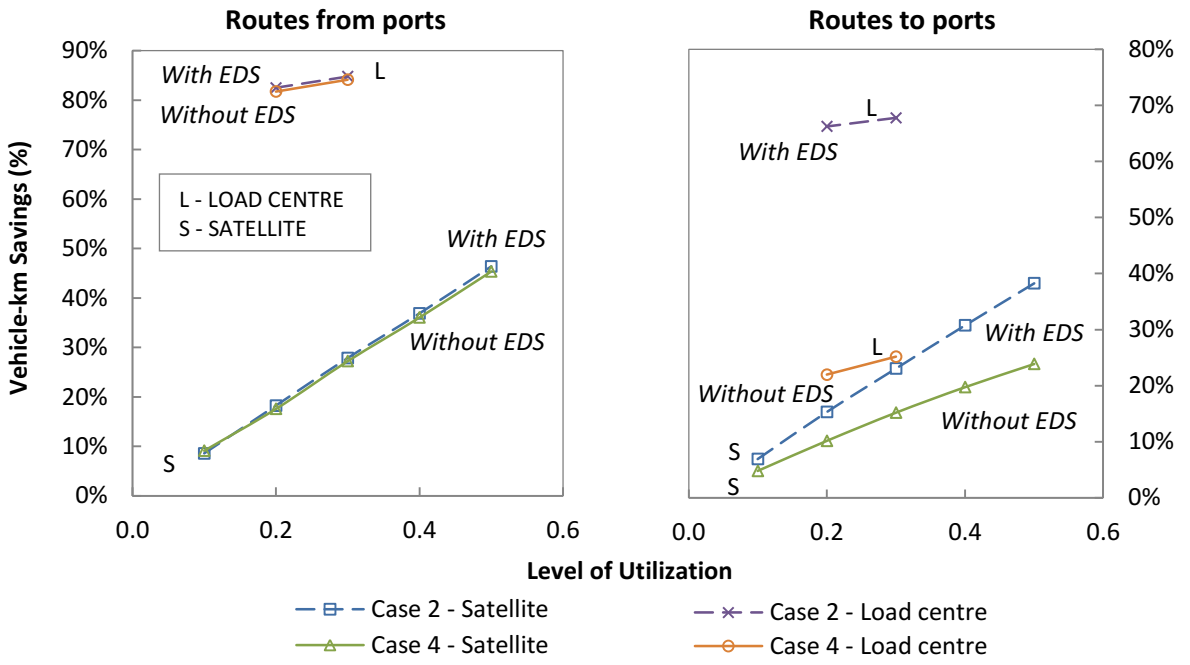


Figure 6.4: Freight vehicle-km savings to routes from and to ports against the level of dry port utilization

The second column of Figure 6.4 is a graph of the freight vehicle-kms savings on routes to ports. It can be observed that all dry port cases present positive freight vehicle-km savings for routes to port. This savings are found to increase with increase in dry port usage. However, the case with empty depot service (case 2) provides higher savings for routes to the port than the case without empty depot service (case 4). This is different to the finding from the system level analysis where the case without EDS provides more benefit to the system. This variation is linked to the level at which the benefit is being analysed. In the case of routes to and from port, providing an EDS reduces the number of empty trips moving southbound destined for existing empty depots in the port city (including at the port). This also reduces the number of trips generated on the return legs of empty trips from the ports and so increases the savings. However, the system analysis considers the overall system and considers all container related trips from all zones. In this case, more benefits are obtained from the case without empty depot because of the proximity of consignees in a number of zones in the Lagos area to the existing empty depot as discussed in Section 6.1.1.

As found in the system analysis, the load centre cases present a much higher freight

vehicle-km savings than the equivalent satellite case. This is the case for routes to ports and routes from ports. However, unlike routes from ports, the benefit of the dry port without EDS is substantially lower than the dry port with EDS. This pattern is linked to the increase in the number of empty trips moving southbound to existing empty depots (which is the direction of travel for routes to ports). The empty depot service prevents empty trips originating in zones outside Lagos from travelling through the port city. Clearly, the functioning of the EDS has a significant impact on the benefit of the dry port for routes to the ports. Graph of the freight vehicle-hrs savings presents similar patterns and has been included in Figure K.2 and K.3 of Appendix G.

6.1.3 Routes to and from zones in the Port City

This analysis explores the potential network benefits of the dry port to shippers in Lagos city. The freight vehicle-kms and freight vehicle-hrs savings obtained from each case is included in Table K.5 and K.6 of appendix K. The first column in Figure 6.5 is a graph of the freight vehicle-km savings to routes from the port city. It can be observed that all dry port cases (with and without EDS) present positive savings using both allocation mechanisms (satellite and load centre mechanisms). The network savings are shown to increase up to 4% and 7.2% respectively for the satellite and load centre mechanism respectively, with increase in dry port utilization. In general, the case without EDS presents more benefit to routes from ports than the case with EDS with the difference between the attainable savings increasing with increase in dry port utilization. This is not surprising since the exclusion of an EDS from the dry port solution reduces the need for empty container trips generated within Lagos to travel long distances across the city to the dry port located in the north (as shown in Figure K.1 of Appendix K). Rather, the empties are returned to existing empty depots which are located within the port city and in closer proximity to majority of the importers.

For routes from zones in the port city, the load centre mechanisms provide benefits up to 5 times higher than those obtained from the equivalent satellite mechanisms. This is similar to the findings outlined in previous sections. For example, as can be seen from column one of Figure 6.5, at 0.2 utilization level, the dry port with EDS presents a benefit of 7% with the implementation of a load centre mechanism compare to a benefit of 1.4% obtained with the implementation of a satellite mechanism. This is the same for the dry port

without EDS and at 0.3 utilization level. This pattern can be linked to the destination of laden containers generated at the off-dock terminals and ports in the relevant allocation mechanisms as illustrated in Figure 5.13. In the case of the load centre, all containers destined for areas beyond lagos are diverted to the dry port and containers exiting the port and off-dock terminals are destined for areas within Lagos only. Thus, the road travel distances and travel time associated with this arrangement is less. Furthermore, with the load centre mechanism all containers destined for zones outside Lagos are diverted to rail thus reducing the travel distance by road and eliminating long road trips through Lagos. On the other hand, in the satellite mechanism, the benefit of the diversion is not maximized since a proportion of container exiting the port by road are destined for zones beyond Lagos and so travel long distances on road through the city.

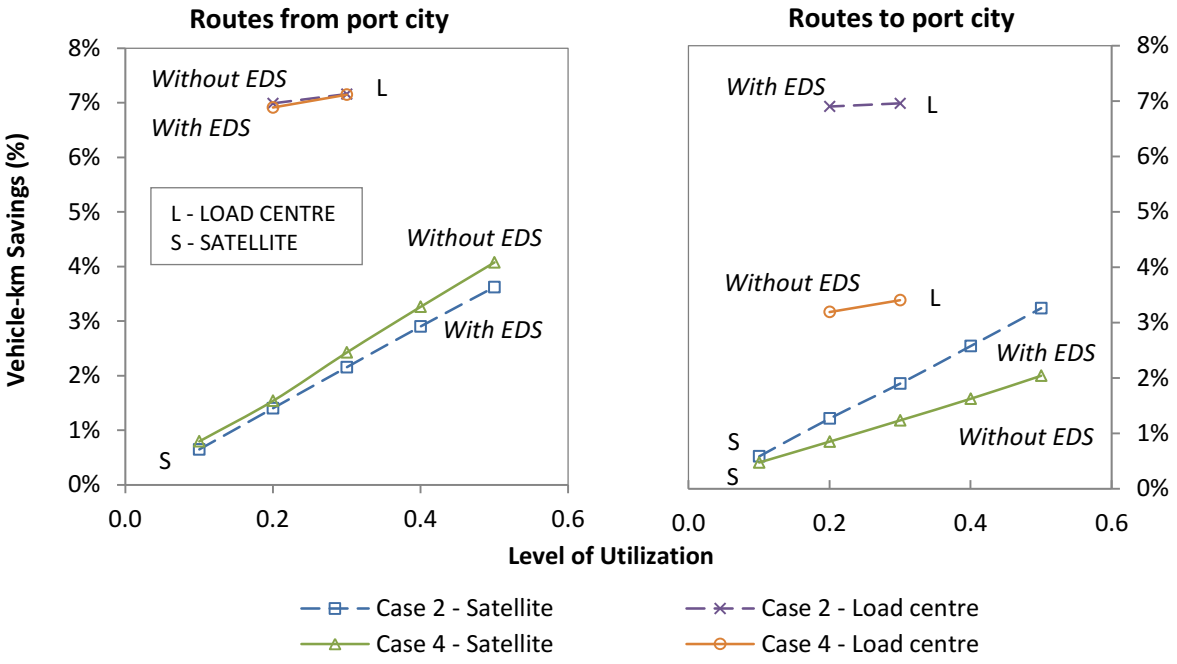


Figure 6.5: Freight vehicle-km savings to routes from and to port city against the level of dry port utilization

The second column of Figure 6.5 is a graph showing the freight vehicle-kms savings of the test cases for routes to the port city (Lagos). As observed, all dry port cases present positive savings which increase up to a savings of 7% with increase in dry port utilization. It can be observed that the dry port with empty depot service (case 2) presents higher benefits for routes to Lagos than the case 4 (the case of dry port without empty depot). This pattern is different to that observed for routes from the port city where the case without an

EDS presents higher savings (see column 1 of figure 6.5). This variation can be linked to the reduction of trips in the directions of travel towards the port city. In this case the inclusion of an empty depot service at the dry port reduces the number of trips destined for empty depots in zones within Lagos. This also leads to a reduction in the benefits obtainable from the load centre mechanism. As can be seen in column 2 of Figure 6.5, the benefit obtained from the case without an EDS are much lower than that obtained from the case with an EDS. In the load centre case without EDS, empty containers generated in zones beyond the dry port travel south bound to existing empty depots in the port city.

It has been found that the dry port with an empty depot facility presents more benefit to routes to the port city but less benefit to routes from the port city. This variation is linked to the geographical positioning of the logistic hubs in the network. The dry port is located to the north of the port city while the ports are located in the south of the port city. Thus if no empty depot is provided in the dry port trucks deliver empties to empty depots located within the city and the scenario presents less benefit to trips to zones (southbound) compared to the dry port case where an empty depot facility is provided. On the other hand, providing no empty depot facility is more beneficial to routes from the port city since truck are forced to deliver empty container to a number of existing empty depots which are located within closer proximity. The benefits presented by all cases are shown to increase with increase in dry port utilization with up to 7.2% savings for load centre cases and up to 4% for satellite cases. This analysis further illustrates the benefit of the load centre mechanism over the satellite mechanism. The freight vehicle-hrs saving suggest similar patterns and is included in Figure K.4 and Figure K.5 of Appendix K for reference.

6.1.4 Link Analysis

The link level analysis considers the impact of the dry port on the trip volumes on major access roadways. The impact is measured by the vehicle number savings calculated by subtracting the container – related volumes on links obtained from each dry port test case from the container – related volumes on links in the do-nothing reference case. Positive values represent a reduction in link volumes and a benefit to the link. The access ways considered for analysis are key links on approach to the port and dry port in directions to and from the port city. A map showing the links considered in the analysis is included in

Figure K.10 of Appendix K.

Links on approach to port

Figure 6.6 are graphs of the link volume savings on port approach presented by dry port cases. The volume savings obtained are the same for equivalent satellite and load centre cases. This is because while containers exiting the ports are destined for various destinations in both cases, the volumes are the same for the same levels of utilisation. The first column of Figure 6.6 relates to a link in the direction from the city to the port (SB) while the second column relates to the port approach in the direction to the city (NB). It can be observed that both dry port test cases (case 2 and case 4) present positive savings on port approaches. This savings increases almost linearly up to 42% with increase in dry port utilization. This is expected since the inclusion of a dry port implies that containers are transferred to dry port via rail which leads to a reduction in the number of containerised freight trips exiting the ports. An increase in dry port utilization implies that more containers are diverted leading to a further reduction in the number of trips exiting the port. The dry port cases provide benefits up to 42% for links to port and up to 39% for links from ports.

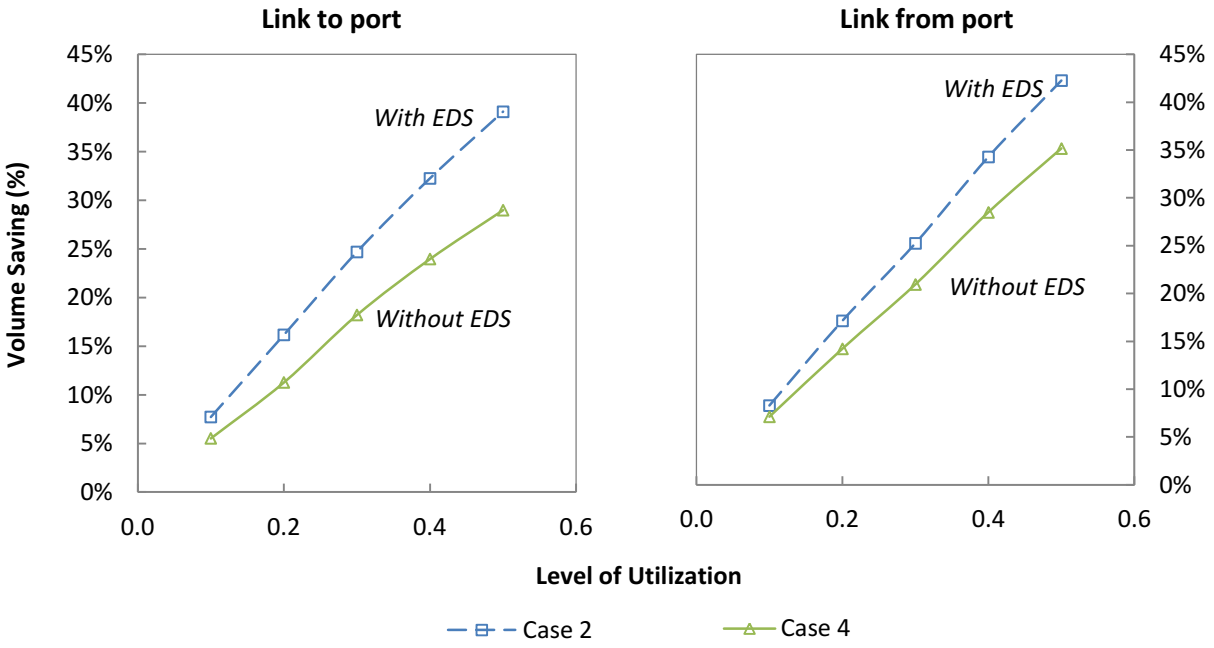


Figure 6.6: Volume savings to link on approach to port in the direction to and from port city

At all levels of utilisation and for both allocation mechanisms, the dry port case with an EDS, presents a higher savings, to links on approach to and from port, than the dry port case without an EDS. This is not surprising since the provision of an EDS prevents empty

containers from journeying southbound by road to existing empty depots in the city. By including an Empty Depot Service within the dry port, empty container trips are directed north bound from the port city to the dry port. While this may increase the number of empty trips on some north bound links, there is a reduction in the number of trailers carrying nothing on approach from port generated after empty containers are off-loaded at the port and so leads to a reduction in the volumes on port approaches. On the other hand in the case without an EDS, empty containers once delivered to the port generate trips on exit from the port. In general, the benefit of the inclusion of an Empty Depot Service within the dry port facility reduces the trips related to empty container otherwise destined to the port.

Links on approach to dry port

Figure 6.7 are graphs of the volume savings relating to the dry port approaches in the direction from the port city (NB) and in the direction to the port city (SB). Negative values represent an increase in link volumes and no benefit to trips on links. It can be observed that at all utilization levels, no benefits are available to trips on approach to the dry port. Furthermore, the negative impact on the approach to dry port increases with an increase in dry port utilization. This is expected since the links are the new entry point into the network from the dry port which acts as a port. However, the case with an EDS presents much more disadvantage to trips on links than the case without an EDS. This pattern can be linked to the increase in the volume of empty trips directed to the dry port.

Unlike the port which is located at the extreme south of the country and bordered by water on one side, the dry port is located inland and is surrounded completely by land and so can be approached from the north and south. The load centre cases present fewer dis-benefits to the approach from and to the dry port since it eliminates laden trips moving from dry port southbound to city and laden trips moving from city northbound to zones beyond the city. In the load centre case, no laden containers move from the city towards the dry port as all containers exiting the port are destined for zones within the city. On the other hand, in the satellite case, a proportion of laden containers exiting the ports and off-dock terminals, are destined for zones beyond the port city and a proportion of laden containers exiting the dry port are destined southbound for zones in the city.

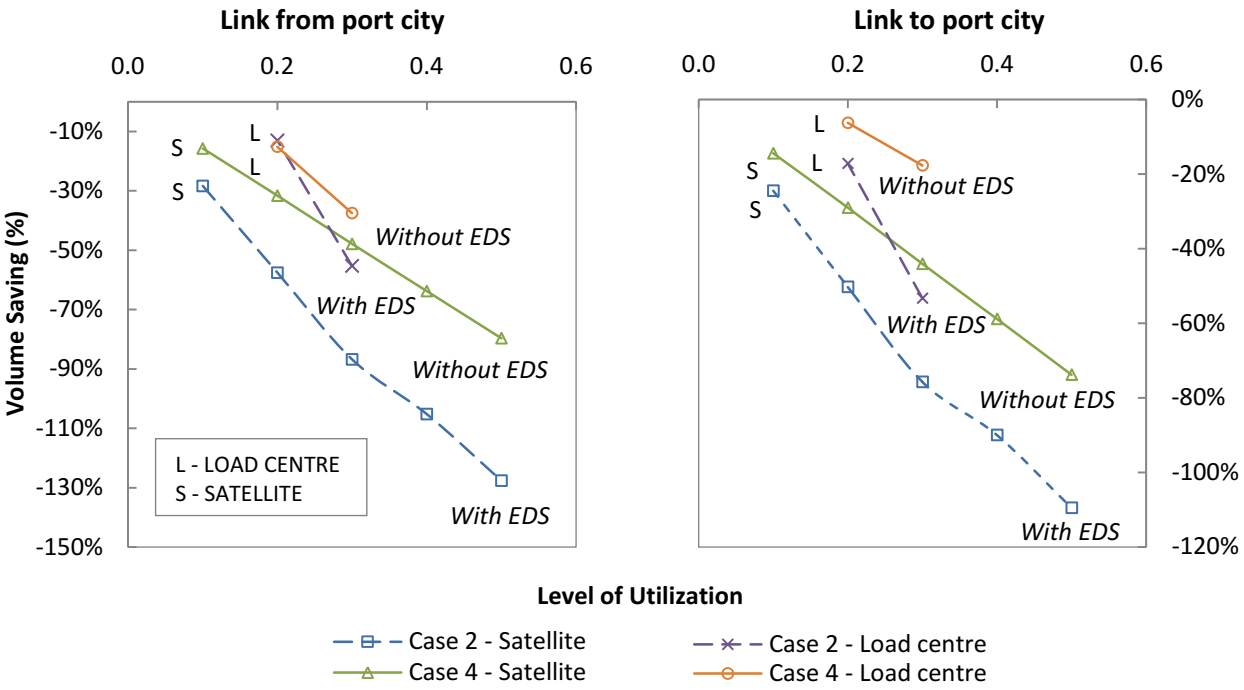


Figure 6.7: Volume savings to link on approach to dry port in the direction to and from port city

The results show that, while the containers have been diverted from the city centre causing a reduction in volumes on route from/to the port, the act increases the volumes on routes to/from the dry port facility. This suggests that the dry port presents a solution that simply delocalizes the congestion problem by shifting it from one location in the network to another. Where such a facility is planned to be a long term solution, it is paramount therefore that officials endeavour to locate them in areas with little existing congestion problems especially on routes on approach to dry port. Such facilities should be ideally located in areas with little existing activities. Of course, although this will reduce congestion in the immediate vicinity of the dry port it could also lead to longer journey distances as such a location may likely be more distant from existing importers. The reduction in congestion in the immediate vicinity of the dry port may therefore be offset by longer driving distances made by the vehicles.

6.1.5 Implication of Findings

The results show that the close dry port with or without an empty depot facility provides positive benefits to routes to and from ports. However, including an empty depot

facility at the dry port provides more benefit to routes to and from ports. Further analysis showed that dry ports with empty depot service presents more savings to routes to the port city but less benefit to routes from the port city. This variation has been linked to the geographical positioning of the logistic hubs in the network and is not surprising since these routes represent travel in opposite directions. Routes from the port city carry the empty containers travelling to the dry port located outside the city. This suggests that the characteristics of the dry port may have alternating impacts depending on the direction of travel. Clearly some routes in the city may benefit more from the provision of empty depot service in the dry port facility and others benefit less.

The fact that the empty depot facility may have varying benefits depending on the routes being accessed is further supported by the findings from the system level analysis which considers the overall benefit of the dry port to the container distribution system as a whole (that is all routes to and from all zones in the network). While some routes may benefit more from the introduction of empty depots, others do not. For example as discussed in Section 6.2.2 routes from the ports benefit more if the dry port provides an empty depot service. However, routes from the port city generally benefit less. This leads to the overall conclusion that the whole system benefits more from the dry port if no empty depots facilities are provided at dry ports (as discussed in Section 6.1). This result shows that the choice to include or omit an empty depot service has some impact on the benefit of the dry port. However, the direction of this impact, whether negative or positive, is dependent on whose benefit this is being considered for. For example while the inclusion of an EDS generally provides more benefit to the importers located in the port city, it presents less benefit to the system as a whole.

The results show that up to five times more benefit can be obtained if the load centre mechanism is applied. This is linked to the elimination of long distance trips originating at port terminals in Lagos. In the load centre mechanism all containers exiting the port gates and off-dock terminals by road are destined for zones within the port city while containers destined for zones beyond the port city are transported by rail. The implication is that more container trips originating from off-dock terminals in zones within Lagos travel shorter distances since they are all destined for zones within the city and saving to travel distance on roads are made by containers destined to zones beyond the city. However, this savings can be reduced if no Empty Depot Service is provided in the dry port

as is shown in Section 6.1.2, load centre benefits to routes to port and to port city decline if no empty depot is provided.

6.2 The Impacts of a Freight Distribution Service (FDS) on the Benefits of the Dry Port

This analysis considers how the provision of a freight distribution services (FDS) may impact the ability of the dry port to reduce congestion. Where this service is available, import containers can be stripped on site and goods transferred to smaller trucks for transportation to consignee. The analysis considers the case where all containers arriving at the dry port are stripped (case 1 and 3) to the case where no containers arriving at the dry port are stripped (case 2 and 4), both of which are extreme scenarios. The implication of a 100% stripping is that no empty trips are generated by traffic through the dry port since no laden container exits the facility. Once the import goods in the containers are transferred to trucks, the empty containers remain on the facility for transfer via rail to the seaport. The round trips associated with both cases are illustrated in Figure 6.8 below.

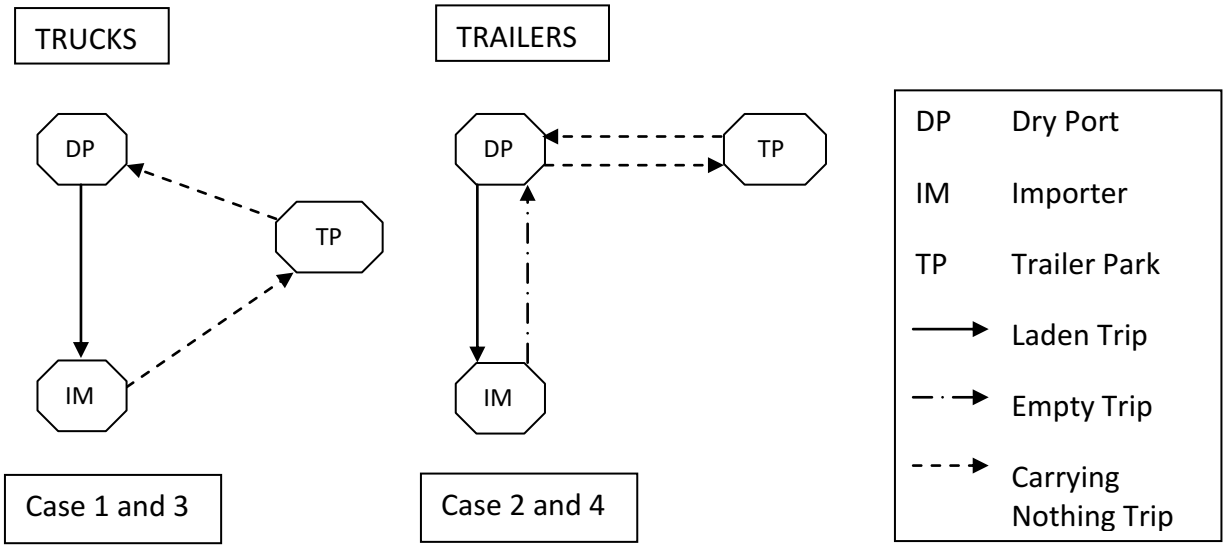


Figure 6.8: Round trips associated with trucks and container trailers in test cases

The extreme cases 1 (dry port with empty depot and with FDS) and 3 (dry port without empty depot and with FDS) would give identical results since 100% of containers are stripped within dry port and so only one of this is considered in the comparison. The analysis is therefore based on the results from test case 3 (case without EDS and with FDS)

and 4 (case without EDS and without FDS). The relationship between case 2 and 4 has been discussed in the previous sections.

6.2.1 System Level Analysis

System level analysis considers the impact of the dry port cases on the overall containerized freight system. Changes to the network condition are gauged by the calculated freight vehicle-km and freight vehicle-hrs savings brought about by the test case. Test cases associated with a positive saving implies that the congestion in the network is reduced by the test case. The freight vehicle-kms and freight vehicle-hrs savings obtained from each case is included in Table K.2 of Appendix K. Figure 6.9 and 6.10 illustrates the relative savings of dry ports with FDS (case 3) and dry port without FDS (case 2 and 4) on road congestion at a system level. Figure 6.9 is a plot of the total hours saved by all container-related trips in the system in percentage against the level of dry port utilization and Figure 6.10 is a plot of the total kilometres saved by all containerised cargo trips in the system in percentage against the level of dry port utilization. The 0% level of utilization represents an unused dry port or the case of no dry port.

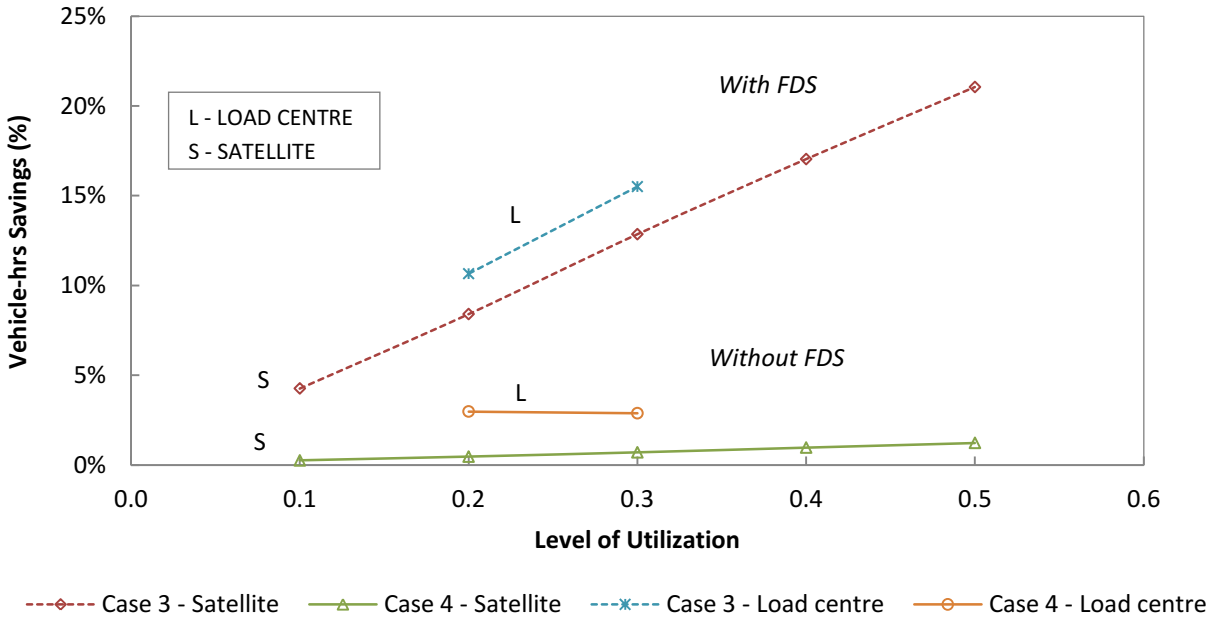


Figure 6.9: Freight vehicle-Hour savings to system against the level of dry port utilization

It can be observed that under the same conditions, the dry port with FDS presents much higher savings than the cases of the dry port without FDS. The case with FDS presents positive savings which increase up to 21% with increase in dry port usage. This is almost 20%

more than the maximum achievable savings of 1.4% obtained in the dry port cases without FDS. These patterns can be linked to the fact that in this extreme case, no empties leave the facility since all containers are stripped within the facility, thus eliminating the empty container trip legs (as illustrated in Figure 6.9) and reducing empty container trips in the network. Also, more savings are made because goods are sent directly to the various distribution warehouses of each importer. On the other hand, in the case without an FDS empty trips still occur and containerized cargo are routed through the importers designated container yards before distribution to the warehouses. The relationships between the alternative cases without FDS (case 2 and 4) have been discussed in the previous sections 6.1.

In the case of a dry port with FDS the freight vehicle-hrs savings increases at a faster rate than the case without FDS, with increase in the dry port usage. This causes the margin between the savings from the cases (with and without FDS) to increases largely with utilization. For example, at 10% utilization, the difference between the saving by the satellite case without FDS and satellite case with FDS is 4% compared to the difference of 8%, 13% and 16% at 0.2, 0.3 and 0.4 utilization levels consecutive. In general, diverting 10% of import container traffic to dry port causes up to a 5% increase in freight vehicle-hrs savings, if an FDS is available in the dry port. This steady increase with usage is linked to a continuous reduction of traffic through the city and a reduction in travel distance on road by containers on route to zones to the north of the city. Furthermore, it can be linked to the direct routing of goods to destination for use, sale or redistribution.

The load centre cases without an FDS provides a higher saving compared to their alternative satellite cases. As was discussed in Section 6.1, this is linked to a reduction in the trips length covered by consignees in zones beyond the port city. The same pattern can be observed for the case with FDS. The load centre case provides a higher savings compared to its alternative satellite case (as can be seen in Figure 6.9 and 6.10). This occurs because in the load centre mechanism containers that use the dry port are destined for zones beyond the port city. Thus, by diverting containers via rail through the dry port which is located to the north of the port city, savings are made from a reduction in travel distances covered by such containers on the road network. This saving is possible because the dry port brings the containers closer to their destination and this benefit is maximised since all containers using the facility are destined for areas beyond the port city.

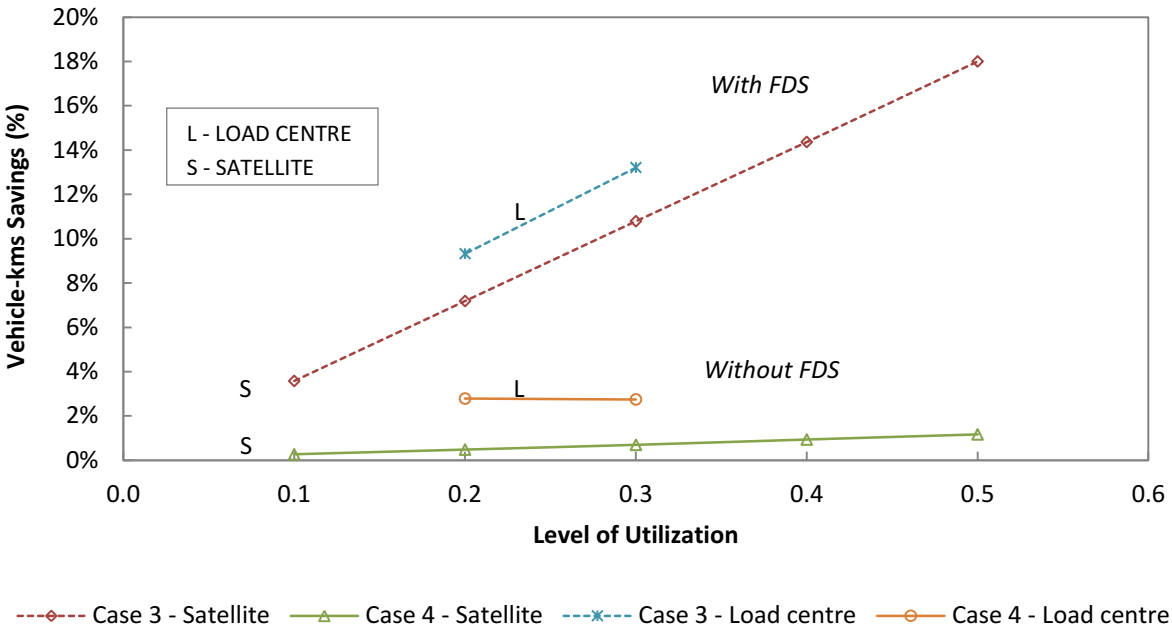


Figure 6.10: Freight vehicle-Kilometres savings to system against the level of dry port utilization

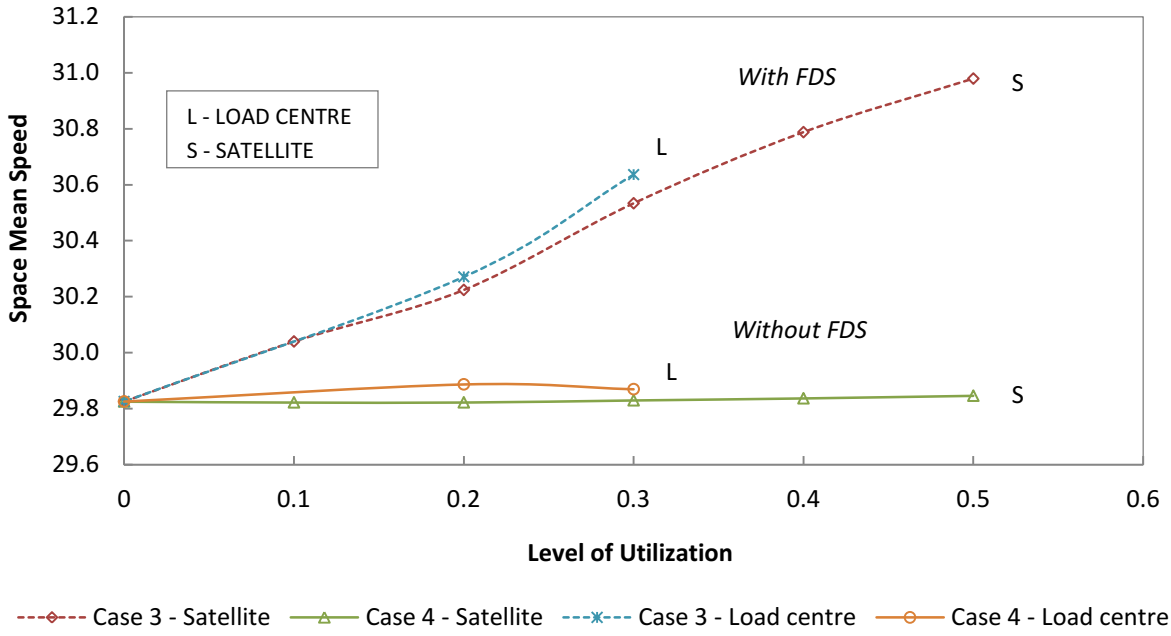


Figure 6.11: Space mean speed in network against dry port utilization.

