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Full Length Research Paper

Inland container depot integration into logistics networks based on network flow model: The Tanzanian perspective

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In response to increasing container volumes, congestion and capacity constraints; ports have embarked on implementation of inland container depots (ICDs) as capacity enhancement strategy. Determination of optimal routing of containers, depot location and number of depots to insert in the logistics network is a challenge faced by many ports today. This paper presents a network flow optimization model for container depot integration in multi-stage logistics network with direct shipment constraints. LINGO mathematical modeling language is used for programming and solving the model using Dar es Salaam port in Tanzania as a case study. The model evaluates various flow scenarios and simultaneously determines container routing options as well as the optimal number of depots to include in the network in order to attain minimal total cost. Partial integration approach is proven by computational result to be a superior strategy for ICD integration into the freight network.

Key words: Inland container depot (ICD), dry ports, network flow optimization, partial integration, cleaning approach, Dar es Salaam Port, Tanzania.

INTRODUCTION

The business environment in which container ports, ocean carriers and logistics service providers are acting is changing rapidly due to changing economic conditions, competition and technology. During the last decade container trade experienced phenomenal growth in terms of container volumes and ship size. Notably, as a result of global economic crisis, the container trade experienced throughput decline by an estimated 9.7% in 2009, to 465.7 million TEUs compared to 506 million TEUs in 2008 (United Nations Conference on Trade and Development., 2010). Nonetheless, the outlook for container shipping is promising and growth is expected to regain momentum as the global economic recovery continues to strengthen (International Monetary Fund, 2011).

Container deliveries at most ports are becoming more concentrated as lager container ships are increasingly deployed in pursuit of economies of scale. Increase in container volumes causes increased pressure on entire logistics network resulting into congestion, high dwell time and higher logistics costs (Japan International Cooperation Agency, 2009; Arvis, 2010; UNCTAD, 2009). Ports are particularly affected by ever increasing container volumes as their operational capability becomes highly constrained. As acknowledged by Cullinane and Wilmsmeier (2011) lack of sufficient container storage space is one the critical challenges facing ports today. Consequently, consistent lack of capacity may cause port customers to shift to competing ports. Traffic volume growth entails a mismatch between port resources (that is, yard capacity, handling facilities and gate capacity) and ability to handle those volumes. This situation leads to congestion as port user end up interfering with each other in the utilization of port resource (Talley, 2009). In light of these constraints, ports have embarked on implementation of inland container depots (ICDs) as operational and capacity enhancement strategy for easing pressure at congested maritime terminals (Haralambides and Gujar, 2011). Dry ports are mature and well established in developed countries and

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are increasingly embraced in developing economies.

Extensive dry ports and ICD related studies have been carried out with focus on developed economies but less has been done with respect to developing economies despite their increasing role in the global supply chain. Major works by Roso (2008), Roso et al. (2009), Notteboom (2008), Rodrigue (2010), Veenstra et al. (2012) and Wilmsmeier et al. (2011) to mention but a few concentrated on Europe and North America. However, in the past few years considerable research works have turned attention to developing countries. Notably the works of Hanaoka and Regimi (2011), Ng and Gujar (2009), Ng and Tongzon (2010), Ng and Cetin (2012), Dadvar et al. (2011), Padilha and Ng (2012), Monios and Wilmsmeier (2012), Wilmsmeier et al. (2011) have extensively examined the ICD phenomenon in Asia with India dominating these studies. Padilha and Ng (2012) turned their attention on Brazil while Garnwa (2009) made a comparative study on dry ports involving Nigeria. Nevertheless, research on evolution and integration of ICDs in the logistics systems covering developing countries and East Africa in particular is still limited and needs to be explored further.

Implementation of ICDs unleashes a set of new challenges upon containerized supply chain. Challenges include effective determination of location and number of depots to insert in the logistics network. Likewise, the allocation of container boxes to each depot and their ultimate routing to final destination in a way that minimizes the transportation cost born by shippers and the economy at large needs to be examined further. In recognition of the competitive environment in which port operates; the trade-offs between cost adding and cost saving properties of ICDs needs to be given due consideration when integrating ICDs with maritime terminals.

