# Optimisation of Intermodal Freight Transport Network

Aaron Agbenyegah Agbo* [1, 2,3], Wenfeng Li[1], Lanbo Zheng[1], Yanwei Zhang[1], Charles Atombo[4, 5]

*[1]School of Logistics Engineering, Wuhan University of Technology, Wuhan, 430070, China.*
*[2]Department of Logistics and Transportation Services, Ghana Prisons Service, P.O. Box 129, Cantonments, Accra, Ghana.*
*[3]Faculty of Business Management, Accra Institute of Technology (AIT), P.O.Box AN-19782, Accra-North, Ghana*
*[4]School of Transportation Engineering, Wuhan University of Technology, Wuhan, 430070, China.*
*[5]Department of Mechanical Engineering, Ho Technical University, P.O. Box HP 217, Ho, Ghana.*

** Corresponding Author; E-mail: aaron.agbo2000@yahoo.com*

**Abstract**

There is a growing demand for freight transportation in recent times due to trade globalisation and increase in technological innovations. Intermodal freight transportation system is perceived to be a sustainable means of bridging the gap between producers and consumers in the worldwide supply and demand chain. Research into maritime-hinterland transportation has been the focus of most researchers currently. The optimisation of intermodal freight transportation network system is therefore very crucial for maritime-hinterland transportation solutions. This paper provides an integrated optimisation model which take into account cost, transit time and carbon emissions and the trade-offs among these factors to ensure sustainable intermodal network systems. A numerical experiment was performed using data from a developing country, Ghana as the focus of this study. The results offer a real insight into how trade-offs among cost, time and carbon emissions could benefit all the stakeholders within the intermodal network system.

*Keywords:*Intermodal Transportation; Freight Transportation; Network Optimization; Maritime Port; Inland Port; Sustainability.

## 1. Introduction

Transportation accounts for about one-third to two-thirds of total logistics costs globally. The importance of freight transportation in the socio-economic development of a nation cannot be overemphasised(Danielis and Torbianelli, 2007, Danielis et al., 2011). The global trend of rapid growth in business has necessitated the need for more sustainable designs and operations in supply chain networks in order to meet market demands in an efficient and effective way. Transportation is important for moving shipment in a logistics system such as raw materials from their place of origin to manufacturers, unfinished products between plants, and finished products to retailers and consumers(Tseng et al., 2005, McCann, 2008).

In recent times, global commerce, advancement in science and technology, and high rate of consumption of goods have elevated the role of transportation in the global world(Bal and Vleugel, 2015). Competitive factors such as efficiency, safety, reliability, reducing lead time, as well as delays, reactivity and whole transportation costs, has necessitated the need for innovation in the design and operation of transportation networks (Ishfaq and Sox, 2012).

The ramification that the interface between transportation investment and the corresponding economic development brings is beyond the basic purpose of transporting goods and people from one geographical point to another (Pekin and Macharis, 2013). There is no doubt that transportation is very important in the operations of a market economy. However, there is still much to be understood about means by which an efficient transportation system can make better the productivity of the economy. There is a broader role played by transportation in improving development and the entire environment (Bichou and Bell, 2007, Bloemhof et al., 2011, Ślusarczyk, 2010).

The transportation sector of a country forms a major part of the economy as it facilitates the development and the very wellbeing of the entire citizen of the nation. Efficient and effective transportation system, therefore, provides economic and social benefits that enable the growth of the economy (Hanaoka et al., 2011). The costs of transportation-related activities in normal supply chain represent between 5-7% of the total revenue from the supply chain. Logistics operations help largely in the design and operations of sophisticated supply networks (Goetz et al., 2007). Transportation costs optimisation within the supply chain has a great potential because transportation is the link between all the echelons of the supply network(Brandenburg et al., 2014, Boukherroub et al., 2015).

Road freight transportation system has been the norm in developing countries over the years as compared with developed countries that are using intermodal transportation system for decades now. Much recognition has been given to intermodal transportation system as a concept that is very promising for its ability to deliver efficient and effective logistics costs reductions despite the concerns of the system's effective usage (Kannegiesser and Günther, 2014).

Intermodal transportation forms the backbone of the global trade in the modern world. Contrary to the traditional systems in which different modes of transportation operates in an independent way, intermodal transportation has the role of integrating all the different modes and services of transportation in order to offer an improved efficiency of the entire distribution process. Intermodal transportation system that offers a remarkable percentage of growth which is parallel to the growth in the amount of transported freight and the ever changing requirements integrated into supply chain (Bergqvist et al., 2010, Bergqvist and Monios, 2014).

Transportation in Ghana is mainly accomplished by road, rail, air and water(Ghana Ministry of Transport (MoT), 2016). However, the country's transportation and communication networks are centred in the southern regions, especially those areas dominated by natural minerals, timber and cash crops. The main connection between the northern and central areas is road system (Ishfaq and Sox, 2010, Li et al., 2015, López and Monzón, 2010, Adanu et al., 2006)

The dominant transportation mode in Ghana for both freight and passengers is the road transportation system. Majority offreight and passenger movements across the length and breadth and in the cities and towns of the country is done by the road transport(Ghana Ministry of Transport (MoT), 2016). The impacts of this unbalanced system of transportation are high rate of vehicular emissions, traffic congestions, safety risks, etc. There is, therefore, the need to introduce the concept of intermodal transportation into the transportation system of the country in order to make the country's transportation system more efficient and sustainable.

In this regard, this paper's contribution is to analyse the main benefits of intermodal transportation with the aim of reducing the total transportation costs, delivery times, and emissions. The paper also seeks the full potentials of intermodal transportation in Ghana (Adanu et al., 2006). The rest of the paper is organised as follows: Section-2 presents brief literature review on intermodal freight transportation and transport network design; Section-3 shows the model design; Section-4 deals with an illustrative case and discussion of the optimisation results and Section-5 gives the conclusion of the study.

