Short Sea Shipping and Intermodality: Connecting East and West
Case study: Karlshamn-Klaipeda Short Sea Shipping Link

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Abstract

In the European Union and especially in the Baltic Sea Region, freight volumes on roads have gone up to a level that there is a need for alternative transport modes. Short Sea Shipping (SSS) is one alternative that is supported by the European Union, due to the potential in reducing traffic on roads and connecting markets. Often SSS suggest the use of vessels whereby cargo is rolled on and off using a ramp with very small capacities usually less than 500 TEU (trailers = 2 TEU), but with increasing cargo traffic, it is not clear if such solutions will be efficient. For ports involved in SSS to meet up this new wave of change, the challenge to make appropriate investments and thus analysis tools are important. Vessel types suitable for a SSS operation (such as roll-on roll-off (RoRo), lift-on lift-off (LoLo), etc.) have been addressed in this paper based on their compatibility and cost effectiveness with the terminal equipments**.** In the European Spatial Development Perspective "development corridors" are seen to be emerging in Europe. These corridors are often transnational and cross many borders. Therefore the corridors require an integrated spatial planning approach that goes beyond purely national policies. Infrastructure investment is seen as one important policy measure to ensure balanced regional development. A new aspect in the development of corridors is the incorporation of Motorways of the Sea and Marco Polo initiatives

The purpose of this study is to develop an optimization model that can select handling equipment and ships from a strategic level. This model can help when investing in systems for handling unitized cargo at port terminals in the context of Short Sea Shipping (SSS). Initial model results indicate that a LoLo vessel with a capacity between (500 and 1000 TEU) capable of completing a SSS voyage, when handling is completed in 48 hours will be less costly than a RoRo, which may have multiple voyages for TEU volumes greater than 1000. But RoRo vessels remain useful for trailers that cannot be transported by LoLo vessels.

Introduction

A main objective of the European Union's (E.U.) *Motorways of the Sea* initiative and especially in the *BalticGateway* and *EastWest* projects is to increase the use of intermodal freight, seaports and terminals in order to take more freight traffic off the road and rail systems (Jan Everett, 2006). The enlargement of the European Union, especially in the East Baltic region offers many tantalizing opportunities and uncertainties for policy makers regarding to the choice of freight transportation systems and transport corridors. The investments and business decisions on seaports, rail networks, and roads in moving cargo between the new members states in the Baltic incites many questions that require further analysis. In particular, the terminals (seaports) require much attention and need to be studied since they are the "nodal point" between the land-based transport networks and marine transport networks. The terminals are often not explicitly taken into account when cargo transportation flows are analyzed at a regional level (Kondratowicz, 1996).

The future extension of the Trans-European Networks (TEN) should reassure economic development of particular regions and facilitate their integration into the global economy. In addition, however, priorities for action should include supplementary measures assuring development of intra-regional links (often referred as missing links). The efficiency and density of these secondary networks is said to be vital for the integration of the regional and urban economies and their competitiveness. Especially, they are expected to strengthen the smaller and medium-sized towns and their function in generating overall regional development.[1]

The economies of the Baltic Sea Region countries are growing faster than the EU average. In addition, regional co-operation is shifting from the provision of support by Western countries (W-BSR) to their Eastern neighbors (E-BSR) - to a more balanced exchange. In 2005 nine of eleven countries had a higher growth rate than the EU average of 2.1 percent. One of the main reasons is the constantly increasing trade within the BSR, with an estimated population of 100 million, driven by deregulation and removal of many customs administrative procedures in the new EU member states and inflow of foreign direct investments to these countries.

Over the recent decades the co-operation between local, regional and national governments in the Baltic Sea Region has been rising and has received additional support from EU enlargement. Intermodal links in the East West Transport Corridor consider the links such as in Figure 1 and in more detail, Figure 2 illustrated the transport links; China/Far East/Black Sea using the Trans Siberian Mercury and Viking railway lines via Vilnius-Klaipeda/ Kaliningrad – Blekinge/Skane- Esbjerg to the UK and Benelux.

Figure 1. East West Transport Corridor reflected by its partnership geography

Figure 2. An attractive transport chain connecting east and west

Background

The growth of the international trade volumes of the BSR countries is expected to develop positively. Until 2020, the total exports of the BSR countries are expected to increase by 48% and the imports by 41%. Important activities includes to prepare investments in ports facilitating the intermodal transport chain, Modal shift towards more sustainable modes as rail and short sea shipping is promoted. Numerous challenges (bottle necks) have been encountered in suggesting SSS solutions e.g. the lack of intermodal liability regime, unequal distribution of incentive measures, lack of comparable statistical data on SSS and other issues in relation to vessels speed and capacity, up to terminal handling and management issues[2]. Managing cargo flows between ports and inland destinations has remained a challenge for terminal operators (Chadwin & Talley, 1990, Notteboom, 1997). Clearly, there is much attention on terminal operators to solve these issues. In order to reach their goals or objectives many terminal operators need technical assistance when selecting handling equipments from a strategic level (for investments), tactical and operational level (for deployment) in order to handle their operations. The decision in selecting which equipments to invest on or to deploy requires and integrated approach. The decision to invest on which equipment may not be difficult for terminals handling small volumes of cargo, however such a decision can be difficult to consider for different types of equipments, with increasing cargo volumes and stricter customer requirements, when several factors, such as congestion, performance, safety etc. needs to be taken into accounts.