This paper presents a model for effective integration of ICDs into logistics network. The model simultaneously determines the number and location of ICDs in the network as well as optimal container routing to the hinterlands that minimize the total costs of the flow. The model uses Dar es Salaam Port in Tanzania as the case study for solving numeric examples.

THE ICD CONCEPT

The freight transport network has experienced an evolution of terminals which connect seaport with their hinterlands. Several names apply to these terminals including inland container (clearance) depots (ICDs), dry ports, container freight stations (CFS) or inland intermodal terminals. As noted by Trainaviciute (2009),Veenstra et al. (2012), Cullinane and Wilmsmeier (2011) and Roso et al. (2009) the dry port concept and conversely that of ICDs is still evolving and thus lacks a unified definition. This paper adopts with modification a definition by United Nations Economic Commission for Europe (UNECE, 1998). Thus, an ICD in this paper refers to:

"*A common-user facility other than a seaport or an airport offering a total package of activities for handling and storage of containers with the inbound and outbound flows by any applicable mode of transport being controlled by customs".*

In strict terms the ICD concept is limited to a facility dedicated to serving containers only as opposed to the dry port concept described by Roso et al. (2009) which encompass both general cargo and containerized freight. Nonetheless, most of activities carried out at ICDs and dry ports are generally the same and hence the rationale for the terms to be used interchangeably. Roso et al. (2009) classifies dry ports into distant, midrange and close dry ports using distance as the sole criteria for classification. This paper focuses on integration into a multistage freight network of "close ICDs" which are located within or at the rim of the port city at a distance of not more than 50 Km from the seaport (Figure 1).

Efficient and effective movement of goods is very critical in today's competitive environment especially for developing countries suffering from crippling logistics costs which limit their competitive ability in the global economy. Putting in place an optimal logistics network design offers great potential for logistics cost reduction and service quality improvement (Gen et al., 2008). It is recognized that attractiveness and economic success of a seaport is increasingly dependent on its ability to integrate into the flexible supply chains connecting it to the hinterland (Haasis, 2010; van Der Horst and de Langen, 2008; Zhang, 2008).

Captivity to national port is becoming less significant as a result of regional economic integration and transport market liberalization. In particular, the quality of hinterland connectivity is having significant effect on the overall door-to-door performance of the logistics chain and especially on choice of a port of call by container shipping lines (Notteboom, 2008; Wiegmans et al., 2008). The impact of the quality of hinterland connectivity on port competitiveness was extensively explored by van der Horst and Langen (2008). As shown by results of this study, insertion of inland container depots in the transport corridors has significant cost implication on container movement.

ICDS: ROLES AND IMPLEMENTATION STRATEGIES

ICDs are generally viewed as partners to seaport terminals by relieving ports of capacity constraints while at the same time offering value added services along the supply chain (Haasis, 2010; Nathan Associates Inc., 2010). Their main functions include handling and storage

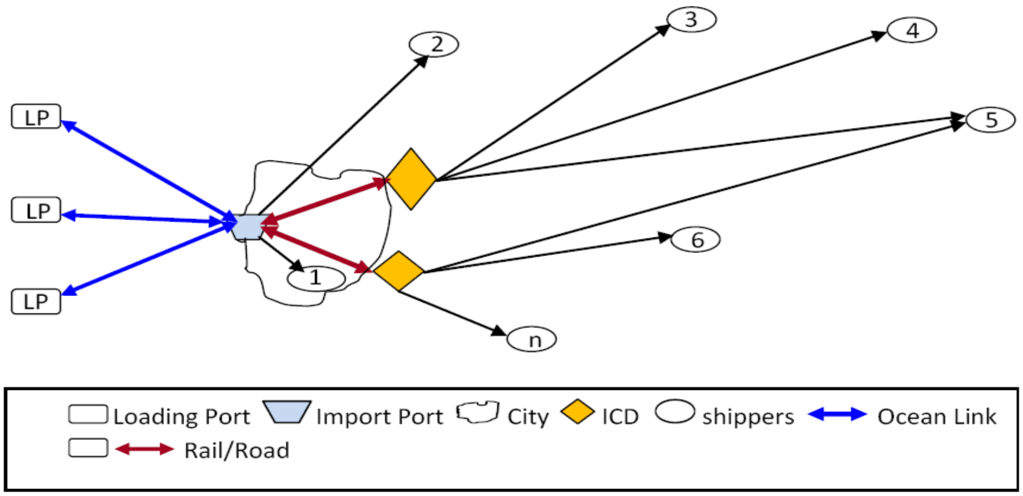


Figure 1. ICD connection to port and shippers/importers.