## 2. Literature Review

Theoretical framework on the requirements of intermodal transportation system as provided by (Hayuth, 1987) shows that there are unique advantages for each transport mode in terms of cost, safety, service, efficiency and reliability. The choice of each transportation system thus depends on its own characteristics. The study of (Hayuth, 1987) also purported that high waiting and turnaround times of sea transportation system could be eliminated with the help of intermodal system. This could reduce transport cost, transit times, and other unreliable circumstances. It is, therefore, imperative to change transportation operations from single mode to integrated intermodal transportation modes (Bai and Sarkis, 2010, Boukherroub et al., 2015).

The past several decades has seen the development of intermodal logistics in the literature of transportation research(Bärthel and Woxenius, 2004, Kreutzberger et al., 2003). General survey and definitions of intermodal transportation problem have been given by many researchers. Some of these studies gave detailed analysis of network design cases and offered general concepts for transportation operations(Woxenius, 2007b, Woxenius, 2007a, Riessen et al., 2015). Other researchers elaborated on the classical facility location problem in transportation, highlighting on their solution methodologies(Woxenius, 2012, Riessen et al., 2015, Crainic and Laporte, 1997). The combination of facility location and network design problems for the creation of an integrated solution methodology for transport activities is performed by some other researchers(Olsson and Woxenius, 2014, Olsson and Woxenius, 2012).

Other papers analysed the problem of intermodal transportation and came out with models for solving the problem (Janic, 2007, Riessen et al., 2015, Crainic and Laporte, 1997). Some studies focused on reviews on intermodal transportation routeing and network design(Bontekoning et al., 2004, Riessen et al., 2015). These papers could not do more than giving a list of means of developing and effective intermodal transportation system. However, some of the papers gave a brief description of intermodal transportation network design, multiple objectives, and on-time service requirement (Xu et al., 2015, Macharis and Bontekoning, 2004).

The development of formulations for the selection of fixed intermodal hubs among the various locations and its further improvement by (Arnold et al., 2004, Arnold et al., 2001) is quite interesting. The demonstration of each network mode as a subgraph with the necessary nodes and links is given by their research.

### *2.1 Transport Network Designs*

Consolidating container transport flows is very essential in the intermodal container transportation system(Barbarino et al., 2010). Flow consolidation is generally done systematically and according to a transport network design. (Woxenius, 2007b)describe a generic framework for consolidating and routeing principles in a transport network. The framework consists of six significantly different theoretical designs namely: direct link, corridor, hub-and-spoke, connected hubs, static routes, and dynamic routes.

An example of the six transport network routes as proposed by (Woxenius, 2007b)is described in figure 1 below. The networks have ten nodes for illustrating the different links used for a transport assignment from the point ‘O’ as origin and point ‘D’ as the destination respectively. It is observed that the theory is based on the assumption that the sufficient supply of infrastructure enables direct links between all terminals in the network and that all terminals are capable of serving as origins and destinations as well as transfer points. With the particular networks, the operator can actually decide whether to operate the links and nodes itself or use subcontracted services by other operators.

*2.1.1 Direct Link*

The direct link transport network is operated directly from O to D. in this alternative design, there is no coordination with transport between the pairs of other O-D, and this type of network does not give consideration to other nodes within the network.

*2.1.2 Corridor*

This type of transport network design is based on using a high-density flow mainly along an artery and short capillary service to nodes off the corridor. The design has nodes which are ordered in a hierarchy. The origin ‘O’ in this design represents a satellite node, and the destination ‘D’ stands for the corridor node.

*2.1.3 Hub-And-Spoke*

The hub-and-spoke layout consists of one node which represents the hub. Transfers by all transports including the adjacent origins and destinations are performed at this node. The operations of this transport network system followbasic principles. However, coordinating a large number of interdependent transport services is a major challenge.

*2.1.4 Connected Hubs*

Connected hub is a hierarchical layout, and the local flows in this transport network design are received at hubs which are in turn connected to other hubs in other regions. The connected hub can be described as a direct link with regional consolidation.

*2.1.5 Static Routes*

The designation of the number of links to use on a regular basis is performed by the transport operator in the static rout transport network system. Unlike the hub-and-spoke network system, the static route design uses several nodes as transfer points along the route through the transfer may not be needed at all the nodes. More often than not, partload may be transferred at the nodes. The remaining loads may stay on the transport means to the next node.

*2.1.6 Dynamic Routes*

The dynamic route design offers maximum flexibility. In this design, links are designated depending on actual demand. The network operator chooses many different routes between the origin and destination. With the dynamic design, transport services are planned heuristically or by employing appropriate optimisation methods. This transport network design creates room for changing routes dynamically during transportation.

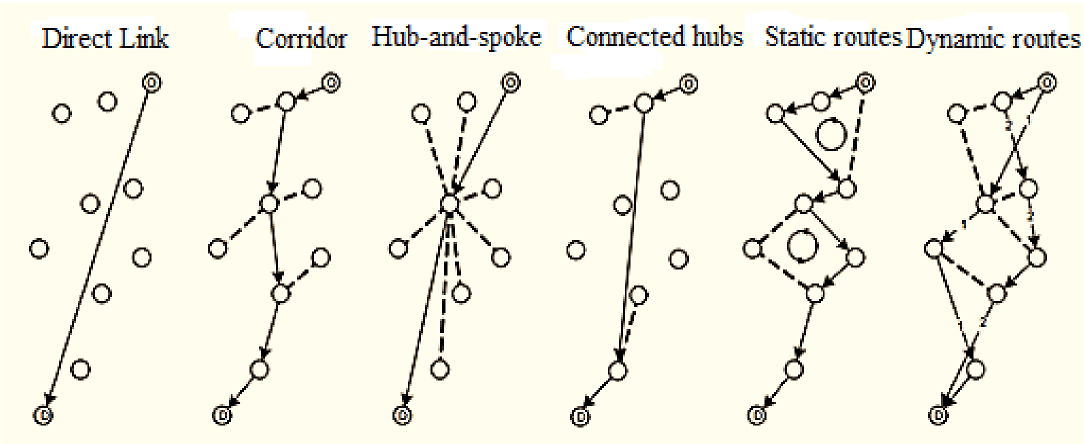


Figure 1: Six options for transport from an origin (O) to a destination (D) in a network of ten nodes.Dotted lines show operationally related links in the network designs. In 'Dynamic routes', two alternative routes are shown; in all other designs, the routeing is predefined.Source: (Woxenius, 2007b)