The Space Mean Speed can also be used as a measure of the traffic condition in the network. It is calculated as the ratio of the total vehicle km to the total vehicle hrs for all container related traffic. The space mean speed at 0.0 utilization level represents the average speed in the network without the dry port (the baseline scenario). The result of this is shown in Figure 6.11 below which plots a graph of space mean speed against the various levels of dry port utilization. Once again, this is done for different dry port cases. It can be

observed that all dry port cases improve the space mean speed of the network. The effect of vehicle-hrs/vehicle-kms does not have a big impact on speed because containers account for a small proportion of the traffic.

6.2.2 Routes to and from the Ports

This analysis considers the overall impact of container-related trips moving from all zones in the network to the ports and for container-related trips from port to all zones in the network. Figure 6.12 are graphs of the freight vehicle-kms savings to routes from and to the ports. The graph of the freight vehicle-hrs saving is included in Figure k.6 and K.7 of Appendix K.

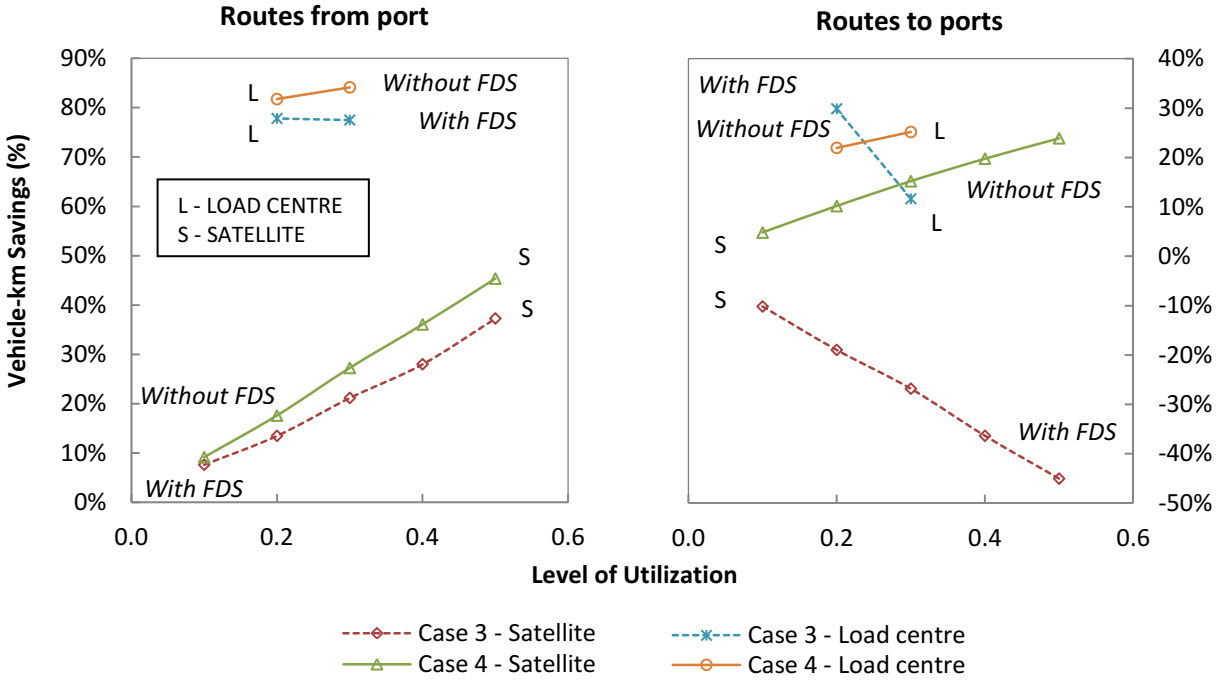


Figure 6.12: Freight vehicle-km savings to routes from and to ports against the level of dry port utilization

It can be observed from column one of Figure 6.12 that all test cases present positive benefits to routes from port and these savings increase with increase in dry port utilization. This is expected since the inclusion of the dry port reduces container trips on these routes as they are diverted to the dry port via rail. Yet, the functioning of the dry port clearly influences the magnitude of this savings. The Satellite case of a dry port with FDS provides the lowest benefit to the routes. This pattern can be explained by the multiple numbers of truck trips generated from a single container load. As the number of containers handled in

the dry port increases, the truck trips increases and so the vehicle hours and kilometres increases.

The graph in column one of Figure 6.12 shows that the load centre mechanism provides higher freight vehicle-km savings than the equivalent satellite case. That is to say that the benefits for routes from ports are substantially improved by the introduction of the load centre mechanism. For example at 0.2 and 0.3 utilization level, the satellite case without FDS provides a savings of 18% and 27% compared to a savings of 82% and 84% which are obtained in the load centre case without FDS. This pattern can be linked to a reduction in the number of trips moving through the city centre due to the diversion of long trips on route to zones outside of the port city. The inclusion of an empty depot causes the marginal variation between the freight vehicle-kms savings obtained in alternative test cases without FDS a pattern which has been discussed in Section 6.1.

The second column of Figure 6.12 is a graph of freight vehicle-kms savings on routes to the ports. Unlike with routes from ports, it can be observed that the dry port with FDS presents negative savings for routes to port. On the other hand, the case of dry port without an FDS presents positive savings to routes at all levels of utilization and the savings increase with increase in dry port usage, a pattern have been discussed in Section 6.1. The negative savings is linked to the multiple numbers of truck trips generated from a single container. As with trips from the ports, as the number of container handled by the dry port increases, the number of truck trips increase.

The identified increase in truck trips on routes to and from ports can be linked to an increase in the number of empty truck trips generated from trailer parks in the port city. The number of which, increases as a multiple of the number of truck trips generated from a single container. While savings are made from the elimination of empty container trailer trips, the rate of the SCL truck trips generated from one container in fact neutralize the gains on this route. The reduced savings can also be linked to the location of trailer parks that serve the dry ports. As was noted in Section 5.6.3 the model is based on the assumption that a proportion of trucks serving the dry port originate from trailer parks in the port city. To explore the impact this assumption may have on the modelled benefit of the dry port, an extreme scenario is considered. The scenario is one that assumes that a 100% of importer using dry ports own vehicles or lease from within their individual zones. Thus, implying that all unit trucks serving the dry port are located within importers zones

and no trailer parks in the port city service the dry port. Figure 6.13 is the result obtained from this assumption.

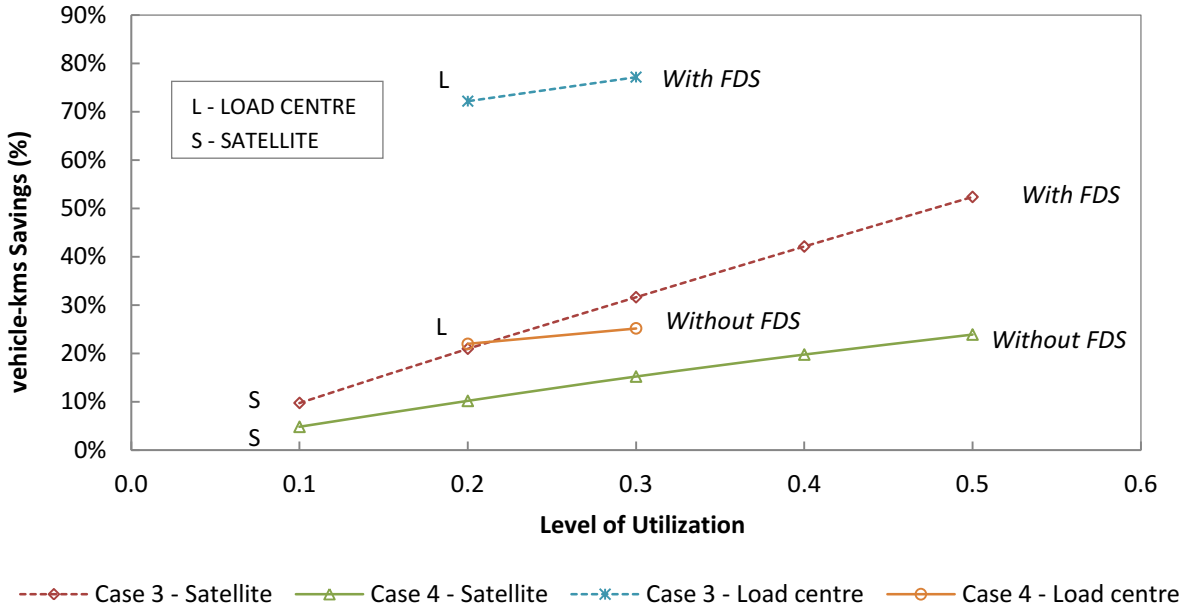


Figure 6.13: Freight vehicle-km savings for routes to ports against the level of dry port utilization (with revised assumption)

Unlike the previous analysis, it can be observed that the dry port case with FDS presents higher savings than that of the case without FDS. Furthermore, the load centre cases provide higher savings than the equivalent satellite cases. This is linked to the reduction in travel distances between consignee's yard and the point where trucks originate and are destined to after delivery of consignment. In the previous case, the impact of the long trip distances are exaggerated by the multiple numbers of trips required to transport a single container load. According to this result, if an FDS is included within a dry port, a significant improvement in the benefits can be achieved by reducing trip lengths between the container destination/origin or the dry port and the origin/destination of the truck. This is achievable by encouraging truck ownership by importers and also by encouraging the development of such trailer parks around a dry port. These trailer parks should be designed specifically to service the dry port. In this alternative trailer park assumption, the pattern obtained for routes from ports are similar to those obtained from the analysis based on the original assumption (Figure 6.12). The alternative assumption is also found to improve then benefit of the dry port with FDS on routes to zones in the port city and is discussed in the Section 6.2.3. Otherwise, it is not found to alter the patterns observed from other levels of analysis.

As observed previously, the load centre cases present higher benefits than the equivalent satellite case (Figure 6.12). This is expected since the load centre cases eliminate the number of trips moving from the port (NB) across the city to zones outside Lagos. However, the positive savings decreases with the increase in dry port utilization. These patterns are consistent with those outlined earlier.

6.2.3 Routes to and from Zones in the Port City

This analysis is concerned with the impact of the dry port cases on routes to and from zones in Lagos city. The freight vehicle-kms and freight vehicle-hrs savings obtained from each case is included in Table K.5 and k.6 of Appendix K. Graphs of the percentage freight vehicle-kms savings to routes from and to the port city against the dry port utilization are in Figure 6.14. Graph of the freight vehicle-hrs saving are similar and have been attached in Figure K.8 and K.9 of Appendix K.

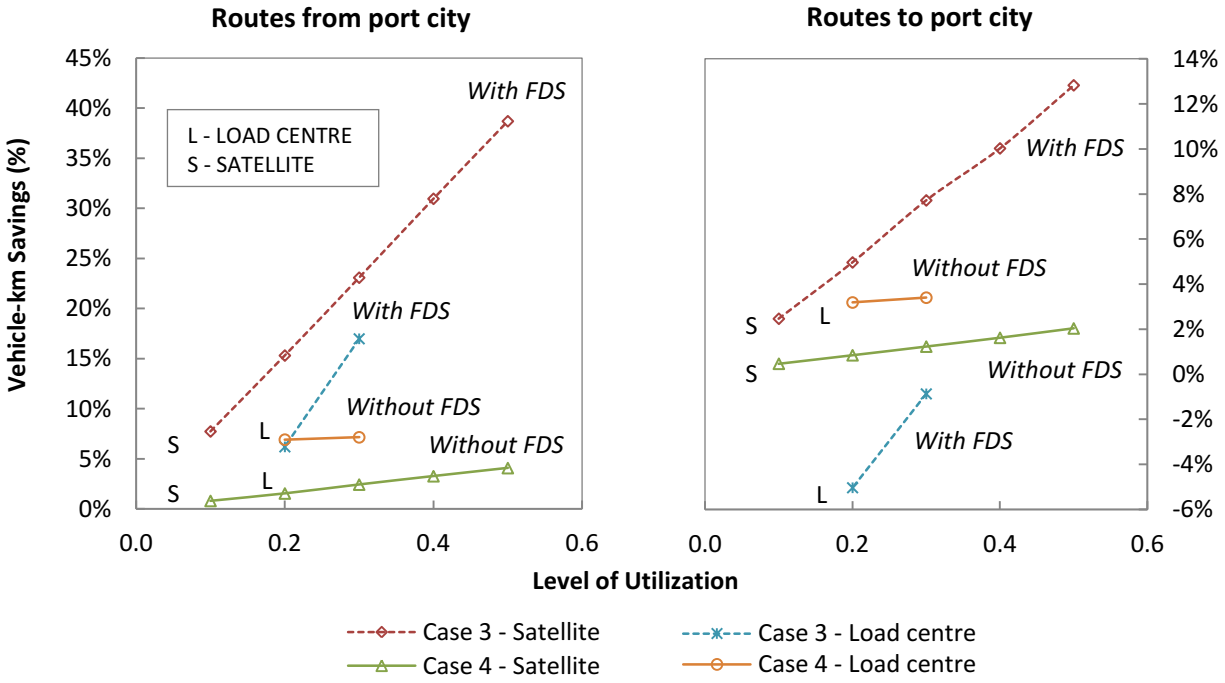


Figure 6.14: Freight vehicle-kms savings to routes from and to zones in port city against dry port utilization

At all levels of utilization the satellite case with FDS provides higher saving, for routes to and from the city, than the satellite case without FDS and the difference between the savings presented increases with increase in the level of utilization. This pattern is linked to the direct routing of goods to distribution warehouses from the dry port and to the

reduction in the empty trips on route since in extreme case with FDS, no containers leave the dry port's gate.

It can also be noted that for the case without FDS, the load centre mechanism present higher benefits to the network than the equivalent satellite mechanism. While for the case with FDS, the load centre mechanism presents lower benefits than the satellite mechanism. This is linked to the multiple numbers of truck trips exiting and entering zones in the port city. In the load centre, the dry port with FDS is not accessible to consignees in zones within the port city (except for some close to the dry port) and so, all containers exiting the port are destined for zones within the port city where they are stripped. The implication is that the large numbers of containers within the port city generate multiple numbers of trucks. On the other hand, in the satellite mechanism, a proportion of importers in the port city, whether close to the dry port or not, can access the FDS included. This provides benefits to the port city by reducing the number of empty trips to the area and reducing the number of trucks generated from container loads in zones. Although the load mechanism reduces the number of trips through the city, since containers destined for zones beyond the city are diverted to the dry port, the generation of multiple truck trips from all containers exiting the port (and destined for zones in the port city) reduce this otherwise benefit.

It can be observed from this graph that all dry port cases present positive benefit to route from the port city and this savings increase with increase in dry port usage. This can be linked to the decrease in the number of trailer and empty trucks moving south bound to ports from trailer parks due to the diversion of container volumes to the dry port. On the other hand, not all dry port cases present positive savings for routes to the city. In particular, the load centre case with FDS presents no savings to routes to the city.

The negative benefit presented by the load centre case with FDS can be linked to the increase in the number of long distance trips to and from trailer parks associated with the location of the dry port's customers in zones beyond the port city. For example, in the load centre case, at 0.2 utilization, all importers using the dry port are located in zones outside Lagos and so trip lengths associated with the dry ports are longer than in the satellite case, where the number of long distance trips are less since only a proportion of the consignees in outer zones use the dry port. This outcome may be biased by the locations from where the trucks originate and so, the original assumption that a proportion of the trucks serving the

dry port originate from trailer parks in the port city is redrafted in other to explore the impact this assumption may have on the modeled benefit of the dry port. The extreme scenario which outlines that a 100% of importer using dry ports own vehicles or lease from within their individual zones is considered. The result from this is included in Figure 6.15 below. It can be observed that by reducing the truck trips lengths between the dry port and trailer parks, an extra savings of up to 26% can be obtained from the dry port case with FDS. This finding illustrates the impact the vehicle ownership culture of importers may have on the benefit of a dry port development.

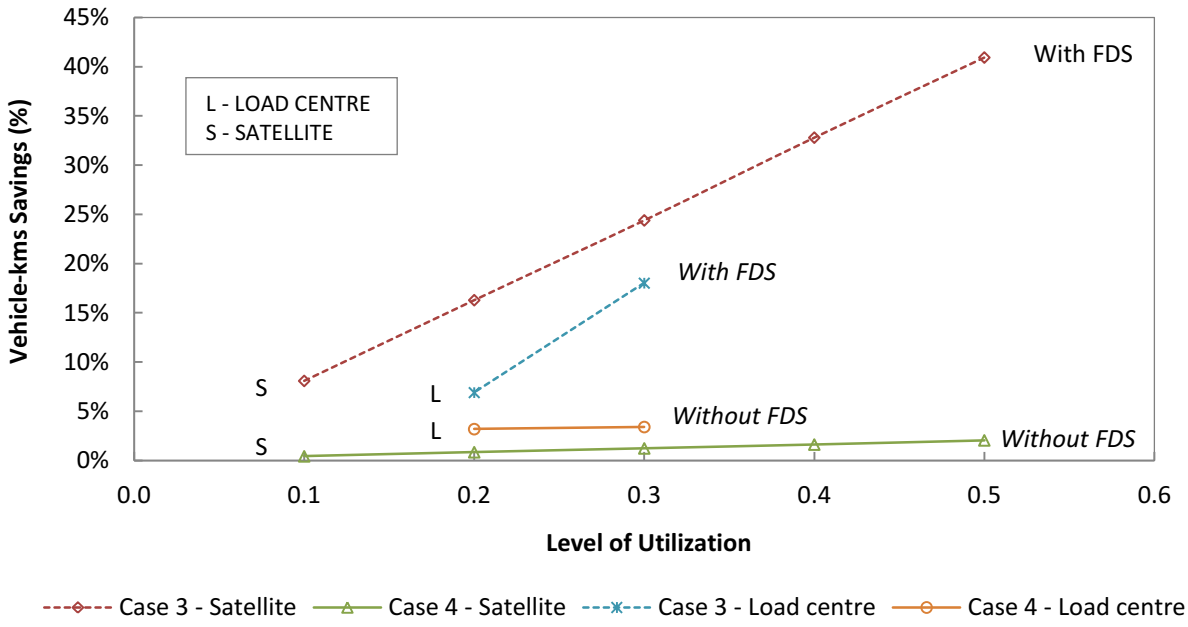


Figure 6.15: Freight vehicle-km savings for routes to the port city against the level of dry port utilization (for the revised assumption)

6.2.4 Link Analysis

The links level analysis considers the impact of the dry port on the trip volumes on major access links to and from the ports and dry ports. The access links considered for analysis are four key links on approach to the port and dry port in the directions to and from the port city. A map showing the links considered in the analysis is included in Figure K.10 of Appendix K.

Figure 6.16 are graphs of the percentage volume savings presented by dry port cases on links on approach to/from port against the utilization. The first column in Figure 6.16 relates to the port approaches in the direction from the city (SB) to the port while the

second relates to the port approaches in the direction to the city (NB) from the port. Positive values represent a reduction in link volumes. Once again, the load centre and satellite case present the same volume saving at the same level of utilisation.

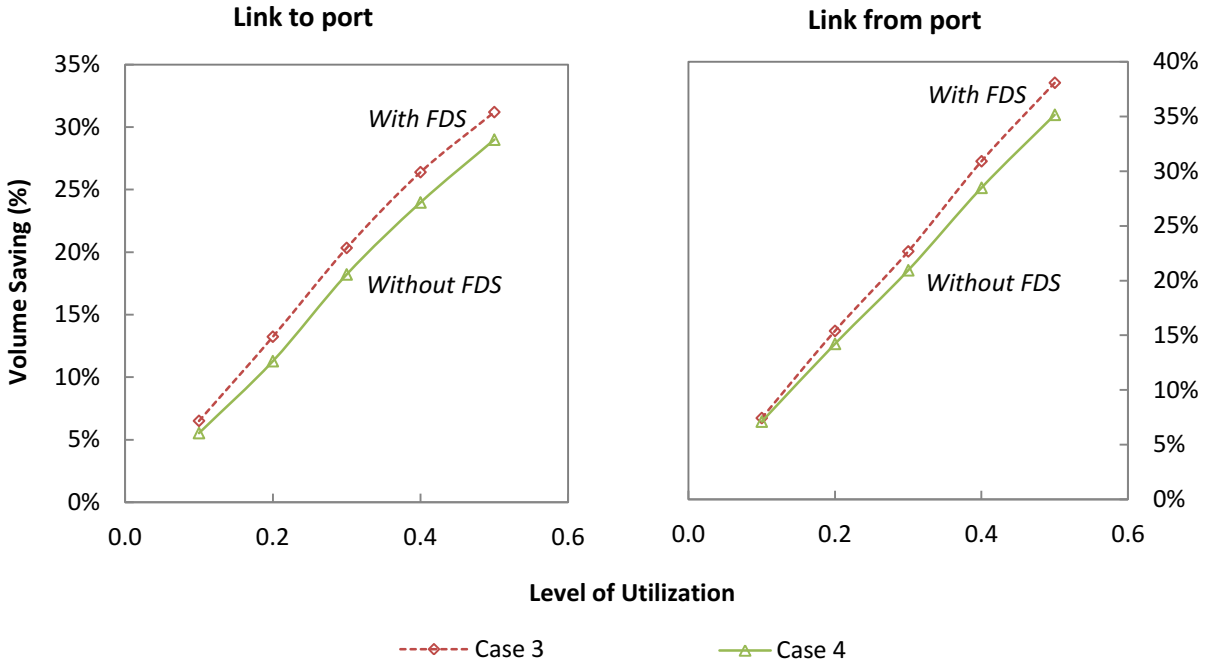


Figure 6.16: Volume savings to link on approach to port in the direction from and to the port city

It can be inferred from Figure 6.16 that all dry port cases presents positive benefits to trips on port approaches to and from the port city at all utilization levels with a benefit of up to 42% achieved depending on the dry port characteristics. The dry port with FDS presents the highest volume savings for the approach link to and from the port city. This is because in the case with FDS, the dry port does not generate empty container trips and so, the empty trips that are otherwise sent to the ports and the trucks that exit after the return are reduced.

Figure 6.17 are graphs of the volume savings relating to the dry port approaches in the direction from the port city (NB) to the dry port and in the direction to the port city (SB) from the dry port. Negative values represent an increase in link volumes and no benefit to trips. It can be observed that at all utilization levels, no benefits are available to trips on approach to the dry port. Furthermore, the negative impact on the approach to dry port increases with an increase in dry port utilization. This is expected since the links are the new entry point into the network from the dry port. The case of the dry port with FDS, presents much higher negative benefits than the cases without FDS. This pattern is linked to the

multiple numbers of distribution truck trips generated from a single container generated at the dry port.

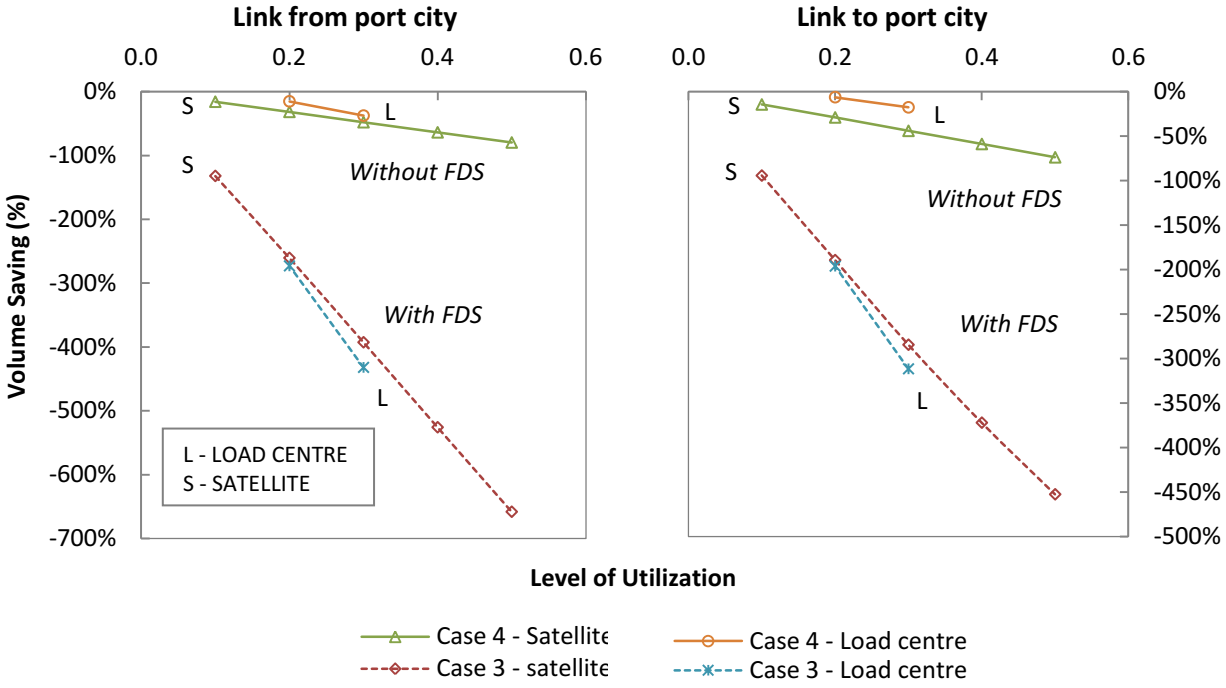


Figure 6.17: Volume savings to link on approach to dry port in the direction from port city

The inclusion of the dry port presents volume savings of up to 42% on approach to and from the ports but presents negative savings of up to -400% on approach to and from the dry port. While the containers have been diverted from the city centre causing a reduction in volumes on route from/to the port, the act increases the volumes on routes to/from the dry port facility. As found in Section 6.1.4 from the dry port test cases without an FDS, this suggests that the dry port solution simply shifts the congestion problems from one location in the network (port vicinity) to another (dry port vicinity).

It is observed from the model that the weighted average speed of traffic on selected links along approach to and from ports, increases by up to 2km/hr when comparing the reference case and the dry port scenarios, depending on the dry port scenario explored. This improvement in speed is linked to the reduction in the containerised cargo traffic on the link brought about by the diversion of traffic to the dry port via rail. This slight change (2km/hr) is consistent with most parts of the network where the weighted average speed of traffic on individual links is found to remain almost steady between the baseline case and the dry port scenarios, with average speed increasing or decreasing by up to 3km/hr. However, more drastic changes are found to occur on links along approach to the dry port facility, where

the weighted average speed of traffic on links are found to decrease by up to 10km/hr. This pattern is linked to the increase of containerised cargo traffic on such links and the capacity restrains currently associated with the links. The slight variation in speed on links in most parts of the network is not surprising since container traffic accounts for a small proportion of total traffic on links (on average 3%). This suggests that while the diversion of container traffic from road to rail may reduce the absolute volume of container traffic on links, the reduced volume is not necessarily substantial enough to significantly improve the speed of travel on such a link. In other to drastically improve the speed of travel on individual links in the network, it may be necessary to combine the dry port solution with other congestion mitigation measures. For links surrounding the dry port the findings support the need to improve the road infrastructure to accommodate the predictable build up of traffic in the surrounding areas of the dry port facility.

The volume capacity ratio on the selected links along approach to and from the port is found to decrease by up to 0.05 with increased use of the dry port facility, suggesting a slight improvement in localised traffic build up on links brought about by the introduction of the dry port solution. This pattern, like the average speed is linked to the diversion of container traffic to the dry port. However, while the dry port solution is found to decrease the volume capacity ratio on the links along the approach to/from the port, the solution is found to have the reverse impact on some other individual links in the network. For example, the volume capacity ratio on selected links along the approach to the dry port facility, are found to increase by up to 0.4 with increased use of the dry port facility. This pattern is linked to the re-routing of container traffic to new links as traffic enters the road network through a new point in the system (the location of the dry port).

These findings are based on the assumption that the capacity of links and volume of non-container related traffic remain the same between the do-nothing reference scenario and dry port scenario. Thus, the increase in volume capacity ratio or a decrease in speed on individual links is due to the increase in container-related traffic alone. While it is safe to assume that the volume of non-container related traffic would remain at least the same, it is likely to increase in reality and an increase in the capacity of such links would have a reducing impact on the volume capacity ratio and an increasing impact on the speed on the links. Thus, an increase in the capacity of such links that otherwise suffer increased volume-capacity ratio and decreased speeds is necessary to accommodate the growth in container-

related traffic volume on such links if the purpose for which the dry port is developed (to reduce congestion) is truly achieved.

6.2.5 Implication of Findings

The dry port without FDS presents the smallest benefits to the system as a whole and to routes to and from the port city. The greatest benefits are observed on routes to and from ports and on the approach links to ports. In general, dry ports with FDS provide higher benefits to the network than that without. For all routes to and from all zones in the network, the dry ports with FDS provide benefits up to 18% more than dry ports without FDS and this Figure increases to 35% for routes to and from zones in the port city.

The results also show that in some cases, the dry port without FDS can provide higher benefits to the network than the dry port with an FDS included, particularly in the case where the dry port facility is serviced by trailer parks within the city and the satellite allocation mechanism is employed. Where truck and trailer arrive from the port city to collect goods at the dry port, the dry port without FDS is found to provide freight vehicle-km and freight vehicle-hr savings of up to 10% and 70% more than the dry port with FDS, for routes from ports and to ports respectively (Figure 6.12). On the other hand, when considering a scenario where vehicles serving the dry port are owned by the importers and the satellite allocation mechanism employed, the dry port with FDS presents a freight vehicle-km and freight vehicle-hr savings of up to 30% more than that presented by the dry port without FDS (Figure 6.13). This findings support the need to encourage the development of trailer parks around the potential dry port development and support the need to encourage a change in the HGV ownership culture to one where the majority are owned by independent importers. This eliminates the trips from trailer parks to dry ports and minimises the travel distance covered by these vehicles in the network. However, the ownership of HGV's by majority of importers could result in lower vehicle utilisation rates than if provided by a third party road haulage services and thereby increase transport costs.

Furthermore, for routes to and from the city, while the load centre case without FDS provides higher benefit than the equivalent satellite case, the opposite is observed for the case with FDS where the load centre mechanism presents lower benefit than the satellite case. This has been linked to the multiple numbers of trips generated from a single

container in the port city. This finding suggests that the load centre mechanism does not enhance saving for increased use of a Freight Distribution Service within a dry port. Yet, the benefits achievable by including the FDS service within the dry port are higher than that achieved by employing just the load centre mechanism within a dry port (see Figure 6.14). The lesson to be learnt from this is that while the use of the dry port may be restricted to importers in zones closer to the dry port, the FDS provided should be made accessible to all importers in the country.

Due to resource restricting this study, average trip lengths were obtained only for SCLs generated at ports and this was assumed to be the same for SCLs generated at off-dock terminals and the importer's facilities. This assumption may be inaccurate as in reality, these trips may be shorter or longer. If the true value is shorter then, the observed percentage savings is bound to be higher for dry ports without FDS but may be lower for dry ports with FDS. However, if it is longer, then the reverse applies. For the dry port with FDS, this variation is linked to its concept which allows importers to send goods directly to relevant warehouses from the facility. This eliminates the initial diversion through the consignee alternative facility. The further away the warehouses are from the consignee's yards the more benefit the FDS may be. This is explored in Section 6.4.

6.3 The Impact of Off-dock Function on Benefit of Dry Port

The previous sections explored the relative saving presented by the dry port with varying characteristics when the stemming process still occurs and the relevant off-dock terminals act as empty depots ('off-dock as is'). This section will explores the impact of a change in the functioning of the off-dock terminal in the container logistic chain, on the dry port benefits identified in the earlier sections. An alternative situation where the off-dock terminals keep only its empty depot status if applicable and the stemming process is eradicated is explored. The effect of the function of off-dock terminals on the dry port benefit is explored by comparing the network saving presented by the test case with off-dock terminal functioning "as is" (obtained in the previous section) against that obtained from the test case with off-dock terminals losing their stemming function and functioning "as empty depots" only. An absolute difference and percentage change in the saving is representative of the difference.

The analysis considers three dry port cases for comparison: case 3 (the case of a dry port with an FDS and without an empty depot), case 2(the case of a dry port without an FDS and with an empty depot) and case 4 (the case of a dry port without an FDS and without an empty depot) as these present distinct cases. The analysis is explored at system and route levels and is outline below.

6.3.1 System Analysis

Table 6.1 shows the container-related freight vehicle-km and freight vehicle-hrs saving brought about by the implementation of the close dry port cases with the off-dock terminals keeping their current functions and with the off-dock terminals functioning as empty depots only. The savings are related to all routes to and from all zones in the system. The absolute difference between the saving from the alternative scenarios (off-dock terminal as is and off-dock as empty depot) is a measure of the extra savings presented by the eradication of the off-dock terminal.

It can be observed that higher savings are available from dry port cases with the off-dock terminals acting as empty depots only. As is expected the absolute difference at respective utilization levels remain almost constant between the dry port cases (case 2, 3 and 4). This is linked to the elimination of containers that previously passed through the off-dock terminals. The initial dry port solution with off-dock terminal “as is” generates additional journeys as a multiple number of containers are routed through the road network to multiple off-dock terminals. When the off-dock terminals function solely as empty depots there is a reduction in container volumes which were originally generated by the stemming process. For each dry port case, this extra benefit is seen to decrease with increase in utilization of the dry port. As has been discussed in the previous sections the dry port solution unlike off-dock terminals allows for containers to be diverted via rail to an alternative port extension.

Table 6.1: Freight vehicle-hrs and vehicle–kms savings to system*

Case 3 – Dry Port without EDS and with FDS									
		Freight vehicle-hrs savings per hour				**Freight vehicle-kms saving per hour**			
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**% change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**% change**
Satellite	0.1	1978	2825	847	30%	494777	74963	25485	34%
	0.2	3900	4662	761	16%	99395	122219	22824	19%
	0.3	5964	6627	663	10%	149246	169119	19873	12%
	0.4	7904	8456	552	7%	198710	215665	16955	8%
	0.5	9767	10208	441	4%	249039	262298	13259	5%
Load Centre	0.3	7194	7369	175	2%	182784	189086	6302	3%
	0.2	4943	5156	214	4%	128969	136618	7649	6%
Case 2 - Dry port with EDS and without FDS									
		Freight vehicle-hrs savings per hour				**Freight vehicle-kms saving per hour**			
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**% change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**% change**
Satellite	0.1	2	853	851	99%	5	25441	25436	100%
	0.2	29	783	754	96%	29	225423	22514	100%
	0.3	61	720	659	92%	58	19409	19351	100%
	0.4	114	668	555	83%	116	16881	16764	99%
	0.5	145	581	436	75%	289	13591	13301	98%
Load Centre	0.3	1229	1401	172	12%	32597	38944	6346	16%
	0.2	1335	1543	209	14%	36562	44225	7663	17%
Case 4 - Dry port without EDS and without FDS									
		Freight vehicle-hrs savings per hour				**Freight vehicle-kms saving per hour**			
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**% change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**% change**
Satellite	0.1	119	978	85	88%	3688	29195	25507	87%
	0.2	217	979	762	78%	6607	29465	22858	78%
	0.3	328	987	660	67%	9581	29481.2	19901	67%
	0.4	451	1006	555	55%	12914	29674	16759	56%
	0.5	572	1009	437	43%	16113	29406	13294	45%
Load Centre	0.3	1339	1512	174	12%	37945	44302	6357	14%
	0.2	1384	1593	210	13%	38506	46179	7673	17%

*The Table compares the savings obtained from having a dry port with the off-dock terminal remaining with the same functions 'off-dock terminal as is' against the saving obtained when off-dock terminal operate as empty depots only. The savings are calculated by subtracting the results from the dry port scenarios with the

relevant off-dock function from the baseline scenario.