The use of optimization tools can be formulated using linear relationships, thus we can model the system using a technique called Integer Linear Optimization Model (ILP).An ILP model for selecting handling equipments will enable port terminals such as Karlshamn and Klaipeda to preview what kind of handling tools shall be required as freight volumes increases at a strategic level. Based on demand forecast the tool can be suitable for choosing handling systems to deploy at tactical level. The aim is to model and represent the process of selecting terminal equipments including choice of ships in a unitized[3] cargo terminal (ports of Karlshamn and Klaipeda) as an ILP based model to exploit the

[1] European Commision *ESDP; European Spatial Development Perspective.* Luxembourg 1999

[2] *European Commission DG for Energy and transport, Synoptic table of bottlenecks in SSS*

[3] Unitised cargo embodies containers and trailers

advantages of such models (e.g. ease of real world representation). Based on the model we expect to be able to compare the performance of different handling systems by considering their cost and capacity. Regarding to handling system performance we expect to be able to suggest suitable shipping systems between LoLo and RoRo for SSS at different capacity levels.

Handling Systems and Performance Measure

How well a terminal is performing can be a difficult issue to address since terminals share variable goals especially public oriented terminals with a public welfare interest as opposed to private oriented terminals with a profit oriented interest. As pointed out by L. Ramstedt 2005, different types of performance measures could be used for different purposes, identifying here the quantitative (e.g. costs) and the qualitative (e.g. environmental) elements. In the case of container terminals high productivity has been an attractive performance aspects but often these are associated with rising costs which is less acceptable. The gap between these two aspects (cost and capacity) can be used as a measure of the competitiveness of the entire terminal, the greater the gap, the more competitive and better off is the terminal and vice versa. However several approaches have been used over the years to estimate terminal performance, the most remarkable (J**.** Holguin-Veras, C. M. Walton; 1996) of which are:

- Moves Per Hour; Within known geometric distances, the performance of handling equipment can be estimated as the number of TEU moved in one hour. This is often the preferred performance measure associated to equipments by production industries.
- Ship Distribution at Ports (SDP): SDP relies on the assumption that the berth occupancy analysis can be performed using the observed ship distribution at ports and, consequently, the number of ships at port is an independent random variable.
- Queuing Theory (QT): In general, the majority of QT applications consider only the ship-berth interface. In these applications basic QT, i.e., birth-dead processes in equilibrium, has been used to provide performance estimates. Other classes of QT models, e.g., queuing network and cyclic queues, have only been sporadically applied
- Simulation Applications: Simulation is increasingly being used today as a powerful tool to estimate the performance of port terminals. However, the time demanded by simulation models and the limited depth to which physical reality lends it self to abstraction has limited efforts on simulation. Some recent port simulation studies include Multi-Agent Based Simulation (MABS) to enhance terminal performance (L.E. Henesey, 2004), simulation of container queues for port investments (M.A. Alatar et al 2006) etc

Apart from the first, the rest of the above performance measures aim at evaluating performance for the entire terminal. A more generalized performance measure for ports has been suggested to be “the average number of calls and the average flow volume or weight of goods over a standard period of time; number of calls per berth and per year, volume or weight of cargo handled per hour, per call or per day, per gang or per crane” (P. Fourgeaud, Nov. 2000). In addition to these, other important factors worth considering in trying to estimate the performance of container terminals includes ratio of loaded to unloaded containers at any one point in time, unproductive moves (e.g. reshuffling of containers), level of automation of gantry cranes, average weight of containers, berth length, total waiting time of equipments as well as environmental effects such as quality of fuel or use of electric energy. All the above factors cannot be considered simultaneously, in a practical situation one has to choose few but sufficient factors necessary to meet the goals in consideration. Our interest however is on the performance of the individual equipments, how it affects the performance of the terminal at large. Consequently, in this study we consider mainly relative performance of equipments measured in moves per hour by introducing cost penalties involved in handling when various equipments are used, then formulating the problem as an integer linear optimization (ILP) model, and solving to determine which equipment types perform better at different capacity levels. Since we use this to compare the equipment the choice of performance measure has little effect on the comparison.

Karlshamn-Klaipeda Case Study

We aim at developing a decision support tool that addresses a real life practical decision problem (selecting handling equipments) in the context of a case study, ports of Karlshamn and Klaipeda which is part of the East West Transport Corridor Research Project. Our interest mainly was on unitized cargo transported between the Port of Karlshamn (Sweden) and the Port of Klaipeda (Lithuania) (Figure 3). For the interest of our study, we have focused on the transport link between the port of Karlshamn and Klaipeda. There is also traffic flows between the port of Karlshamn and other ports such as Ventspils in Latvia, Kaliningrad in Russia, Århus in Denmark etc. Among other things the two ports actively engage in passenger traffic, rendering cruise services, dry bulk transportation (timber, fertilizers, gravel etc), liquid bulk transportation (mainly hydrocarbon products) and unitized cargo (trailers and containers).