The intermodal freight transport network model is used for the planning at the tactical level of decision making. The network representation details are presented in figure 2 and 3below. We used the idea of dynamic routeing. In this model, the shipments of containers are performed from different international maritime ports to domestic maritime ports. From the domestic maritime ports, the containers are then transported to a hinterland port in an integrated network to the distribution terminals within the designated hinterland cities. In order to achieve intermodal benefits, three main transportation modes are usednamely road, railway and waterway depending on the availability of the modes, but there must be the use of at least two modes at all times in the intermodal freight transport concept. However, the last mile delivery of containers may be done by road.

## 3. An integrated freight transportation model

In this model, the shipments of containers are performed from different international maritime ports to domestic maritime ports. From the domestic maritime ports, the containers are then transported to a hinterland port in an integrated network to the distribution terminals within the designated hinterland cities. To achieve intermodal benefits, three main transportation modes are used namely road, railway and waterway depending on the availability of the modes, but there must be the use of at least two modes at all times in the intermodal freight transport concept. However, the last mile delivery of containers may be done by road.

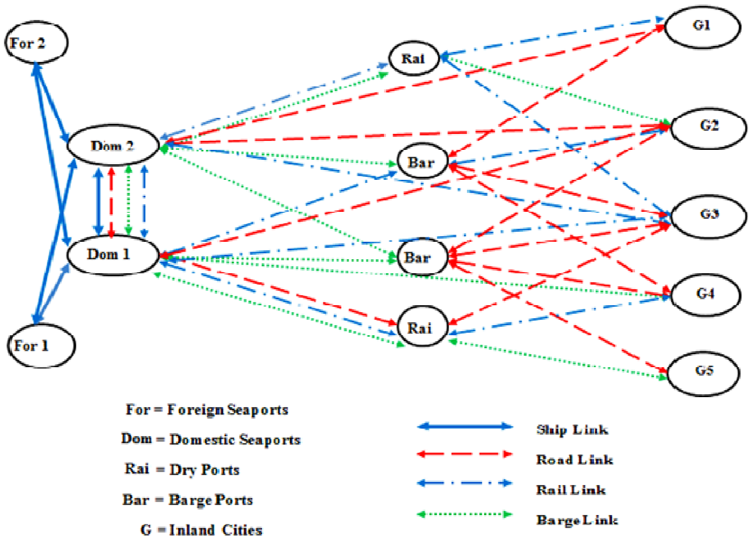


Figure 2: A schematic representation maritime and hinterland intermodal container shipment network.

## 3.1 The optimisation model (bi-objective)

The bi-objective optimisation deals with two objectives namely cost minimization and transit time minimization objectives. This optimisation model has more advantage over the single objective optimisation model in practice. Two main considerations to make in the planning of integrated transportation network is cost and transit time. In the model formulation of the intermodal freight transport network, the modal choice is made by the logistics service providers.For the purpose of simplicity, this study eliminates the constraints of capacity for sea leg container transportation.

It is worth stating that the main focus of this study is on the transportation optimisation of container freight from the marine port terminal to the inland port terminal. Also, modal split concept is highly considered since intermodality has more to do with modal split in achieving environmental sustainability goals, etc. it is assumed in this research that transit times are deterministic in nature at all the modes of transportation as this assumption is suitable for the tactical planning situation.

For the attainment of the environmental benefits of intermodal system, there is the need to analyse the effects of the different carbon emission requirements within the intermodal system. In this vein, carbon emission limits as adopted by the government for transport operations are incorporated into the model which represents extra constraints. The mathematical model and descriptions are shown as follows.

3.2 Model formulation for the integrated network

$N$ Set of nodes, $N = For \cup Dom \cup Rai \cup Bar \cup G$ , where $For =$ foreign maritime ports, $Dom =$ domestic seaports, $Rai =$ dry ports connected by rail, $Bar =$ barge or river ports, $G =$ inland cities.

$S$ set of arcs, $S = S_{ForDom} \cup S_{DomFor} \cup S_{DomRai} \cup S_{RaiDom} \cup S_{DomBar} \cup S_{DomG} \cup S_{GDom} \cup S_{SRaiG} \cup S_{GRail} \cup S_{GRail} \cup S_{BarG} \cup S_{GBar}$ for all (i, j) ∈ AXY, (i, j) represents the arc from i ∈ X and j ∈ Y, and X, Y ∈$\{For, Dom, Rai, Bar, G\}$

Decision variables

$\phi t_{ij}$ Aggregate container shipment quantity from node $n_i$ to $n_j$, (i, j) ∈ S

$\phi \ddot{\varepsilon}_{ij}$ Empty container shipment quantity from node $n_i$ to $n_j$, (i, j) ∈ S

$\phi \bar{Ḷ}_{ij}$ Loaded container quantity from node $n_i$ to $n_j$, (i, j) ∈ S

$\nabla\rho_{ij}$ Quantity of vehicles assigned from node $n_i$ to$n_j$, (i, j) ∈ S and $n_i n_j \notin For$

Parameters

$K$ Average carbon emissions in kg/TEU for a network.