of containers, cargo consolidation and distributions as well as receipt and delivery of containers. In addition, customs clearance and maintenance of containers are other valued added services provided at ICDs (Rodrigue et al., 2010; Dadvar et al., 2011). Container depots are increasingly becoming extensions of the maritime terminals on the landside. It is acknowledged that most of ports especially those located in urban areas have little options for expansion.

Introduction of ICDs in the suburbs of the port city or even within the city itself becomes a faster and viable mitigation measure against congestion and capacity constraint as compared to green field projects for new ports. The essence and attractiveness of inland terminals is captured by van Klink (2000) who states that "by investing in inland terminals and participating in their operations, a sea port can establish itself in inland regions. Inland terminals may be considered as extended gates through which transport flows can be better controlled and adjusted to match conditions in the port itself". The extended gate notion is further supported by Veenstra et al. (2012) who argue that the extended gate function of the dry port can generate substantial benefits in terms of modal shift, logistics performance and regional development.

Apart from physical capacity expansion, other gains from ICDs include reduced truck congestion at the seaport gates, port yard and city roads as well as reduced CO_2 emissions especially when the inland terminal is connected to the sea terminal by rail.

In Europe and North America major players in the inland freight distribution centers include port operators, rail companies, shipping companies, logistics service providers and real estate companies (Trainaviciute, 2009; Rodrigue et al., 2010). Based on Asian experience ownership and operation of ICDs take different forms including public, private or public-private partnership (Hanaoka and Regmi, 2011). Noticeably, dry ports in India, are predominantly owned and operated by state-owned firms, with Container Corporation of India Limited (CONCOR) being the flagship operator (Ng and Gujar 2009; Haralambides and Gujar, 2011). In East Africa, the private sector plays a major role in operation of ICDs primarily due to capital, technical and financing reasons. For example in Tanzania all operational ICDs are owned and operated by private companies even though public-private partnership (PPP) is highly encouraged.

Partial integration vs. cleaning approach

The traditional approach of integrating ICDs with port has been that of *partial integration.* This strategy involves transfer of containers in excess of the seaport design capacity to ICDs with the remaining container traffic being processed directly at the maritime terminal facilities. Recently, the *cleaning approach* is being advocated as the best strategy for integrating ICDs into freight networks (Nathan Associates Inc., 2010; Haasis, 2011). The *cleaning* approach is centered on "relocating all container processing activities from the marine terminals to ICDs, including all the handling of outside trucks". Under this setting, all import containers are transferred to inland depots immediately upon discharge from ocean going ships.

Thus, customs clearance and container delivery activities are transferred to ICDs instead of taking place at the seaport terminal. It is further argued by Nathan Associates Inc (2010) that ICDs should be located as close as possible to the seaport terminal as a prerequisite for implementation of the cleaning approach strategy. However, Woxenius et al. (2004) prefer introduction of "close dry port" not as close as possible to the maritime terminal but at the rim of the port city.

This approach aims at moving trucking activities outside the port and city streets through introduction of rail shuttle service connecting inland terminals with the seaport.