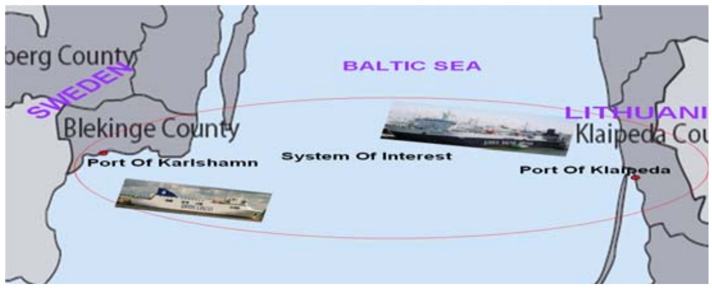

Figure 3 Karlshamn-Klaipeda link over the Baltic Sea

Port of Karlshamn – Sweden: Sweden has a foreign domestic traffic of approximately 152 million tons as at 2005 (SCB, 2005), and hence constitutes one of the backbone economic forces within the Baltic region. The port of Karlshamn is one among the top five ports in Sweden and situated in the South Eastern part of the country. The port of Karlshamn, owned 100% by the Karlshamn municipality, with an annual turn over of about 5 million tons as at 2005[4], average growth rate of about 20% to 30%, has a strategic location at the centre of a fast industrializing South Eastern part of Sweden with easy access to the rest of the Baltic States. With the present need to facilitate sustainable business, intermodal transport, stake holder cooperation etc, along the East-West transport haul (East West Transport Corridor)[5], the potential of the port of Karlshamn to handle its own share of the expected to double traffic volumes in Europe by 2020[6], is not to be doubted. The growth in RoRo container traffic (figure 4) from a timidly low value of about 16500 in 2001, witnessing a triple score of about 45000 as at 2005, is a strong positive indicator of the potential of the port of Karlshamn to handle unitized cargo. The overall rapid growth rate is supported by the port's placement position within Sweden in cargo turn over, moving from the 7th position in 2004 to the 5th position in 2005.[7]

[4] *Port Of Karlshamn Web site; http://www.karlshamnshamn.se/eng/boardofdirectors.html last access 2006-11-09*
[5] *East West Transport Corridor Project, site http://www.eastwesttc.org/websites/eastwest/sd_page/23/1/index.php? last access 2006-11-09*
[6] *Eurostat; 2006 http://epp.eurostat.ec.europa.eu last access 2006-11-09*
[7] *Karlshamn Hamn Årsredovisning 2005*

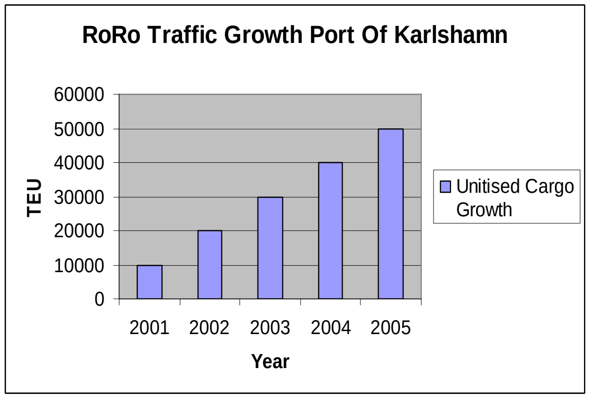

Figure 4 Growth in RoRo container traffic for the port of Karlshamn 2001 to 2005
Source Årsredovisning Karlshamn Hamn 2005

Port of Klaipeda-Lithuania: With the collapse of the Soviet Union, came the ultimate independence of Lithuania (September 1991) along with other Baltic states (Latvia, Estonia) and subsequent joining of the EU (May 2004). This rapid political restructuring has opened the doors for new business opportunities within and between the Baltic States and the rest of Europe, with a remarkable influence on the movement of cargo. Lithuania has witnessed a steady economic growth rate in the recent years from 7.3% in 2004 to about 8.4% in 2006[8], with transport constituting one of the main economic backbones. The port of Klaipeda is the largest port in Lithuania and has an annual port cargo handling capacity of over 21.8 million tons at the end of 2005[9] which amounted up to 23.5 million tons during the third quarter of 2006. Figure 5-3 shows the growth of container cargo volume in the port of Klaipeda from 1997 to 2006. The port of Klaipeda is owned and managed by the Klaipeda State Seaport Authority, and thus the state government plays a key role in shaping regulatory policies. While the growth in container freight can be seen as successful in Klaipeda, attaining more than 47% by 2004[10] it has witnessed a decline during the first half of 2006, partly as a result of stiff increase in competition among the East Baltic ports and partly due to the emergence of new players in the container handling market[11]. If nothing is done such fierce competition will remain a threat to container growth for the port of Klaipeda especially as most ports are looking to upgrade, and improve their services. The situation becomes even more complex with rising freight volumes. One way to go about such problems is to optimize resource usage and deployment, to help reduce unnecessary expenses and improve service quality.

Marine Leg Karlshamn-Klaipeda

For a ship with an average speed of 18 Knots, it takes approximately 15 hours to cover the 223 sea miles distance, from the port of Karlshamn to the port of Klaipeda and vice versa, thus completing one round trip every 48 hours. Presently, a minimum of two ships (LISCO Patrias & Kaunas) owned and operated by AB DFDS LISCO[12] offers RoPax services between Karlshamn and Klaipeda. The two ships are scheduled such that one ship makes a call at the port of Karlshamn while the other calls at the port of Klaipeda almost daily.