$Ktrans_{i,j}$ Emissions from origin $n_i$ to destination $n_j$ in kg/TEU, $(i, j)$ ∈ S

$Q_{cc}$ Clearance cost for the individual loaded containers imported (TEU)

$Q_{ee}$ Clearance cost for loaded container for export (TEU)

$Q_{yy}$ Costs for other import operations, e.g. documentations (per TEU)

$Q_{ff}$ Costs for other export operations, e.g. documentations (per TEU)

$Ⴟ_{ij}$ Quantity of container for a vehicle on an arc (i, j) ∈ S

$Ⴟ\dot{ſ}_{ij}$ Fixed cost for a vehicle on an arc (i, j) ∈ S

$\nabla\alpha_{ij}$ Available vehicle from node $n_i$ to $n_j$, $(i, j)$ ∈ S where $n_i, n_j \notin For$

$Csq_i$ Supply quantity of container of node $n_i$, $n_i \in For \cup G$

$Cdq_i$ Demand quantity of containers of node $n_i$, $n_i \in For \cup G$

$ECsq_i$ Empty container supply quantity of node $n_i$, $n_i \in For \cup G$

$ECdq_i$ Empty container quantity of node $n_i$, $n_i \in For \cup G$

$Cthrocp_i$ Capacity of container throughput of node $n_i$s, $n_i \in Dom \cup Rai \cup Bar$

$Chq_i$ Cost of handling containers in node $n_i$, $n_i \in Dom \cup Rai \cup Bar$

$C\omega_i$ Time for handling containers in node $n_i$ per TEU, $n_i \in Dom \cup Rail \cup Bar$

$C\varphi_i$ Cost of storage of containers in node $n_i$ per hr/TEU, $n_i \in Dom \cup Rai \cup Bar$

$C\beta_i$ Time for storage of container in node $n_i$ per TEU, $n_i \in Dom \cup Rai \cup Bar$

$Ctrans_{ij}$ Cost of shipment from node $n_i$ to $n_j$ in \$/ TEU, $(i, j) \in S$

$Trans\beta_{ij}$ Cost of shipment time from node $n_i$ to $n_j$ in hr /TEU, (i, j) ∈ S

The Objective functions for the scenarios

(1) Cost minimisation

$$\Big(\sum_{(i,j)\in S} Ctrans_{i,j} \times \phi t_{i.j} + \sum_{(i,j)\in S} 2 \times \big(Chq_i \times \phi t_{i,j} + \sum_{(i,j)\in S, n_{i \notin For \cup C}} (C\varphi_i \times C\beta_i\big) \times \phi t_{i,j}\big) + Dom + \sum_{(i,j)\in S_{DomFor}} \big(Q_{ee} + Q_{ff}\big) \times \phi \bar{Ḷ}_{i,j} + \sum_{(i,j)\in S_{ForDom}} Q_{yy} \times \phi \ddot{\varepsilon}_{i,j} + \sum_{(i,j)\in S_{PFor}} Q_{ff} \times \phi \ddot{\varepsilon}_{i,j} + \sum_{(i,j)\in S, n_{i \notin} For, n_{i \notin F}} Ⴟ\dot{ſ}_{i,j} \times \nabla\rho_{i,j} \div \sum_{i \in For} (Csq_i + Cdq_i)\Big) \qquad (1)$$

(2) Time minimisation

$(\sum_{(i,j)\in S} Trans\beta_{i,j} \times \phi t_{i,j} + \sum_{(i,j)\in S} 2 \times (C\omega_i) \times \phi t_{i,j} + \sum_{(i,j)\in S, n_i \notin For \cup C} C\beta_i \times \phi t_{i,j}$
$) \div \sum_{i\in For}((Csq_i + Cdq_i) \times 24)$ (2)

Constraints:

The restrictions for the optimisation are given as follows:

$\sum_{(i,j)\in S}(Ktrans_{i,j} \times \phi t_{i,j}) \div \sum_{i \in For}(Csq_i + Cdq_i) \leq K$(3)

$\sum_{(k,i)\in S} \phi t_{ki} = \sum_{(i,j)\in S} \phi t_{i,j,} \forall n_i \in Dom \cup Rai \cup Bar$ (4)

$\sum_{(i,j)\in S} \phi t_{ij} = Csq_{i,} \forall n_i \in For\ U\ G$ (5)

$\sum_{(i,j)\in S} \phi t_{i,j} = Cdq_j, \forall n_j \in For \cup G$ (6)

$\sum_{(i,j)\in S_{ForDom}} \phi \ddot{\varepsilon}_{ij} = ECsq_i, \forall n_i \in For$ (7)

$\sum_{(i,j)\in S_{DomFor}} \phi \ddot{\varepsilon}_{ij} = ECdq_j, \forall n_j \in For$ (8)

$\nabla\rho_{ij} \leq \nabla\alpha_{ij}, \forall(i,j) \in S, n_i \notin For, n_j \notin For$ (9)

$\phi t_{ij} \leq \Xi_{ij} \times \nabla\rho_{ij}, \forall(i,j) \in S, n_i \notin For, n_j \notin For$ (10)

$\sum_{(i,j)\in S} \phi t_{ij} \leq Cthrocp_i, \forall n_i \in Dom \cup Rail \cup Bar$ (11)

$\phi t_{ij} = \phi \ddot{\varepsilon}_{ij} + \phi \bar{L}_{ij}, (i,j) \in S_{ForDom} \cup S_{DomFor}$ (12)

$\phi t_{ij} \in Z^+, \forall(i,j) \in S$ (13)

$\phi \ddot{\varepsilon}_{ij} \in Z^+, \forall(i,j) \in S_{ForDom} \cup S_{DomFor}$ (14)

$\phi \bar{L}_{ij} \in Z^+, \forall(i,j) \in S_{ForDom} \cup S_{DomFor}$ (15)

$\nabla\rho_{ij} \in Z^+, \forall(i,j) \in S, n_i, n_j \notin For$ (16)

Aggregated unit costs of the loaded and empty containersare presented in objective function (1). Inbound and outbound flow of containers is contained in one formula. The aggregate unit costs consists of storage cost,terminal operation cost, shipment cost, customs clearance cost, and fixed cost of using inland vehicles (trucks, rail and barges). The second objective function (2) of the model is made to reduce the complete individual transit times such as storage time, shipment time, and terminal operating time.