CONTAINER FLOW MODELING IN FREIGHT NETWORKS WITH ICDS

It is recognized that introduction of ICDs will result into cost savings to shippers and the economy at large, through avoidance of surcharges and demurrages imposed by shipping companies whenever there is congestion delays. However, dry ports are also cost adding nodes in the freight network in terms of haulage cost between port and the inland depot as well as additional handling and re-marshalling costs at the ICD. Due to the identified tradeoffs between cost adding and cost saving properties of inland container depots, and in recognition of competition for hinterlands by ports, it is apparent that location, container routing and allocation of containers to ICDs need to be optimized. Terminal location is recognized as an important factor for efficient cargo flows due to its direct and indirect influence on physical distribution cost, timeliness and environmental effects (Sule, 2001; Sirikijpanichkul and Ferreira, 2005). When locating dry ports, consideration should also be given to availability of land, proximity to utilities and transport facilities as well as socio-economic factors (Zarinbal, 2009; Melo et al., 2005).

Apart from qualitative and descriptive studies on ICDs (Roso, 2008; Roso et al., 2009; Woxenius et al., 2004; Haasis, 2010) attempt has been made to analyze the dry port dynamics using operation research techniques. Wei et al. (2010) developed a factor evaluation model for dry port location based on fuzzy-ANP method. Ng and Gujar (2009b) used the mixed integer programming to model dry port choice by users in India. Haralambides and Gujar (2012) introduced an eco-DEA model to evaluate dry port efficiency while taking into account transport related emissions.

In this paper ICD integration problem involves determination of number of depots to insert in the network and allocation of container boxes to be routed through container depots in such a way that customer demands are met at minimum shipping cost. In this regard the problem is addressed as a network flow problem in a multistage logistics network with direct shipment constraint as depicted in Figure 2.

In general, such a problem is considered NP-hard and difficult to solve (Lin et al., 2009). However, Roy (2005) proposes linear programming models for such a network flow problem particularly when potential location sites are known as is the case with ICDs evaluated in this paper. In this paper we present a linear optimization model which is implemented using LINGO Mathematical Modeling Language and Solver. The model simultaneously determines the optimal number ICDs to include in the network as well as the routing option that result into the minimum containers shipping costs to final destinations. The model uses current and proposed ICDs at Dar es Salaam Port, Tanzania as a case study for demonstration of numerical examples.

GENERAL MODEL FORMULATION

Model parameters

P: Set of ports in the model

H: Set of demand points representing hinterlands served by ports under consideration

J: Set of ICDs in the model

Dem_i : Total TEU demand at demand node i , $d \in H$

C_{ij}^{I} : TEU haulage cost from node i to node k , where $i \in P$ and $j \in J$

C_{ij}^{d} : ICD node costs

q_i : Net container flow (outflow - inflow) at node i

C_{ik}^{h} : TEU transport cost from node i to node k , where $i \in P$ and $k \in H$

C_{jk}^{h} : TEU transport cost from node j to node k , where $j \in J$, $k \in H$

U_{ij}^{J} : Maximum throughput capacity at ICD j

U_{ik}^{h} : Limit on TEUs shipped directly from port to hinterlands

$SUPP_i^D$: Import TEU through Port i

Decision variables

x_{ik}^{h} : TEUs shipped directly to hinterland i

x_{ij}^{v} : TEUs from port to ICD j

x_{jk}^{v} : TEUs from ICD j to hinterland k

x_v : Number of ICDs in the network

Minimize Z

$$\sum\sum c_{ik}^{h} x_{ik}^{h} + \sum\sum c_{ij}^{I} x_{ij}^{v} + \sum\sum c_{jk}^{h} x_{jk}^{v} + \sum\sum C_{ij}^{d} x_{ij}^{v} \ldots\ldots \quad (1)$$

Subject to

$$\sum x_{ik}^{h} + \sum x_{ij}^{v} \le \sum SUPP_i^D \ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\sum_{i \in J} x_{jk}^{v} - \sum_{i \in P} x_{ij}^{v} = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