The percentage change shows the proportion of the savings that is associated with the elimination of the off-dock terminals. By comparing the values for each case, it can be observed that the perceived network benefit of the eradication of the off-dock stemming function is highest in case 2 (dry port without FDS) where at low dry port utilizations almost 100% of the benefit is associated with the eradication of the stemming function at the off-dock terminal. On the other hand, in case 3 (dry port with FDS), the benefit of the eradication compared to the benefit from the dry port without eradication is much lower. This pattern is linked to the increased benefit presented by the inclusion of the FDS within the dry port as has been discussed in the previous section. While the eradication presents high benefits, the saving from the inclusion of an FDS is more.

While the network benefit of removing the stemming function increases with dry port utilization in the case without EDS (case 3 and 4), it decreases with dry port utilization in the case with EDS (case 2). This pattern can be linked with the inclusion of an empty depot within the dry port facility which compels consignees in the city to return empty containers to the dry port facility which is located further away than the existing empty depots located within the city. This result supports the use of the existing off-dock terminals as empty depots since this role presents greater benefits in terms of the network impact associated with container-related traffic.

It can also be observed that the extra benefits of eradicating the stemming functions of the off-dock terminals are lower for the load centre cases than for the satellite cases. A pattern, which can be linked to the concept of the load centre mechanism where all container destined for zones beyond the city are diverted via rail to the dry ports. The implication is that all containers which are sent through the off-dock terminals make shorter trips as they are destined for zones within the city.

6.3.2 Routes to and from Ports

Table 6.2 shows the percentage savings obtained from the alternative off-dock terminal cases. It outlines a comparison of the freight vehicle-hrs savings for routes to and from ports. A plot of the percentage savings will show patterns similar to those discussed in Section 6.1 and 6.2. However, the values of the savings are seen to vary with the function of

the off-dock terminals within the dry port solution. The freight vehicle-kms savings present similar patterns and are included in Table K.7 of Appendix K for reference.

For all satellite cases, it can be observed that at respective dry port utilization levels, the off-dock terminal functioning as empty depot only present lower savings to routes from ports than the off-dock remaining with the same function. This reduced benefit is linked to the increase in the number of container trips that exit the ports and travel longer distances by road directly to zones beyond the city. In the previous case, a proportion of containers leaving the ports are stemmed to off-dock terminals located within the city (they travel over shorter distances) from where they are distributed to the zones beyond the city. This result shows that off-dock terminals provide benefits to routes from ports, by allowing otherwise long road distance travelling containers to be diverted to zones within shorter distances from where they are directed to various destinations. While this may be beneficial to routes from ports, other routes do not benefit as these container are sent over longer distances to their destination, via alternative routes from such zones. This is apparent from the increased benefit to the overall system by the eradication of the off-dock terminals. On the other hand, the “off-dock as empty” presents higher benefit for dry port functioning as load centre because containers travelling such long distances to zones beyond the city do not exit the port gates and are otherwise not stemmed to off-dock terminals.

For routes to port, the cases with off-dock as empty depots only presents up to 18% higher benefits than the cases where off-dock remain with stemming function. It can be observed that the highest extra benefit is achieved at the lowest utilization (0.1). This is the case were the lowest volumes of containers are diverted through the dry port. However, this is not a practical volume because of the capacity constraint at the port. In reality, for the off-dock terminals to be eradicated, the dry port should be developed to work at higher levels of utilization to accommodate the practical capacity constraints at the seaport. As utilization increases however, the gain presented by the elimination of the off-dock reduces which is linked to a reduction in the volume of containers that were previously routed through the off-dock terminals. Yet, it is clear that replacing the multiple off-dock terminals with this single dry port solution will present added benefits on routes to port.

Table 6.2: Freight vehicle-kms savings to routes to and from ports

Case 3 - Dry port without EDS and with FDS							
		Routes from Ports			**Routes to Ports**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	7.3%	-5.5%	-12.8%	-6.7%	11.8%	18.5%
	0.2	12.3%	1.9%	-10.4%	-11.7%	5.3%	17.0%
	0.3	20.0%	10.3%	-9.7%	-15.8%	-1.9%	13.9%
	0.4	26.9%	18.8%	-8.1%	-22.5%	-9.8%	12.7%
	0.5	35.8%	28.9%	0.0%	-27.7%	-18.3%	0.0%
Load centre	0.3	73.6%	75.2%	1.6%	20.7%	25.1%	4.4%
	0.2	73.3%	74.8%	1.6%	33.4%	39.4%	6.0%
Case 2 - Dry port with EDS and without FDS							
		Routes from Ports			**Routes to Ports**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	8.1%	-3.6%	-11.7%	5.8%	24.0%	18.2%
	0.2	16.7%	6.2%	-10.5%	13.0%	29.6%	16.5%
	0.3	26.0%	16.3%	-9.6%	19.8%	34.2%	14.4%
	0.4	34.6%	26.5%	-8.1%	25.8%	38.3%	12.5%
	0.5	43.6%	36.7%	-6.9%	32.0%	41.5%	9.6%
Load centre	0.3	80.0%	80.0%	0.0%	60.6%	60.6%	0.0%
	0.2	77.4%	77.4%	0.0%	59.7%	59.7%	0.0%
Case 4 - Dry port without EDS and without FDS							
		Routes from Ports			**Routes to Ports**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	8.6%	-3.7%	-12.3%	5.0%	23.3%	18.3%
	0.2	16.0%	5.7%	-10.4%	10.5%	27.3%	16.8%
	0.3	25.1%	15.5%	-9.6%	15.7%	30.1%	14.4%
	0.4	33.6%	25.6%	-8.0%	20.2%	32.3%	12.1%
	0.5	42.2%	35.4%	-6.9%	23.6%	32.9%	9.3%
Load centre	0.3	79.1%	80.6%	1.6%	24.0%	28.8%	4.7%
	0.2	76.7%	78.6%	1.9%	20.6%	26.7%	6.1%

On the other hand, in most cases, the off-docks as empty present higher benefit for dry port functioning with a load centre mechanism. This is because with the load centre mechanism, containers travelling long distances to zones beyond the city do not exit the port gates. The container trips originally generated from the off-dock terminals are destined to areas within the city only and so, the elimination of this step produces more

benefits since containers can be sent directly from the ports to these locations within the city. However, the benefit of the dry port with load centre mechanism is less sensitive to the eradication of the stemming function and not much benefit is gained by this act.

6.3.4 Routes to and from Port City

Table 6.3 includes the freight vehicle-kms savings for routes to and from the port city. It outlines the savings from the alternative off-dock cases (off-dock remaining with stemming and empty depot functions /off-dock functioning as empty depot only). A plot of the savings from the dry port cases with off-dock as empty depot presents patterns similar to those discussed in Sections 6.1 and 6.2. The freight vehicle-hrs savings present similar patterns and are included in Table K.8 of Appendix K for reference.

Table 6.3: Freight vehicle-kms for routes to and from port city

Case 3 - Dry port without EDS and with FDS							
		Routes from port city			**Routes to port city**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	7.7%	10.0%	2.3%	2.5%	4.9%	2.4%
	0.2	15.3%	17.4%	2.1%	5.0%	7.2%	2.2%
	0.3	23.1%	24.8%	1.7%	7.7%	9.6%	1.9%
	0.4	31.0%	32.4%	1.5%	10.0%	11.7%	1.7%
	0.5	38.7%	39.9%	1.2%	12.8%	14.1%	1.2%
Load centre	0.3	17.0%	17.7%	0.8%	-0.9%	-0.1%	0.8%
	0.2	6.2%	7.2%	1.0%	-5.0%	-4.1%	1.0%
Case 2 - Dry port with EDS and without FDS							
		Routes from port city			**Routes to port city**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	0.6%	3.0%	2.3%	0.6%	3.0%	2.5%
	0.2	1.4%	3.4%	2.0%	1.3%	3.4%	2.2%
	0.3	2.2%	3.8%	1.7%	1.9%	3.8%	1.9%
	0.4	2.9%	4.3%	1.4%	2.6%	4.2%	1.6%
	0.5	3.6%	4.7%	1.1%	3.3%	4.5%	1.3%
Load centre	0.3	7.2%	7.9%	0.7%	7.0%	7.7%	0.8%
	0.2	7.0%	7.9%	0.9%	6.9%	7.8%	0.9%
Case 4 - Dry port without EDS and without FDS							

		Routes from port city			Routes to port city		
	Utilization	Off-dock terminal as is	Off-dock terminal as empty	Absolute change	Off-dock terminal as is	Off-dock terminal as empty	Absolute change
Satellite	0.1	0.8%	3.1%	2.3%	0.5%	2.9%	2.4%
	0.2	1.5%	3.6%	2.1%	0.8%	3.0%	2.2%
	0.3	2.4%	4.2%	1.7%	1.2%	3.2%	1.9%
	0.4	3.3%	4.7%	1.4%	1.6%	3.3%	1.6%
	0.5	4.1%	5.2%	1.2%	2.0%	3.3%	1.3%
Load centre	0.3	7.2%	7.9%	0.7%	3.4%	4.2%	0.8%
	0.2	6.9%	7.9%	1.0%	3.2%	4.2%	1.0%

The absolute difference between the saving from the alternative scenarios (off-dock terminal as is and off-dock as empty depot) is a measure of the extra benefit presented by the eradication. As is expected the values at respective utilization levels remain almost constant between the dry port cases (case 2, 3 and 4). For all cases (2, 3 and 4), this absolute difference decreases with increase in dry port utilization, suggesting that the net benefit of the eradication diminishes with increased use of the dry port. This is expected since the benefit is linked with the volumes of containers moving through the off-dock terminals. The increased use of the dry port reduces the number of containers exiting the port and diverted through these off-dock terminals.

It can be observed that for all cases, the eradication of the stemming function (off-dock as empty) presents higher benefit than the alternative (off-dock as is). However, for the dry port case without FDS (case 2 and 4), the added benefits presented by the eradication of the off-dock terminals accounts for over up to 83.6% of the total benefit. However, this value reduces to 23.8% for the dry port with FDS (case 3). While the eradication of the off-dock terminals allow substantial added value to the case without FDS (case 2 and 4), the added value is less significant compared to the benefits attained by including an FDS within the dry port (case 3).

6.3.5 Implication of Findings

The results shows that while stemming through off-dock terminals may provide benefits to routes from the ports by diverting otherwise long distance travelling container from port to off-dock terminals in zones within shorter distances, eradicating the stemming

function is beneficial to the other routes considered since it eliminates the trips on routes between the port and the off-dock terminals. This is apparent from the increased benefit to the overall system and to routes to and from the city.

It is clear that the greatest benefit from converting the off-dock terminals into empty depots is obtained at low levels of dry port utilization. This is because higher volumes of containers exiting the port by road are sent directly to importers rather than first going through the off-dock terminals. This is however not a realistic scenario as the off-dock terminals are created to increase the seaport capacity. Thus, if eradicated, the dry port must function at high utilization levels that allow it to accommodate the practical capacity constraints at the sea port.

This result shows that the use of multiple numbers of off-dock terminals for stemming within the container distribution system has a negative benefit on the road network while on the other hand, the inclusion of the dry port solution presents a positive benefits to the road network. Furthermore, while including the dry port solution within the existing system has positive benefits on congestion in the road network, eliminating these off-dock terminals will magnify the benefit of any implemented dry port case. While off-dock terminals increase the capacity for port terminals, their use has been shown to be detrimental to the efficiency of the road network. Furthermore when the off-dock terminals are replaced by an empty depot service, providing an empty depot service at the dry port presents less savings to the overall system. This finding suggest that maximum benefits can be attained by converting existing off-dock terminals to empty depots and developing the dry port to handle only empty containers generated from the Freight Distribution Service provided within the facility.

6.4 Sensitivity of Results to Average Trip Lengths

In Sections 6.1 and 6.2, the benefits presented by the implementation of the alternative dry port solutions are based on the assumption that the average trip length of Stripped Container Loads (SCLs) generated at consignee designated yards is the same as that from the port. This section explores the sensitivity of the results obtained in the previous sections to the assumed trip lengths. It does this by comparing the results obtained from the initial assumed trip length with those obtained from two alternative trip lengths scenarios.

The savings obtained from the reference case where the trip length is assumed to be the same as that from the port (x) is compared to that obtained when the assumed average trip lengths is decreased by 50% (x/2) and increased by 100% (2x). These alternative average trip lengths explored represent two extreme cases (an expected minimum and maximum possible average trip length) and are listed in Table 6.4 below. Only case 3 (dry port without Empty depot and with FDS) and case 4 (dry port without empty depot and without FDS) are considered in this analysis as these represent two opposite cases and are representative of the other two alternatives. The analysis is carried out at system and route level.

Table 6.4: Average trip lengths explored

Commodity type	**2x**	**x**	**x/2**
Intermediate/raw goods	288	144	72
Finished goods	374	187	93.5
Perishable consumer goods	128	64	32

A sensitivity index is used to quantify the sensitivity of the results (vehicle-hrs and vehicle-kms savings) to changes in the average trip length. The sensitivity Index (SI) is calculated as $SI = \left| (\mathrm{Dmax} - \mathrm{Dmin})/\mathrm{Dmax} \right|$ where, Dmax and Dmin represent the maximum and minimum output values respectively, resulting from varying input parameter over two extremes (Hamby, 1994). Values close to one implies that output variable is correlated to the average trip lengths.

6.4.1 System Analysis

Figure 6.18 are the graphs of the absolute and percentage freight vehicle-kms savings to the system obtained from dry port case 3 and 4 with the alternative average trip length scenarios. The absolute savings represents the freight vehicle-km or freight vehicle-hrs savings presented by the dry port case. The percentage savings is the absolute savings as a percentage of the equivalent base-line scenario. Table 6.5 includes the sensitivity index of the saving associated with the alternative average trip length scenarios.

It is observed that the dry port case 3 (dry port with FDS) is sensitive to the average trip length with a 100% increase in trip length leading to up to 25% increase in network savings. Particularly, it can be observed that the absolute savings vary by up to ±29% with a variation in the average trip length. On the other hand, case 4 (dry port without FDS) is not

significantly sensitive to the average trip length with a 100% increase in trip length leading to up to 0.6% increase in savings. This pattern is linked to the concept of the FDS which is a service that allows importers send goods directly to their various distribution warehouses for sale or use. This service eliminates the initial diversion through the consignee yards and so reduces the total travel distance and time of the goods. The further away the warehouses are from the consignee yards, the more savings can be made and vise versa. While the trip length may influence the absolute value of savings provided by case 3 it has no impact on case 4 as the travel distance of SCLs between the baseline case and the dry port test cases (case 4) remain the same. This is because containers are sent to the consignee designated yards as in the do-nothing reference scenario and the average trip lengths remain constant.

On the other hand, the percentage saving, for both case 3 and case 4 are found to be sensitive to the average trip length (row 2 of Figure 6.18). While for case 4 the assumed average trip length has almost no effect on the absolute savings presented, the percentage savings changes by up to ±0.3 in value which is up to ±13% in terms of the relative percentage change. The relative percentage savings represents the change in saving relative to the savings obtained from the initially assumed trip length scenarios. The percentage saving for case 3 is also found to be sensitive to the average trip length with changes found to be up to ±3 in value which is up to ±20% in terms of the relative percentage change.

In general, the percentage savings from case 4 are found to increase with a decrease in the average trip length while the percentage savings for case 3 are found to increase with increase in the average trip length. These patterns are linked to the change in total trip lengths and the absolute savings available. For example in case 3, an increased average trip length presents higher savings but also a higher total vehicle trip length in the do-nothing reference scenario which influences the magnitude of the percentage savings. On the other hand, in case 4, although absolute saving do not increase substantially, an increase in average trip length increases the total trip length in the do-nothing reference scenario substantially thus, leading to a decrease in percentage savings.

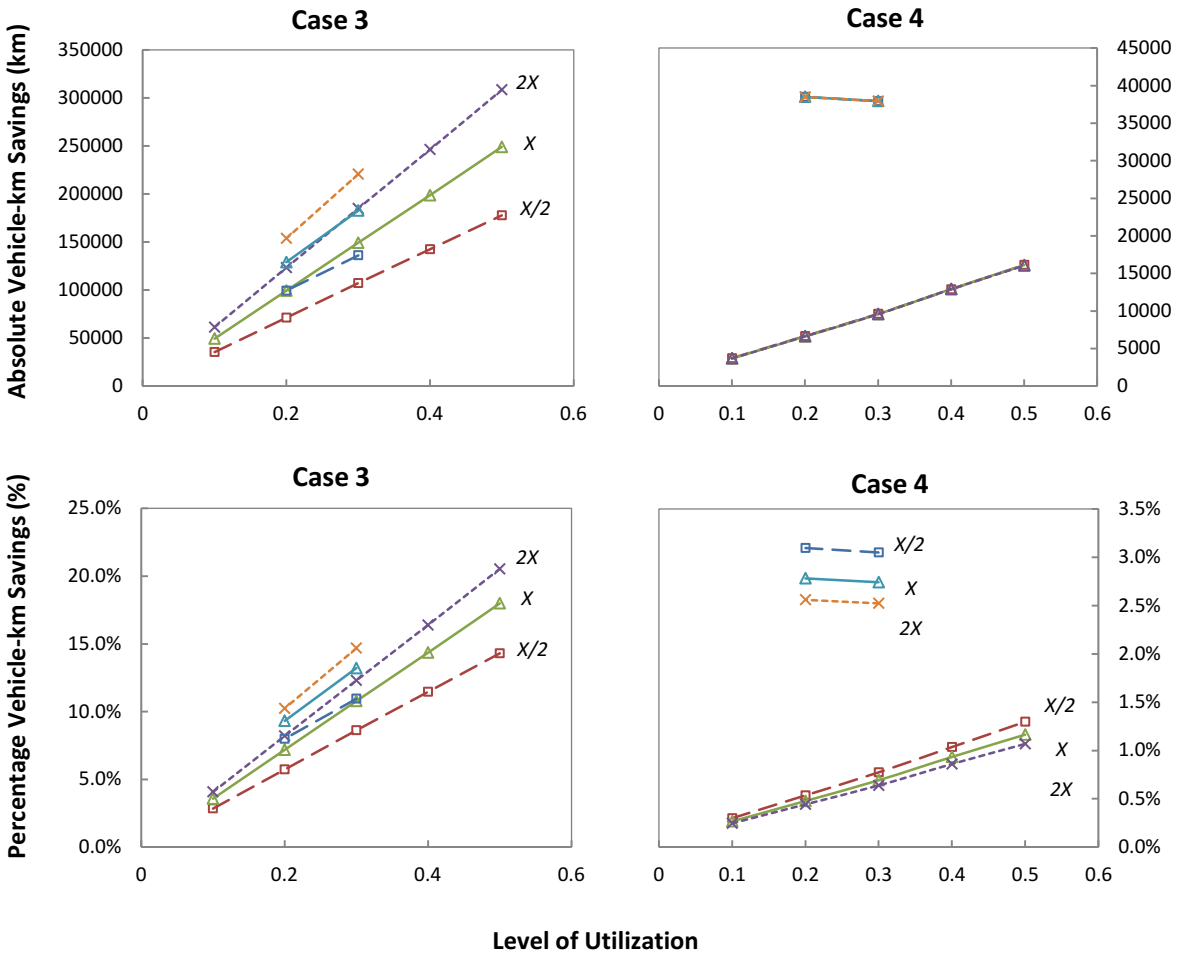


Figure 6.18: Absolute and percentage freight vehicle-kms savings to the system against the level of utilization

Table 6.5: Sensitivity Index by dry port case

	Sensitivity index for absolute savings						
	Satellite					Load centre	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.38	0.39	0.38	0.38	0.39	0.34	0.34
Case 4	0.04	0.02	0.03	0.03	0.02	0.01	0.01

	Sensitivity index for percent savings						
	Satellite					Load centre	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.25	0.26	0.24	0.25	0.26	0.20	0.16
Case 4	0.10	0.19	0.21	0.20	0.20	0.17	0.18

6.4.2 Route Analysis

Figure 6.19 includes graphs of the absolute and percentage freight vehicle-kms

savings to routes from ports for the three average trip length scenarios and Table 6.6 includes the sensitivity index of the savings associated with the average trip length scenarios. Figure 6.20 includes graphs of the absolute and percentage freight vehicle-kms savings to routes leading to ports from the alternative average trip length scenarios and Table 6.7 includes the sensitivity index of the saving associated with the alternative average trip length scenarios. Figure 6.21 is the graph of the absolute and percentage savings to routes from zones in the port city the for the three average trip length scenarios and Table 6.8 includes the sensitivity index of the saving associated with the average trip length scenarios. Figure 6.22 is the graph of the absolute and percentage savings to routes to ports for the three average trip length scenarios and Table 6.9 includes the sensitivity index of the saving associated with the alternative average trip length scenarios.

It is observed that the absolute and percentage savings for routes to and from port presented by both dry port cases does not significantly change with changes to the average trip length (Figure 6.19 and 6.20). Specifically, the percentage savings changes by up to ±1.2 in value which is up to ±5% in terms of the relative percentage change in savings. The relative percentage change in savings represent the change in savings relative to the savings obtained from the initially assumed trip length scenarios.

On the other hand, it is observed that the savings for routes to and from zones in the port city are more sensitive to changes to the average trip length (Figure 6.21 and 6.22). For case 3 (dry port with FDS), the absolute savings for routes from the port city vary by up to ±16% and the percentage savings vary by up to ±1.4 with a change in the average trip length. Also, for routes to the port city, it is observed that the absolute savings vary by up to ±50% while the percentage savings vary by up to ±8 with a change in average trip length. In contrast, for case 4 (dry port without FDS), the absolute savings are shown to be less sensitive (Table 6.8 and 6.9), with the absolute savings changing by less than ±3%. On the other hand, the percentage savings are more sensitive with savings changing by up to ±13%, in terms of the relative percentage change in savings, with a change in the average trip length. This represents a value change of up to ±0.3% in percentage savings. This pattern is similar to that observed in the system analysis and has been linked to the elimination of the initial diversion through the consignee yards by the inclusion of an FDS thus leading to a reduction in the total travel distance and time of the goods. The same pattern is observed for routes to zones in the port city and from the freight vehicle-hrs savings.

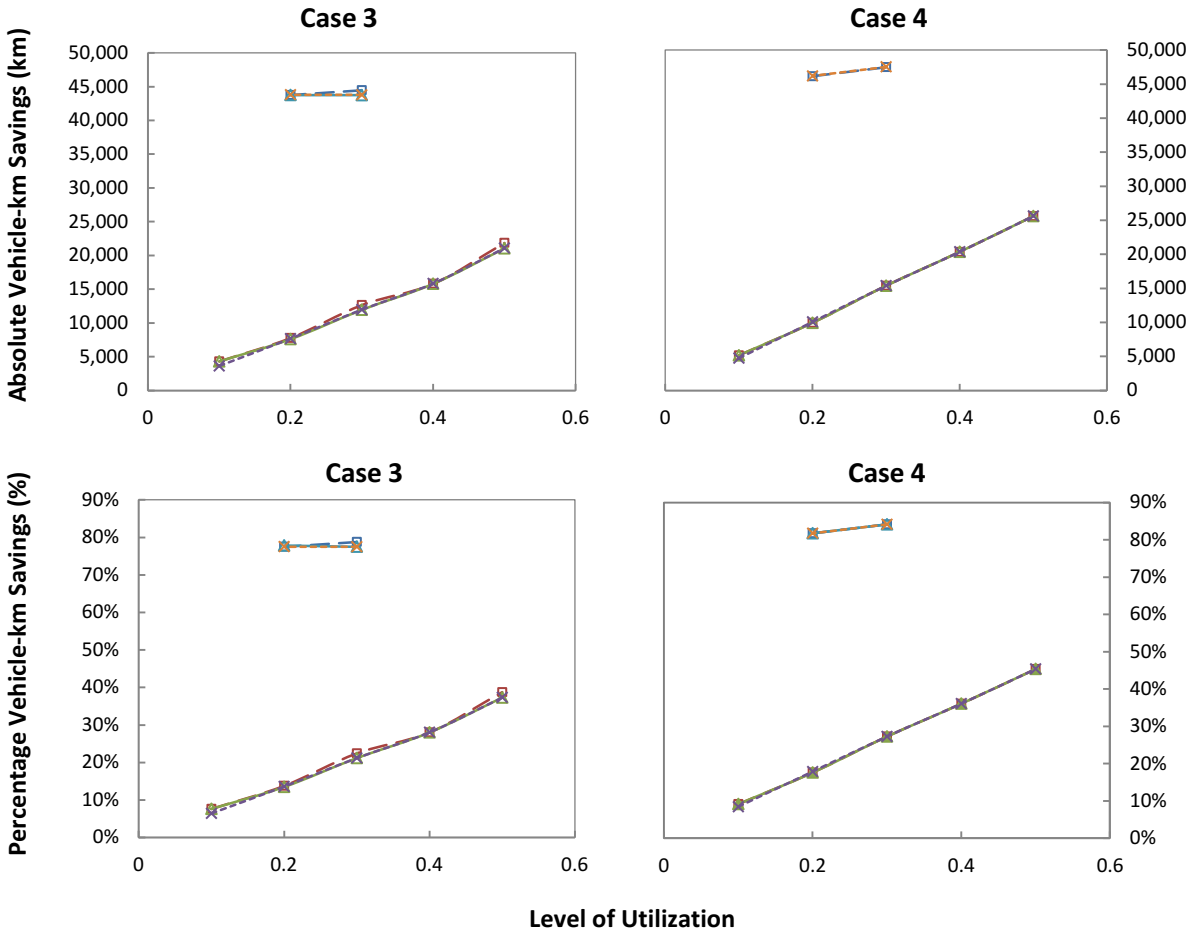


Figure 6.19: Absolute and percentage freight vehicle-kms savings for routes from ports against the level of utilization

Table 6.6: Sensitivity Index by dry port case

	Sensitivity index for absolute savings						
	Satellite					**Load centre**	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.06	0.05	0.02	0.03	0.02	0.01	0.01
Case 4	0.11	0.07	0.03	0.03	0.02	0.01	0.01

	Sensitivity index for percent savings						
	Satellite					**Load centre**	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.07	0.04	-0.03	0.02	0.03	0.02	0.00
Case 4	0.02	0.06	0.03	0.02	0.01	0.00	0.00

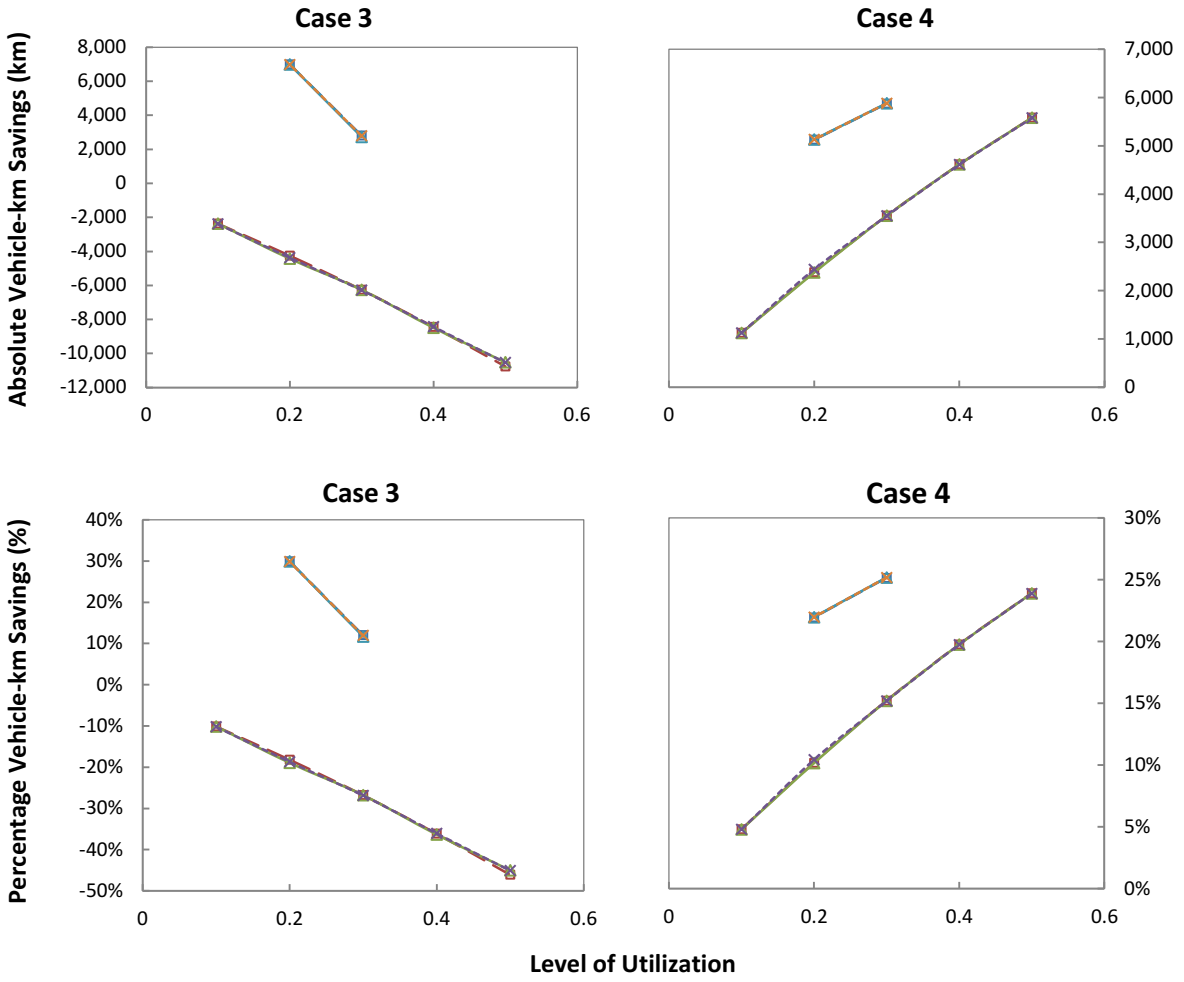


Figure 6.20: Absolute and percentage freight vehicle-kms savings for routes to ports against the level of utilization

Table 6.7: Sensitivity Index by dry port case

	Sensitivity index for absolute savings						
	Satellite					**Load centre**	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.01	0.03	0.00	0.00	0.02	0.01	0.01
Case 4	0.00	0.03	0.00	0.00	0.00	0.00	0.00

	Sensitivity index for percent savings						
	Satellite					**Load centre**	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.01	0.03	0.00	0.00	0.02	0.01	0.00
Case 4	0.00	0.03	0.00	0.00	0.00	0.00	0.00

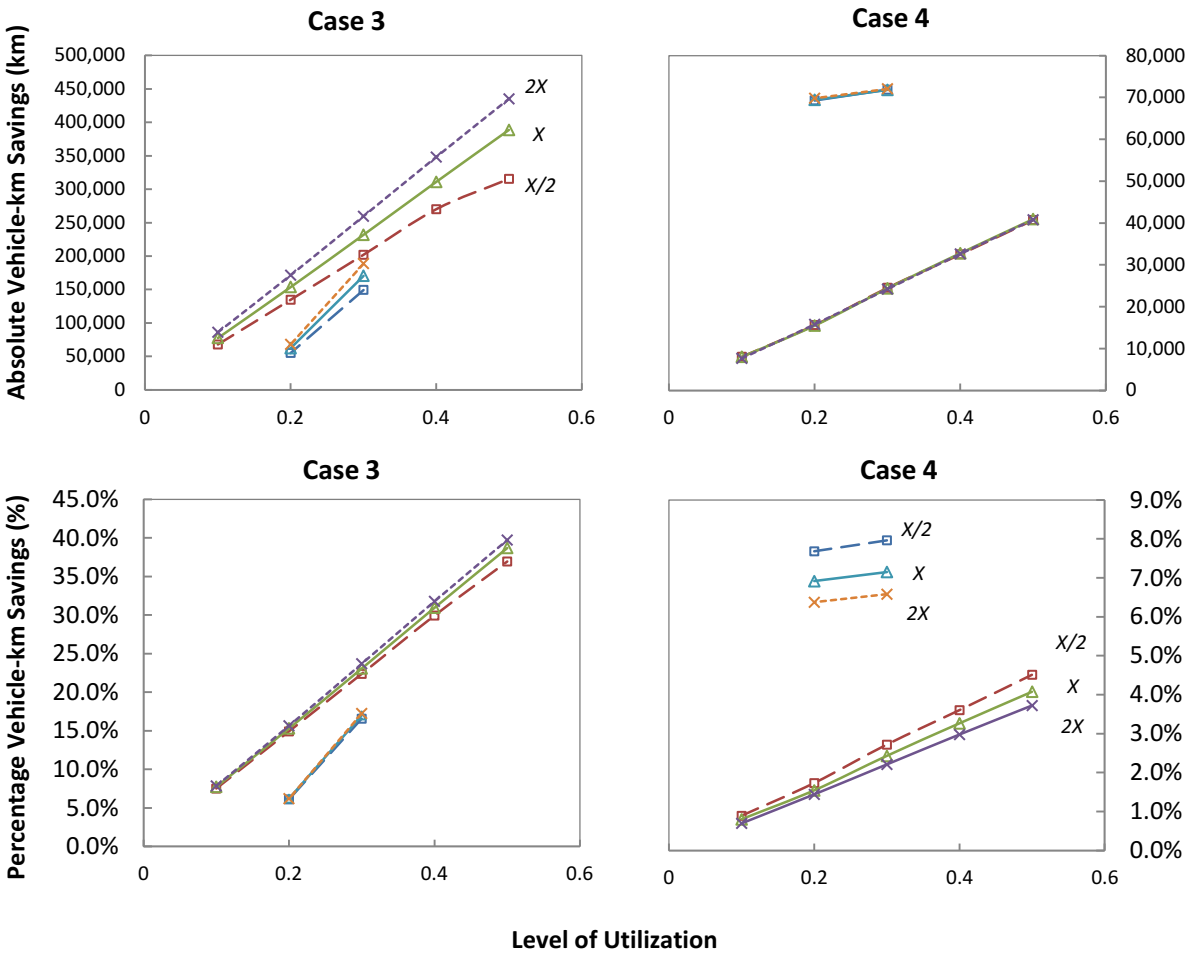


Figure 6.21: Absolute and percentage freight vehicle-kms savings for routes from zones in port city

Table 6.8: Sensitivity Index by dry port case

	Sensitivity index for absolute savings						
	Satellite					**Load centre**	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.21	0.22	0.22	0.22	0.28	0.21	0.21
Case 4	0.00	0.01	0.01	0.00	0.00	0.00	0.00

	Sensitivity index for percent savings						
	Satellite					**Load centre**	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.04	0.05	0.06	0.06	0.07	0.04	0.02
Case 4	0.22	0.17	0.19	0.17	0.18	0.17	0.17

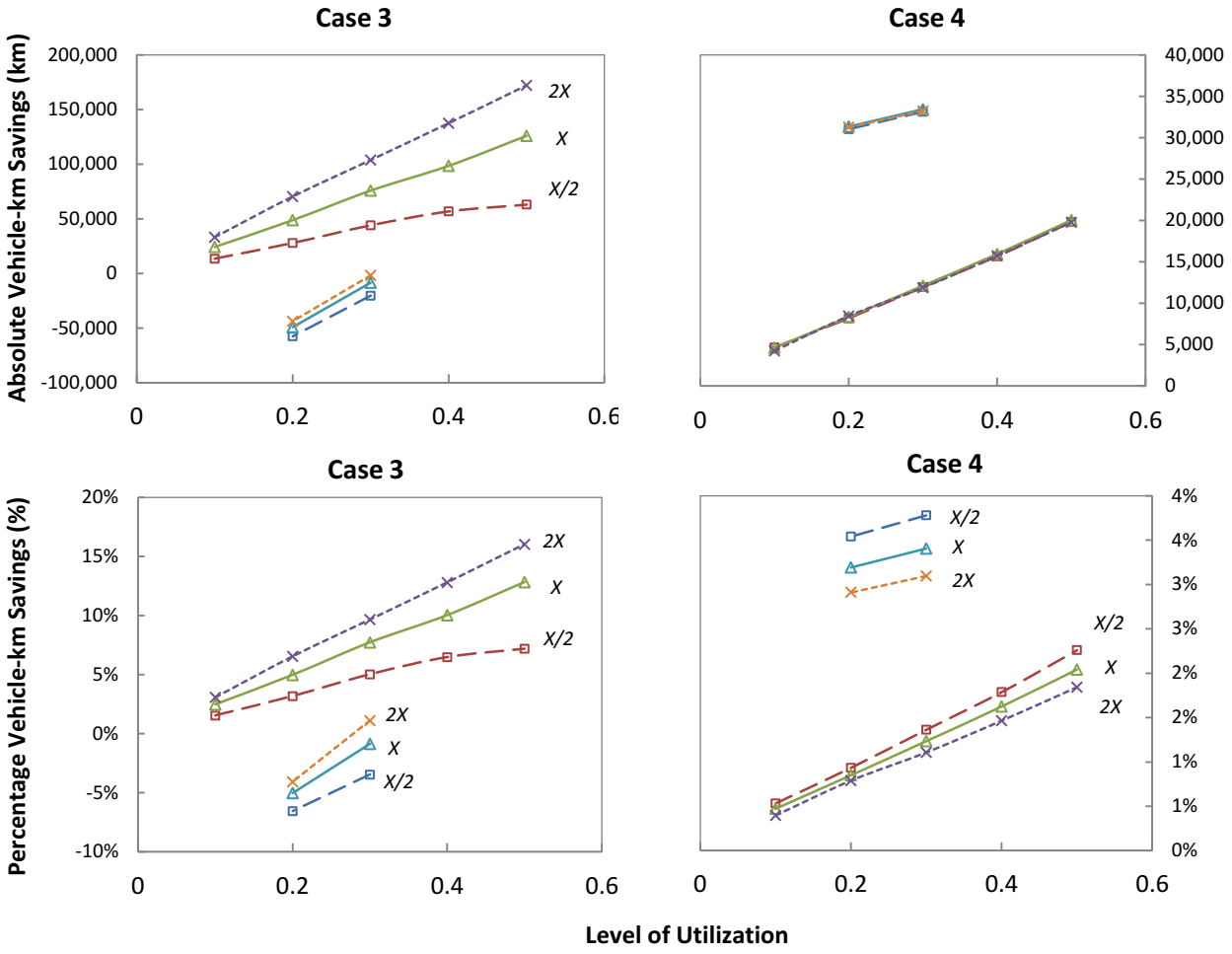


Figure 6.22: Absolute and percentage freight vehicle-kms savings for routes to zones in port city.