The model uses the definition of unit or average transit time. The sum of transit time of each container routeing throughout the whole network which includes the storage time in each node gives the total time of transit. Dividing the total transit time by the total amount of container helps to obtain the per unit transit time. Limits for carbon emissions adopted by the government and other relevant authorities are contained in constraint (3). The balancing of container inflows and outflows at the various transport nodes is contained in constraint (4). The supply and demand constraints of the total containers are represented in constraints (5) and (6). Constraints (7) and (8) accounts for the supply and demand constraints of the containers. The Constraint (5.44) shows the number of vehicles in the separate hinterland arc. The definition of the relationship between container transport quality and the number of available vehicles in each inland arc is contained in constraint (9). Constraint (10) defines the capacity constraint of the transport nodes. Constraint (11) contains the relationship that exists among the total loaded container quantity, the empty container quantity, and the container quantity in the transport links. Non-negative constraints are contained in constraints (12) – (16).

The model is formulated to optimise the transit cost and time. It also considers the requirements of the environment. These requirements are given as constraints as contained in the model formulation. The individual objective modelling results are needed as the parameters in finding solutions to the modelling problem. Figures 4 to 6 shows Pareto frontier plottings for the compromise between costs and transit times.

When fixed transit time dots are used, the optimal cost values are obtained and the value range of transit time is gained from the two end points.

The Mixed Integer Linear Programming approach is appliedin solving the given problem. This kind of model is usually used when some unknown variable are required to be integers, and they are non-deterministic polynomial-time hard (NP-hard). In this research, the MILP solver CPLEX is used to get the Pareto optimal set. In addition to the generation of Pareto Frontier, this case analyses the different compromised solutions of the generated Pareto Frontier to gain insight for supporting resilient, sustainable planning.

## 4.Illustrative case and optimisation results

Ghana's maritime trade has seen significant development over the years (Ghana Ports and Harbour Authority (GPHA), 2007, Agbo et al., 2017). Ghana has two major maritime ports namely, the Tema Port and the Takoradi Port. These ports are regulated by the Ghana Ports and Harbour Authority (GPHA). The shipping industry in Ghana with major entities such as the ship-owners Agents Association of Ghana (SOAG) and the Ghana Institute of Freight Forwarders (GIFF) has contributed immensely to the economic and trade development in Ghana. The Ghana Shippers' Council is formed with the sole aim of protecting and promoting the interest of shippers in Ghana. The Council ensures conducive and transparent environment to maintain business efficiently at the ports (Ghana Ports and Harbour Authority (GPHA), 2007, Ghana Ports and Harbour Authority (GPHA), 2005).
The throughput of Ghana's cargo has seen a great increase from 8,727,049million metric tonnes in 2008 to 12,145,496million metric tonnes in 2015 (Ghana Ports and Harbour Authority (GPHA), 2016b). This drastic growth in cargo throughput is attributed to the country's population increase. The phenomenon has significantly impacted the consumption rate of both local and exotic goods. Coupled with this, the remarkable use of Ghana's maritime ports by the neighbouring landlocked countries- Burkina Faso, Mali, and Niger – has played a major role in the cargo growth (Ghana Ports and Harbour Authority (GPHA), 2016b, Ghana Ports and Harbour Authority (GPHA), 2016a) (Table 1-2).

Table 1: Tema Port Performance 2003 – 2015 (Ghana Ports and Harbour Authority (GPHA), 2016b)

| Years | Vessel Call (Units) | Total Cargo Traffic | Export | Import | Transit | Transhipment | Container Traffic |
|---|---|---|---|---|---|---|---|
| | | Tonnes | | | | | TEU |
| 2003 | 1,172 | 7,391,268 | 809,589 | 5,490,893 | 885,093 | 138,520 | 305,868 |
| 2004 | 1,381 | 8,447,655 | 1,072,006 | 6,403,422 | 764,128 | 71,082 | 342,882 |
| 2005 | 1,643 | 9,249,977 | 1,182,469 | 6,936,688 | 875,325 | 155,815 | 392,761 |
| 2006 | 1,994 | 8,046,838 | 955,084 | 5,675,027 | 887,589 | 339,841 | 425,408 |
| 2007 | 1,672 | 8,378,682 | 1,099,094 | 6,120,583 | 843,656 | 119,209 | 489,147 |
| 2008 | 1,568 | 8,727,049 | 1,099,094 | 6,259,412 | 864,307 | 195,326 | 555,009 |
| 2009 | 1,634 | 7,406,490 | 1,305,451 | 5,694,280 | 509,124 | 192,565 | 525,694 |
| 2010 | 1,787 | 8,696,951 | 981,075 | 6,823,488 | 447,071 | 236,615 | 590,147 |
| 2011 | 1,667 | 10,748,943 | 1,154,826 | 8,431,531 | 614,078 | 171,195 | 756,899 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2012 | 1,521 | 11,468,962 | 1,532,139 | 9,383,462 | 530,457 | 50,403 | 824,238 |
| 2013 | 1,553 | 12,180,615 | 1,477,390 | 10,014,243 | 620,668 | 51,748 | 841,989 |
| 2014 | 1,504 | 11,126,355 | 1,463,273 | 8,922,550 | 577,277 | 163,305 | 732,382 |
| 2015 | 1,514 | 12,145,496 | 1,303,090 | 10,043,146 | 722,508 | 76,752 | 782,502 |