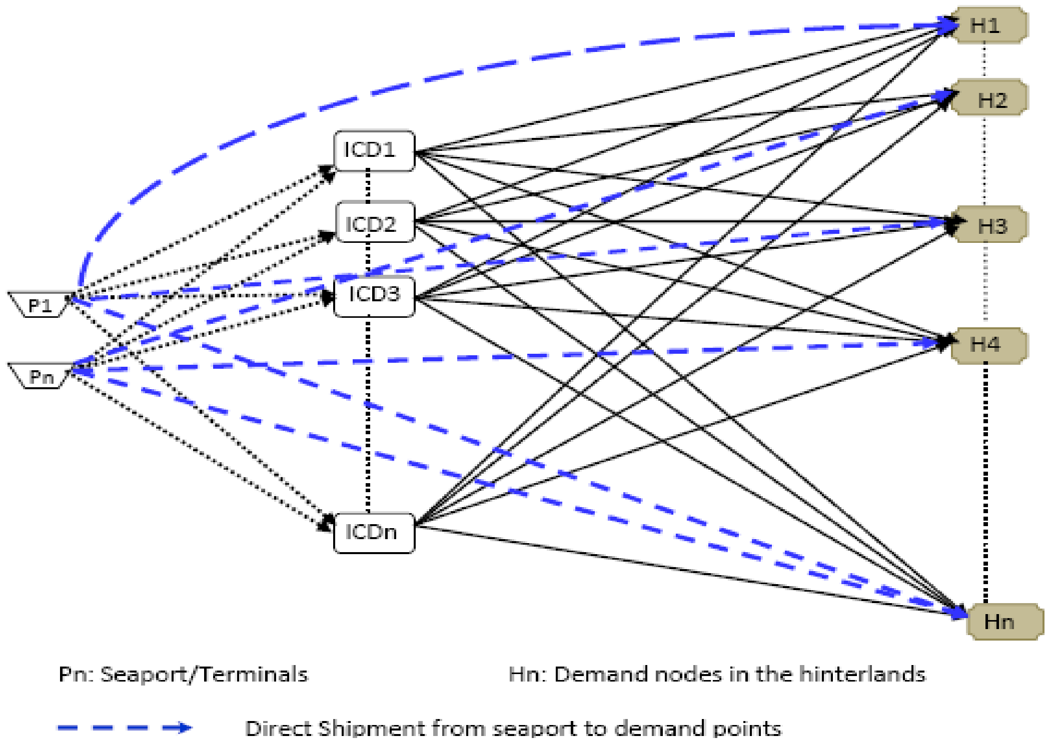


Figure 2. ICD integration into transport networks.

$$\sum_{d \in H} Dem_i \leq \sum SUPP_i^D \quad \ldots\ldots\ldots\ldots \quad (4)$$

$$Dem_i \leq \sum_{i \in P}^{n} x_{ik}^h + \sum_{k \in H}^{n} x_{jk}^v \quad \ldots\ldots\ldots\ldots \quad (5)$$

$$x_{ij}^v \leq U_{ij}^J \quad \ldots\ldots\ldots\ldots \quad (6)$$

$$\sum x_{ik}^h \leq U_{ik}^h \quad \ldots\ldots\ldots\ldots \quad (7)$$

$$x_{ik}^h, x_{ij}^v, x_v, x_{jk}^v \geq 0, \quad Integer \quad \ldots\ldots \quad (8)$$

Constraints description

The objective function 1 minimizes the total cost of moving containers imports from the port to final destination, being the sum of the cost for direct shipment to demand point in the hinterland, haulage cost from port to ICD, transportation cost from ICDs to hinterlands and ICD node costs. ICD cost includes two extra lifts at the container depot, re-marshalling cost, removal costs and facilitation fees. Constraint 2 ensures that the total outbound TEUs from ports to the hinterland do not exceed the container imports for the given period.

Constraints 3 stipulate that the net flow at each ICD must equal to zero since all ICDs are transhipment nodes. Constraint 4 seeks to ensure that the sum of the TEUs delivered to cargo centers in the hinterlands equals container imports for the period under consideration. Constraint 5 specifies that the number of TEUs flowing into any node at the hinterland do not exceed the sum of containers delivered directly from port and those received via ICDs. Constraint 6 ensures that container channeled through an ICD cannot exceed the ICD's throughput capacity for the given period. In this study the ICD throughput capacity was deduced from slot capacity data of each ICD using the formula below.

$$V = GS * WD * H * F_1 / DT * F_2 \quad (9)$$

Where:

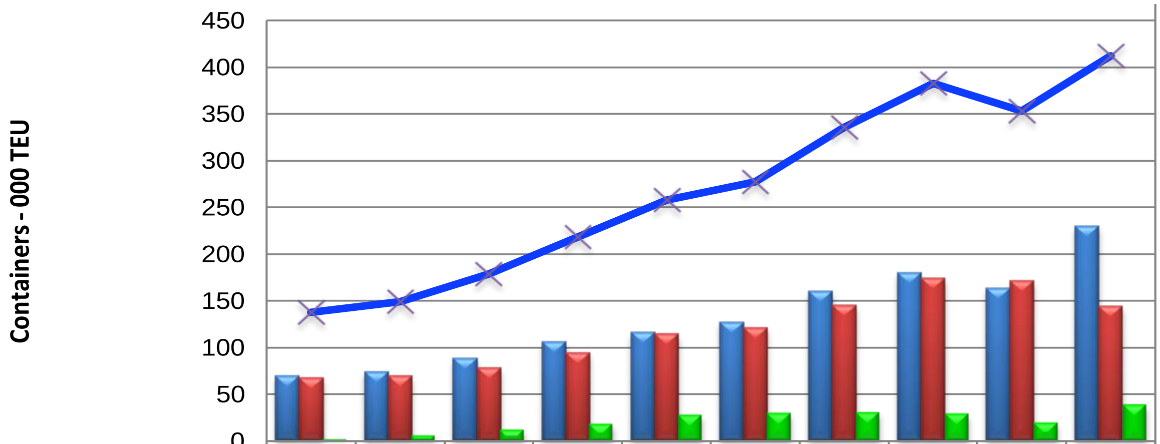
V : Annual throughput volume in TEUs

GS : Number of twenty feet equivalent ground slots (TEUs)

WD : Number of working days in the period (that is, 365 days per year)

H : Average stacking height of container units (3 tiers for the case of Dar es Salaam ICDs)

F_1: Efficiency factor for staking to account for empty slots (0.8 for Dar es Salaam)



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Import	69	74	88	106	116	127	160	180	163	230
Export	67	69	78	94	114	121	145	174	171	144
Transhipment	2	6	12	18	28	30	30	29	19	38
Total	138	149	178	218	258	278	335	383	353	412

Figure 3. Container throughput at Dar es Salaam Port.

DT : Mean dwell time at ICD

F_2 : Peak factor $(1 \leq F_2 \leq 1.5)$

Based on available data the average container dwell time at Dar es Salaam ICDs is 11 days. Constraint 7 restricts TEUs directly shipped from port to final destination to the optimum capacity that can be handled by seaport facility without inducing congestion surcharges. Constraint 8 defines nonnegative parameters which must also be integers.

THE CASE OF DAR ES SALAAM PORT, TANZANIA

Dar es Salaam Port is the major logistics gateway for Tanzania and its neighboring land locked countries of Rwanda, Burundi, Malawi, Zambia, Uganda and Democratic Republic of Congo. Based on the Dar es Salaam Port Master Plan, East African Corridors Diagnostic Study reports and interviews made for this study noted that ICDs operating in the proximity of the port, were licensed for operations in Tanzania since 2007. This step was taken to expand port capacity as container throughput exceeded the design port capacity of 250 thousand TEUs per annum in 2005 (Figure 3). Before licensing of inland terminals, shipping lines used to impose punitive congestion surcharges due to long ship waiting times. Currently, 7 ICDs located within and in the outskirts of Dar es Salaam city are fully operational. These ICDs are under separate private ownership and operation. Six of them are linked to the sea port by roads hence containers being shuttled by trucks thus straining both the port gates and city roads. The port is also connected by rail to a distant dry port of Isaka located 971 km from the port. Isaka serves as a port linkage to the landlocked countries of Rwanda and Burundi. Due to the urgency of tackling the congestion problem experienced during the period of 2006 and 2007 some of the licensed ICDs were not optimally located, remain ill equipped, lack ICT facilities, have limited gate capacity and generally operate inefficiently. Considering the shortcomings of the current ICD system in Tanzania, the government through Tanzania Port Authority (TPA) is planning to establish one large ICD to serve Dar es Salaam port under public private partnership (PPP) arrangement.