Table 6.9: Sensitivity Index by dry port case

	Sensitivity index for absolute savings						
	Satellite					Load centre	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.59	0.60	0.58	0.59	0.63	0.91	0.24
Case 4	0.00	0.03	0.01	0.00	0.00	0.00	0.00

	Sensitivity index for percent savings						
	Satellite					Load centre	
	0.1	0.2	0.3	0.4	0.5	0.3	0.2
Case 3	0.50	0.52	0.48	0.49	0.55	1.32	0.61
Case 4	0.26	0.16	0.19	0.18	0.19	0.18	0.18

6.4.3 Implication of Findings

This section considers the impact of the assumed average trip length of Stripped Container Loads on the obtained findings. It has been found that routes to/ from port, unlike routes to/from the port city, are not significantly sensitive to changes in the average trip lengths. The results show the benefit obtained from the dry port with FDS decreases with a decrease in SCL average trip lengths. The implication of this is that shorter trip lengths from consignee yard to distribution warehouse will lead to improved benefits from the dry port as the case with longer inter-zonal SCL trips lengths presents lower benefits. This pattern is the same at all levels of utilization. This finding suggests that the magnitude of the benefit presented by the FDS to the road network is influenced by the distribution patterns of individual importers. However, while the trip length has been shown to influence the magnitude of savings provided by the dry port with FDS, it does not appear to affect the general pattern of the benefit of the inclusion/exclusion of a Freight Distribution Service. Except for routes to and from ports, the case with FDS presents benefits higher than those provided by the case without FDS (case 4). However, as the average trip length decreases, the difference between the benefits presented by both dry port cases (with and without FDS) reduces. A linear increase (2x) or decrease (x/2) changes the difference by up to 4% and 6% for the overall system and routes to and from port respectively.

6.5 Implications and Overview of Findings

Table 6.10 to 6.12 summarises the key findings relating to the freight vehicle-kms savings obtained from the varying dry port solutions in the study and observed at different aggregate levels of the road network. The savings are given as a percentage of the do-nothing reference case and the freight vehicle-km associated with this is included in Table G.1 of Appendix G. Table 6.10 outlines the percentage freight vehicle-kms savings obtained by diverting an additional 10% of port traffic to a dry port with varying characteristics. Table 6.11 includes the percentage freight vehicle-kms savings obtained by diverting the maximum tested percentage of port traffic (50% for satellite allocation mechanism and 30% for load centre allocation mechanism) to a dry port with varying characteristics. Table 6.12 includes the range of the difference in the savings brought about by the inclusion and

exclusion of two operational variables in the dry port solution namely, an Empty Depot Service (EDS) and a Freight Distribution Service (FDS), and the container allocation mechanism employed (Satellite or Load centre). The lower values present the minimum deviation in the savings which is mostly obtained at lower dry port utilization while the higher values present the maximum difference in the savings which is mostly obtained at the highest dry port utilization level.

It is clear that the savings achievable by the implementation of such a dry port may increase with increase in the usage of the dry port and the magnitude of this increase depends on the characteristics of the dry port and also on the part of the network being assessed. For example, routes to and from ports have been observed to benefit from the highest freight vehicle-km and freight vehicle-hrs savings. However, the dry port solution was found to present comparatively lower savings to the system as a whole (Table 6.10).

It is found that the close dry port can provide a network savings of up to 80% depending on the level of dry port usage, the services provided within the facility and the operational function of the facility. Particularly, it has been shown that the network savings are most sensitive to the inclusion of a Freight Distribution Service within the dry port. As seen in Table 6.12, a benefit of up to 52% more can be attained by the inclusion of such a facility. On the other hand, the benefits are less sensitive to empty depot variable. While some routes have been shown to benefit more from the inclusion of an empty depot facility within the dry port, others have not. Furthermore, the difference between the benefits with or without empty depots has in most cases been found to be marginal. It is therefore worth noting that in a case where there is a restriction of space, priority should be given to the inclusion of an FDS as oppose to an empty depot.

The results show that the benefit of the dry port varies depending on the part of the network being accessed. The dry ports with an FDS are shown to provide savings of up to 20% to the system and up to 39% to routes to and from the city. However, much higher benefits of up to 78% are observed for routes to and from port and up to 40% on approach to port. The benefit presented by a dry port without FDS is almost insignificant to the system and to routes to and from zones with benefits reaching up to 7%. However, such a solution can provide much higher benefits of up to 84% for routes to and from ports and up to 35% on link approaches to and from the ports.

Table 6.10: Increase in savings with utilization of dry port

Increase in percentage freight vehicle-kms savings by diverting 10% of port container traffic to dry port											
		System		**Route from port**		**Route to port**		**Route from port city**		**Route to port city**	
		Load centre	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**
EDS	with	-0.4	0.3	3.0	9.4	1.6	8.0	0.3	0.7	0.1	0.7
	without	-0.2	0.1	3.0	9.4	3.2	4.1	0.3	0.8	0.2	0.4
FDS	With	5.0	5.0	0.0	6.8	11.0	10.4	8.2	8.0	11.1	17.0

Table 6.11: Percentage savings at the highest level of dry port usage (%)

		System		**Route from port**		**Route to port**		**Route from port city**		**Route to port city**	
		Load centre	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**
EDS	with	3	0	84	46	68	38	7	4	7	3
	without	3	1	84	45	25	24	7	4	3	2
FDS	With	15	20	78	37	68	52	17	39	18	33

Table 6.12: Range of change in percentage savings with change in variables

	System		**Route from port**		**Route to port**		**Route from port city**		**Route to port city**	
	Load centre	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**	**Load centre**	**Satellite**
EDS	0 - 1	0 - 1	0 - 1	0 - 1	43 - 44	5 - 14	0	0	3 - 4	0 - 1
FDS	7 - 11	3 - 18	2 - 7	2 - 8	50 - 52	5 - 18	0 - 10	7 - 35	4 - 15	8 - 39

It has been found that the benefit of the dry port varies depending on the operational function of the dry port. While benefits are obtained when the dry port is provided to serve everyone (satellite case), the dry port presents more benefit to all routes when it serves only consignee located in zones beyond the city (load centre case). Particularly, the close dry port presents up to 40% higher benefits by functioning as a load centre to zones beyond the city (Table 6.11). The increased benefit presented by the load centre mechanism has been linked to a decrease in the road travel distance of container trips destined to zones outside the port city as they are routed through the rail line to the dry port. This encourages the need for a logistic system which ensures that only containers destined to such areas are diverted to the dry port. This can be possible with improved communication and transparency between the shipping lines and terminal operator to ensure that such containers are optimally positioned within the vessel to ensure efficient transfer and handling at shore and rail sidings. While this may be challenging, the achievable savings encourage the need to try. On the other hand, this may not be totally viable as there are many other factors affecting ship stowage plans and doing so could create problems in other parts of the logistics chain.

While the literature review in Chapter 2 suggests that port cities housing majority of import containers, employ close dry port solutions that serve the city for mitigating congestion, this study suggest that a close dry port serving regions beyond the port city presents more benefits to the network. The fact that a higher benefit is achieved by serving consignees in zones outside the city only, may justify moving the dry port further away from the port city with the purpose to serve the regions beyond Lagos only.

Furthermore, the results have shown that the network benefits of including a Freight Distribution Service within the dry port vary with individual importer's distribution patterns. Specifically, it is found to be influenced by the location of the trailer parks serving the dry port and the average trip length of trucks carrying stripped container loads (SCLs). A case where importers use their own vehicles or lease from within individual zones presents higher benefits while the perceived benefit of the dry port with an FDS is higher where longer inter-zonal SCL trips occur between the importers and the point of use or redistribution.

Another key finding is that the existence of road-only off-dock terminals with full customs clearance facilities in the logistic chain magnifies the road congestion and the dry

port solution provides a better alternative to this arrangement as it presents higher benefits. While off-dock terminals increase the capacity of port terminals, their use has been shown to be detrimental to the efficiency of the road network since these off-dock terminals are not rail connected. This finding supports the localization of such inland terminals that service the port to areas outside the city and shows the importance of an intermodal connection to service the link between the seaport and such a facility. Furthermore, when the off-dock terminals are converted to empty depot, providing an empty depot service at the dry port becomes detrimental to the network. This finding suggests that in the case of Lagos, a maximum network benefits can be attained by converting existing off-dock terminals to empty depots and developing the dry port to handle only empty container generated from the Freight Distribution Service provided within the facility.

The data included in Table 6.10 to 6.12 can be multiplied by the freight vehicle-kms savings from the do-nothing reference scenario (Table G.1 of Appendix G), to give the absolute value of the relevant network savings. These results are obtained from extreme cases and so represent maximum limits. For example the case with FDS represents a scenario in which all containers arriving at the dry port are stripped within the facility. While this may be an extreme scenario and may not necessarily be realistic, the benefits available in reality would lie within the extremes identified. These findings relate particularly to close dry port solution geographically located at the rim of the port city. The findings are applicable to import oriented port cities with majority of import containers destined first for areas in the city before redistribution to areas beyond the city. This situation is particularly common for developing port cities with a population that accounts for a minor part of the national population.

The modeling framework developed in this thesis can be applied by other port cities in developing countries. With respect to the transferability of findings, the absolute values from the model would vary depending on the specific case study. However, general patterns relating to characteristics necessary to improve the benefit of the dry port is expected to be similar for port cities in developing countries having their ports to the south of the country.

Chapter 7

Conclusions

In the final chapter of this thesis, the objectives of the research are revisited and results are summarised. Based on the findings of this thesis, the chapter concludes by outlining areas for further research.

7.1 Revisiting Objectives and Research Questions

At the beginning of this thesis, a number of research objectives were drawn:

1. Review and compare dry port solutions presently employed in a number of port cities around the world, with the aim to determine the similarities and differences between the dry pot strategies employed and identify the characteristics that make them effective in reducing road network congestion within the port city.
2. Propose a framework for modelling freight transport in developing countries. That builds outwards from a conventional urban traffic modelling approach by integrating an element of supply chain modelling and applies a generalised cost function within the traffic assignment to account for factors which influence freight routing decisions in a developing country.
3. Quantify the ability of close dry ports to reduce congestion while considering the impact of its characteristics on its ability to do this through the reduction and re-direction of container-related traffic volumes in a road network.

Objective 1 is fulfilled in Section 2.2 where it is found that dry port solutions employed in congested port cities are characterised by the provision of a combination of basic added value services. Most commonly these are empty depots and warehousing for distribution and consolidation. The size and capacity of the dry port facilities are found to be strongly related to the characteristics of the trade structure including the port's throughput and the volumes of transhipment and empty containers. Furthermore, for congested port cities the dry port solutions are found to be located close to major consumption and production regions, and so act as load centres to these areas which house the port's main customers.

Objective 2 is fulfilled in Section 4.2 where the frame work for the model employed in this study is presented. The model focuses on the effect of container-related cargo trips derived from an understanding of the container logistics process.

The proposed framework can be considered under two levels; the demand level and the transport and supply level. The demand level relates to estimating trip matrices for the container-related traffic and estimating the volumes of non-container related traffic on links. The transport and supply level constitutes the link generalised cost function and the algorithm associated with the traffic assignment model. The World Bank's HDM-vehicle Operation Cost functions are integrated within the assignment model to capture factors that influence freight routing choice in developing countries like Nigeria.

The traffic assignment model proposed is a multiclass assignment model where each container-related vehicle class is associated with an individual generalised cost function and at the same time contributes to the cost function of the other vehicle classes. The generalised cost function constitutes of the vehicle operating cost and travel time cost components which are used to measure the resistance perceived by a trucker as a hindrance to his journey through links in the road network of Nigeria. The World Bank's HDM IV model is used for calculating the vehicle operating costs under the developing country's road conditions. Non-container related traffic are input as exogenous variables for each link (in PCU's) and are estimated using a simple regression model. The classes of traffic combine on links in proportion to their PCU values leading to congestion when flow is near capacity. It is assumed that each class of vehicle carrying container-related cargo always chooses the route that minimises the truck operator's cost.

It is acknowledged that a stronger model would have been obtained if all trips had been modelled in full. However, time and monetary restrictions meant that this could not be achieved and some approximations had to be made. Furthermore, the analysis in this study is concerned with container movement only, and so the model is developed to focus on this aspect. Other freight trips are categorised with non-freight trips under a single class termed "non-container related trips". The framework allows for an analysis of the impact of a container logistic pattern on freight demand within a transport system. The process can also be applied to other key cargo packages originating from the ports.

Objective 3 is addressed through a comparative analysis of a hypothetical case study. A number of research questions were outlined to address this objective and the following paragraphs provide a summary of the findings with regards to each question.

Question 1: How effective are close dry ports in reducing congestion?

The close dry port referred to in this study is located at the rim of the port city. Such

a dry port has been found to reduce congestion to a varying level in different parts of the network. The dry port is found to be most effective in reducing congestion (producing the highest benefit) along routes to and from the ports and in the vicinity of the port. Particularly, potential savings of up to 84% can be achieved on routes to and from ports with the benefits varying with the adopted operational strategy and the level of dry port utilization. Lower benefits are achieved if considering a wider number of routes in the road network. For routes from and to the zones in the port city, the close dry port is found to provide saving of up to 40% again depending on the operational functions and the level of dry port utilization. While for all routes to and from all zones in the network, the close dry port is found to provide saving of up to 20%.

The logistic benefit from container related traffic alone over estimates the network benefit of the dry port as some of the capacity freed up by shifting a proportion of freight to the dry port would accrue to non-container related traffic. However, it is clear that the highest benefits of the dry port are achieved in relation to the port surroundings and routes to and from the port. Elsewhere, the benefit the dry port provides to the congestion problems in the port city is less significant. It is therefore important to ensure that other alleviation measures are adopted in parallel to achieve an overall more significant reduction in congestion.

Question 2: How do various levels of dry port utilization affect its ability to improve network efficiency?

In general, the benefit of the dry port to the network has been found to increase with increased utilization of the dry port, implying that a high level of patronage of the dry port is crucial to achieve the required benefits. While government directives may be used to force modal shift, it can be encouraged by making considerable investments to achieve an acceptable level of maintenance and services. In a free market, a shift from road to railway can be ensured if the quality and reliability of the rail services are at par or better than those offered by road and the pricing charges are comparable. This requires both a reform of existing railway operating systems and an improvement/ consistency in the frequency of freight services provided. Specific to the case of Lagos, there would be a need to refurbish and convert narrow gauge rail lines to standard gauge and also to renovate/build new rail links and sidings to/from ports.

A solution that provides the optimal level of service and benefit to the network is

one that could be of interest to the governing bodies in Lagos but has not been included in this study. It however presents an avenue for future research.

Question 3: How do the characteristics of the dry port solution affect its ability to reduce congestion?

The dry port characteristics explored in this study are found to vary the network benefit presented by the dry port solution, albeit to varying levels. Firstly, the inclusion/exclusion of a Freight Distribution Service is found to vary the network savings by up to 52%. Specifically, it is found that the inclusion of an FDS within the dry port increases the benefit of the dry port to the network. Also, the dry port which employs a load centre mechanism and so serves importers in zones beyond the city limits only, has been found to improve its benefits by up to 40% more than when the dry ports serves the whole country (satellite mechanism). However, these savings are maximised if the majority of importers patronising the dry ports use their own vehicles or lease from within their individual zones and from zones around the dry port.

Furthermore, the inclusion/exclusion of an Empty Depot Service is found to vary the savings by up to 15% only, if the dry port serves the whole country, but up to 45% if the dry port serves zones beyond the city limit. Its impact varies largely depending on the routes analyzed. While the exclusion of an empty depot has been shown to improve benefits on certain routes, in other cases, the inclusion of an empty depot has improved benefits. The decision on whether to include an EDS should be based on the expected benefits. For port cities like Lagos facing problems with congestion in the city and on the approach to ports, the decision should be driven by the results from the route level analysis, which suggests that the inclusion of Empty Depot Services increases the benefit of the dry port. These findings show the importance of carrying out such analysis in port cities to determine the specific characteristics of the dry port that magnify its benefits

Specific to the case of Lagos, the stemming function of the off-dock terminals within the container distribution system is found to present a negative benefit to the road network. While the off-dock terminals increase the capacity for port terminals its use is detrimental to the efficiency of the road network. Eliminating these off-dock terminals will magnify the benefit of the dry port. Furthermore if the off-dock terminals are converted to empty depots, providing an empty depot service at the dry port may become detrimental to the network. These suggest that higher benefits can be attained by converting existing off-

dock terminals to empty depots and developing the dry port to handle only empty container generated from the Freight Distribution Service provided within the facility.

However, in a situation where off-dock terminals are not converted, it is most beneficial to ensure that the dry port is used by consignees located beyond the city limits or located within a closer proximity to the dry port than the port.

Question 4: What if any are the negative effects of dry ports?

While the dry port solutions explored are found to provide benefits to the network, some negative impacts were observed. Mainly, it is found that the dry port presents adverse effects on links on the approach to the dry port. While the containers have been diverted away from the city centre causing a reduction in container-related volumes on route to/from the port, the act increases the volumes on routes to/from the dry port facility as it becomes a new trip generation point to the network. This suggests that the dry port solution simply shifts a congestion problem from one location in the network (port vicinity) to another (dry port vicinity). Although the dry port solution might create congestion around the dry port, it reduces congestion across the network as a whole.

Where such a facility is planned to be a long term solution, it is paramount therefore that transport/government officials endeavour to locate such facilities in areas with little existing congestion problems especially on routes on leading to the dry port. Such facilities should be ideally located in areas with little existing activities. Of course, although this may help with congestion in the immediate vicinity of the dry port it could also lead to longer journey distances as such a location may likely be more distant from existing importers.

Question 5: Finally, what are the implications of the results for the choices available to decision makers?

In general, given the location for the dry port, it is clear from these findings that the network benefits can only be maximized within an ideal set of characteristics. These refer to the functions of the dry port, the services to be provided and the minimum capacity for which to design the dry port and its intermodal connections.

The process outlined in this research can be used to identify the dry port characteristics to be set out in a situation once the dry port location has been selected. It can be used by policy makers to explore the various levels of dry port utilization and characteristics required to reduce congestion in port cities. It can then be used to determine

the required capacities relating to rail, site area and equipment. Thus, this thesis presents a method which governing bodies can use to identify the specifications and characteristics that should be in place for a dry port solution to improve the efficiency of freight transportation and reduce congestion in the port city.

Dry port solutions, as a measure for mitigating congestion, are likely to be opposed by road transport operators and the owners of unimodal inland terminals (such as off-dock terminals) who favour arterial priority schemes, dedicated lanes for port access and longer port operating hours. This is due to the direct effects the dry port solution may have on their customer base. It is the place of the governments who control the port authorities to set out strategies and policies that govern the dry port operations and have a positive impact on the transport network.

The magnitude of the network benefits identified are specific to the case of Lagos Nigeria however, findings relating to the relative benefits of the including or exclusion of the explored operational characteristics can be related to import oriented port cities with majority of import containers destined first for areas in the city before redistribution to areas beyond the city. A situation which is particularly common for developing port cities with a population that accounts for a minor part of the national population.

The research findings support the implementation of dry ports as a measure for reducing congestion in port cities. It quantifies the impact of dry port characteristics on the benefit of a dry port. These findings are significant as they highlight the importance of selecting the right configuration of dry port strategies.

The main limitations of the research relate to the methods for collecting data used in the model and the basis on which model assumptions are made. Firstly, proportions used in the model are based on gate and road traffic count often carried out over a short periods of time. In future work, traffic data should be collected over longer periods of time to obtain a more complete and reliable picture. Also, data should be collected through various sources to confirm completeness and reliability. Finally, as discussed in section 5.8, some assumptions (such as the approximation of trips related to laden export containers and the estimation of non-container related traffic on links) are made due to the lack of data. In future work, these assumptions may be revisited on the basis of new data. For example laden export trips can be modelled if information on the point of drop off for import to the point of collection for exports is known.

7.2 Recommendations for Further Research

While this study has made substantial contribution to the field of dry port research, there are a few points relating to further research directions which spring out of it.

- Starting with the freight transport model two aspects can be extended. Firstly, in Section 4.2, other factors such as pilfering and armed robbery are also found to present operational constraints to the freight industry and so to some extent influence route choice. Thus future work can be done to expand the generalised cost in the assignment model. Secondly, the model could be expanded to cover different cargo types - general cargo, liquid bulk and dry bulk. Each of which has its own supply chain characteristics and can be modelled using a framework similar to that employed for containerised cargo. Finally, to allow for the benefit from private traffic to be explored, an O-D matrix for private traffic could be estimated from traffic surveys and then assigned to the network along with the freight. This would need a substantial count of private vehicle flows on links in the road network.

- Related to the impact of dry port characteristics on its benefit, there is a need to find a solution that provides the optimal level of service and benefit to the network as well as one that presents the optimal combination of characteristics and the benefit to the network. This would lead to the further work of finding a solution that minimises the cost of development and operation of the dry port and maximises the benefit to the network.

- A cost benefit analysis has not been undertaken in this research as this is not the focus of the research. Where the aim of the decision maker is to define dry port characteristics that maximise the net benefits to all stakeholders, the quantified road transport benefits and other benefits such as the impact on port capacity can be compared against the capital and operating costs of the dry port and associated rail link within the framework of a cost-benefit analysis.

- The dry port solution is found to present a negative impact on some links in the network depending on their location. On such links however, these negative impacts can be eliminated with an increase in road capacity and the introduction of

alternative congestion mitigation measures. An avenue for further research therefore is to define a framework that can be employed by policy makers and infrastructure developers in developing countries in order to identify the levels of dry port usage at which it becomes necessary to increase road capacities in order to maximise congestion benefits from the dry port solution. Such a framework should be supported by a method through which such works can be prioritised.

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Appendix A: Container Port Statistics

There are two main ports in Lagos, Apapa and Tin Can Island, which lie approximately 5km apart. Each comprises a number of terminals, some of which handle mainly containers, and some of which are multi-purpose, with containers accounting for a relatively small proportion of their throughput. This appendix details the volume of containers that moved through the Lagos ports terminals between the years 2007 to 2009. It also presents a breakdown of the container import volumes in 2009 by commodity type. The data included in this appendix is sourced from Lagos port terminal operators and Nigerian Ports Authority (NPA).

Table A.1: Lagos port terminals throughputs (2009)

Port		Inward (TEUs)		Outward (TEUs)		Terminal throughput (TEUs)	Market Share (%)
	Terminal	**Laden**	**Empty**	**Laden**	**Empty**		
Apapa	ABTL	328	-	-	-	328	0.0
	ENL	301	-	-	-	301	0.0
	APMT	226,859	-	24,387	196,713	447,959	49.4
	GDNL	12	-	-	382	394	0.0
Tin Can Island	Joseph dam Ltd	112	-	-	-	112	0.0
	TICT	127,751	-	23,143	68,674	219,568	24.2
	Port and Cargo	72,834	-	12,509	46,295	131,638	14.5
	Five Star Logistics	27,605	-	1,456	15,080	44,141	4.9
	PTML	31,902	-	9,224	22,082	63,208	7.0
	Total	487,704		70,719	349,226	907,660	100

Table A.2: Container traffic statistics Apapa port terminal (2008)

Month	**Inward**				**Outward**			
	Laden		**Empty**		**Laden**		**Empties**	
	20F	40F	20	40	20F	40F	20F	40F
January	12,199	7,124			1,013	211	6,696	4,253
February	8,488	4,622			961	462	5,974	4,329
March	9,386	5,542			907	393	11,074	7,416
April	10,668	6,022			1,272	537	11,995	5,964
May	11,050	6,610			1,346	1,061	10,039	5,910

June	8,581	4,999			1,160	392	6,425	5,109
July	10,014	5,186			1,172	266	9,291	4,727
August	11,302	6,745			696	568	7,884	7,392
September	10,595	6,502			744	194	13,671	6,905
October	7,005	4,422	133	158	635	204	3,784	3,078
November	10,450	6,935			777	193	9,232	6,260
December	9,503	8,074			665	336	8,926	5,885
Total	119,241	72,783	133	158	11,348	4,517	105,081	67,228

Table A.3: Import container traffic statistics Tin Can island port terminal (2008)

Month	**Terminal import traffic**						**Total**
	FIVE STAR	**TICT**	**JOSDAM**	**PCLT**	**PTML**	**KLT**	
January	515	6,997	-	4,869	1,158	-	13,539
February	294	6,874	-	6,584	1,027	132	14,911
March	113	8,786	-	6,902	1,957	123	17,881
April	303	8,855	-	5,559	1,960	-	16,677
May	70	4,605	-	5,225	635	184	10,719
June	2,147	15,973	1	9,839	1,326	151	29,437
July	716	13,646	-	7,378	1,495	303	23,538
August	1,623	11,260	-	6,158	1,851	408	21,300
September	2,101	13,045	-	8,264	1,809	74	25,293
October	2,032	11,488	-	7,453	2,056	84	23,113
November	3,742	12,297	1	10,028	2,662	420	29,150
December	5,205	25,546	8	13,819	2,791	153	47,522
Total	18,861	139,372	10	92,078	20,727	2,032	273,080

Table A.4: Container traffic statistics Apapa port terminal (2007)

Month	**Laden**				**Empty**			
	APMT	**GDNL**	**ABTL**	**ENL**	**APMT**	**GDNL**	**ABTL**	**ENL**
January	19,201	-	-	5	16,607	-	-	-
February	17,021	-	-	18	19,336	-	-	-
March	15,352	-	-		16,900	-	-	-
April	12,587	-	-	701	13,035	-	-	53
May	18,358	5	-	-	22,761	-	-	-
June	12,839	-	-	12	13,854	-	-	-
July	20,569	-	209	26	20,530	-	-	-
August	21,467	-	-	-	21,504	-	-	-
September	21,344	-	-	-	23,354	-	-	-
October	24,110	-	18	-	14,344	-	-	-
November	18,479	-	6	2	20,833	-	-	-
December	20,185	-	48	9	24,829	-	-	-
Total	221,512	5	281	773	227,887	-	-	53

Table A.5: Import Container traffic statistics Tin Can island port terminal (2007)

Month	Terminal import traffic						Total
	FIVE STAR	TICT	JOSDAM	PCLT	PTML	KLT	
January	591	11,253	-	6,590	2,811	280	21,525
February	396	2,488	-	1,871	3,046	184	7,985
March	532	8,834	-	2,972	2,141	138	14,617
April	-	9,851	-	65	2,806	246	12,968
May	3,719	8,194	-	3,068	2,071	650	17,702
June	94	6,303	-	5,003	2,228	143	13,771
July	5,707	12,245	-	3,864	2,134	-	23,950
August	410	8,230	-	3,024	3,968	-	15,632
September	1,934	10,703	-	4,698	1,568	257	19,160
October	792	7,724	-	3,183	3,990	144	15,833
November	1,829	9,164	-	6,194	3,234	698	21,119
December	1,433	10,132	-	4,295	3,131	-	18,991
Total	17,437	105,121	-	44,827	33,128	2,740	203,253

Table A.6: Classification of import commodities (2009)

Commodity	2009 (TEUs)	Commodity category
INDS RAW MATERIALS	69,488	I
ELECTRICAL MATERIALS	55,444	F
VEHICULES & ACCESSORIES	37,015	F
CERAMICS TILES;MARBLES;	31,340	F
MACHINES/EQUIPMENTS	27,490	I
VEH.SPARE PARTS.& ENGIN	25,379	F
CHEMICAL PRODUCTS	23,555	I
MANUFACTURED PRODUCTS	19,562	F
PAPER & PAPER PRODUCTS	17,942	F
TYRES,TUBES & WHEELS	16,410	F
VARIOUS SPARE PARTS	14,006	F
MILK AND DAIRY PRODUCTS	13,751	C
FOOD PRODUCTS	12,506	C
STEEL	12,170	I
ALUMINIUM/PRODUCTS	11,706	I
PVC PRODUCTS	8,158	I
PHARMACEUTICAL PRODUCTS	7,593	C
MOTORCYCLES	7,421	F
GLASSWARE	5,390	F
CONSTRUCT.MATERIALS	5,276	I
METAL & METAL PRODUCTS	5,073	I
HOUSEHOLD ITEMS	4,556	F
TRUCKS CATERPILLAR CRAN	4,437	I
RICE	3,834	C

FROZEN SEAFOOD	3,617	C
TELECOMUNICATION APPLIA	3,185	F
MALT	2,907	C
SANITARY WARES	2,636	C
PETROL PRODUCTS	2,523	F
FURNITURE PRODUCTS	2,341	F
MEDICAL APARRATUS	2,270	F
COSMETICS PRODUCTS	2,143	C
ALL TYPES OF INDUSTRIAL	2,027	I
EDUCATION MATERIALS	2,024	F
BATTERIES	1,855	F
PERSONAL EFFECTS	1,775	C
LAMINATED/PAPER SHEET	1,693	F
CIGARES/CIGARETTES	1,624	F
COMPUTER ACCESSORIES	1,616	F
NON ALCOHOLIC & FRUIT D	1,553	C
PLASTIC MATERIALS	1,535	F
TEXTILE PRODUCTS	1,526	F
BEVERAGES	1,363	C
COILS/STEELS	1,177	I
CORN	869	C
STATIONERIES	861	F
PAINTS,DYES,PIGMENTS &E	843	I
MISCELLANEOUS	823	C
OIL (EDIBLE)	765	C
Others	2,600	-

Where I – Intermediate/ raw materials, F – consumer durable goods, C – consumer perishable goods

Appendix B: Container Supply Chain Profile and Urban Traffic Congestion in Lagos

B.1 Off-dock Terminals and ICDs

This section presents a list of the 66 companies that own terminals with the right to express clearing services and the location of existing Inland Container Depots.