Table 2: Takoradi Port Performance (2006 – 2015) (Ghana Ports and Harbour Authority (GPHA), 2016a)

| Year | Vessel call (Units) | Total Cargo Traffic | Export | Import | Transit | Container Traffic |
|---|---|---|---|---|---|---|
| | Tonnes | | | | | TEU |
| 2006 | 610 | 4,720,000 | 3240000 | 1,480,000 | 256,094 | 51,042 |
| 2007 | 594 | 4,050,000 | 2540000 | 1,510,000 | 75,599 | 52,226 |
| 2008 | 615 | 4,020,000 | 2330000 | 1,680,000 | 209,890 | 52,372 |
| 2009 | 956 | 3,370,000 | 2110000 | 1,260,000 | 14,485 | 47,828 |
| 2010 | 1277 | 4,010,000 | 2290000 | 1,720,000 | 1,185 | 53,041 |
| 2011 | 1798 | 4,940,000 | 2810000 | 2,090,000 | 31,883 | 56,595 |
| 2012 | 1664 | 5,310,000 | 2960000 | 2,350,000 | 5,958 | 60,746 |
| 2013 | 1364 | 5,450,000 | 3450000 | 1,990,000 | 38,710 | 52,373 |
| 2014 | 1387 | 4,750,000 | 3030000 | 1,720,000 | 32,093 | 61,355 |
| 2015 | 1525 | 4,700,000 | 2840000 | 1860,000 | 60,250 | 58,093 |

According to Roso (Kovacs et al., 2008), the increase in population and a greater economic activity has a direct bearing on maritime container freight transport. This situation consequently results in land surface freight transport growth. The phenomenal increment is, however, affecting the operations of ports and ports business in some ways. On the one hand, the situation is creating lack of space at the ports areas for smooth and efficient operations. On the contrary, the condition is increasing road congestion due to more usage of trucks which is culminating in increased lead-time. These unfavourable conditions are currently prevailing at the maritime ports of Ghana (Ghana Ports and Harbour Authority (GPHA), 2005). To ensure healthy competition with neighbouring ports of the country, there is the need for proactive measures to transport cargo from the maritime ports to the hinterlands and the landlocked neighbouring countries.

## 4.1 Optimisation results

In the analysis, three scenarios were generated. The data for the experiment is presented in Table 3. In each of the scenarios, the analysis took into consideration compromise between the total cost of transportation and the total transit time (Table 4). This offers results as presented in Table 4 below. The parameters are present in Table 5. The locations of the ports are shown in Figure 3.

In the first scenario, the minimisation of only the total transport cost is considered. The optimisation for this objective is provided in the first column of Table 6. The result suggests that 44% of the total freight containers should be transported using road transport from the maritime ports. 34% is to be transported by barge through inland waterway and 22% by railway.


Figure 3: The map of Ghana showing the locations of the ports and linkages. Source: (Ghana Ports and Harbour Authority (GPHA), 2013)

Similarly, in the second scenario, consideration is given to time minimisation. The minimum time is optimised during the analysis. From the optimisation, 69% of freight containers are to be transported by using trucks directly from the maritime ports and container volume of 31% is to be delivered by rail. It is worth stating that, here, inland waterway mode of transport is not considered due to the slow nature of barges which affects total transit time and lead time as well.

For the third scenario, bi-objective optimisation is performed. This optimisation used an integrated approach. The result obtained reveals that direct delivery of freight containers from maritime ports should be of 56% in volume by road transport, 9% by barge and 35% by rail.

From the scenarios and analysis, it could be observed that, when considering cost minimisation only, the obvious choice of transport mode is the barge (inland waterway). This mode of transport produces the least amount of emission of carbon as compared to the other modes. Also, for the minimisation of transit time with minimum lead time considerations, the use of road transport is the most appropriate. However, trucks produce the greatest quantity of carbon emissions. Thus, the balance between cost minimisation and environmental considerations must have some compromise.

Cargo routeing is severely affected by the objectives of optimisation considerably in the sea leg. Tema port is an established international shipping hub. For import routes to the region, many shipping lines call Tema Port first and then Takoradi Port or link Tema and Takoradi ports by the services of feeder vessels (figure 2 and 3). The transit time for a ship/barge between Tema and Tema ports is about one day. If a customer in Takoradi wants lowest transportation cost, his containers should be discharged at Takoradi Port. However, if there is the need for fast delivery, then the containers must be discharged at Tema and then trucked to Takoradi which will take more time.

As revealed by the results of the numerical example obtained from the modelling in this experiment, when $K$ is less than 535 kg, feasible solution could not be obtained. To show the effects of $K$ value, the results have been obtained at three groups of $K$ values when a feasible solution exists. In carbon restriction A and B, $K$ values are set as 535 kg and 565 kg, respectively. In Carbon Requirement C, $K$ value is set as 595 kg or greater. Restriction C indicates that when $K$ value is more than 595 kg, the variation of $K$ value will not affect the Pareto Frontier scope.

The results of the numerical experiments of the three requirements of carbon are presented in figure 4 to 6. These are in the forms of Pareto Frontiers which represents the container distribution by the various transport modes. 80 points were used to obtain the Pareto Frontiers with the needed demands for trade-offs or balance necessary for costs and transit times. The cost objective was achieved by dots optimisation for fixed time. For uniform distribution, and to get the region for feasible solution, 80 transit times were used as model constraints. In figures 4 to 6, the modal split of the results is presented. They show the percentage of the modal split of the container distribution by the various transportation modes.

It can be seen from the results of the analysis that increasing barge usage causes a decrease in the $K$ value. Similarly, the $K$ value increases when we increase the use of trucks. This is quite not surprising because the accepted notion is that the use of barge is more environmentally sustainable than that of trucks. In this vein, there is the need to create the awareness of customer in choosing more environmentally friendly transportation modes. With this, service operators, when designing an intermodal freight transport network can design it in such a way that more sustainable modes are made use of more than the unsustainable ones. Where possible, and as permitted by geographical features, the use of barge and rail should be increased, and the use of trucks should be decreased.