Several reasons accounts for the importance of the Karlshamn Klaipeda shipping link:

- Connects Sweden and the Baltic States
- Meet the EU SSS goals

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[8] *Department of Statistics to the Government of the Republic of Lithuania; Change of GDP 2002-2006*
[9] *Report; Activity of Klaipeda and Neighbouring Ports in 2005 (http://www.portofklaipeda.lt/)*
[10] *The statement was made in a Seminar of ministers of Transport and the World Bank by Mr. Alminas Maciulis, State Secretary of the Lithuanian MoTC.*
[11] *Report; Cargo Turn over for the port of Klaipeda for the first half of the year 2006 (http://www.portofklaipeda.lt/)*
[12] *DFDS LISCO is a subsidiary of DFDS Tor Lines which offer shipping services in several other European countries, Germany, UK, Denmark, Holland etc. DFDS LISCO is the owner of 7 ships and 4 multipurpose vessels.*

- Connect several old important transport routes, such as Corridor IX running south from Klaipeda to the Black Sea and Iran and also the Trans Siberian Corridor running East via Moscow towards India and China.
- The link connects to a strategic SSS network over the Baltic that offers a considerable potential suitable enough to support effective trade within the Baltic States and Europe.
- The link can be regarded as part of the most active waterways across the Baltic given that it is cutting across high traffic shipping links connecting Russia with other European countries such as Holland, Germany and Denmark etc.

Model Development using Integer Linear Programming Optimization Model (ILP) for Port Terminals

With a given demand of inbound/outbound TEU volume at a container terminal several decisions regarding different equipments needs to be considered. These decisions are interconnected and in most cases decisions about given equipment usually has a direct or indirect influence on decisions about other equipments. One of the very early decisions is the vessel choice with respect to the type and capacity appropriate for transportation. Once the appropriate vessel or vessels have been chosen, it then becomes necessary to provide complementary facilities at the port of call that can service the vessel upon arrival. Thus a given choice of vessel will influence a decision on berth usage in case the vessel is a LoLo and ramp in case the vessel is RoRo or RoPax.

For the chosen berth(s), the appropriate type and number of quay cranes will be selected. Quay cranes will need yard vehicles to move the containers, thus a decision about quay cranes will have an influence on the decision about yard vehicles. Yard vehicles will require yard or mobile cranes to off load the containers, thus selecting yard vehicles enforces the decision about yard cranes and the whole process can be followed way down the handling chain until the cargo units are loaded into the truck for outbound transport or onto the ships in case it is inbound. In an optimization model we combine all the different restrictions about the entire system and seek for non-conflicting optimal decisions values. Figure 5 is our proposed simple generic ILP model represented as a tree. The entire process has been simplified to enable model clarity given that there are a multitude of constraints which must be satisfied before a solution can be obtained.

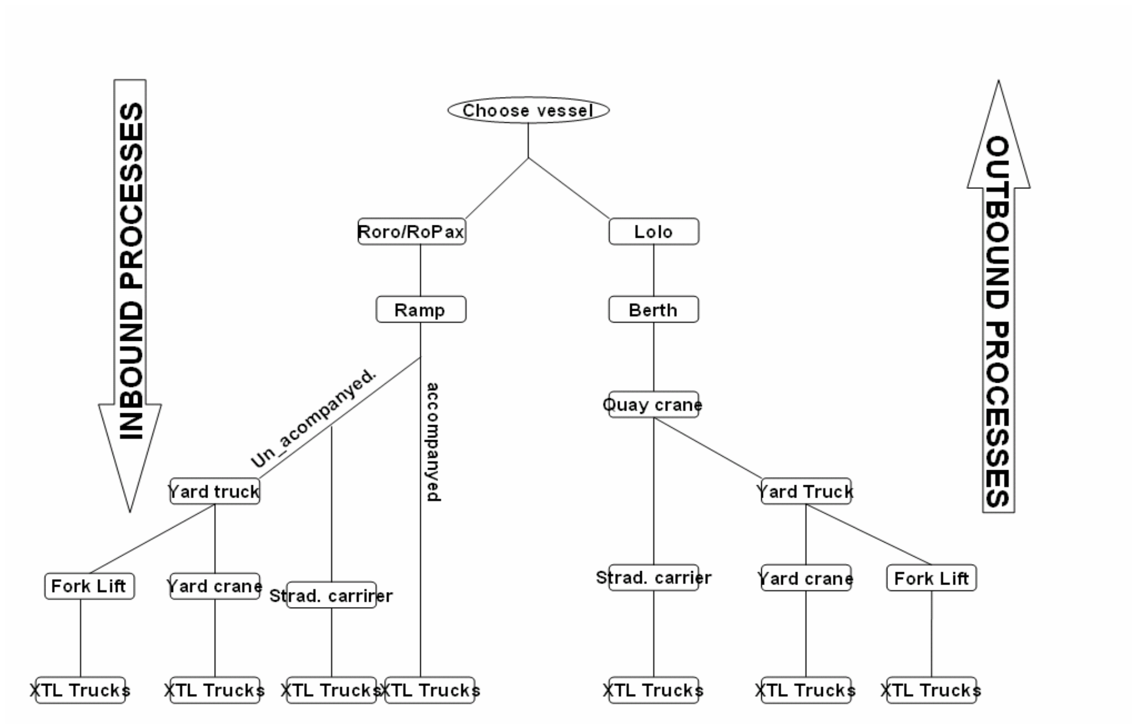

Figure 5 Simple generic ILP Model represented as a tree

The generic model as shown above can possibly be applied to most port terminals since the main handling systems for SSS are either RoRo/RoPax or LoLo services and handling operations are roughly in the same order, except for some cases that employ use of special purpose tools e.g. in automated terminals using RS/AS system. The tree can be expanded to incorporate a wide range of terminal equipments. However, the parameters under which the equipments selection is optimized can vary greatly from one port to another, likewise the constraints governing operations.