Table B.1: List of companies on express port clearance by Nigerian Customs Services

No	Companies with express services
1	7-Up Botling Comp. Plc
2	A.G Leventis Nigerian Plc
3	Ade-Oniagba Nigeria Limited
4	Agro & Allied chemical Ltd
5	Airline Services And Logistics
6	Allison Ltd
7	Ashaka Cem. Plc
8	Berger Paints Plc
9	Beta industries (glass/distribution)
10	Big Treat Plc
11	BUA Flour Mill, INTERNATIONAL LTD
12	Cadbury Nigeria Plc
13	Cap Plc
14	Cement Co. Of North.Nig.Plc
15	Champion Brew Plc
16	Chellarams Plc
17	Cocacola nig ltd
18	Columbia Salt
19	CONSOLIDATED BREWERIES
20	Costaim (W A) Plc
21	Cotecna Limited (Cotecna Destination Inspection Limited (CDIL)
22	Crown Flour

23	Cummins West Africa Ltd
24	Dangote Cement Plc
25	Dangote Flour Mills Plc
26	Dangote Sugar Refinery
27	Doyin Investment
28	Evans Medical Plc
29	Fidson Health Care Plc
20	First Aluminium Nig. Plc
31	Flour Mills Nig. Plc
32	Friesland Food Nig eria Ltd
33	FrigoGlass Ind. Nigeria Ltd
34	Glaxo Smithkline Con.Nig.P
35	Guinness Nigeria Plc
36	Honeywell Flour Mill Plc.
37	International Breweries
38	Ipwa Plc
39	John Holt engineering Plc
40	Julius Berger Nig. Plc
41	Lafarge Wapco Plc
42	Leventis Foods Ltd
43	May And Baker Nigeria Plc
44	Multi-Trex Intergrated Food
45	Multiverse Plc
46	N. Nig. Flour Mills Plc
47	National Salt Co.Nig.Plc
48	Neimeth International Pharmarcy
49	Nestle Nigeria Plc
50	Nig Bottling Co.Plc
51	Nigerian Aviation Handling
52	Nigerian Brew Plc
53	Nigerite Ltd
54	P Z Cussons Nigerian Plc
55	SEAGOLD Fishing Ltd
56	SGS Societe General De Surveillance S.A
57	Tantalizers Plc
58	Tarabaroz Fisheries
59	Timothy banfield
60	Transnational Corp.Of Nig
61	U A C N Plc
62	U T C Nig.Plc
63	Unilever Nigeria Plc
64	Union Diagnostic And Clinical
65	Vitafoam Nig. Plc
66	Vono Products Plc

Table B.2: List of active off-dock terminals and their container throughputs

Public off-dock terminals	No	Area	Inwards (TEUs)				Outwards (TEUs)			
			2006	2007	2008	2009	2006	2007	2008	2009
Aces bonded warehouse	15	Ilasamaja	52	87	104	120	68	95	111	126
ACS	16	Oba Akran	2,943	2,048	3,868	3,513	4,215	3,794	4,297	3,536
BCT	3	Kiri-Kiri	1,162	1,450	1,826	2,000	1,325	1,721	1,931	2,053
Comet Nigeria Limited	20	Warehouse rd	0	1,853	2,345	2,110	0	1,967	2,401	2,162
Creseada International bonded warehouse	7	Matori	3,013	2,524	2,067	2,228	3,027	2,544	2,034	2,251
CW Private bonded warehouse	15	Ilasamaja	0	76	121	140	0	62	133	159
Daddo International Ltd	1	TinCan	-	-	-	-	-	-	-	-
DENCA BONDED TERMINAL	10	Amuwo Odofin ind.	8,053	11,549	9,742	10,284	7,133	11,536	9,384	10,045
DUNCAN	2	TinCan Island	2,962	3,179	1,826	2,433	2,779	2,996	1,337	1,624
FALCON Freightlink PVT.LTD	21	Eric Moore / Iganmu	2,295	2,446	3,334	3,962	2,062	2,365	3,144	3,584
FANO	9	Amuwo Odofin	2,285	1,862	1,604	1,723				
Fenwick International	1	TinCan Island								
GMT	14	Okota / Oke Afa	2,915	3,690	3,163	3,265	3,115	3,802	3,436	3,411
Hull Blyth (HBX)	12	Kiri-Kiri	11,636	10,600	14,536	18,374	12,523	10,836	14,251	18,946
Ilasamaja bonded warehouse	15	Ilasamaja	0	48	74	100	-	0	82	110
Ikorodu Lighter Terminal warehouse		Ikorodu	-	-	-	-	-	-	-	-
JAELITH	11	Amuwo Odofin	3,236	4,058	4,676	4,985	3,655	3,134	3,774	3,525
KCT bonded warehouse	3	Kiri-Kiri	2,334	2,621	2,837	3,000	2,431	2,511	2,914	3,098
KLT 4	3	Kiri-Kiri								
MICHELLE	21	Eric Moore / Iganmu	2,187	3,292	1,593	2,347	2,201	3,280	1,746	2,386
MID Maritime services LTD	1	TinCan	2,324	2,852	3,366	3,842	2,341	2,882	3,381	3,867
MIGFO NIG.LTD	8	Ilasamaja	5,271	3,677	5,484	6,891	4,664	3,938	6,395	7,681
NACFA(National Clearing and Forwarding Agency)	3	Creek Rd	-	-	-	-	-	-	-	-
NAHACO	17	Ikeja	-	-	-	-	-	-	-	-
Odi-olowo bonded warehouse	15	Ilasamaja	0	199	258	300	0	207	267	319

Port Express Services	5	Amuwo Odofin	3,149	3,098	4,221	4,432	3,220	3,211	4,267	4,611
Ramcad warehouse	3	Kiri-Kiri	-	-	-	-	-	-	-	-
SAPID Agencies LTD	6	Surulere	3,119	2,738	2,237	2,641	-	-	-	-
SDV	13	Kiri-Kiri	0	20,881	32,049	27,143	0	19,923	32,061	28,041
SIFAX	4	Ibafon	2,602	6,396	11,511	19,667	2,634	6,511	12,011	20,521
Swift Freight International	18	Ikeja	0	63	134	100	0	72	151	113
Zeek NIG LTD	1	TinCan	-	-	-	-	-	-	-	-
Lilypond Terminals	19	Ijora	-	-	-	-	-	-	-	-
		TOTAL	61,538	91,287	112,976	125,600	57,393	87,387	109,508	122,169

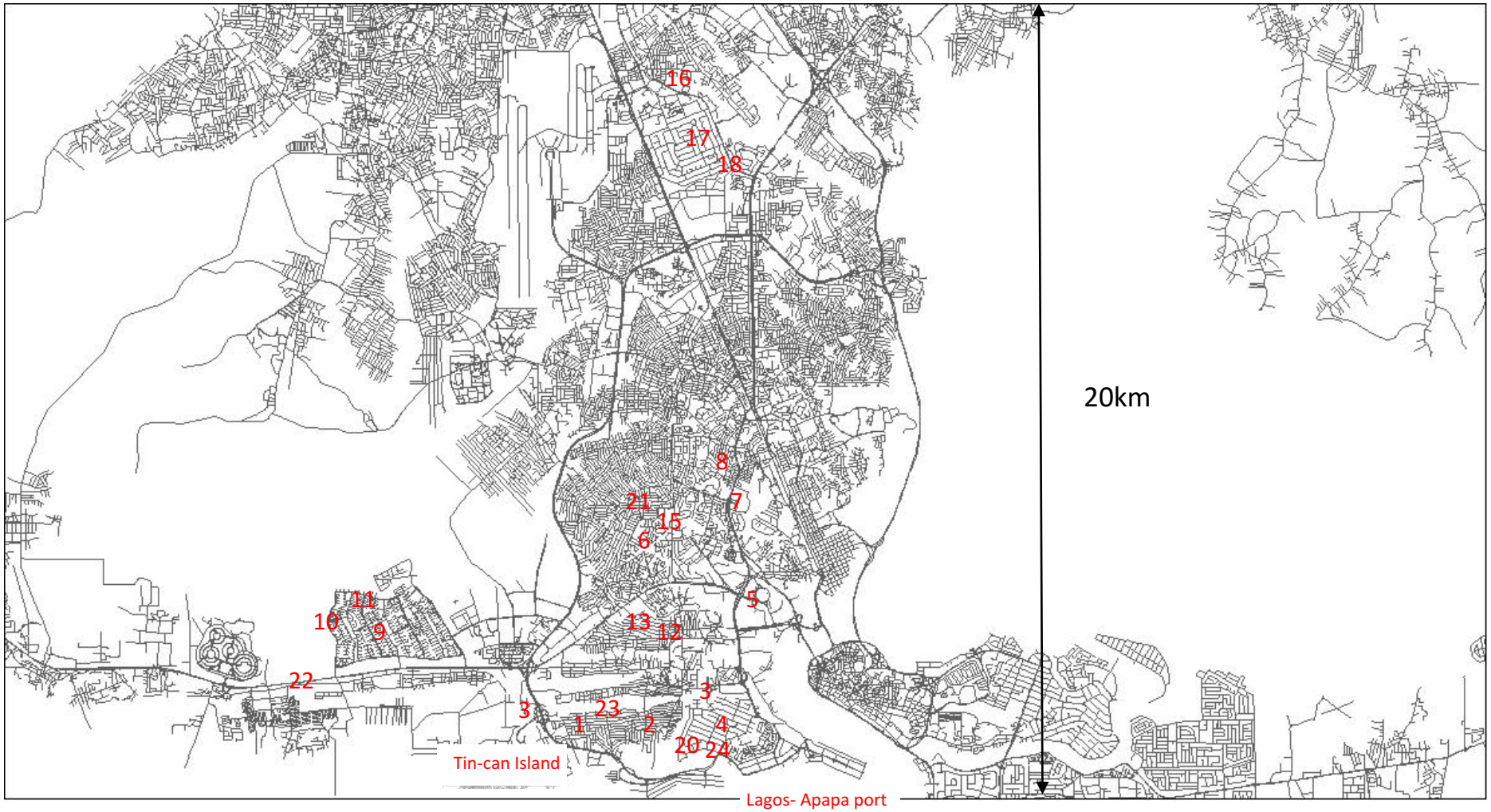


Figure B.1: Location of off-dock terminals in relation to Lagos ports

B.2 Container Shipping Profile

Table B.0: Empty depots used by major shipping lines

Shipping line	Empty depot used
Maersk	Lilypond/GMT
CMA CGM	SDV
Delmas	Sifax
OTAL	Hull Blyth
MSC	Vicoma /Sifax
PIL	HBX
MOL	SDV
GOLDSTAR	Sifax
CHINA SHIP	HBX
K LINE	Vicoma / HBX
NYK Logist	Demca
Grimaldi	SKLINE
Messina	SDV
All	Ports

Table B.4: Market share of shipping lines (2009)

Shipping line	TEUs	Market share (%)
MAERSK / SAFMARINE	135,691	27.5
CMA CGM/ DELMAS/ OTAL	115,092	23.32
MSC	54,832	11.11
GOLDSTAR	41,040	8.32
PIL	32,522	6.59
GRIMALDI	27,699	5.61
MOL	25,092	5.09
CHINA SHIP	14,602	2.96
K LINES	8,087	1.64
HAPAG LLOY	6,910	1.4
MESSINA	6,484	1.31
COSCO	6,268	1.27
MARUBA	4,647	0.94
NYK LOGIST	4,348	0.88
NORDANA LINE	4,132	0.84
NILEDUTCH	3,082	0.62
BACO LINES	2,806	0.57
ATLANTIC BULK CARRIER	43	0.01

Table B.5: Profile of shipping service

Trade	Lines	Local Agent	Frequency	Terminal	Port
Atlantic Europe	OTAL/Delmas	CMA CGM DELMAS	Weekly	TICT	APAPA/TINCAN
Atlantic Europe	MSC	MSC NIGERIA	Weekly	PORT AND CARGO/ FIVE STAR LOGISTICS	TINCAN
Atlantic Europe	Grimaldi	GRIMALDI NIGERIA	Weekly	PTML	TINCAN
Atlantic Europe	MAERSK/ SAFMARINE	MAERSK NIGERIA	Weekly	APMT/PORT & CARGO	APAPA/TINCAN
Atlantic Europe	HAPAG LLYOD	HULL BLYTH	Weekly	APMT/TICT	APAPA/TINCAN
Atlantic Europe	ZIM	LAGOS AND NIGER	Weekly	TICT	TINCAN
Atlantic Europe	CHINA SHIPPING	COMMET	Weekly	FIVE STAR	TINCAN
Atlantic Europe	MOL	MOL NIGERIA	FORTHNIGHTLY	APMT	APAPA
Med Europe	MSC	MSC NIGERIA	Weekly	PORT AND CARGO/ FIVE STAR LOGISTICS	TINCAN

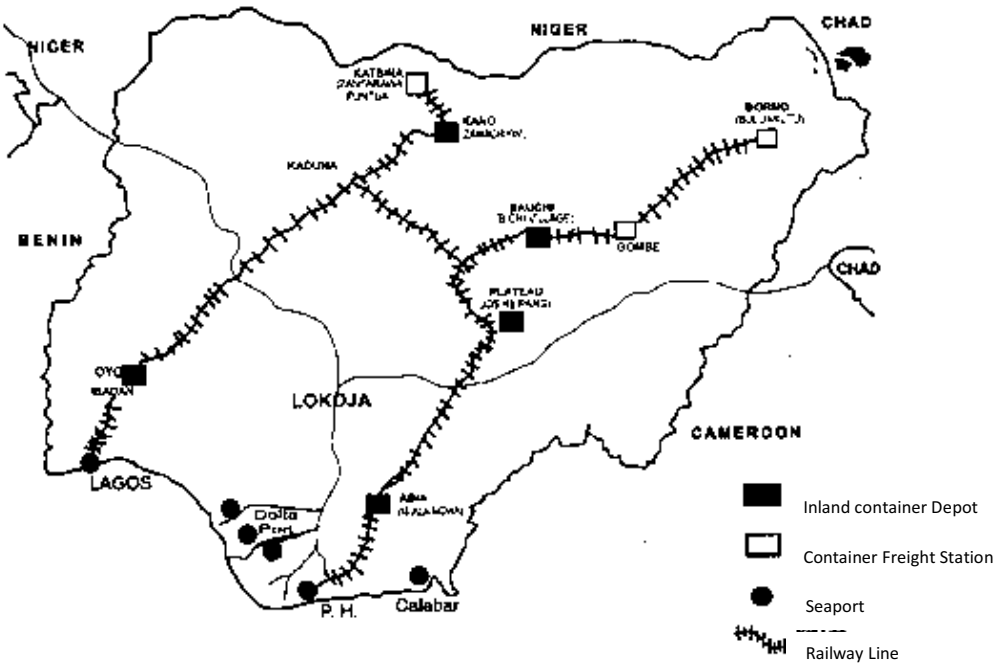


Figure B.2: Location of ICDs and railway lines in Nigeria (source: Nigerian Ports Authority)

B.3 Urban Traffic Congestion in Lagos

The Red zones represent areas with highest level of congestion and blue zones represent areas with the lowest level of congestion

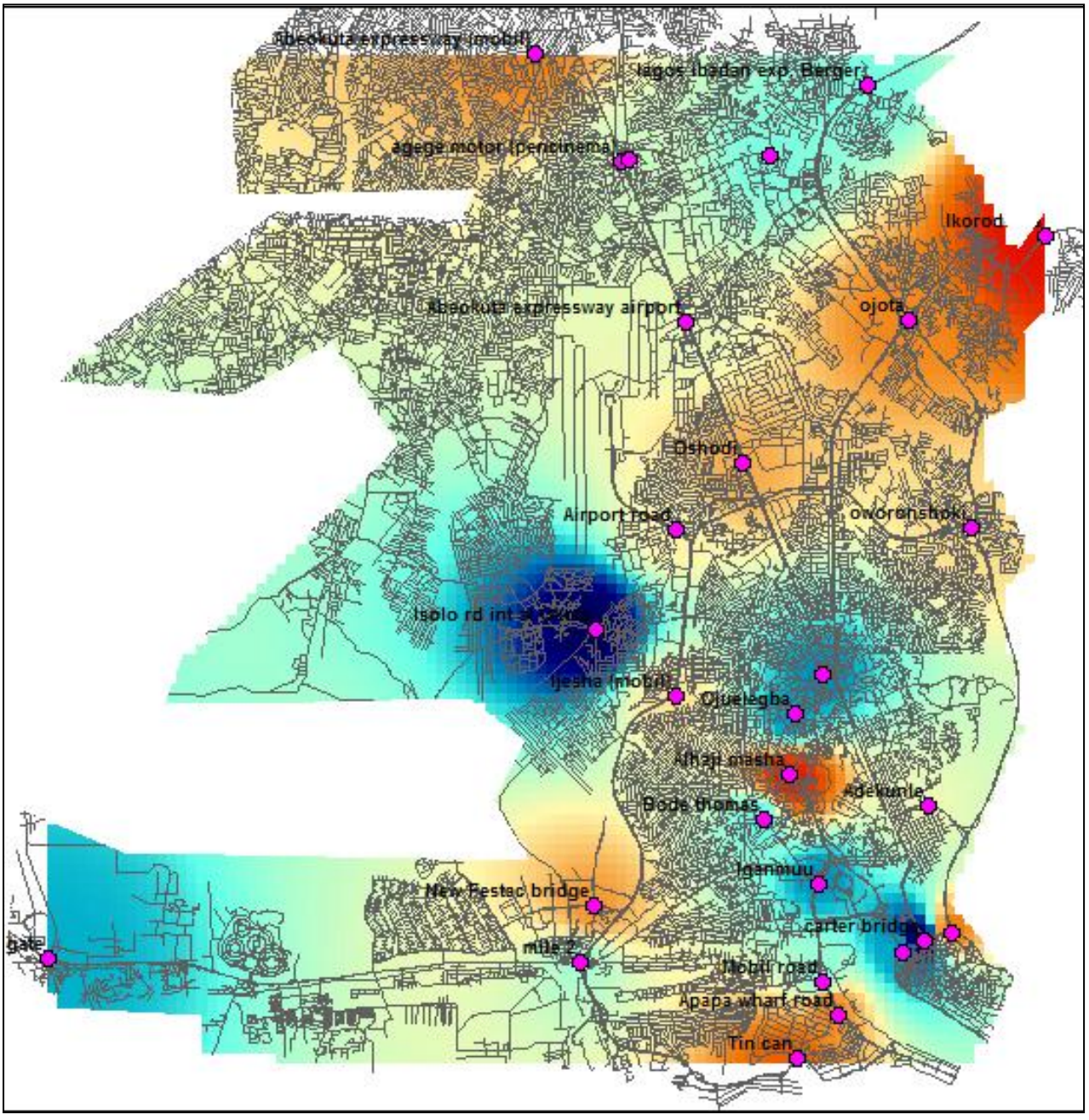


Figure B.3: Grid Map illustrating the dispersion of congestion within Lagos
(Source: Schematic map produced using survey from LAMATA, 2008)

Appendix C: Factors Affecting Traffic Routeing Patterns

A survey was carried out, in December 2009, to obtain information on the factors which influence a trucker's route selection. A number of truck operator where approached and questioned in person. From this exercise, a total of 32 replies were received. The questionnaire used in the survey is included in Table C.1. The findings from this survey is summarised in section 4.2.4.1 and Table 4.1 of this thesis.

The weights column uses a scale of 1 to 3 to represent the importance of individual factors in the route selection process, where 1 = Very important, 2 = important and 3 = Not important. The priority column ranks the factors in order of priority, from the most important (1) to the least important (10). This illustrates the relative importance of each factor.

Table C.1: Truck drivers' questionnaire

No	Factors*	weight	priority
1	Toll charged roadways and bridges on route		
2	Journey time on roadways en- route, which is influenced by the level of traffic.		
3	Road surface conditions of roadway on route and General road structure		
4	Type of roadway used. i.e. whether it is an expressway, trunk road or secondary road		
5	Availability of backhaul cargo.		
6	Drivers hours, and where the drivers like to take their rest breaks (including good overnight rest stops on the longer routes)		
7	Urban congestion black spots or the existence of by-passes		
8	Safety on route/roadway		
9	Cargo features e.g. Weight, perishability, fragility		
10	Size of vehicle (height and width)		

*Truck drivers were also asked to include any other factors considered when choosing their preferred route between any one O-D pair

These parameters are factors that a trucker may take into consideration during his route selection process. The characteristics of the roads in relation to these factors, will then determine the paths selected for use on routes to any destination.

Appendix D: Vehicle Operating Cost Functions – the World Bank HDM-VOC Model

The link performance function as discussed in section 4.2 comprises travel time and operating cost components. Both depend on speed of travel which is dependent on a number of factors including the road conditions, traffic condition and the vehicle characteristics (see Figure D.1)

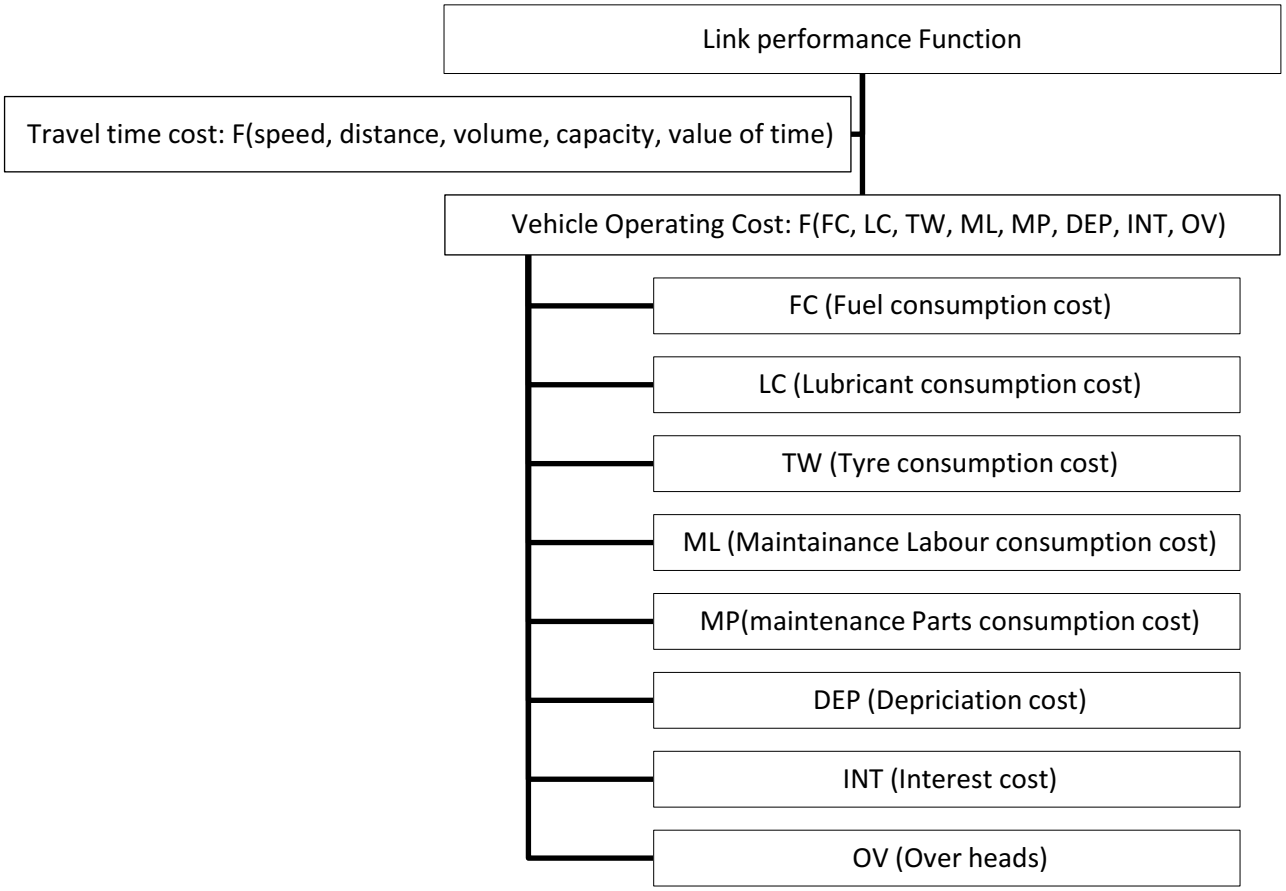


Figure D.1: Components of the Vehicle Operating Costs in the link performance function

This section described the relationship proposed by the World Bank within its HDM-

VOC model to estimate the vehicle operating cost components for a given vehicle.

The growing need for economic appraisals in developing countries motivated the need for the study of vehicle operating costs in developing countries. One of such earliest research was a literature review sponsored by the World Bank and carried out by de Weille (1966). The objective of this literature review was to derive a homogenous approach for calculating vehicle operating cost savings from existing literature. Following this, the Bonney and Stevens (1967) undertook a study of operating costs in developing countries. Their findings provided insight into the impact of bituminous, gravel and earth roads on the operating costs in Africa. Following on from this work, a number of research studies into the Vehicle Operating Cost (VOC) in developing countries have been undertaken including those by Daniels(1974), Hide et al (1975), and Watanatada et al (1987a). The research by Watanatada et al, (1987a) forms the basis of the HDM-VOC models which has influenced a number of VOC models developed since.

Bein (1993) identified and reviewed nine major VOC models from different countries. For models such as the Australian ARFCOM model, the contribution of the HDM is minor while others such as the New Zealand NZVOC model, the influence is rather significant. In general, VOC models are either based on mechanistic principles or multiple linear regression curves used to develop predictive relationships as a function of operating conditions. The latter models do not allow for local calibration since vehicle characteristics are not explicitly considered. The mechanistic model predicts that the VOC is proportional to the forces acting on a vehicle. Such models are more flexible as they allow for changes to vehicle characteristics when applying the model to alternative conditions.

This study is based on the World Bank's HDM-VOC model as proposed by Watanatada et al (1987a). The World Bank proposes four sets of equations for predicting vehicle operating costs. These equations predict the effect of the vehicle operating conditions on the vehicle operating cost components. These equations are based on four primary cost studies carried out in Kenya, the Caribbean, India and Brazil. Of the four studies, the Brazil equation are generally recommended for use by the World Bank as they are based on large data set covering a range of conditions and are based on mechanistic principles which relate the fuel consumption to forces opposing motion of representative vehicle classes. The Brazil data set forms the basis for the default parameters included in the HDM-VOC models.

The steps proposed by the World Bank to compute the Vehicle Operating Cost for a given vehicle type is as follows.

1) Compute the average operating speed of the vehicle. This is based on some limiting physical and traffic factors.
2) For each components of the vehicle operating costs, compute the amount of resources consumed for a unit time (s) or distance (km). The components of the Vehicle operating costs are outlined in figure D.1 and the consumption relationships are discussed in the following sections of this appendix.
3) Apply the appropriate unit cost to the amount of resources consumed (as calculated in step 2) to establish the operating cost component per unit time (s) or distance (km) on link. These unit costs can vary between countries. The unit costs applied in this study are outlined in Table D.1 of this Appendix.
4) Derive the operating cost component associated with each link by multiplying the operating costs components per unit time (s) or distance (km) by the travel time (s) or length (km) of the link.
5) Sum up operating cost of each component to obtain the total vehicle operating cost per link.

The following section is a brief summary of the relationships adopted to compute the vehicle speed and resource consumed as contained within the following publications (Bennett and Greenwood, 2001; Archondo-Callao and Faiz, 1994; Watanatada et al, 1987a; Watanatada et al, 1987b; Biggs, 1988; Bennett, 1989a; McLean, 1991; du Plessis and Schutte, 1991).

The choice of the relationships to adopt is based on the simplicity and their appropriateness to the case of Nigeria. The economic situation and characteristics of vehicles used in Nigeria can be different to those used in the study countries and so local calibration of these equations is undertaken where possible. The simplified relationships adopted here are acceptable for use in the link performance function since the assignment process is based on relative choices. Readers are referred to these publications for a thorough description of the relationships adopted here.

D.1 Vehicle Speed Prediction

There are a number of factors that are believed to influence the speed of a vehicle on a road; these factors can be considered within the groups identified in Figure D.2. The vehicle characteristic influence the performance limitations of the vehicle and so its speeds. The road conditions relate to the limitations of the road alignment and surface conditions on the speed of travel. The traffic conditions relate to the effect of the effect of volume and the available gaps in the traffic stream for overtaking, on speeds. The travel environment impacts speed the desired speed of travel. For example, roads on levelled terrain would induce a higher desired speed compared to rolling or mountainous terrain. This is illustrated in the research by AUSTROADS (1989) and Mclean (1981) who show that the overall desired speed of travel range from 70km/h on mountainous roads to 120km/hr on level roads. On the other hand, research on the effect of the characteristics of drivers on speed has been inconsistent as findings from studies are at odds with one another (Bennett and Greenwood, 2001). Other factors that have been shown to influence speed includes weather conditions, visibility and speed restrictions.

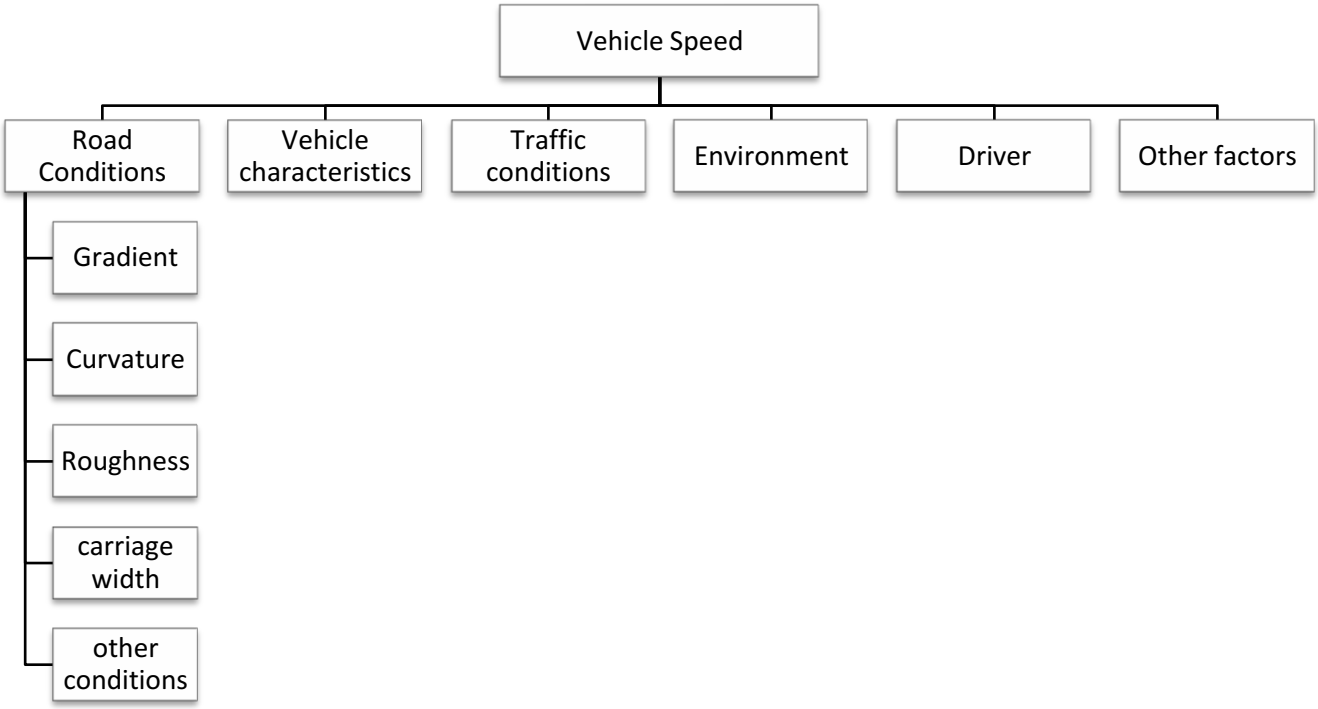


Figure D.2: Factors influencing speed

Within the HDM model, the travel speed can be considered as being mainly

dependent on the road conditions, vehicle characteristics and the traffic conditions. The free speed achievable by the vehicle is linked with the former two while the later relates to the reduction of free speed due to traffic volume on roads. The effect of the link volumes on free speed is derived from the speed-flow model which relates speed to the volume on links. The speed-flow model predicts that the speed of the vehicle decreases from the free-speed with increase in volume. The speed-model adopted in this study is that proposed by Hoban, et al (1994) and has been highlighted in the body of this thesis (Section 4.2.4.2).

The HDM speed prediction model was first developed by Watanatada, et al (1987) within the HDM-3 model and was further modified for inclusion in the HDM-4. The model was developed using speeds measured at a point on a road in Brazil. The basis for the model is that the speed of a vehicle is limited by a series of constraints acting on the driver. These constraints are in the form of the constraining speeds and are a function of the vehicle characteristics (e.g engine power, gross weight and brake capacity) and the road condition (e.g gradient, curvature, carriage width and surface roughness). The constraints include the limiting driving speed, the limiting braking capacity speed, the limiting curve speed, the limiting road surface condition speed and the limiting desired speed. The free speed is taken as the minimum of these constraints. The model does not consider speed-change cycles on roads and works with aggregate description of road and surface conditions. The reader is referred to Bennett (2001) for a detailed review of the relationships applied in HDM-4.

D.2 Component of the Vehicle Operating Costs

D.2.1 Fuel Consumption Cost

Over the past years, a number of studies have been undertaken into the fuel consumption of motor vehicles. In general, fuel consumption models can be considered under empirical based models that relate fuel consumption to specific operating conditions and mechanistic based models that relate the consumption to the forces opposing motion.

One of the more comprehensive mechanistic fuel consumption models was developed by Biggs (1988) and adopted in the HDM-4 model. This model relates fuel consumption to the magnitude of power required to maintain engine operation in motion.

The fuel consumption relationships in the model consider the forces opposing motion, internal vehicle forces, engine speed and impact of acceleration/deceleration on fuel use. Due to the lack of resource for detailed calibration in this study, a simple relationship that ignores the impact of acceleration on fuel consumption is employed. This is derived from the HDM-3 model which uses the relationship of the forces opposing motion to predict the fuel consumption using a series of regression parameters. The reader is referred to Watanatada, et al. (1987) and Archondo-Callao, et al. (1994) for details of the relationships applied in HDM-3.

D.2.2 Tyre Consumption Cost

In general, tyres are consumed continuously over the journey either through the wearing of the tread or the wearing of the carcass. The friction of the tyre against the pavement surface results in the wearing of the tread, while the forces acting on the vehicle in motion, results in stresses and strains being applied to the tyre carcass. Depending on the condition of the carcass, the tyre is discarded or rethreaded once the tread reaches a certain depth. Tyre consumption models try to capture the consumption of tyres under real life conditions. Such models can be classified under mechanistic based and empirical based models. The mechanistic models relate the tyre consumption to the forces on the car in motion and are generally developed from controlled experiments, while the empirical models relate the tyre consumption directly to operating road conditions and are developed from fleet survey data.

The tyre consumption model adopted in HDM models are based on the wear of tyres due to tyre slip. This arises as the tyres deflect during the driving and braking transition. Watanatada, et al. (1987) developed the model which is adopted in HDM model for considering tread wear and carcass failure.

D.2.3 Maintenance Part consumption Cost

Maintenance costs are often a significant component of the Operating Costs. Maintenance part consumption unlike fuel consumption is based strongly on aggregate empirical relationships drawn from a large number of observations. While most relationships relate

maintenance parts to road roughness, speed and vehicle age, other factors which are also influential cause a large scatter in data of this nature. For example, maintenance parts data for a fleet of vehicles may be influenced to different levels by maintenance policies and drivers behaviours.

The HDM-3 Brazil relationship for parts consumption in trucks was found to be linear over all values of roughness explored and so the relationship proposed for use in HDM-3 is adopted here. The maintenance parts consumed are derived as a function of the road roughness and the vehicle age.

D.2.4 Maintenance Labour Consumption Cost

Maintenance labour hours are derived as a function of the parts consumed. NDLI (1995) proposes that the relationships derived for calculating the labour hour in the India study should be used in countries with low unit labour costs, arguing that the low labour costs encourages the substitution of parts for labour when possible. As with Nigeria, the cost of labour is relatively cheap compared to the cost of parts and so there is a tendency to repair parts rather than replace them. In light of this, the simple labour consumption model proposed by Bennett (1996d) is applied.

D.2.5 Lubricant Consumption Cost

The engine oil consumption cost constitutes a small component of the total running costs. A number of studies have related oil consumption to factors like roughness (Watanatada, et al, 1987), road geometry (CRRI, 1982) and speed (Schutte, 1981). The relationship adopted in this study is the one proposed by Pienaar (1984) and used in HDM-4, which disaggregates lubricant consumption into those due to contamination and those due to operation.

D.2.6 Depreciation Cost

This is the loss in value of a vehicle over time and cannot be restored by repairs or constant maintenance. This component is sensitive to the vehicle utilization and service life. This relationship is given as:

$$DEP = \frac{1}{LIFE\ \ AKM}$$

Where

DEP is the vehicle depreciation as a fraction of a new vehicle price per km

AKM is the average number of kilometres driven per vehicle per year.

LIFE is the average vehicle service life in years

While other models for predicting service life exist, the relationship used in this study is selected because of its simplicity. The reader is referred to Bennett (2001) for a review of alternative relationships.