It was realised from the analysis that any slight deviation in the value of $K$ would have a remarkable effect on the range of the Pareto Frontier since the maritime transport produces massive carbon emissions due to the distance it covers in the intermodal supply chain mileage. Emphatically, it is paramount to strategically deal with environmental issues in the intermodal freight transport system design because of the $K$ value sensitivity.

For environmental considerations, it is very crucial to limit the use of road transport in an intermodal freight transportation. It is also prudent to reduce the use of trucks in long distance freight transportation to save cost. The best alternative for both cost reduction and emissions minimisation is the use of rail or barge for inland transportation. Given this, it is imperative for governments and private organisations to consider investing a substantial amount of capital into the development of intermodal infrastructures. Rail and water transport must receive the necessary attention with the development of inland dry ports and river ports.

More detailed information about the results concerning the barge ports and inland railroad quantity of transport obtained from the numerical experiment on the requirement of carbon in situations A and C shown in Table 6. Carbon requirement A and C represent situations of two extremities with requirement A having strict carbon requirement of 535 kg at the lower limit and requirement C having less strict carbon requirement of 590 kg at the ceiling. The latter case does not offer many constraints on choice of transportation modes. Under strict carbon requirements (requirement A) usage of rail and barge increased.

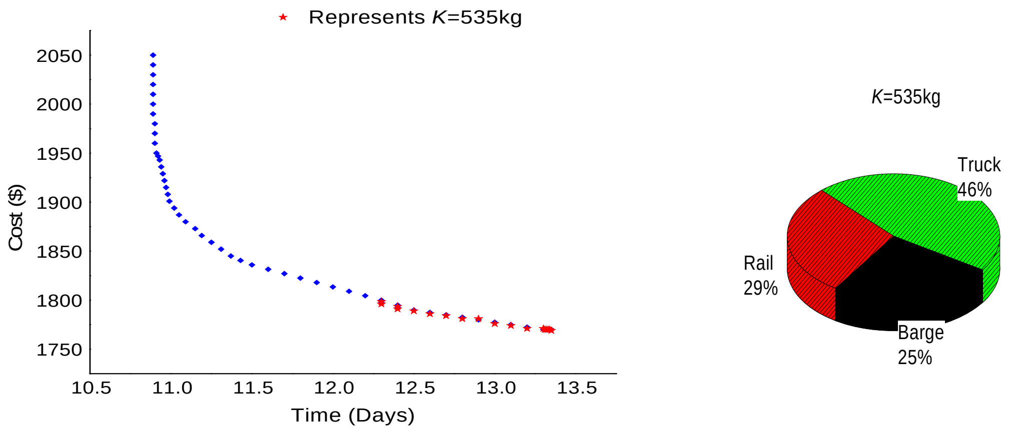


Figure 4: Carbon Requirement AModelling results (K=535 kg)

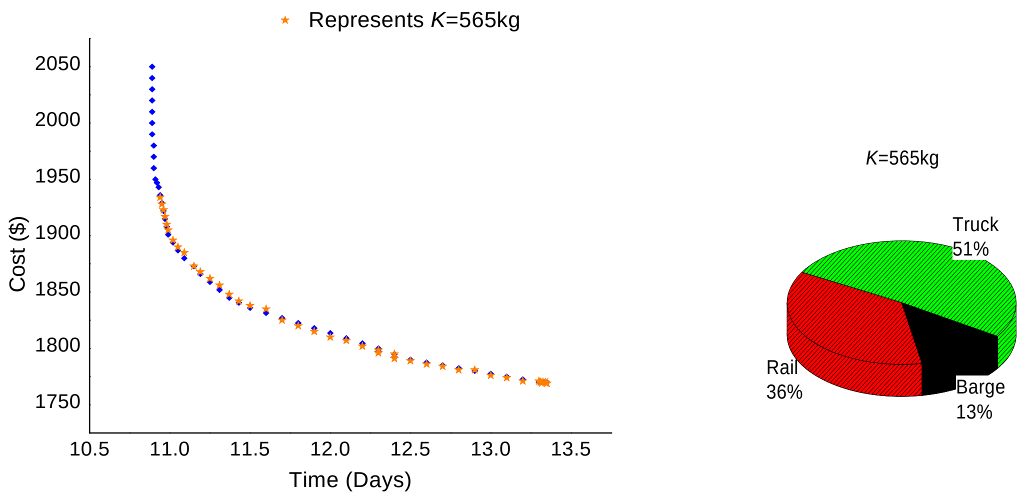


Figure 5: Carbon Requirement B Modelling results (K=565 kg).

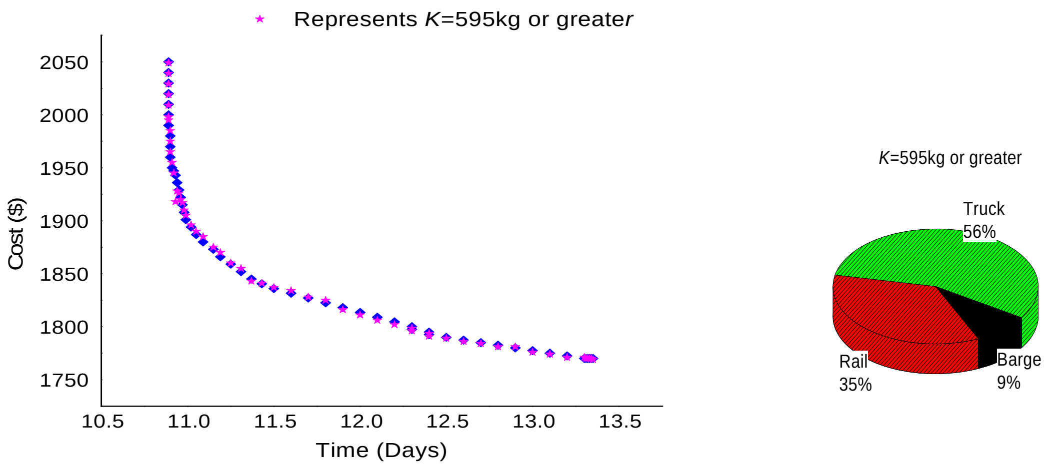


Figure 6: Carbon Requirement C Modelling results (K=595 kg and above)