Model Description

Optimization models represent problem choices as decision variables and seek values that maximize or minimize objective function of the decision subject to constraints on variable values expressing the limits on possible decision choices (L. Radin 2000). If such a model can be described using a linear objective function together with linear constraints then it is termed a linear program. If in addition all decision variables are discrete (binary or integers), then the model is referred to as an integer linear program. Nearly all optimization models are based on some assumption justifiable enough to represent a good approximation of physical reality. The validity of the optimal solution will depend on how well or to what extent the assumptions hold.

ILP Fundamental Assumptions

i. *Static Parameters;* All parameters used in the ILP model are assumed static and deterministic with respect to different capacity changes and also with respect to time.
ii. *Demand;* In particular, we assume that the demand (in TEU), for which equipments are needed is deterministic. Our goal is to select suitable equipments on a strategic base, that can handle a given demand volume (TEU).
iii. *Loading/Unloading;* We assume both processes of loading and unloading to be the same, practically, the handling of loading and unloading of cargo slightly differs. The reason is because our interest is on capacity issues which demand the same handling equipments both in loading and unloading.
iv. *Equipment Performance;* The average performance of each equipment has been estimated based on three factors, namely the distance to which the equipment has to move when in operation, the load carrying capacity of the equipment, and the preferred total number of hours the terminal operate. Where the terminal has a 24 hour operation in a day, the equipment is regarded to perform at it maximum output.
v. *Yard Capacity;* We assume the total area of yard allocated for stacking inventories can be calculated
vi. *Time Window t;* While the model time window can be adjusted, we assume that for SSS operations it is necessary to consider small time windows (e.g. 48 hours) for handling.
vii. *TEU Calculation;* Vessel's carrying capacity has been considered in TEU units, and each trailer has been converted to TEU equivalent (in this case 2 TEU).
viii. *Full Load and Half Load;* Since it is difficult to consider any load utilization of a ship in the model we chose to consider 50% and 100% utilization levels.
ix. *Distance traveled by yard equipments in yard;* we assume that all yard equipments used to transport containers travels approximately the same distance in estimating their performance.

Decision Variables

At a given value of TEU demand D, we decide on the optimal values of the following:

- Type and number of equipments to use at terminal e.g. Quay cranes, Yard cranes, Fork lifts, Yard Vehicles etc
- Type, number and load utilization of vessel (ship) to use for transportation e.g. RoRo/RoPax ships, LoLo ships etc
- Number of trucks to use for outbound TEU
- Number of train blocks
- Number of berths and ramps to use
- Number of yard blocks required to line and/or stack containers

Objective

Our objectives include the following;

- ✓ Minimize the total cost incurred as a result of the different choices of equipments needed, by selecting the most cost effective system.
- ✓ Minimize cost of transport from both shipper and terminal perspective by suggesting vessel choice that incur minimal cost at terminal e.g. an all RoRo solution, or all LoLo solution or a combination both.

Hence summing all these together we get:

Minimize Z = handling cost + transport cost
Where we suggest considering;
Handling cost = fuel cost + administrative cost + insurance cost + labor cost +
Transport cost = fuel cost + berth cost or ramp cost + insurance cost + consumables +
Several other parameters can be included to the above.

Constraints

I. *Demand;* All TEU demand should be satisfied by the chosen transport
II. *Demand Equipments;* All TEU demand should be satisfied by the chosen set of handling equipments
III. *Demand Trucks and Train;* Based on TEU demand, there should be sufficient truck and train capacity to serve the terminal
IV. *Quay Cranes per Vessel;* There is a limit to the number of quay cranes that can service each LoLo vessel at a time and no quay crane is used to handle cargo transported in a RoRo vessel.
V. *Accompanied RoRo Trailers;* If TEU volume is accompanied, handling equipments are not used.
VI. *Ships per berth;* There is a limited number of ships using one berth at the same time
VII. *Ships per ramp;* There is a limited number of ships using one ramp at the same time
VIII. *Yard Vehicles per Quay crane;* There is a limit to the number of yard vehicles that can be served at the same time by each Quay crane
IX. *Yard Vehicles per RoRo;* There is a limit to the number of yard vehicles that can serve a RoRo vessel at the same time.
X. *Yard Vehicles per Yard crane;* Only a certain number of yard vehicles are allowed to serve a yard crane at the same time.
XI. *Trucks per loading equipments;* loading equipments such as yard crane can only process a certain number of trucks at a time.
XII. *Train per loading equipments;* The number of loading equipment processing each train blocks at a time is limited due to congestion.
XIII. .Non-stacking equipments per container block; in using equipments to lay container blocks, only a certain number of equipments can be selected for use in one block at the same time.
XIV. Stacking equipments per container block; in selecting equipments to stack containers, only a certain number of equipments can be selected for use in one stack at the same time.
XV. Blocks allocated to containers; If yard is not full, then unaccompanied containers and those not transported by truck and train has to be aligned in blocks.
XVI. Stack Blocks allocated to containers; If yard is full, then unaccompanied containers and those not transported by truck and train has to be stacked in blocks.
XVII. Container blocks limited by yard: The number of container blocks lined in yard depends on the allocated yard area
XVIII. Usage of equipments; If equipment is used a fixed cost is incurred
XIX. Usage of facilities; if berth or ramp is used then a fixed cost is incurred.