While it is generally agreed that such a facility is needed, there is no consensus among stakeholders regarding the proper location of a new ICD. On one hand TPA has proposed Kisarawe area some 40 km from the port for the new facility (Ubwani, 2010). On the other hand, BNSF Railway (2009) in their consultancy report to the Minister of Infrastructure Development designated Ilala Rail Yard (4 km from the port) as the best location for the new intermodal facility as compared to Kisarawe (Table 1). Through implementation of the planned dry port, the government and the port authority are determined to re- optimize the entire freight system. At present ICDs located within Dar es Salaam handle about 60% of all container throughputs with 40% being handled directly by the port. At this rate, port congestion has been minimized and congestion surcharges have been eliminated. Likewise, container dwell time has decreased from an average of 26 days (2007) to an average of 11 to 15 days.

Table 1. Current and Planned ICDs at Dar es Salaam Port.

ICD Code	ICD Name	Distance from port (km)	Annual Import Throughput Capacity (TEUs)	Ownership/ Operation	Operational Status
ICD 1	AMI	12	27000	Private	Operational
ICD 2	MOFED	2	52000	Private	Operational
ICD 3	TRH	3	48000	Private	Operational
ICD 4	MALAWI CARGO CENTER	2	23000	Private	Operational
ICD 5	DICD	2	12500	Private	Operational
ICD 6	UBUNGO	14	95000	PPP	Operational
ICD 7	AZAM	7	13000	Private	Operational
ICD 8	KISARAWE	40	250000	To be known	Planned
ICD 9	ILALA RAIL YARD	4	200000	To be known	Planned

Source: Port master plan, interviews and google earth.

Container imports through Dar es Salaam port are used as input for the optimization model developed earlier. And since the model is potentially a strategic planning tool, container forecast for 2014 obtained from the port master plan are used for numerical computations. Container imports through Dar es Salaam port is forecast to reach 312 thousand TEUs (excluding transhipment volumes) by 2014 and this figure is used as input for the model. Two scenarios are evaluated in this model. The first scenario evaluates the total logistics costs under the “cleaning approach strategy” whereby all import containers are routed through ICDs. The second scenario evaluates the “partial integration strategy” whereby some of containers are channeled through inland depots while others are shipped directly from port to final destinations.

As reported in the Eye for Transport (January 20, 2009), it has been established that the Dar es Salaam port can efficiently process and deliver 350 TEUs on daily basis given that yard density level is kept at 65%. Based on this as well as the design and operational capacity of Dar es Salaam port, an upper limit of 120 thousand TEUs per annum is set for containers that can be processed and shipped directly from the port to importers under the partial integration strategy.

MODEL IMPLEMENTATION AND RESULTS

The problem defined is a linear optimization formulation for minimum cost network flows. In modeling the problem several assumptions and considerations were made, namely;

1) There is only one source node (Dar es Salaam Port) and 9 ICDs including 7 fully operational ones and planned depots (ICD 8 and 9). The distant Isaka Dry Port is not included in the model calculation as it does not primarily serve the port capacity constraint but rather positions the port closer to its hinterlands.
2) The number and locations of current and proposed ICDs are known (exogenous model), hence the model evaluates the optimality of location, number of ICDs to be included in the network and optimal routing options for attaining the minimum cost for container flows through the port.
3) The installation and fixed costs of the terminals are not considered.
4) The capacity (annual throughput) of ICDs is know and limited.

As indicated by the computational results the partial integration approach results into more than 4% savings in total logistics costs as compared to the cleaning approach. As depicted in Figure 4, the option of operating without ICDs could result into more than 11 percent in logistics costs savings. Based on results shown in Figure 4 we can conclude that the total shipment cost increases as the number of TEUs shipped through ICDs increases.

In an ideal situation where the port has sufficient capacity to handle all cargo through put the cost of the flow would be minimal with zero ICDs (Figure 4). Likewise, computational results have shown that implementation of the cleaning approach requires more ICDs as compare to the partial integration strategy. For Dar es Salaam port implementation of the cleaning approach would require 3 ICDs to be inserted in the network while only one ICDs is required for the partial integration strategy (assuming that planned ICDs are operational). Appendixes 1 and 2 show the number of container depots which need to be integrated into the freight network in order to attain the optimal flow under both partial and cleaning strategies.