D.2.7 Interest Cost

The interest cost refers to the opportunity cost of vehicle ownership. This is the residual amount of capital tied up in the vehicle which may normally be invested elsewhere. The value is derived as the average of the residual vehicle value which decreases linearly from full purchase price at the end of year 0 to zero at the end of the vehicle service life. This relationship is given as:

$$INT = \frac{1}{2}\ \frac{AINV}{100}\ \frac{1}{AKM}$$

Where

INT is the interest charge as a fraction of the average new vehicle price per km

AINV is the annual interest charge on investment in percent

D.2.8 Overhead Cost

The overhead cost per 1000 veh-km (OVR) is calculated using the equation:

$$OVR = \frac{1000\ OA(100 - PP)}{100\ V\ HRWK}$$

Where

OA is the annual overhead cost in cost/year

V is the computed vehicle speed in km/h

HRWK is the annual working hours of vehicle

PP is the percentage of vehicle use on private trips

D.3 Vehicle operating cost parameters

The characteristics of vehicle classes and the unit costs inputted in calculating the vehicle operating costs are summarised in Table D.1 below.

Table D.1: Characteristics of representative container related vehicle

Vehicle characteristics	**Semi-trailer**	**Unit truck**
Tare weight (t)	14t	12t
Load carried (t)	30t	20t
Maximum rated vehicle power (metric HP)	400HP	300HP
Gross vehicle weight in tons	44t	32t
Speed at which vehicle is assumed to operate without constraint (km/hour)	60 -100	80
Passenger Car Equivalent	2.2	1.8
Tire wear Data		
Number of tires available (#)	18	10
Cost of rethreading	$130	110
Vehicle utilization data		
Average number of kilometers driven per vehicle year (km)	90,000	75,000
Average number of hours driven per vehicle per year (hours)	2,500	2,000
Ratio of driving time and total trip time (total time includes loading, unloading, stopping for fuel/meal, and layovers.	30%	10%
Average vehicle service life in years	7	5
Average age of vehicle in kilometers	20,000	30,000
Passengers per vehicle	2	2
Unit costs		
Cost of new vehicle (Currency -Naira)	$63,000	$32,000
Fuel cost per litre (currency/liter)	$1	$1
Lubricant cost per litre (currency/liter)	$1.5	$1.5
cost of new tire	$450	$500
Cost per crew hour of vehicle operation (currency/hour)	$3	$3
Cost per labor-hour of vehicle repairs and maintenance (currency/hour)	$4	$4
Cargo holding cost per vehicle-hour (currency/hour)	$15	$15
annual interest rate in % per year	10%	10%
Lump sum Overhead cost (in currency) per vehicle-km (currency)	$2	$2

D.4 References

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Appendix E: Transport Network Representation

E.1 Transport Network Representation - the Zonal System

This section outlines the zonal system that is developed for use within the traffic model in this study. The zones can be grouped into states and local government areas. Table E.1 presents a list of the zones and the typical areas within them. The locations of these zones are illustrated in Figure E.1.

Table E.1: The zonal system

No	Zone ID	Group	Areas Clustered in Zones	State
1	1	Lagos Zones	Papa Ashafa, Dopemu, Magbon	Lagos
2	2		Agege	Lagos
3	3		Abule-egba	Lagos
4	4		Alaba, Amukoko,Ojo-Alaba, Ajegunle	Lagos
5	5		Ibafon, Olodi Apapa	Lagos
6	6		Alakuko, Meiran, Abule-egba, Oke-Odo, Suberu oje	Lagos
7	7		Idimu, Egbeda, Alimosho, Alagba, Ifako-Agege	Lagos
8	8		Ilapo, Command, Ikola, Ayobo, Ipaja, Olorunda	Lagos
9	9		Isheri-olofin, Ejibo, Egbe, Agodo, Ikotun, Balogun, Iseri-osun, Ijedodo,	Lagos
10	10		Festac town, Amuwo Odofin housing estate, Suru-Alaba, Amuwo ind.	Lagos
11	11		Amuwo , Oluti, maza-maza	Lagos
12	12		Kiri Kiri	Lagos
13	13		Trade fair, Okokomaiko, Alaba,Satellite town, Abule Ado	Lagos
14	14		Ijora, costain	Lagos
15	15		Malu Area	Lagos
16	16		Liverpool, Burma rd., Dockyard rd.	Lagos
17	17		Commercial rd, wharf road area, Creek rd., warehouse rd.	Lagos
18	18	Port Zones	Apapa Quays - Port terminals	Lagos
19	19		TinCan Island - Port terminals	Lagos
20	20	Lagos Zones	Ifako- Agege	Lagos
21	21		Alagbado	Lagos
22	22		Maryland, GRA	Lagos

23	23		Opebi, Ikeja, Oba Akran, Allen, Adeniyi Jones	Lagos
24	24		Oregun, Agidingbi, Adekunle, Ogba,Alausa, Ikosi 1	Lagos
25	25		Ojudo, Aguda	Lagos
26	26		Ikorodu	Lagos
27	27		Ito-iddo, Oyingbo	Lagos
28	28		Ebutemetta, Oyingbo, Oke ira	Lagos
29	29		Onike, Yaba, Iwaya, Ojuelegba, Sabo,Makoko	Lagos
30	30		Lagos, Ikoyi, Obalende	Lagos
31	31		Victoria Island	Lagos
32	32		Lekki, rest of eti-osa	Lagos
33	33		Idiaraba, Idi-oro, Fadeyi, Papa Ajao, Mushin, Onipanu, Ilupeju,	Lagos
34	34		All of Ojo	Lagos
35	35		Isolo, Isage tedo, Ilasamaja	Lagos
36	36		Orile-Oshodi, Oshodi, Mfoluku, Shogunle	Lagos
37	37		Ejibo, Egbe, Agodo, Ikotun	Lagos
38	38		Ijegun, Iseri-Oshun, Oke-Afa	Lagos
39	39		Somolu, Igbobi, Abule-Ijesha, Akoka	Lagos
40	40		Obanikoro, Anthony, Bariga, Pedro, Abule-Okuta, Gbagada,	Lagos
41	41		Ogudu, Ojota	Lagos
42	42		Ketu, Mile12, Ikosi-Ketu, Magodo 2, Ikosi 2	Lagos
43	43		Magodo 1, Iseri-Oke, Iseri-Olofin	Lagos
44	44		Cooker, Ijesha-Tedo	Lagos
45	45		Orile-Iganmu, Iganmu, Eric moore, Oke-Ira, Alaka	Lagos
46	46		Ikate, Surulere, Lawanson,Itire	Lagos
47	47		Epe	Lagos
48	48		Badagri	Lagos
49	100	Dry Port	Close Range Dry port	
50	110	Zones outside Lagos	Ogun 1	Ogun
51	111		Ogun 2	Ogun
52	112		Ogun 3	Ogun
53	113		Ogun 4	Ogun
54	114		Oyo	Oyo
55	115		Osun	Osun
56	116		Ondo, Ekiti	Ondo,
57	117		Abia	Abia
58	118		Adamawa	Adamawa
59	119		Akwa Ibom	Akwa
60	120		Anambra	Anambra
61	121		Bauchi	Bauchi
62	122		Bayelsa	Bayelsa
63	123		Benue	Benue
64	124		Borno	Borno
65	125		Cross River	Cross
66	126		Delta	Delta

67	127		Ebonyi	Ebonyi
68	128		Edo	Edo
69	130		Enugu	Enugu
70	131		Federal Capital Territory	Abuja
71	132		Gombe	Gombe
72	133		Imo	Imo
73	134		Jigawa	Jigawa
74	135		Kaduna	Kaduna
75	136		Kano	Kano
76	137		Katsina	Katsina
77	138		Kebbi	Kebbi
78	139		Kogi	Kogi
79	140		Kwara	Kwara
80	141		Nassarawa	Nassarawa
81	142		Niger	Niger
82	143		Plateau	Plateau
83	144		Rivers	Rivers
84	145		Sokoto	Sokoto
85	146		Taraba	Taraba
86	147		Yobe	Yobe
87	148		Zamfara	Zamfara

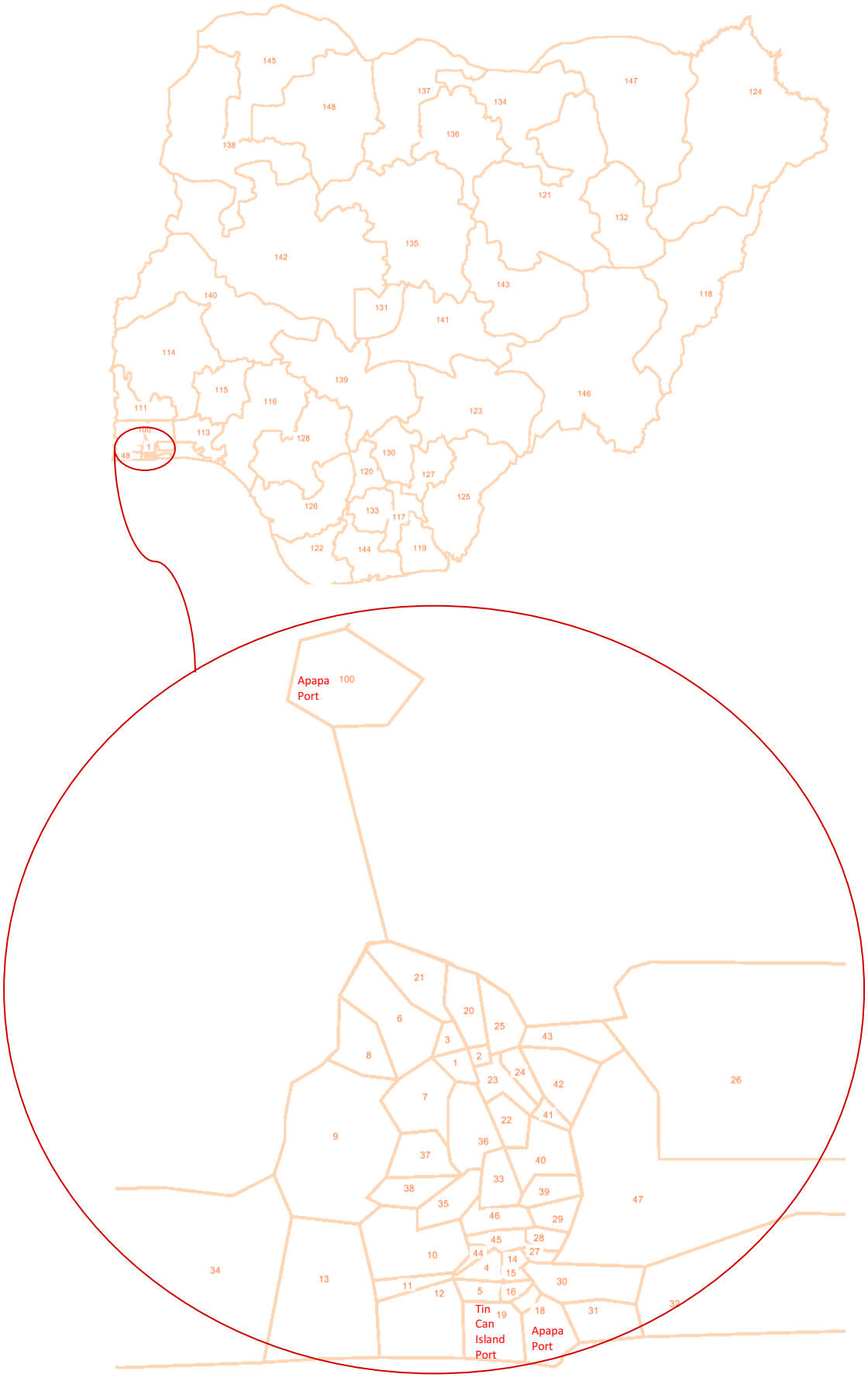


Figure E.1: The zonal system

E.2 Transport Network Representation - Data Sources

Table E.2 Data sources for compiling the transport network representation

No	Data Source
	Data Sources used to Compile Zonal system
1	Digest of statistics. Lagos Bureau of Statistics, Ministry of Economic planning and budget (2010)
2	Road map of Lagos. Brunel engineering Ltd (2007)
3	Lagos state government household survey. Ministry of housing, Lagos (2010)
4	Socio-economic data from Nigerian Bureau of statistics (unpublished)
5	GIS Land use database provided by Gisolutions Nigeria Ltd
6	GIS point of Interests database provided by Gisolutions Nigeria Ltd
	Data sources used to compile Road and rail network
1	GIS map of road and rail network provided by Gisolutions Nigeria Ltd
2	Revised Inventory of Federal Highways. Federal Ministry of transportation Highway planning and design department (2007)
3	Road statistics report. Lagos state Ministry of Work and Infrastructure (2005)
4	Highway Manual part 1- Design. Federal Ministry of works and housing (2006)
5	Nigerian road network rehabilitation and maintenance study. Federal Ministry of works and housing (1999)
6	Master plan for an integrated transport infrastructure. Federal Ministry of Transport (2002)
7	Road transport Industry report. Augusto and Co Ltd (2009)
8	Road survey Reports. Bollore international LTD (2007)
9	Road inventory Reports. Julius Berger Nigeria Plc (2008)
10	Google Earth images of Lagos, Nigeria
11	Road map of Nigeria, 2005 edition, Julius Berger Nigeria PLC
12	Road map of Lagos, Nigeria
13	Road map of Lagos showing the 22 LGA
14	Nigerian spot height database provided by Gisolutions Nigeria Ltd

Table E.3: Capacity of links (Source: Highway manual for Nigeria)

	2-Lane , 2-way Travel		Multilane highway		Freeway(PCU/lane/hr)	
	Capacity	Speed(km/hr)	Capacity	Speed(km/hr)	Capacity	Speed(km/hr)
Urban	1,500	60	1,700	100/80	2,200	120

Table E.4: Restriction due to lateral obstructions

Lane width(m)	3.65	3.35	3	2.75
Highway Type	Effective percentage of capacity (F_w)			
2-Lane , 2-way Highway	85	73	66	60
2-Lane, 1-way Divided highway	90	87	82	73

E.3 Non-container related link volumes – Test for Correlation

This section includes the results obtained from testing the correlation of some exploratory variables proposed for use in the regression analysis reported in Section 5.3.1 of the thesis.

Source	SS	df	MS		Number of obs =	27
					F(2, 24) =	25.51
Model	.006767458	2	.003383729		Prob > F =	0.0000
Residual	.003183188	24	.000132633		R-squared =	0.6801
					Adj R-squared =	0.6534
Total	.009950646	26	.000382717		Root MSE =	.01152

Proptruck	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ToPort	-.010057	.0014575	-6.90	0.000	-.0130652	-.0070489
ToPort2	.000314	.0000441	7.12	0.000	.000223	.000405
_cons	.0851879	.0098813	8.62	0.000	.0647938	.105582

Source	SS	df	MS		Number of obs =	27
					F(2, 24) =	11.81
Model	.004935312	2	.002467656		Prob > F =	0.0003
Residual	.005015334	24	.000208972		R-squared =	0.4960
					Adj R-squared =	0.4540
Total	.009950646	26	.000382717		Root MSE =	.01446

Proptruck	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ToExit	-.0076377	.0015729	-4.86	0.000	-.010884	-.0043913
ToExit2	.0003068	.0000643	4.77	0.000	.0001741	.0004394
_cons	.0545792	.0075451	7.23	0.000	.0390068	.0701516

Source	SS	df	MS		Number of obs =	27
					F(1, 25) =	6.96
Model	.054202951	1	.054202951		Prob > F =	0.0141
Residual	.194598016	25	.007783921		R-squared =	0.2179
					Adj R-squared =	0.1866
Total	.248800967	26	.009569268		Root MSE =	.08823

Proptruck	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
population	-1.46e-07	5.54e-08	-2.64	0.014	-2.60e-07	-3.21e-08
_cons	.273186	.05801	4.71	0.000	.1537122	.3926598

Source	SS	df	MS		Number of obs =	27
					F(1, 25) =	2.09
Model	.01917297	1	.01917297		Prob > F =	0.1609
Residual	.229627998	25	.00918512		R-squared =	0.0771
					Adj R-squared =	0.0401
Total	.248800967	26	.009569268		Root MSE =	.09584

Proptruck	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
population~y	-4.64e-07	3.21e-07	-1.44	0.161	-1.13e-06	1.97e-07
_cons	.1604206	.0296874	5.40	0.000	.0992783	.221563

Source	SS	df	MS		Number of obs =	27
					F(1, 25) =	0.16
Model	.001620514	1	.001620514		Prob > F =	0.6890
Residual	.247180453	25	.009887218		R-squared =	0.0065
					Adj R-squared =	-0.0332
Total	.248800967	26	.009569268		Root MSE =	.09943

Proptruck	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
networkden~y	-.0001456	.0003596	-0.40	0.689	-.0008863	.0005951
_cons	.1322143	.0233306	5.67	0.000	.084164	.1802646

Source	SS	df	MS		
Model	.001938696	1	.001938696	Number of obs	= 27
Residual	.246862271	25	.009874491	F(1, 25)	= 0.20
				Prob > F	= 0.6615
Total	.248800967	26	.009569268	R-squared	= 0.0078
				Adj R-squared	= -0.0319
				Root MSE	= .09937

Proptruck	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Employment	.0000231	.0000522	0.44	0.662	-.0000844	.0001307
_cons	.1030408	.0569526	1.81	0.082	-.0142553	.220337

Appendix F: Gate Counts and Trailer Park Surveys

This section summarises the result from the ports and off-dock terminal gate counts. It also included a summary of the trailer park survey.

F.1 Port Gate Counts

A 12hr gate count is undertaken to obtain the hourly distribution of containers exiting/entering port gates. This survey is carried out over three consecutive days. The result from this survey is summarised in Table F.1 and F.2 below.

Table F.1: Trailers Entering Port Gates

From	Until	Apapa Gate			Tin Can Gate1			Tin Can Gate 2		
		Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
7:00	8:00	37	18	15	1	3	9	36	28	26
8:00	9:00	38	27	67	4	7	7	32	39	25
9:00	10:00	66	55	72	45	24	36	33	41	23
10:00	11:00	74	89	63	55	56	34	37	42	16
11:00	12:00	75	83	72	55	52	27	34	30	22
12:00	1:00	94	97	79	35	56	37	30	49	31
1:00	2:00	83	36	101	33	58	17	33	41	31
2:00	3:00	92	57	59	23	52	48	30	37	22
3:00	4:00	73	63	81	32	58	25	34	41	41
4:00	5:00	55	92	60	0	72	22	32	35	26
5:00	6:00	55	75	29	32	26	28	37	35	32
6:00	7:00	53	25	39	7	11	0	51	40	48
Total:		795	717	737	322	475	290	419	458	343

Table F.2: Trailers Exiting Port Gates

From	Until	Apapa Gate			Tin Can Gate1			Tin Can Gate 2		
		Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
7:00	8:00	51	87	18	0	4	13	7	27	18
8:00	9:00	25	69	35	10	26	47	11	32	28
9:00	10:00	47	75	78	40	31	9	14	41	14
10:00	11:00	53	59	73	13	33	29	18	38	24
11:00	12:00	56	94	61	30	25	11	17	31	25
12:00	1:00	69	83	70	26	35	33	21	33	25
1:00	2:00	28	54	92	34	48	38	29	35	32
2:00	3:00	46	80	65	23	29	21	32	40	23
3:00	4:00	44	52	78	41	47	27	37	43	29
4:00	5:00	66	63	65	52	34	31	41	44	28
5:00	6:00	46	74	56	36	60	26	37	46	31
6:00	7:00	55	54	43	27	38	33	36	54	46
Total:		586	844	734	332	410	318	300	464	323

F.3 Off-dock Terminal Gate Counts

A 12hr gate count is undertaken to obtain the hourly distribution of containers exiting/entering off-dock terminal gates. This survey carried out at a select number of terminals. The result from this survey is summarised in Table F.3 and F.6 below.

Table F.3: Trailers entering off-dock Terminal Gates (Day 1)

From	Until	GMT	SIFAX	SDV	Lily Pond	DENCA	Hull Blyth	MIGFO
7:00	8:00							
8:00	9:00		4					
9:00	10:00		7	14		3	9	
10:00	11:00	3	10	13	12	5	6	11
11:00	12:00	4	8	5	28	8	14	
12:00	1:00	5	5	16	30	5	6	10
1:00	2:00	4	5	8	40	11	8	
2:00	3:00	2	6	11	35	11	9	11
3:00	4:00	4	7	10	45	8	13	
4:00	5:00	4	7	4	30	4	9	5
5:00	6:00	7	5	13	12	5	7	
6:00	7:00				18			
Total:		33	64	94	250	60	81	37

Table F.4: Trailers entering off-dock Terminal Gates (Day 2)

From	Until	GMT	SIFAX	SDV	Lily Pond	DENCA	Hull Blyth	MIGFO
7:00	8:00							
8:00	9:00		5					
9:00	10:00	4	3	7	10	2	7	
10:00	11:00	6	6	12	26	4	6	5
11:00	12:00	10	2	10	22	8	6	
12:00	1:00	2	10	15	10	10	12	7
1:00	2:00	4	4	12	26	3	14	8
2:00	3:00	8	5	6	35	6	6	10
3:00	4:00	2	3	9	14	4	7	
4:00	5:00	7	6	13	26	2	7	5
5:00	6:00	3	3	8	2	7	9	11
6:00	7:00				7			7
Total:		46	47	92	178	46	75	53

Table F.5: Trailers entering off-dock Terminal Gates (Day 1)

From	Until	GMT	SIFAX	SDV	Lily Pond	DENCA	Hull Blyth	MIGFO
7:00	8:00							
8:00	9:00		2					
9:00	10:00	3	2	2		1	5	
10:00	11:00	7	5		3	3	3	
11:00	12:00	10	5	8	13	5	4	11
12:00	1:00	3	4	7	25	4	8	9
1:00	2:00	3	5	9	43	7	7	
2:00	3:00	4	5	4	28	10	9	10
3:00	4:00	5	5	7	38	5	10	
4:00	5:00	2	8	10	40	6	7	1
5:00	6:00	7	9	10	28	11	8	
6:00	7:00				22		6	
Total:		44	50	57	240	52	67	31

Table F.6: Trailers entering off-dock Terminal Gates (Day 2)

From	Until	GMT	SIFAX	SDV	Lily Pond	DENCA	Hull Blyth	MIGFO
7:00	8:00							
8:00	9:00				2			
9:00	10:00	2	3	3		2	8	
10:00	11:00	4	2	1	20	1	7	3
11:00	12:00	7	5	7	20	9	11	
12:00	1:00	5	4	5	15	5	13	4

1:00	2:00	3	10	7	18	3	8	
2:00	3:00	2	3	3	32	11	16	7
3:00	4:00	2	6	10	30	7	6	5
4:00	5:00	8	5	5	30	4	7	
5:00	6:00	5	3	13	35	3	11	4
6:00	7:00				43		2	3
Total:		38	41	55	245	45	89	26

F.3 Trailer Park Survey

Information on the capacity and the location of the trailer parks in the Lagos Area is collated through a field survey. The survey covered 158 trailer parks where the operators were required to specify the number of vehicles (by classification) parked on site. The field work was carried out in conjunction with the National Bureau of statistics, Nigeria. A summary of the results from this survey is included in Table F.7 below.

Table F.7: Summary of results from survey of trailer parks in the Lagos area

Zone ID No	Area	Taxi	Bus	Tipper	Trailer	Lorry	Tanker	Truck	Luxurious Bus
1	Papa Ashafa	10	50	0	0	0	0	0	0
	Dopemu	40	30	30	10	0	0	25	0
	Magbon	10	20	0	0	0	0	0	0
2	Agege	20	130	30	0	0	10	0	0
3	Abule Egba	25	90	60	0	0	0	5	0
4	Alaba	20	100	0	10	0	0	0	0
	Amukoko	0	30	0	0	0	0	0	0
	Ojo-Alaba	20	50	0	0	0	0	0	0
	Ajegunle	30	70	0	0	0	10	0	0
5	Ibafon	0	60	0	15	5	0	5	0
	Olodi-Apapa	0	110	0	10	10	10	0	0
6	Alakuko	0	50	0	0	0	0	0	0
	Merian	15	25	0	0	0	0	0	0
	Abule Egba	25	90	70	0	0	0	5	0
	Oke odo	0	30	0	0	0	0	0	0
	Suberu Oje	10	20	0	0	0	0	0	0
7	Idimu	10	50	0	0	0	0	0	0
	Egbeda	10	50	0	0	0	0	0	0
	Alimosho	10	60	0	0	0	0	0	0
	Alagba	0	50	0	0	0	0	0	0
	Ifako Agege	20	60	20	0	0	5	0	0
8	Ilapo	10	70	0	0	5	0	0	0

	Command	0	50	5	0	0	5	0	0
	Ikola	0	0	0	0	0	0	0	0
	Ayobo	10	50	0	0	10	10	0	0
	Ipaja	20	70	0	0	10	10	0	0
	Olorunda	5	35	0	0	0	0	0	0
9	Isheri Olofin	5	40	0	0	5	5	5	0
	Ejibo	10	70	10	0	10	20	10	0
	Egbe	10	100	0	0	10	0	5	0
	Agodo	10	40	0	0	5	0	0	0
	Ikotun	10	100	0	0	10	0	5	0
	Balogun	0	40	0	0	0	0	0	0
	Isheri Osun	5	40	0	0	5	0	0	0
	Ijedodo	0	30	5	0	0	5	0	0
	Igando	0	60	5	0	5	0	0	0
	FHA Estate	0	20	0	0	0	0	0	0
	Egan	0	40	5	0	5	0	5	0
	Abesan	10	50	0	0	0	0	0	0
10	Festac town	20	50	0	0	0	10	0	0
	Amuwo odofin	10	40	0	0	0	10	0	0
	Suru-alaba	20	50	0	0	0	0	0	0
	Amuwo	10	40	0	0	0	5	0	0
11	Amuwo	20	80	0	20	0	5	0	0
	Oluti	10	40	0	0	0	0	0	0
	Maza maza	20	70	0	0	10	0	0	0
12	Kiri kiri	10	100	0	30	10	0	10	0
13	Trade Fair	10	70	0	0	0	0	10	0
	Okokomaiko	20	90	5	0	10	0	10	0
	Alaba	0	0	0	0	0	0	0	0
	Satellite town	10	90	0	0	0	0	0	0
	Abule Ado	10	40	0	0	0	0	0	0
14	Ijora	40	100	0	30	40	0	20	0
	Costian	0	60	0	20	20	0	0	0
15	Malu Area	0	40	0	0	0	0	0	0
16	Liverpool Rd	0	40	0	0	0	0	0	0
	Burma Rd	0	40	0	0	0	0	0	0
	Dockyard Rd	0	40	10	20	20	30	10	0
17	Commercial Rd	0	40	0	0	0	0	0	0
	Wharf Rd	0	20	0	20	0	40	10	0
	Creek Rd	10	20	0	20	0	0	10	0
	Warehouse Rd	8	20	0	0	0	0	0	0
18	Apapa Quays	0	20	0	40	0	30	10	0
19	TinCan Island	0	90	0	50	0	40	20	0
20	Ifako agege	20	90	5	0	0	0	10	0
21	Alagbado	10	40	0	0	0	0	0	0
22	Maryland	10	20	0	0	0	0	0	0

	GRA	10	10	0	0	0	0	0	0
23	Opebi	10	20	0	0	0	0	0	0
	Ikeja	10	60	0	0	0	0	0	0
	Oba Akran	10	20	0	0	0	0	0	0
	Allen	5	20	0	0	0	0	0	0
	Adeniyi Jones	5	20	0	0	0	0	0	0
24	Oregun	5	20	0	0	0	0	0	0
	Agidingbi	5	20	0	0	0	0	0	0
	Adekunle	5	20	20	20	20	0	0	0
	Ogba	10	70	0	0	0	0	10	0
	Alausa	10	20	0	0	0	0	0	0
	Ikosi 1	5	20	20	20	0	0	20	0
25	Ojudu	20	110	0	0	20	0	10	0
	Aguda	10	40	0	0	0	5	0	0
26	Ikorodu	20	130	20	0	0	0	20	0
27	Ito Iddo	20	50	0	0	20	0	20	25
	Oyingbo	20	70	0	0	30	0	20	30
28	Ebute metta	10	20	0	0	0	0	0	0
	Oyingbo	20	70	0	0	30	0	20	30
	Oke Ira	10	40	0	0	0	0	0	0
29	Onike	10	20	0	0	0	0	0	0
	Yaba	20	80	0	0	0	0	0	0
	Iwaya	10	20	0	0	0	0	0	0
	Ojuelegba	20	90	0	0	10	0	0	20
	Sabo	10	20	0	0	0	0	0	0
	Makoko	10	20	0	0	0	0	0	0
30	Lagos	10	40	0	0	0	0	0	0
	Ikoyi	10	30	0	0	0	0	0	0
	Obanlende	20	220	0	0	0	0	0	0
	Idumota	5	60	0	0	0	0	0	0
31	Victorial Island	10	40	0	0	0	0	0	0
32	Lekki	10	40	10	0	0	0	0	20
	Ibeju Lekki	10	40	10	0	0	0	0	20
	Eti – osa	10	40	0	0	0	0	0	0
33	Idiaraba	5	20	0	0	0	0	0	0
	Idi-oro	10	40	0	0	5	0	0	0
	Fadeyi	5	40	0	0	0	0	0	0
	Papa Ajao	5	40	0	0	0	0	0	0
	Mushin	20	50	0	0	5	0	0	0
	Onipanu	5	40	0	0	5	0	0	0
	Ilupeju	5	20	0	0	0	0	0	0
	Matori	5	10	0	0	5	0	0	0
	Challenge B.S	5	20	0	0	0	0	0	0
	Palmgrove	20	60	0	0	0	0	0	0
34	Ojo	20	130	0	0	10	0	5	10

35	Isolo	20	80	5	0	10	0	5	0
	Isaga tedo	5	40	0	0	0	0	0	0
	Ilasamaja	5	20	0	0	0	0	0	0
36	Orile Oshodi	5	100	0	0	0	0	0	0
	Oshodi	20	210	0	0	20	0	5	20
	Mafoluku	5	20	0	0	0	0	0	0
	Shogunle	5	20	0	0	0	0	0	0
37	Ejibo	10	70	10	0	10	20	10	0
	Egbe	10	100	0	0	10	0	5	0
	Agodo	10	40	0	0	0	0	0	0
	Ikotun	10	100	0	0	10	0	5	0
38	Ijegun	10	40	0	0	0	0	0	0
	Iseri Oshun	5	40	0	0	5	0	0	0
	Oke Afa	10	60	0	0	0	0	0	0
39	Somolu	10	40	0	0	0	0	0	0
	Igbodi	5	40	0	0	0	0	0	0
	Abule Ijesha	5	20	0	0	0	0	0	0
	Akoka	10	40	0	0	0	0	0	0
	CMS	5	20	0	0	0	0	0	0
40	Obanikoro	20	40	0	0	0	0	0	0
	Anthony	20	50	0	0	0	0	0	0
	Mende	5	20	0	0	0	0	0	0
	Bariga	10	50	0	0	0	0	0	0
	Pedro	5	30	0	0	0	0	0	0
	Abule Okuta	5	20	0	0	0	0	0	0
	Gbadaga	20	50	0	0	0	0	0	0
	Oworonsoki	20	60	0	0	0	0	0	0
41	Ogudu	10	40	5	0	7	0	0	0
	Ojota	20	230	0	0	20	0	0	0
42	Ketu	20	240	60	0	20	0	10	0
	Mile 12	10	140	10	0	0	0	0	0
	Ikosi-ketu	10	40	0	0	0	0	0	0
	Magodo 2	5	20	5	0	0	0	0	0
	Ikosi 2	5	20	10	10	10	0	10	0
43	Magodo 1	5	0	0	0	0	0	0	0
	Iseri Oke	5	40	0	0	0	0	0	0
	Iseri Olofin	5	40	0	0	5	5	5	0
44	Coker	5	60	0	0	0	0	0	0
	Ijesha tedo	5	70	0	0	0	0	0	0
45	Orile Iganmu	5	40	0	0	0	0	0	0
	Iganmu	5	40	0	0	0	0	0	0
	Eric Moore	5	40	0	0	0	0	0	0
	Oke Ira	5	40	0	0	0	0	0	0
	Alaka	10	40	0	10	10	0	5	0
46	Ikate	10	40	0	0	0	0	0	0

	Surulere	10	40	0	0	0	0	0	0
	Lawanson	5	50	0	0	0	0	0	0
	Itire	5	60	0	0	0	0	0	0
47	Epe	20	50	10	0	5	0	0	0
	Agbowa	10	40	5	0	0	0	0	0
	Ekedo	5	30	5	0	5	0	0	0
	Ejirin	5	30	10	0	5	0	0	0
	Sum:	1,613	4,335	475	355	517	290	375	175

Appendix G: Port and Off-dock Terminal Gate Interviews

The aim of the survey was to approximate the mean trip lengths and trip length distribution for vehicles carrying each defined commodity class (intermediate/raw goods, consumer durable and consumer perishable goods). This involved determining the destination of trucks that carry goods which were originally in containers. This survey is concerned with stripped container loads and NOT full container loads. So, only unit-trucks were approached for questioning. Drivers were often unwilling to stop and it was difficult to systematically stop trucks so, the approach to vehicles was quite random. The survey is carried out on approach to the port between 7:00 – 19:00 over 3 days. The questionnaire used is included below.

A total of 1498 responses were retrieved of which 1302 replied “NO” to question 1. The responses are collated and used to determine the trip length distribution and average length associated with each commodity class. Furthermore, the outcome of the survey is used to estimate the proportion of truck exiting the ports that are carry goods that were originally containerized. Based on the sample, 13.1% of trucks exiting the ports were carrying goods that originated from container loads. The responses that answered “Yes” to question 1 are included in table G.1-1 to G.1-3.

G.1 Questionnaire

1) Was your cargo containerised? Yes/No. If yes proceed to question 2.

2) What type of goods are you carrying.....?
   If specified proceed to question 4 else proceed to question 3.

3) What category does the goods you are carrying fall under? Please tick

Import Commodity Type	
Building Materials	
Chemical Preparation	
Cycles (including Auto cycles	
Cycles (spares	
Domestic wares	
Electrical materials	
Fans, refrigerators, Tv, Radios	
Iron and aluminium sheets	
Machinery and spares	
Marble chips	
Milk	
Motor spares	
Paper and stationeries	
Pharmaceuticals	
Plastic wares	
Provision and confectioneries	
Tyres and tubes	
Textile materials	
Others	

4) Where is you Van / Truck heading to.....?
   Please specify the area.....

5) Type of Vehicle? Please specify name of vehicle and categorize.

No of tyres	**Truck**
(4 tyres)	T4
(8 tyres)	T8
(above 8 tyres)	T>8

G.2 Summary of Survey Responses

The responses are grouped into three categories by the cargo type (consumer perishable goods, consumer durable goods and intermediate/raw goods).