Since the model is complex, it was studied more as sub models consisting of terminal model (main model), yard model (for yard utilization), and yard discharge model (for intermodal) all build into a single model shown above.

ILP Mathematical Formulation

We consider the sets represented by the following;

Set I represents the set of all handling equipments used in the terminal.

Set QC $\subset I$ represents the set of quay cranes used in processing ships.

Set YC $\subset I$ represents the set of all yard cranes used in terminal.

Set L $\subset I$ represents the set of all loading equipments used in terminal.

Set M $\subset I$ represents the set of all terminal equipments used in stacking containers

Set P $\subset I$ represents the set of all terminal equipments used in laying blocks, no stacks

Set YV $\subset I$ represents the set of all yard vehicles used in terminal

Set J represents the set of all vessels or ships used for transport

Set LOLO $\subset J$ represents ships used in transportation that are only LoLo

Set RORO $\subset J$ represents ships used in transportation that are only RoRo

For each given equipment $i \in I$, we consider parameters represented by

- CE_i: Costs of equipment $i \in I$ based on; fuel consumed, labor, fixed cost (administration, energy, etc), insurance, repair and maintenance etc., all within a given time window (e.g. 24 hours).
- Av_i := (TEU moves per hour) *(Time Window) for equipment i $i \in I$
- f_i := fixed cost incurred in using equipment i, $i \in I$

For each vessel j $\in$ J we consider parameters represented by

- CV_j: Costs of vessel j $\in$ J based on crew costs, consumables, port dues, cost of fuel, repair and maintenance, insurance etc within a given operation.
- As_j := average TEU capacity for vessel j, $j \in J$
- f_j := fixed cost incurred in using vessel j, $j \in J$

We further consider the following parameters;

- D := TEU demand
- Time Window := the length of time in hours to complete handling
- AT := ratio of accompanied TEU volume in RoRo vessel
- B_{max} := number of vessels per berth for the time period
- R_{max} := number of vessels per ramp for the time period
- VQ_{max} := number of quay cranes that can load/unload each vessel at a time
- QV_{max} := number of yard vehicles a quay crane can load/unload at a time
- RV_{max} := number of yard vehicles per RoRo vessel
- YV_{max} := number of yard vehicles per yard crane
- RT := number of trucks allocated to loading equipment at the same time
- RN := number of train allocated to loading equipment at the same time
- TC := average truck capacity
- NC := average capacity for each train block
- EG := allowed number of equipments per container block, no stacks
- ES := allowed number of equipments per container block with stacks
- CY := container yard allocated to lining and stacking containers
- CA := area occupied by one container block
- Z := number of containers in one block lined in time t
- ε := 0.0001, a small number to minimize number of trucks and train
- M := arbitrarily large number (e.g. 1000000), to control binaries

The following variables are used in the model (i.e. determined by optimization):

$0 \leq Y_j$ integer, vessels or ships, $j \in J$

$0 \leq X_i$ integer, terminal handling equipments $i \in I$

$0 \leq$ R integer, number of ramps

$0 \le$ B integer, number of berths
$0 \le$ K integer, number of trucks required
$0 \le$ N integer, number of train blocks required
$0 \le$ G integer, container blocks on yard, no stacks
$0 \le$ S integer, stacked container blocks on yard
$0 \le Br_j$ binary, is 1 when transport Y_j is used and zero otherwise, $j \in J : RORO$
$0 \le Bl_j$ binary, is 1 when transport Y_j is used and zero otherwise, $j \in J : LOLO$
$0 \le Be_i$ binary is 1 when equipment X_i is used and zero otherwise, $i \in I$

Minimize (ILP)

$$Z = \sum_{j \in J} CV_j * Y_j + \sum_{i \in I} CE_i * X_i + \sum_{i \in I} f_i * Be_i + \sum_{j \in RORO} f_j * Br_j + \sum_{j \in LOLO} f_j * Bl_j + \varepsilon(K+N)$$