CONCLUSION AND RECOMMENDATION FOR FURTHER RESEARCH

It is recognized that congestion is the most urgent concern to be dealt with by Dar es Salaam Port and other ports in similar situations. However, based on model result, the entire logistics network for container flow from

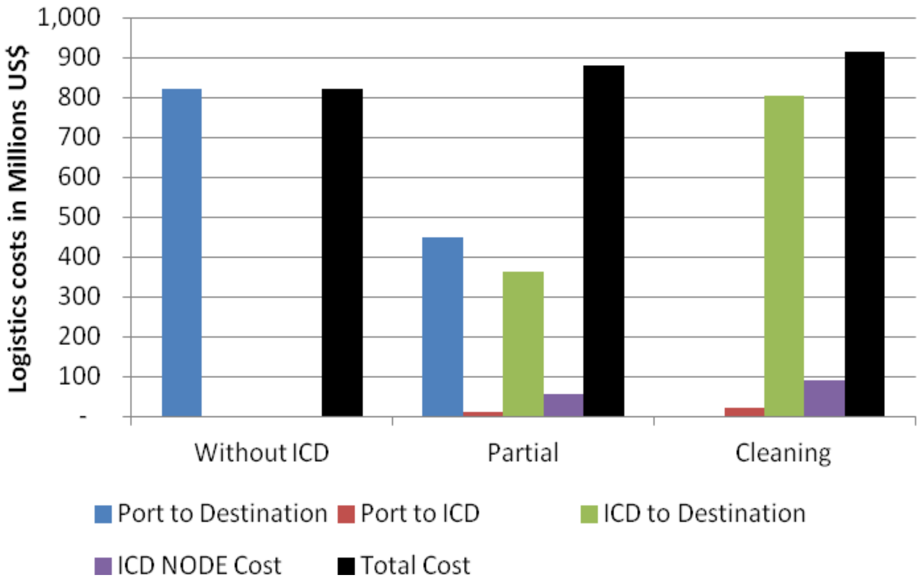


Figure 4. Cost structure with and without ICD including cleaning and partial integration strategies.

Dar es Salaam port to the hinterlands needs to be re-optimized. This can be attained by adopting the partial integration strategy and implementing the proposed new ICD at Ilala Railway yard (ICD9 in the model) as well as transferring the activities of the remaining depots to the new intermodal terminal.

Direct clearance and delivery of containers from port should be facilitated up to a level beyond which congestion surcharges will be induced. This will ensure that port capabilities, facilities and space are fully utilized and consequently giving the port a competitive advantage by avoiding incremental costs of using ICDs particularly for cargoes which are price elastic and bound for hinterlands subject to inter-port competition. Likewise, this strategy will keep down the cost of doing business for countries using Dar es Salaam port with a potential of gaining a competitive edge in the global market.

Although there is considerable literature on dry ports and inland terminals most of them are qualitative and descriptive. The contribution made by this paper was introduction of the network flow optimization model that presents tools for quantitative evaluation and solving ICD location problem. Equally important, the model is potentially useful re-optimization tool for the entire Port-ICD-Hinterland network for efficient and cost effective flow of containers. As such, the model presented in this paper is a useful strategic planning tool for optimized integration of ICDs in the transportation network. The model can be used by port and transport planners as well transit facilitation agencies for inland terminal and network infrastructure planning.

Through this study a number of areas for further research have been identified. The major areas are (i) Modeling of allocation of containers at operational and tactical level needs to be explored further. There is a need to determine the best way of allocating containers to port terminals and ICDs taking into account ship schedules, yard capacities and available slots (ii) As ICDs assume the “extended gate” function of maritime container terminals, the changing regulatory relationship between stakeholders need to be re-examined. In particular the liability regime for freight needs to be clearly defined to ascertain the roles of ports, shipping lines, shippers/consignees and ICDs as cargo moves to and from port.

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