Table G.1: Summary of interview responses (consumer Perishable goods)

Interview No	Specified Goods	Destination	Vehicle Class
1	Stock Fish	Ilupeju	T8
2	Groundnut oil	Daleko	T>8
3	Fish	Ikotun	T>8
4	Groundnut oil	Bodija	T>8
5	Groundnut oil	Daleko	T>8
6	Milk	Ikorodu	T>8
7	Filled Milk	Odoguyan	T>8
8	Milk	Odoguyan	T>8
9	Milk	Odoguyan	T>8
10	Groundnut oil	Daleko	T8
11	Groundnut oil	Isolo	T8
12	Groundnut oil	Isolo	T8
13	Fish	Ijora	T>8
14	Fish	Ikotun	T>8
15	Fish	Oshodi	T>8
16	Crimps	Oshodi	T8
17	Fish	Ikotun	T>8
18	Groundnut oil	Daleko	T>8
19	Groundnut oil	Daleko	T>8
20	Groundnut oil	Ibadan	T>8
21	Groundnut oil	Ibadan	T>8
22	Crimps	Oshodi	T>8
23	Crimps	Oshodi	T>8
24	Fish	Isolo	T>8
25	Fish	Abimboa way	T>8
26	Fish	Ekiti	T8
27	Fish	Oshodi	T8
28	Groundnut oil	Mokola	T8
29	Fish	Bariga	T>8
30	Fish	Ikotun	T>8
31	Fish	Oshodi	T>8
32	Fish	Ikotun	T>8
33	Fish	Oshodi	T>8
34	Sugar pack	Orile	T>8
35	Fish	Oshogbo	T8
36	Milk	Isolo	T>8
37	Milk	Isolo	T>8
38	Fish	Agric	T>8

Table G.2: Summary of interview responses (consumer Durable goods)

Interview No	Specified Goods	Destination	Vehicle Class
1	Paper	Matori	T>8
2	Paper	Matori	T>8
3	Paper	Matori	T>8
4	Paper	Matori	T>8
5	Tyres	Eric moore	T>8
6	Paper	Matori	T>8
7	Total Oil	Ijora	T8
8	Electronics	Akure	T>8
9	Generator Parts	Oregun	T>8
10	Fridges	Ilupeju	T>8
11	Generators	Toll gate	T>8
12	Refrigerators	Ilupeju	T>8
13	Ceremics	Sabo gari	T>8
14	Paper	Oshodi	T>8
15	Construction Machine	Abeokuta	T>8
16	Construction Machine	Abeokuta	T>8
17	Construction Machine	Abeokuta	T>8
18	Paper	Matori	T>8
19	Refrigerators	Ilupeju	T>8
20	Cars	Ikeja	T6
21	Textile Material	Isolo	T>8
22	Glass	Onitsha	T>8
23	Refrigerators	Ilupeju	T8
24	Electronics	Alaba	T>8
25	Bajaj Machine	Ilupeju	T8
26	Tractor	Mokola	T>8
27	Textile Material	Isolo	T8
28	Glass	Onitsha	T>8
29	Electronics	Costain	T8
30	Textile Material	Isolo	T>8
31	Cars	Kaduna	T>8
32	Glass	Onitsha	T>8
33	Glass	Onitsha	T>8
34	Glass	Onitsha	T>8
35	Generator Parts	Kudirat way	T>8
36	Glass	Onitsha	T>8
37	Spare parts	Onitsha	T>8
38	Construction Machine	Abeokuta	T8
39	Refrigerators	Ilupeju	T>8
40	Spare parts	Ikeja	T>8
41	Spare parts	Ikeja	T>8
42	Iron Sheet	Benin	T>8
43	Refrigerators	Ilupeju	T>8
44	Electronics	Ibadan	T>8
45	Textile Material	Isolo	T>8

46	Cars	Ilorin	T>8
47	Generators	Toll gate	T>8
48	Generators	Toll gate	T>8
49	Cars	Ilorin	T>8
50	Refrigerators	Ilupeju	T>8
51	Generator parts	Oregun	T>8
52	Bajaj Boxes	Ilupeju	T>8
53	Glass	Onitsha	T>8
54	Cars	Akure	T>8
55	Iron Sheet	Agbara	T>8
56	Textile Material	Isolo	T>8
57	Generator parts	Oregun	T8
58	Tyres	Sabo gari	T>8
59	Glass	Onitsha	T>8
60	Textile Material	Isolo	T>8
61	Tyres	Sabo gari	T>8
62	Generator parts	Isolo	T>8
63	Electronics	Ilupeju	T>8
64	Refrigerators	Ilupeju	T>8
65	Bajaj Boxes	Ilupeju	T>8
66	Refrigerators	Ilupeju	T>8
67	Construction Machine	Abeokuta	T>8
68	Construction Machine	Abeokuta	T>8
69	Total Oil	Ijora	T8
70	Construction Machine	Abeokuta	T>8
71	Cars	Abuja	T>8
72	Electronics	Ilupeju	T>8
73	Textile Materials	Ikorodu	T6
74	Glass	Onitsha	T>8
75	Ceremics	Orile	T8
76	Paper	Matori	T>8
77	Total Oil	Ijora	T>8
78	Generators	Toll gate	T>8
79	Paper	Matori	T>8
80	Air Conditioner	Ebute metta	T>8
81	Paper	Matori	T>8
82	Air Conditioner	Ebute metta	T>8
83	Generators	Toll gate	T>8
84	Tractors	Costain	T8
85	Tractors	Costain	T>8
86	Bagco Bag	Eric moore	T>8
87	Pipes	Ojodu Berger	T8
88	Electronics	Abuja	T>8
89	Cars	Akure	T8
90	Glass	Onitsha	T>8
91	Electronics	Wharf rd	T>8

Table G.3: Summary of interview responses (Intermediate/raw goods)

Interview No	Specified Goods	Destination	Vehicle Class
1	Aluminium	Ikeja	T>8
2	Aluminium	Ikeja	T>8
3	Aluminium	Ikeja	T>8
4	Aluminium Sheet	Ikeja	T>8
5	Aluminium	Ikeja	T>8
6	Aluminium	Ikeja	T>8
7	Aluminium	Benin	T>8
8	Aluminium Sheet	Benin	T>8
9	Chemical	Eric moore	T>8
10	Chemical	Eric moore	T>8
11	Tiles	Orile	T8
12	Tiles	Orile	T>8
13	Raw Material	Eric moore	T>8
14	Chemical	Anthony	T>8
15	Chemical	Eric moore	T>8
16	Raw Material	Kaduna	T>8
17	Raw Material	Kaduna	T>8
18	Chemical	Ilupeju	T8
19	Chemical	Sango	T>8
20	Chemical	Sango	T>8
21	Soda	Odoguyan	T>8
22	Soda	Odoguyan	T>8
23	Chemical	Ilupeju	T8
24	Chemical	Ilupeju	T8
25	Raw Material	Odoguyan	T>8
26	Raw Material	Odoguyan	T>8
27	Tiles	Orile	T>8
28	Chemical	Oshodi	T8
29	Chemical	Ijora	T>8
30	Raw Material	Oshodi	T>8
31	Chemical	Onitsha	T>8
32	Soda	Ikorodu	T>8
33	Chemical	Oba Akran	T>8
34	Chemical	Oba Akran	T>8
35	Aluminium	Ikeja	T>8
36	Aluminium	Ikeja	T>8
37	Soda	Ilupeju	T>8
38	Ceremics Tiles	Sabo gari	T>8
39	Raw Material	Oshodi	T>8
40	Raw Material	Ikorodu	T>8
41	Raw Material	Ikorodu	T>8
42	Chemical	Oshodi	T>8
43	PVC	Isolo	T>8
44	Chemical	Oba Akran	T>8
45	Chemical	Oba Akran	T>8
46	Chemical	Oba Akran	T>8

47	Aluminium Sheet	Abuja	T6
48	Chemical	Eric moore	T>8
49	Chemical	Oba Akran	T>8
50	Chemical	Oba Akran	T>8
51	Tiles	Orile	T>8
52	Chemical	Ikeja	T>8
53	Ceremics Tiles	Sabo gari	T>8
54	Chemical	Ilupeju	T>8
55	Soda	Odoguyan	T>8
56	Chemical	Agbara	T>8
57	Chemical	Jos	T>8
58	Chemical	Oba Akran	T8
59	Tiles	Orile	T8
60	Soda	Odoguyan	T>8
61	Chemical	Eric moore	T8
62	Chemical	Ogba	T>8
63	Tiles	Orile	T>8
64	Aluminium Sheet	Ikeja	T>8
65	Aluminium Sheet	Abuja	T>8
66	Aluminium Sheet	Abuja	T>8
67	Tiles	Orile	T>8

Appendix H: Gravity Model Calibration

The observed SCL trip distribution patterns obtained from the road side interviews reported in Appendix G are compared with the simulated SCL trip length distribution patterns.

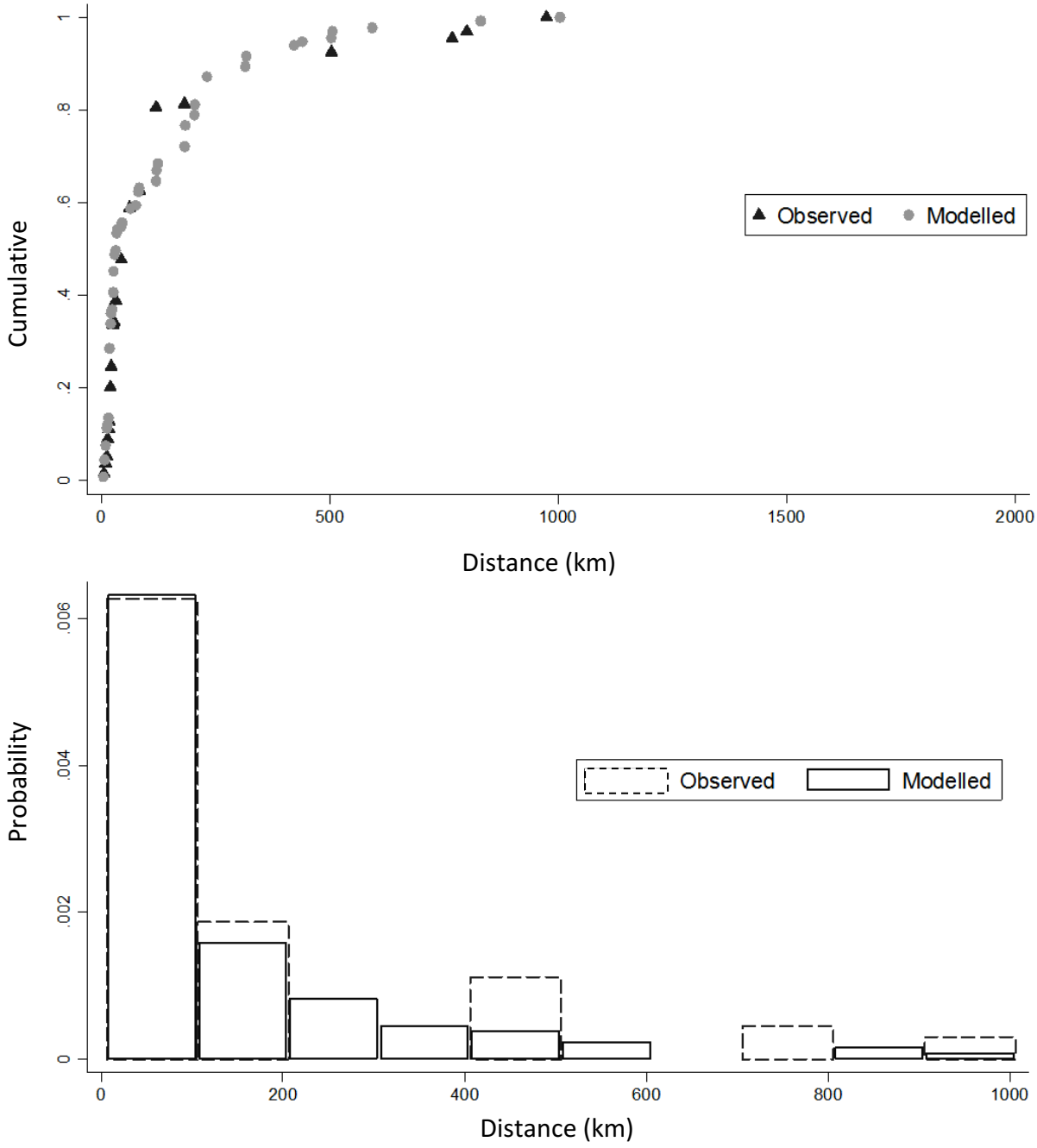


Figure H.1: Trip length distributions for Intermediate/raw commodities

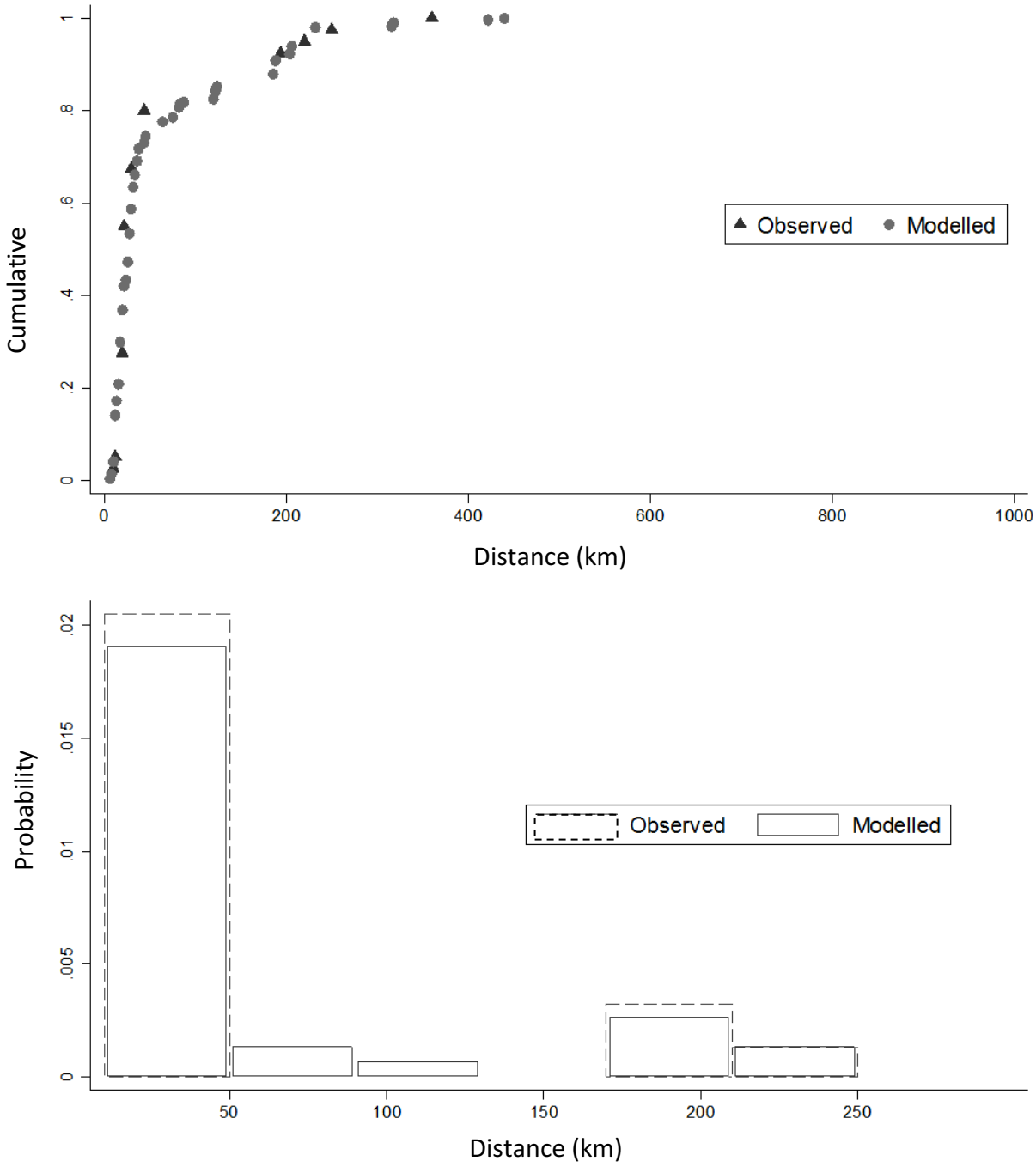


Figure H.2: Trip length distributions for consumer Perishable commodities

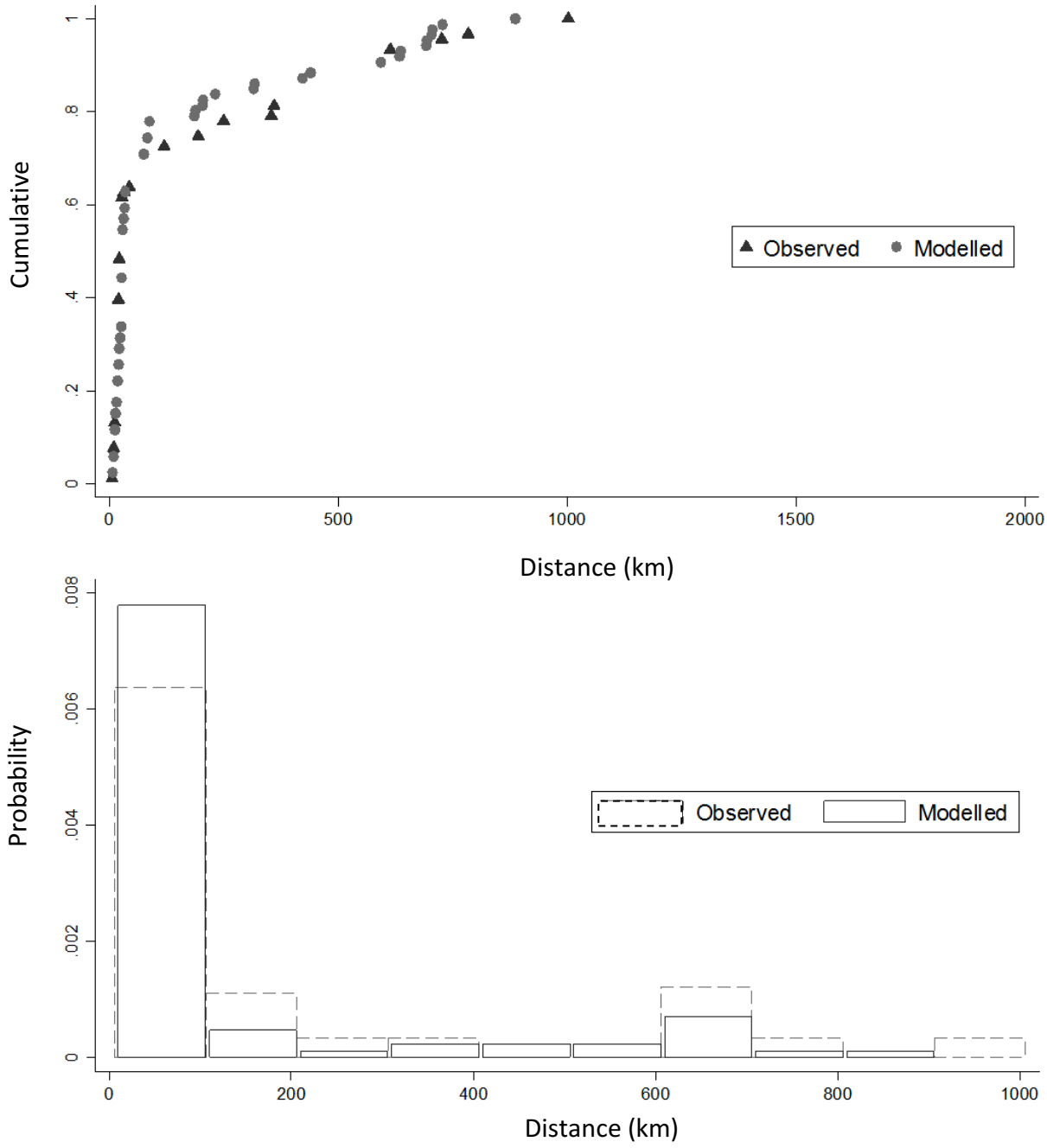


Figure H.3: Trip length distributions for consumer durable commodities

Appendix I: Manual Road Traffic Count Survey

Manual classified link counts were carried out over 12 hours between the hours of 7:00 and 19:00 on key routes in the study area. The freight vehicles are classified under one of six categories: trailer, tanker, van, trucks, tipper and tractor. The link volumes derived from the count is used to validate the model.

The sites for comparison were selected to include key exit routes from the ports and the port city. The locations of the link counts within the study area are detailed in Table I.1 and Figure I.1 below. Table I.2 to I.3 is a summary of the traffic count.

Table I.1: Location and date of traffic count surveys

ID	**Location**
1a	Creek road bridge from Apapa
1b	Creek road bridge to Apapa
2a	Wharf road from Apapa
2b	Wharf road to Apapa
3a	KiriKiri road to Mobil
3b	KiriKiri road from Mobil
4a	Eko Bridge to Apongbon
4b	Apongbon to Eko Bridge
5a	Lagos Badagry Expressway to Mile 2
5b	Lagos Badagry Expressway from Mile 2
6a	Apapa-Oshodi Expressway from Mile 2
6b	Apapa-Oshodi Expressway to Mile 3
7a	Agege motor road from Mushin
7b	Agege motor road to Mushin
8a	Isolo road to Isolo
8b	Isolo road from Isolo
9a	Ikorodu/Mobolaji bank Anthony from

9b	Ikorodu/Mobolaji bank anthony to
10a	Agege motor road to Agege
10b	Agege motor road from Agege
11a	Lagos-Ikorodu expressway to Ikorodu
11b	Lagos-Ikorodu expressway from Ikorodu
12a	Lagos-Ibadan Expressway from Ibadan
12b	Lagos-Ibadan Expressway to Ibadan
13a	Abeokuta Expressway from Oshodi
13b	Abeokuta Expressway to Oshodi

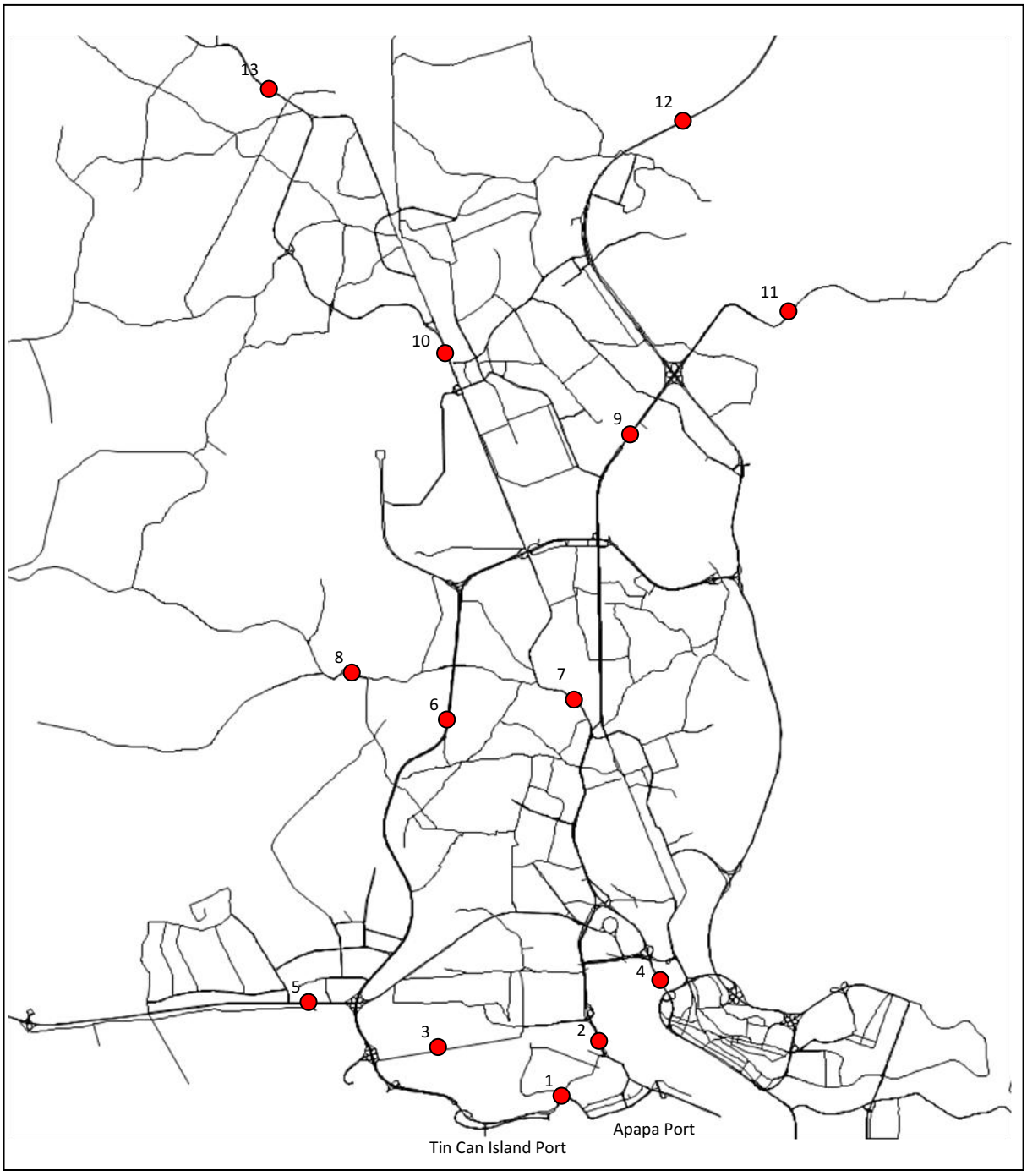


Figure I.1: location of selected sites in study area

Table I.2: Summary of 12 hr traffic count of container Trailers

No	LOCATION	7:00 - 8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	Total
1a	Creek road bridge from Apapa	156	93	61	91	131	137	129	59	68	57	63	81	1,126
1b	Creek road bridge to Apapa	77	102	90	89	90	102	90	92	85	103	97	91	1,108
2a	Wharf road from Apapa	28	40	57	70	50	66	60	57	66	83	98	68	743
2b	Wharf road to Apapa	56	66	98	109	139	124	110	72	101	77	58	49	1059
3a	KiriKiri road to Mobil	33	14	20	25	28	31	42	28	30	40	60	25	376
3b	KiriKiri road from Mobil	24	40	29	38	41	48	63	68	50	43	56	32	532
4a	Eko Bridge to Apongbon	0	5	8	6	17	23	17	40	44	10	24	13	207
4b	Apongbon to Eko Bridge	7	5	2	2	15	14	14	27	16	7	7	3	119
5a	Lagos Badagry Expressway to Mile 2	49	30	49	22	50	43	52	43	19	18	5	3	383
5b	Lagos Badagry Expressway from Mile 2	11	18	20	15	15	22	26	20	25	22	22	12	228
6a	Apapa-Oshodi Expressway from Mile 2	30	26	20	18	30	39	74	71	62	66	58	110	604
6b	Apapa-Oshodi Expressway to Mile 3	40	50	54	62	67	85	90	69	64	67	49	37	732
7a	Agege motor road from Mushin	9	9	5	7	16	22	23	14	12	7	3	7	134
7b	Agege motor road to Mushin	7	10	9	21	22	25	34	24	28	24	31	23	258
8a	Isolo road to Isolo	8	4	9	2	4	8	5	8	3	14	5	6	76
8b	Isolo road from Isolo	3	1	1	4	2	6	4	5	4	5	3	3	41
9a	Mobolaji bank Anthony from Ikorodu	13	8	8	13	34	79	106	64	28	61	100	49	563
9b	Mobolaji bank Anthony to Ikorodu	33	41	28	39	78	58	69	76	70	43	44	62	641
10a	Agege motor road to Agege	8	4	12	8	22	27	11	16	19	26	10	13	176
10b	Agege motor road from Agege	10	12	8	15	14	15	22	21	20	24	20	22	203
11a	Lagos-Ikorodu expressway to Ikorodu	4	7	4	1	2	3	4	5	3	2	1	1	35
11b	Lagos-Ikorodu expressway from Ikorodu	2	4	1	2	3	2	5	6	8	5	3	1	42
12a	Lagos-Ibadan Expressway from Ibadan	51	40	48	26	46	42	48	53	44	51	54	48	551
12b	Lagos-Ibadan Expressway to Ibadan	5	30	21	40	36	29	30	17	34	40	24	15	321
13a	Abeokuta Expressway from Oshodi	11	11	7	16	15	12	6	7	17	6	12	8	128
13b	Abeokuta Expressway to Oshodi	12	10	12	4	18	17	14	13	10	14	12	9	145

Table I.3: Summary of 12 hr traffic count of vans and trucks

No	LOCATION	7:00 - 8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	Total
1a	Creek road bridge from Apapa	156	101	67	92	132	151	138	71	83	71	76	85	1219
1b	Creek road bridge to Apapa	46	79	60	64	50	71	64	65	58	43	64	45	710
2a	Wharf road from Apapa	69	53	70	67	99	83	65	71	54	42	40	36	749
2b	Wharf road to Apapa	42	63	53	105	89	78	124	139	99	55	62	45	954
3a	KiriKiri road to Mobil	39	40	39	55	63	44	62	41	50	46	69	75	623
3b	KiriKiri road from Mobil	50	50	79	42	61	67	85	49	65	86	54	80	767
4a	Eko Bridge to Apongbon	12	16	31	18	70	42	7	75	67	25	38	22	423
4b	Apongbon to Eko Bridge	47	57	65	47	143	131	44	90	116	35	141	67	983
5a	Lagos Badagry Expressway to Mile 2	7	16	18	19	22	12	8	16	120	135	75	21	469
5b	Lagos Badagry Expressway from Mile 2	16	13	21	18	12	12	16	19	6	4	7	11	155
6a	Apapa-Oshodi Expressway from Mile 2	121	91	126	72	94	119	101	96	48	52	73	40	1034
6b	Apapa-Oshodi Expressway to Mile 3	78	82	101	102	97	119	129	99	112	105	94	71	1188
7a	Agege motor road from Mushin	125	76	102	78	88	112	86	75	34	47	47	8	878
7b	Agege motor road to Mushin	57	56	103	133	138	125	128	114	132	135	103	74	1297
8a	Isolo road to Isolo	7	4	5	4	10	12	15	31	30	5	9	9	141
8b	Isolo road from Isolo	6	4	2	4	8	9	22	18	10	5	3	3	94
9a	Mobolaji bank Anthony from Ikorodu	0	19	9	11	3	8	7	10	10	4	13	4	98
9b	Mobolaji bank Anthony to Ikorodu	11	23	33	49	37	44	40	42	67	57	50	31	484
10a	Agege motor road to Agege	142	89	81	89	133	113	175	161	136	129	131	216	1596
10b	Agege motor road from Agege	61	79	91	104	119	129	145	98	102	101	69	57	1153
11a	Lagos-Ikorodu expressway to Ikorodu	56	103	58	90	35	46	18	43	35	30	39	16	569
11b	Lagos-Ikorodu expressway from Ikorodu	43	46	47	64	83	70	78	67	98	82	66	61	802
12a	Lagos-Ibadan Expressway from Ibadan	83	68	85	67	68	44	81	60	81	71	67	67	842
12b	Lagos-Ibadan Expressway to Ibadan	49	25	49	56	43	25	45	22	23	22	32	33	424
13a	Abeokuta Expressway from Oshodi	108	69	69	92	110	134	111	147	184	172	149	132	1476
13b	Abeokuta Expressway to Oshodi	120	93	117	109	116	134	106	81	129	115	108	114	1342

Appendix J: Roadside Interviews

The survey was carried out with the aim to determine the proportion of port related truck trips on specified links. Roadside interview surveys were conducted specifically for this study over 12 hour periods between the hours of 7:00 and 19:00. Only vans and trucks were approached for questioning as these are the vehicle types that car stripped container loads.

The survey sites were selected to include key exit routes from the ports and the port city. Due to resource constraints only a limited number of points could be selected. Thus site that are prone to congestion were given higher priority. Roadside interviews were not possible on bridges as no safe site could be found. The locations selected for these surveys are listed in Table J.1 and the questionnaire used is included in section J.1. Figure I.1 of Appendix I shows the location of the survey points on a map.

The interview sheets were checked at random for errors. Any record that could not be rationalised was not used in the analysis. Table J.2 and J.3 summarises the number of responses received at each location and the outcome of the survey.

Table J.1: Location of road side interviews

ID	Location
2a	Wharf road from Apapa
2b	Wharf road to Apapa
3a	KiriKiri road to Mobil
3b	KiriKiri road from Mobil
5a	Lagos Badagry Expressway to Mile 2
5b	Lagos Badagry Expressway from Mile 2
11a	Lagos-Ikorodu expressway to Ikorodu
11b	Lagos-Ikorodu expressway from
12a	Lagos-Ibadan Expressway from Ibadan
12b	Lagos-Ibadan Expressway to Ibadan

J.1: Questionnaire

1. Where are you coming from?
2. Port (B) Off-dock terminal (C) Warehouse (D) Other Specify.....

3. Please specify exact origin. If Off-dock terminal or port,
    a. Please specify exact one…….. Else, specify an area.....

4. Where are you going?
    a. (A) Port (B) Off-dock terminal (C) Warehouse (D) Other Specify.....

5. Please specify exact Destination. If Off-dock terminal or port,
    a. Please specify exact one…… Else, specify an area.....

6. What type of goods are you carrying? .....

7. What category does the goods you are carrying fall under? Please tick

Import commodity type	**Please Tick**
Building Materials	
Chemical Preparation	
Cycles (including Auto cycles	
Cycles (spares	
Domestic wares	
Electrical materials	
Fans, refrigerators, Tv, Radios	
Iron and aluminium sheets	
Machinery and spares	
Marble chips	
Milk	
Motor spares	
Paper and stationeries	
Pharmaceuticals	
Plastic wares	
Provision and confectioneries	
Tyres and tubes	
Textile materials	
Others	

6) Types of Vehicle

Category	**Van**	**Trucks**
4 Tyres	V4	T4
6 Tyres	V6	T6
8 Tyres	V8	T8
Above 8 Tyres	V>8	T>8

J.2 Summary of Survey Results

The finding obtained from this survey are summarised in Table J.2 and J.3. The result relates only to Truck/vans carrying container-related cargo (SCL).