Subject to the following constraints;

i. Demand transport $\sum_{j \in J} As_j * Y_j \ge D$

ii. Demand Equipments: $\sum_{i \in I} Av_i * X_i \ge D$

iii. Demand Trucks and Train: $K + N \ge (D - (1-AT)* \sum_{j \in RORO} As_j * Y_j)$

iv. Quay crane per vessel : $VQ_{max} * Y_j \le \sum_{i \in QC} X_i$, $j \in J : LOLO$

v. Accompanied RoRo Trailers $\sum_{i \in YV} Av_i * X_i \ge (1-AT)* \sum_{j \in RORO} As_j * Y_j$

vi. Ships per berth: $\sum_{j \in LOLO} Y_j \le B_{max} * B$

vii. Ships per Ramp: $\sum_{j \in RORO} Y_j \le R_{max} * R$

viii. Yard Vehicles per Quay crane: $QV_{max} * X_j \le \sum_{i \in YV} X_i$, $j \in QC$

ix. Yard Vehicles per RoRo: $RV_{max} * Y_j \le \sum_{i \in YV} X_i$, $j \in RORO$

x. Yard vehicles per yard cranes $YV_{max} * X_j \le \sum_{i \in YV} X_i$, $j \in YC$

xi. Trucks per loading equipments: $RT * X_i \le K$, $i \in L$

xii. Train per loading equipment : $RN * X_i \le N$, $i \in L$

xiii. Non-stacking equipments per container block : $EG * G \le \sum_{i \in P} X_i$

xiv. Stacking equipment per container block: $ES * S \le \sum_{i \in M} X_i$

xv. Blocks allocated to containers : $G * Z \ge (D - (1-AT)* \sum_{j \in RoRo} As_j * Y_j)$

xvi. Stack Blocks allocated to containers; $S * Z \ge (D - (1-AT)* \sum_{j \in RoRo} As_j * Y_j)$

xvii. Container blocks limited by yard; $G * CA \le CY$

xviii. Usage of equipments: $X_i \le M * Be_i$, $i \in I$

xix. Usage of ship's facilities:

A. Control cost of ramp: $Y_j \le M * Br_j$, $j \in RORO$

B. Control cost of berth: $Y_j \le M * Bl_j$, $j \in LOLO$

Results and Analysis

In making a decision on the choice of handling equipments to invest on or to deploy for an operation, one key issue to consider is how much TEU capacity there is to be handled. We assume as said earlier that the TEU demand is known in advance. Based on this capacity, it is important, that handling is completed within a time window that will meet customer demands. We have considered a 48 hour maximum for the time window because one trip for our case study (Karlshamn-Klaipeda-Karlshamn) is completed within 48 hours. This time window is then used by the ILP model to calculate the average capacity output and some cost parameters (e.g. fuel, labor etc) for each handling equipment. Handling equipments could vary greatly in terms of restrictions laid on operations and operational cost incurred. We consider the case for the most common and yet highly useful equipments such as quay cranes, fork lifts, yard vehicles, yard cranes, tugmasters etc.

To configure the model to suit the case study for the paper, interviews and discussions were conducted with some representatives of the port of Karlshamn and port of Klaipeda with expert knowledge on unitized cargo handling. Thus we configure our model based on information obtained from these interviews.

i. Incremental increase in demand of 100TEU for each scenario
ii. An average distance of 400m from container location to destination is considered in estimating the performance values for transfer equipments (yard vehicles).
iii. More than half of the inbound/outbound TEU capacity is considered to be handled by truck and train at variable ratios, in an intermodal operation.
iv. About half of the RoRo container traffic volume is accompanied.
v. A truck or trailer has a capacity equivalence of 2 TEU and train block an equivalence of 4 TEU for full capacity
vi. Each LoLo vessel may be serviced by 1, 2, or 3 quay cranes in a single 1 berth
vii. Each RoRo is associated a ramp during handling and one ramp can be used by two RoRo ships within the time window considered
viii. The container yard area in this case was taken to be about 3000 square meters.

Since the cost incurred by external trucks and train are not part of the terminal cost, it was left out from the parameters considered. In table 1, we present some estimates of parameters used in our model. The total cost is the sum calculated per day including capital cost of equipment.

Equipment	Performance	Cost (Total/day)SEK
Quay Crane	(30-32)TEU/hour	119592
RTG	(28-35) TEU /hour	40656
Tugmaster	(13-25) TEU /hour	34056
Fork lift	(23-32) TEU /hour	33480
Trailers	(8-20) TEU /hour	10920
Mafis	(7-18) TEU /hour	3120
Straddle Carriers	(32-42) TEU /hour	51336
Contchamp	(28-38) TEU /hour	56280
RoRo150	(150-200)TEU	234637
RoRo200	(217-240) TEU	271582
RoRo250	(252-320) TEU	293807
RoRo350	(352-390) TEU	327032
LoLo500	(400-500) TEU	250110
LoLo1000	(800-1000) TEU	343708
LoLo1500	(1300-1500) TEU	375576
Truck capacity	2 TEU	N/A
Train capacity	4 TEU	N/A

Table 1 Model parameters *Source: ports of Karlshamn, Klaipeda and scientific literature*

The ILP model output is presented as an instance of the generic model shown above *(figure 12)* with equipment type and number for different TEU volumes. In addition, the type and number of vessels, trucks and train capacities are also displayed. We interpret these results as a suggestion for which equipments to invest on i.e. strategic level decision. Based on the nature of the demand the model can be useful for tactical level decision planning in deploying already existing equipments in an optimal set up that minimizes redundancies. The required facilities such as berths, ramps and container blocks lined in yard are also estimated. In the following tables (Tables 7-2 & 7-3), we present results for a given range of demand values (0-2000 TEU), iterating at demand levels of 100 TEU, the results for 21 scenarios are displayed on the table below. The handling time window is considered to be the time during which handling must be completed, and the equipments are therefore selected to complete handling within this time window.