Table 3: Experiment data (Ghana Ports and Harbour Authority (GPHA))

| *Empty container percentage* | | *Cost of customer clearance per TEU ($)* | | *Port handling costs ($)* | | *Carrying capacities in TEU* | | | *Inland cities demand* |
|---|---|---|---|---|---|---|---|---|---|
| Import | Export | Import | Export | Import | Export | Truck | Rail | Barge | |
| 85 | 15 | 125 | 95 | 170 | 80 | 2 | 115 | 45 | 1400TEU for each city |

Table 4: Parameters

| | *Ship* | *Rail* | *Barge* | *Truck* |
|---|---|---|---|---|
| Variable transportation cost ($/km) | 0.22 | 0.17 | 0.19 | 4 |
| Average speed (km/h) | 40 | 70 | 30 | 70 |
| Carbon footprint (kg/ton-km) | 0.086 | 0.206 | 0.085 | 0.474 |

Table 5:Mode Usage Rate in three scenarios with different Optimisation Objective portfolios (experimental results)

| *Mode Usage Rate* | *Scenario A (Minimum Cost)* | *Scenario B (Minimum Time)* | *Scenario C (Minimum Cost plus Minimum Time)* |
|---|---|---|---|
| Truck | 44% | 69% | 56% |
| Barge | 34% | 0% | 9% |
| Rail | 22% | 31% | 35% |

Table 6: Container quantity to be transported by inland railroad and river ports (experimental results)

| | | *Carbon requirement C (K≥595kg)* | *Carbon requirement A (K=535kg)* |
|---|---|---|---|
| | City | Usage (TEU) | Usage (TEU) |
| Dry Port (Railway) | D0 – Kpong | 2,585 | 4,551 |
| | D1 – Yeji | 1,629 | 3,181 |
| | D2 – Tamale | 4,105 | 1,669 |
| | D3 – Kete Krachi | 11,332 | 0 |
| | D4 – Kumasi | 13,548 | 14,993 |
| | Subtotal | 33,199 | 24,394 |
| River Port | B0 – Kpong | 410 | 1,628 |
| | B1 – Yeji | 1,388 | 7,121 |
| | B2 – Kete Krachi | 5,107 | 14,991 |
| | Subtotal | 6,905 | 23,740 |

| | | |
|---|---|---|
| Total by Dry Ports and River Ports | 40,104 | 48,134 |

The findings from the study present many implications in practice for intermodal freight transport system design. There is the need for critical considerations when planning freight transport system from maritime ports to hinterland ports. The transport system planning and optimisation must take into account the requirements of freight customers and available transport infrastructure.

Cost reduction and lead time minimization should not be the only focus of freight service operators. Restrictions on carbon emissions must be given maximum attention during the freight transport network planning. Adjustments and compromises should be made wherever possible to meet environmental requirements in the intermodal freight transport system design.

With this model, freight service providers can gain more insight into how to perform trade-offs regarding cost reduction, transit time, and carbon emission requirements thereby making their operations and services more sustainable. The use of road transport favours the reduction of transit time. However, road transport presents the highest total transport costs and is a major contributor to carbon emissions. In this regard, it is advisable not to use road freight when customer requirements are not restricted to transit time reduction. Also, it is very suggestive to use road transport for only short distances whenever possible.

The use of barge and rail in the intermodal freight transport system offers opportunities for reducing last-mileage performed by road transport to that of the total mileage of the freight transportation. This provides benefits of cost reduction and enhances environmental sustainability. Also, governments and freight service providers also benefit from this by ensuring cleaner environments and have good global image and reputations regarding environmental protection and carbon footprint. Thus, the choice of barge and rail is preferable where there are stringent government regulations on production of carbon emissions from organisations and companies.

From the study, much could be gained by logistics and freight service providers about how to optimise intermodal freight transport networks and plan ahead of time by applying the model. By developing intermodal infrastructures such as river ports, dry ports, railways, etc., sustainable transport modes could be decided when planning intermodal systems. However, it is worth stating here that this requires the collaboration of governments, service providers and private partners.

## 5. **Conclusion**

A unique approach to the optimisation of integrated transport network design problem with Ghana situation in this case. The purpose of the survey was to design integrate freight transportation system taking into consideration cost, time and environmental factors as an integrated network optimisation approach.

Using numerical experiments, the study demonstrated the applicability of integrated transportation system network with bi-objective optimisation approach. For cost minimisation, the experiment suggests the use of barge (inland waterway) as the best choice of transportation mode by freight service operators. Also, the selection of barge offers the best mode of freight transportation for the reduction of emissions thereby making the system environmentally sustainable. From the research, it became known that the selection of road transportation for long distance freight transportation is detrimental to cost savings and carbon reduction. It is, therefore, prudent for service providers to use trucks mainly for short distances, and when lead-time is most importance factor. The combination of barge and rail in an intermodal transportation system provides the ultimate solution regarding economic and environmental sustainability.

This study provides many contributions relevant to both academic researchers and those working in organisations and industries. The research has set forth the stage for researchers who are interested in researching into sustainability of maritime-hinterland intermodal freight transportation system, considering emissions of carbon. The model formulation and its practical application offer a deeper understanding for intermodal transport network optimisation. Researchers who wish to solve similar intermodal transport network problems in other countries with a larger number of domestic ports and container capacity can use the results of the experiment. Both governmental and individual logistics service providers willing to improve upon environmental sustainability can learn practical lessons from the experiments.

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