Table J.2: Summary of origin and destination of trucks

ID	Location	Total No of observations	No of vehicles							
			From Ports	To Port	From Off-dock terminals	To Off-dock terminals	From warehouse	To warehouse	From Others	To others
2a	Wharf road from Apapa	100	18	18	22	14	16	36	44	32
2b	Wharf road to Apapa	100	100	0	0	3	0	15	0	82
3a	KiriKiri road to Mobil	200	189	0	9	0	2	3	0	197
3b	KiriKiri road from Mobil	200	98	0	0	121	9	10	93	69
5a	Lagos Badagry Expressway to Mile2	79	0	10	0	0	0	0	79	69
5b	Lagos Badagry Expressway from	300	71	4	33	2	19	6	177	288
11a	Lagos-Ikorodu expressway to Ikorodu	100	22	0	0	0	12	7	66	93
11	Lagos-Ikorodu expressway from	100	26	0	0	0	3	1	67	97
12a	Lagos-Ibadan Expressway from	298	0	0	0	0	0	0	298	298
12	Lagos-Ibadan Expressway to Ibadan	297	124	0	0	0	28	0	145	297

Table J.3: Vehicle Categories

ID	Location	Total No of observations	Vehicle Type				
			T>8	T8	T6	V6	V4
2a	Wharf road from Apapa	100	50	21	1	11	9
2b	Wharf road to Apapa	100	0	0	0	0	0

3a	KiriKiri road to Mobil	200	193	3	4	0	0
3b	KiriKiri road from Mobil	200	197	2	1	0	0
5a	Lagos Badagry Expressway to Mile 2	79	9	43	7	9	11
5b	Lagos Badagry Expressway from	300	104	133	8	22	33
11a	Lagos-Ikorodu expressway to Ikorodu	100	85	3	5	2	5
11	Lagos-Ikorodu expressway from	100	62	0	14	3	21
12a	Lagos-Ibadan Expressway from	298	200	0	91	0	1
12	Lagos-Ibadan Expressway to Ibadan	297	268	1	17	0	11

Appendix K: Result and Analysis

K.1 Result from analysis

Table K.1: Results from Baseline scenario simulation

	Freight Vehicle-hrs (per hour)	Freight Vehicle- kms (per hour)
System Analysis	46,396	2,282,099
Route to port	530	23,361
Route from port	981	56,453
Route to zones	17,888	981,636
Route from zones	17,608	1,003,944

Table K.2: Savings to the system

Distribution		Freight Vehicle-hrs savings (per				Freight Vehicle-kms savings (per			
		Case1	Case2	Case3	Case4	Case1	Case2	Case3	Case4
Satellite	0.1	1,978	2	1,978	119	49,478	5	49,478	3,688
	0.2	3,900	29	3,900	217	99,395	29	99,395	6,607
	0.3	5,964	61	5,964	328	149,246	58	149,24	9,581
	0.4	7,904	114	7,904	451	198,710	116	198,71	12,914
	0.5	9,767	145	9,767	572	249,039	290	249,03	16,113
Load centre	0.3	7,194	1,229	7,194	1,339	182,784	32,597	182,78	37,945
	0.2	4,943	1,335	4,943	1,383	128,969	36,562	128,96	38,506

Table K.3: Savings to routes from ports

Distribution		Freight Vehicle-hr savings (per hour)				Freight Vehicle-kms savings (per			
		Case1	Case2	Case3	Case4	Case1	Case2	Case3	Case4
Satellite	0.1	72	79	72	84	4,303	4,837	4,303	5,157
	0.2	121	164	121	157	7,611	10,292	7,611	9,932
	0.3	196	255	196	247	11,952	15,726	11,952	15,383
	0.4	264	340	264	330	15,809	20,821	15,809	20,363
	0.5	351	428	351	415	21,050	26,185	21,050	25,613
Load centre	0.3	723	785	723	776	43,734	47,875	43,734	47,497

	0.2	716	760	716	752	43,757	46,570	43,757	46,150

Table K.4: Savings to routes to ports

Distribution		**Freight Vehicle-hr savings (per hour)**				**Freight Vehicle-kms savings (per**			
		Case1	**Case2**	**Case3**	**Case4**	**Case1**	**Case2**	**Case3**	**Case4**
Satellite	0.1	-35	31	-35	26	-2,375	1,619	-2,375	1,121
	0.2	-62	69	-62	56	-4,431	3,579	-4,431	2,375
	0.3	-84	105	-84	83	-6,266	5,390	-6,266	3,551
	0.4	-119	137	-119	107	-8,494	7,190	-8,494	4,614
	0.5	-147	170	-147	125	-10,521	8,941	-10,521	5,581
Load centre	0.3	110	322	110	128	2,720	15,830	2,720	5,881
	0.2	177	317	177	109	6,980	15,476	6,980	5,130

Table K.5: Savings to routes from zones in port city

Distribution		**Freight Vehicle-hr savings (per hour)**				**Freight Vehicle-kms savings (per hour)**			
		Case1	**Case2**	**Case3**	**Case4**	**Case1**	**Case2**	**Case3**	**Case4**
Satellite	0.1	1,334	84	1,334	125	77,625	6,507	77,625	8,017
	0.2	2,626	185	2,626	238	153,708	14,088	153,708	15,474
	0.3	3,977	293	3,977	381	231,708	21,636	231,708	24,368
	0.4	5,354	396	5,354	512	310,774	29,134	310,774	32,765
	0.5	6,682	495	6,682	640	388,487	36,369	388,487	40,923
Load centre	0.3	2,835	1,151	2,835	1,151	170,500	71,786	170,500	71,786
	0.2	951	1,121	951	1,121	62,214	69,416	62,214	69,416

Table K.6: Savings to routes to zones in port city

Distribution		**Freight Vehicle-hr savings (per hour)**				**Freight Vehicle-kms savings (per hour)**			
		Case1	**Case2**	**Case3**	**Case4**	**Case1**	**Case2**	**Case3**	**Case4**
Satellite	0.1	429	77	429	76	24,239	5,733	24,239	4,632
	0.2	866	166	866	129	48,773	12,449	48,773	8,337
	0.3	1,378	250	1,378	184	75,806	18,638	75,806	12,106
	0.4	1,746	337	1,746	237	98,463	25,286	98,463	15,939
	0.5	2,262	432	2,262	296	125,949	31,995	125,949	20,026
Load centre	0.3	21	636	21	636	-8,494	33,420	-8,494	33,420
	0.2	-782	612	-782	612	-49,389	31,333	-49,389	31,333

K.2 Location of consignees and empty depots

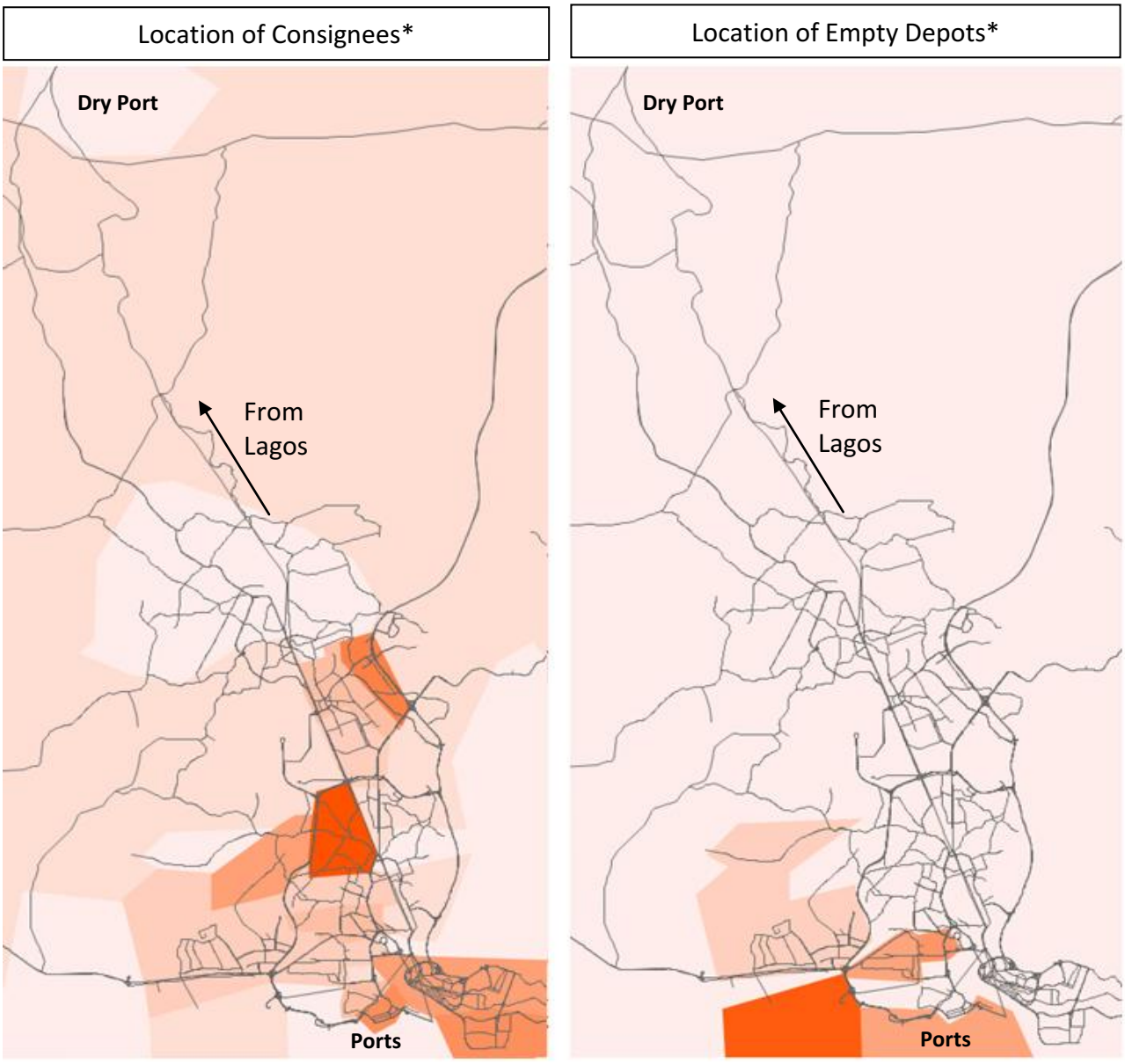


Figure K.1: A representation of the concentration of consignees and existing empty depots in zones within the port city. (*The dark shades region represents areas with higher concentration of importers and empty depots)

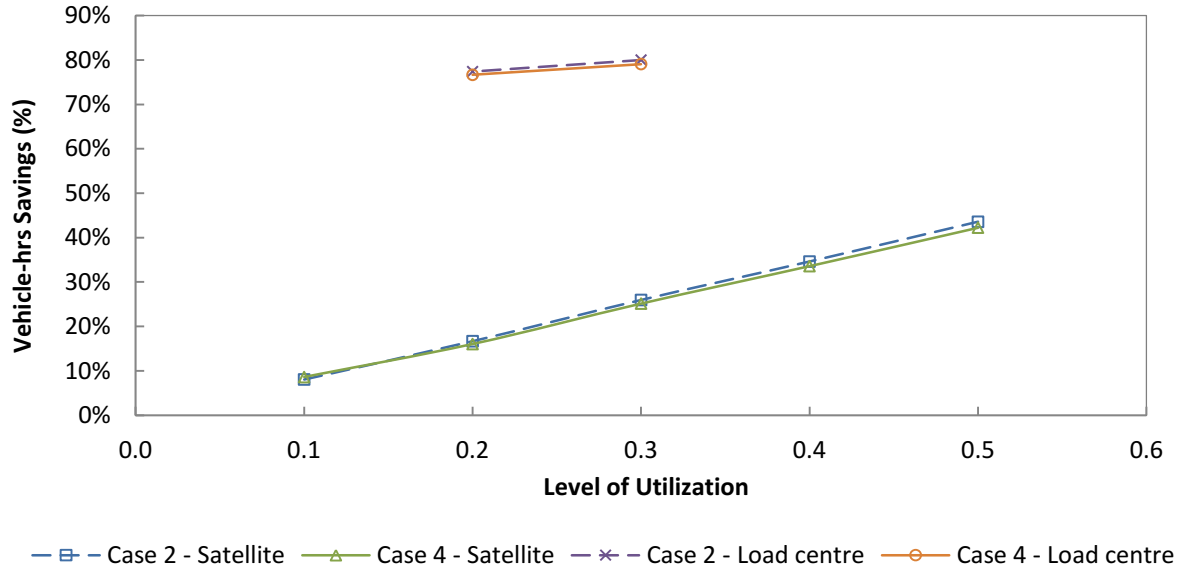


Figure K.2: Vehicle-hrs savings to routes from ports against the level of dry port utilization

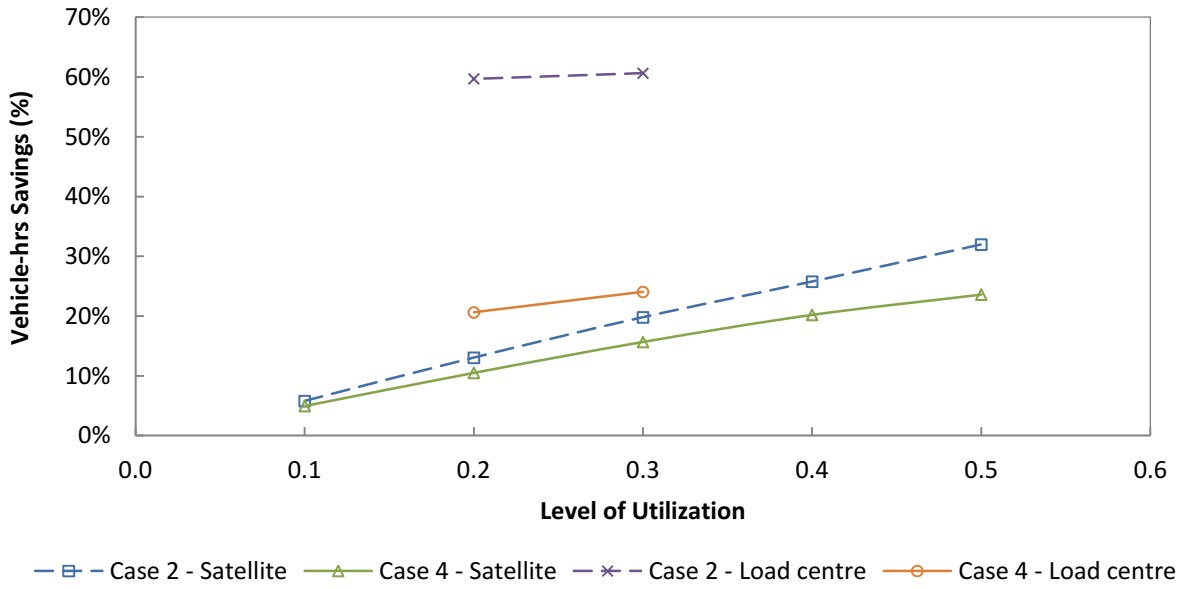


Figure K.3: Vehicle-hrs savings to routes to ports against the level of dry port utilization

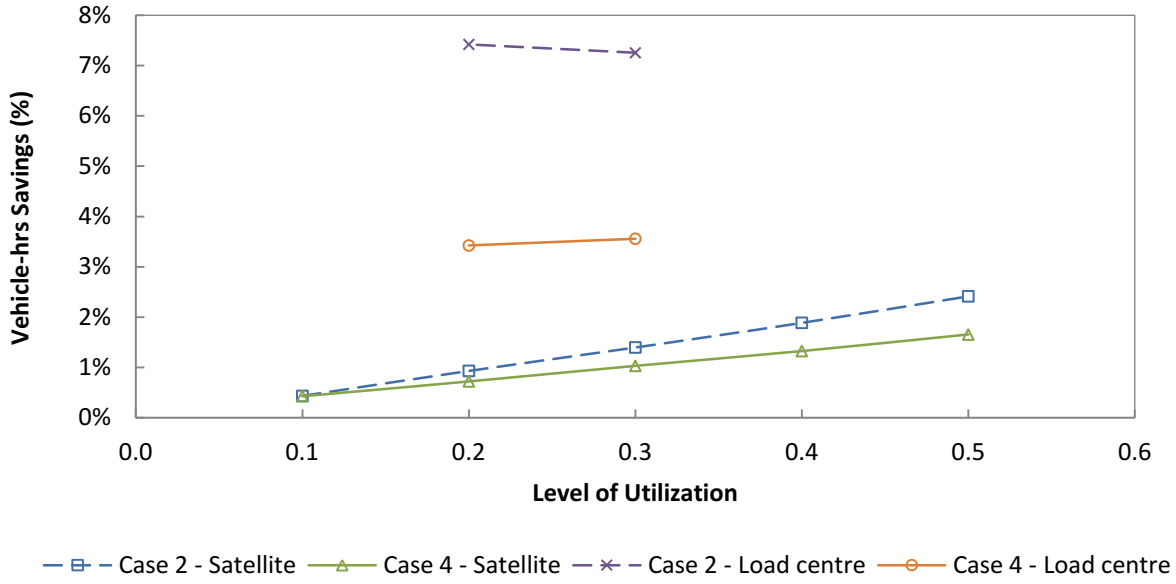


Figure K.4: Vehicle-hrs savings to routes to port city against the level of dry port utilization

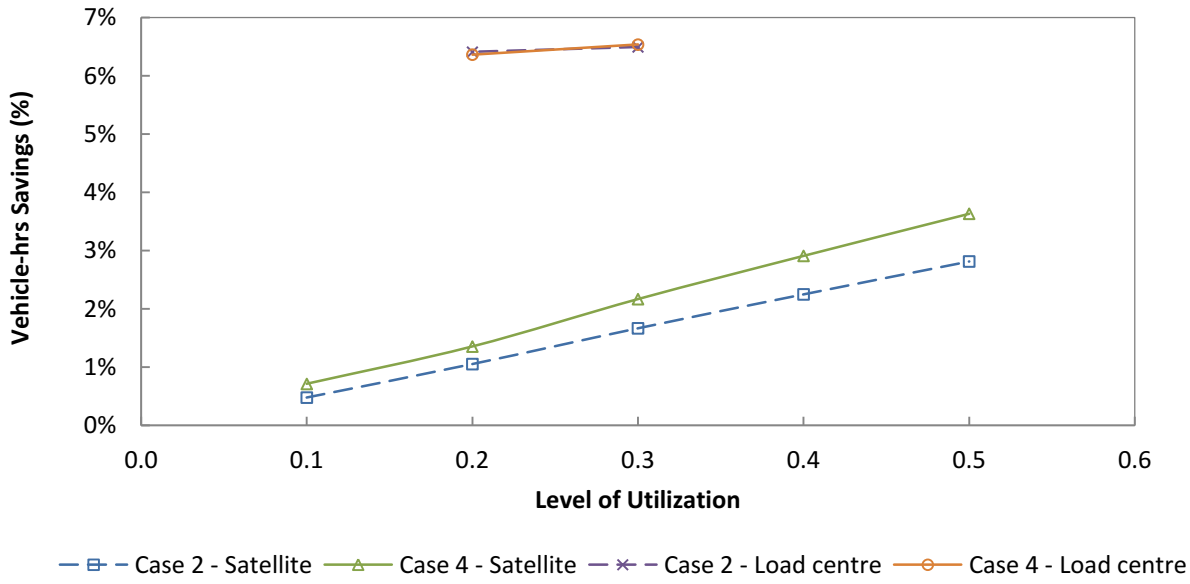


Figure K.5: Vehicle-hrs savings to routes from port city against the level of dry port utilization

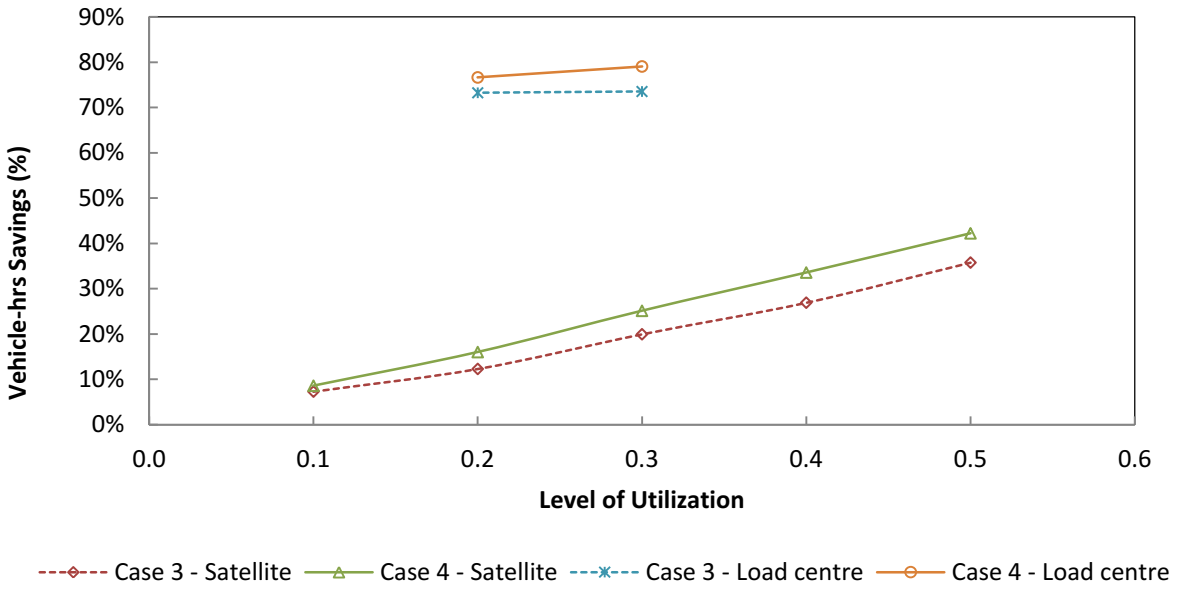


Figure K.6: Vehicle-hrs savings to routes <u>from</u> ports against the level of dry port utilization

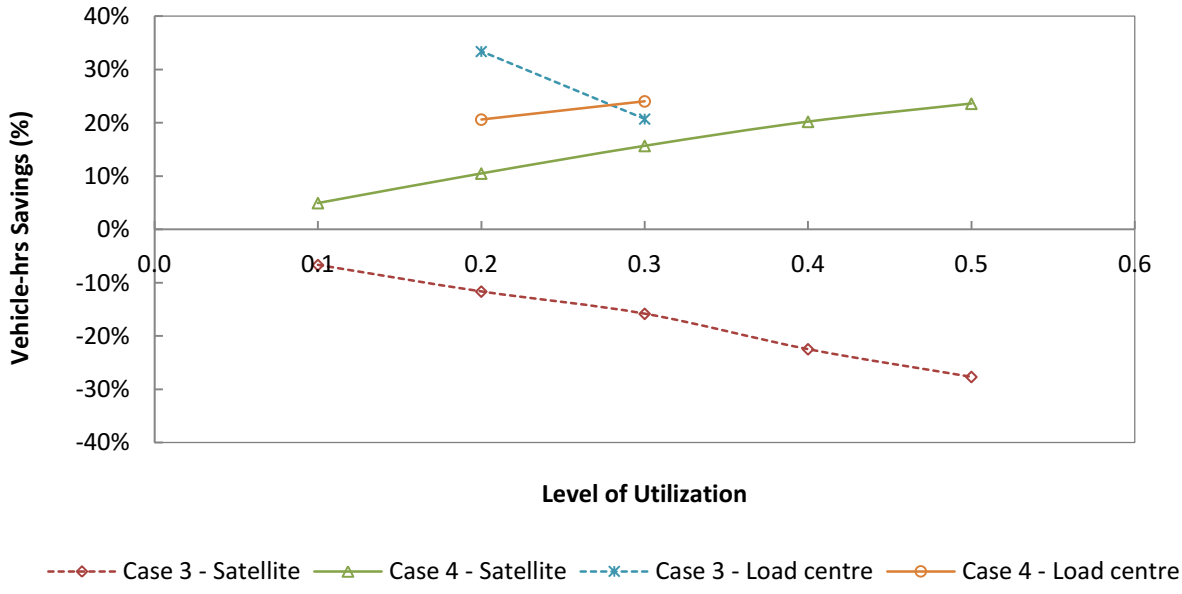


Figure K.7: Vehicle-hrs savings to routes <u>to</u> ports against the level of dry port utilization

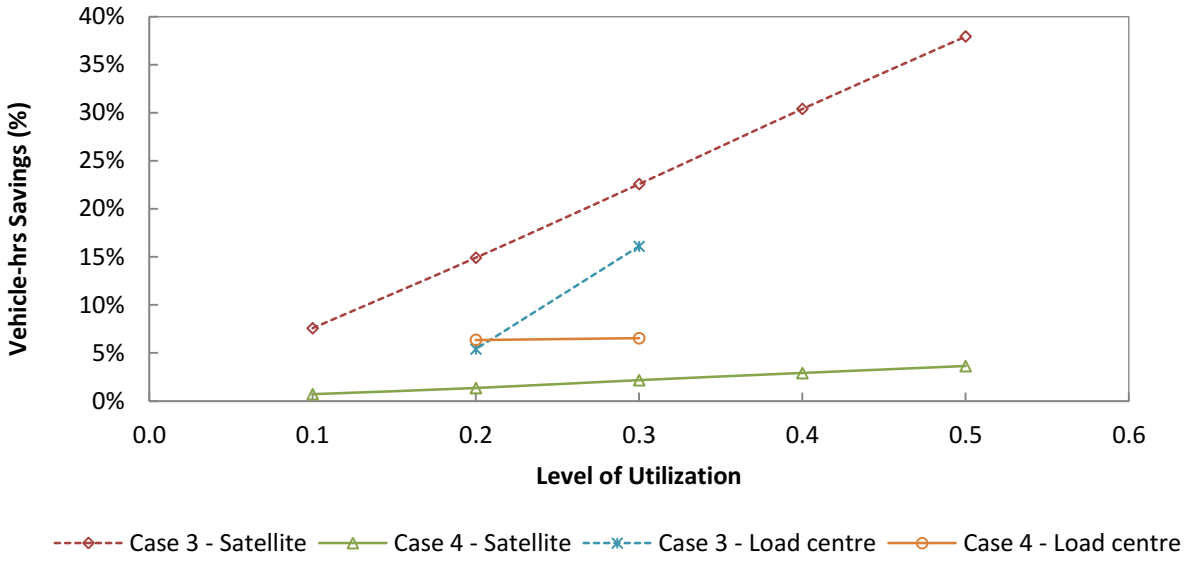


Figure K.8: Vehicle-hrs savings to routes from zones in port city against dry port utilization

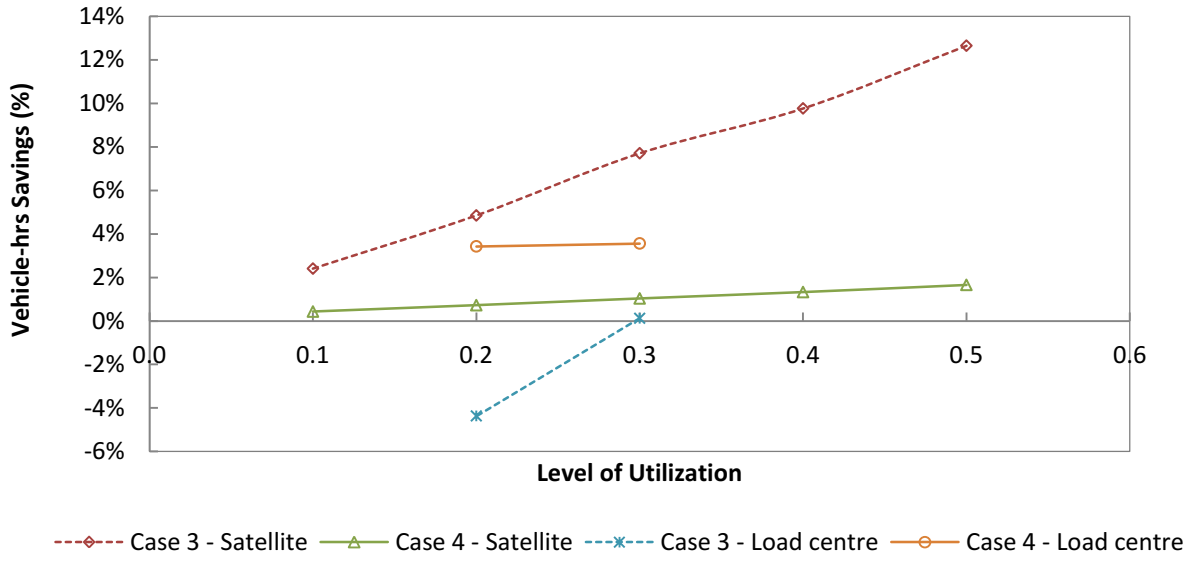


Figure K.9: Vehicle-hrs savings to routes to zones in port city against dry port utilization

Table K.7: percentage Vehicle-kms savings for routes to and from ports

CASE 3							
		Routes From Ports			**Routes to Ports**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	7.6%	-5.9%	-13.5%	-10.2%	7.8%	17.9%
	0.2	13.5%	2.1%	-11.4%	-19.0%	-2.4%	16.6%
	0.3	21.2%	10.7%	-10.5%	-26.8%	-12.7%	14.1%
	0.4	28.0%	19.6%	-8.4%	-36.4%	-23.7%	12.7%
	0.5	37.3%	30.2%	0.0%	-45.0%	-35.9%	0.0%
Load Centre	0.3	77.5%	78.8%	1.3%	11.6%	15.2%	3.5%
	0.2	77.8%	79.2%	1.4%	29.9%	35.0%	5.1%
CASE 2							
		Routes From Ports			**Routes to Ports**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	8.6%	-3.7%	-12.3%	6.9%	24.6%	17.7%
	0.2	18.2%	6.6%	-11.6%	15.3%	31.2%	15.9%
	0.3	27.9%	17.4%	-10.5%	23.1%	37.3%	14.2%
	0.4	36.9%	28.4%	-8.5%	30.8%	43.3%	12.6%
	0.5	46.4%	39.2%	-7.1%	38.3%	47.3%	9.0%
Load Centre	0.3	84.8%	84.8%	0.0%	67.8%	67.8%	0.0%
	0.2	82.5%	82.5%	0.0%	66.2%	66.2%	0.0%
CASE 4							
		Routes From Ports			**Routes to Ports**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	9.1%	-3.9%	-13.0%	4.8%	22.5%	17.7%
	0.2	17.6%	6.2%	-11.4%	10.2%	26.3%	16.2%
	0.3	27.2%	16.8%	-10.4%	15.2%	29.4%	14.2%
	0.4	36.1%	27.6%	-8.4%	19.8%	32.3%	12.6%
	0.5	45.4%	38.2%	-7.2%	23.9%	32.9%	9.0%
Load Centre	0.3	84.1%	85.5%	1.4%	25.2%	28.7%	3.5%
	0.2	81.7%	83.5%	1.7%	22.0%	26.6%	4.7%

Table K.8: percentage Vehicle-hrs savings for routes to and from study

CASE 3							
		Routes From Study Area			**Routes To Study Area**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	7.6%	9.9%	2.4%	2.4%	5.1%	2.7%
	0.2	14.9%	17.1%	2.2%	4.8%	7.3%	2.5%
	0.3	22.6%	24.3%	1.8%	7.7%	9.8%	2.1%
	0.4	30.4%	31.9%	1.5%	9.8%	11.7%	1.9%
	0.5	37.9%	39.2%	1.2%	12.6%	14.0%	1.4%
Load Centre	0.3	16.1%	17.0%	0.9%	0.1%	1.0%	0.9%
	0.2	5.4%	6.6%	1.2%	-4.4%	-3.2%	1.1%
CASE 2							
		Routes From Study Area			**Routes To Study Area**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	0.5%	2.9%	2.4%	0.4%	3.2%	2.8%
	0.2	1.1%	3.1%	2.1%	0.9%	3.4%	2.5%
	0.3	1.7%	3.4%	1.8%	1.4%	3.6%	2.2%
	0.4	2.2%	3.7%	1.5%	1.9%	3.8%	1.9%
	0.5	2.8%	4.0%	1.2%	2.4%	3.9%	1.4%
Load Centre	0.3	6.5%	7.4%	0.9%	7.3%	8.2%	0.9%
	0.2	6.4%	7.5%	1.1%	7.4%	8.5%	1.1%
CASE 4							
		Routes From Study Area			**Routes To Study Area**		
	Utilization	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**	**Off-dock terminal as is**	**Off-dock terminal as empty**	**Absolute change**
Satellite	0.1	0.7%	3.1%	2.4%	0.4%	3.2%	2.7%
	0.2	1.4%	3.5%	2.2%	0.7%	3.2%	2.5%
	0.3	2.2%	4.0%	1.8%	1.0%	3.2%	2.2%
	0.4	2.9%	4.4%	1.5%	1.3%	3.2%	1.9%
	0.5	3.6%	4.8%	1.2%	1.7%	3.1%	1.4%
Load Centre	0.3	6.5%	7.5%	0.9%	3.6%	4.5%	0.9%
	0.2	6.4%	7.5%	1.2%	3.4%	4.6%	1.1%

K.3 Location of key links on approach to the port and dry port

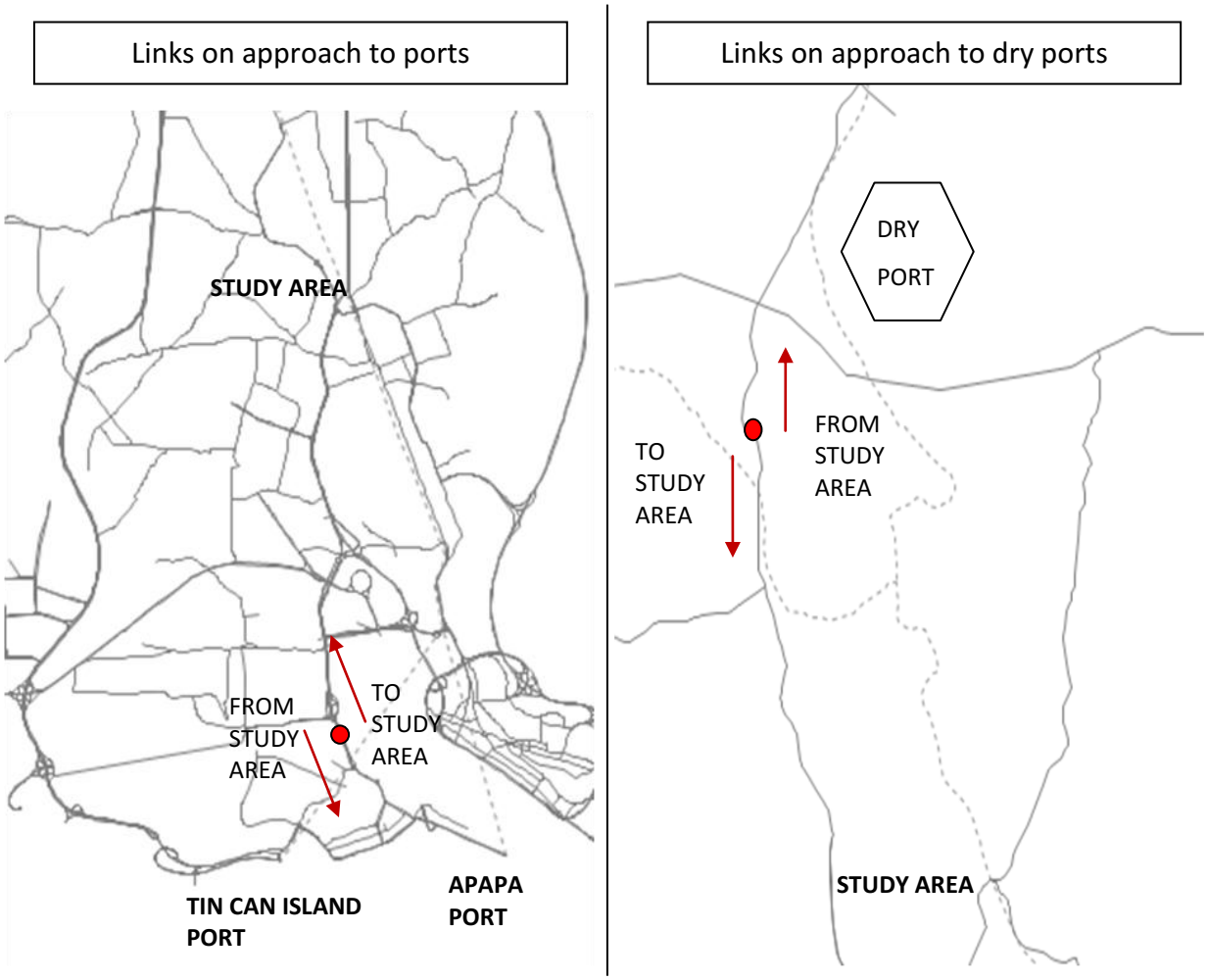


Figure K.10: Map showing the links considered in the link analysis