Key to tables 2 and 3

QC = Quay Crane SC = Straddle Carrier RTG = Rubber Tyred Gantry YV = Yard Vehicle (terminal trailers and mafis) FL = Fork Lift	TM = Tugmaster RS = Reach Stacker (Contchamp) Lxxx = fully utilized LoLo capacity xxx TEU Lxxx* = half utilized LoLo capacity xxx TEU Rxxx = fully utilized RoRo capacity xxx TEU Rxxx* = half utilized RoRo capacity xxx TEU	Rm = Ramps Bt = Berths G=non-stacked container blocks S = stacked container blocks Tcost = Total cost of operation

TEU	Ship Type		Equipments							Facilities				Tcost (SEK)
	RoRo	LoLo	QC	SC	RTG	Y V	FL	TM	RS	Rm	Bt	G	S	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	R150*	0	0	0	0	2	1	2	1	1	0	5	0	812604
200	R150	0	0	0	1	4	0	3	1	1	0	10	0	824351
300	R250	0	0	0	1	4	0	3	1	1	0	15	0	864253
400	0	L500*	1	1	0	8	3	5	1	0	1	20	0	883516
500	0	L500	1	1	0	8	3	5	1	0	1	25	0	885016
600	R150	L500*	1	1	0	8	3	5	1	1	1	30	0	1077650
700	R150	L500	1	1	0	8	3	5	1	1	1	35	0	1079150
800	R250	L500	1	1	0	8	3	5	1	1	1	40	0	1119050
900	0	2xL500	2	2	1	16	4	10	1	0	2	45	0	1166980
1000	0	2xL500	2	2	1	16	4	10	1	0	2	50	0	1166980
1100	R200*R350	L500	1	1	0	8	3	5	1	1	1	50	5	1349230
1200	0	L500* L1000*	3	3	0	24	8	14	1	0	2	50	10	1354390
1300	0	L500 L1000*	3	3	0	24	8	14	1	0	2	50	15	1355890
1400	0	3xL500	3	3	0	24	8	14	1	0	3	50	20	1445200
1500	0	3xL500	3	3	0	24	8	14	1	0	3	50	25	1445200
1600	R250	L500 L1000*	3	3	0	24	8	14	1	1	2	50	30	1588560
1700	R250	3xL500	3	3	0	24	8	14	1	1	3	50	35	1637980
1800	0	2xL500 L1000*	4	4	0	32	11	19	1	0	3	50	40	1645020
1900	0	4xL500	4	4	0	32	11	19	1	0	4	50	45	1734330
2000	0	4xL500	4	4	0	32	11	19	1	0	4	50	50	1734330

Table 2 Output results with Handling Time Window = 24 Hours (50% accompanied for all RoRo volumes)

TEU	Ship Type		Equipments							Facilities				Tcost (SEK)
	RoRo	LoLo	QC	SC	RTG	Y V	FL	TM	RS	Rm	Bt	G	S	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	R150*	0	0	0	0	2	1	2	1	1	0	5	0	848943
200	R150	0	0	0	1	4	0	3	1	1	0	10	0	869615
300	R350*	0	0	0	0	2	1	2	1	1	0	15	0	903300
400	0	L500*	1	1	0	8	3	5	1	0	1	20	0	1007130
500	0	L500	1	1	0	8	3	5	1	0	1	25	0	1008630
600	R250* R350*	0	0	0	0	2	1	2	1	1	0	30	0	1131960
700	R250 R350	0	0	0	1	4	0	3	1	1	0	35	0	1153470
800	R250	L500	1	1	0	8	3	5	1	1	1	40	0	1241300
900	0	L1000	2	2	1	16	4	10	1	0	1	45	0	1307180
1000	0	L1000	2	2	1	16	4	10	1	0	1	50	0	1307180

1100	2xR350R200	0	0	0	0	8	3	5	1	1	0	50	5	1470610
1200	0	L500* L1000*	2	2	1	16	4	10	1	0	2	50	10	1472070
1300	0	L500 L1000*	2	2	1	16	4	10	1	0	2	50	15	1473570
1400	0	L500* L1000	2	2	1	16	4	10	1	0	2	50	20	1475070
1500	0	L500 L1000	2	2	1	16	4	10	1	0	2	50	25	1476570
1600	R250	2xL500* L1000*	2	2	1	16	4	10	1	1	3	50	30	1639950
1700	0	2xL500 L1000*	2	2	1	16	4	10	1	0	3	50	35	1642950
1800	0	2xL500 L1000*	2	2	1	16	4	10	1	0	3	50	40	1642950
1900	0	2xL500* L1000	2	2	1	16	4	10	1	0	3	50	45	1834920
2000	0	4xL500	2	2	1	16	4	10	1	0	3	50	50	1835730

Table 3 Output results with Handling Time Window = 48 Hours (50% accompanied for all RoRo volumes)

Additionally the number of trucks and train are estimated (Table 3) that will manage congestion within the terminal

TEU	**Trucks**	**Train**
0	0	0
100	3	2
200	10	5
300	14	7
400	40	20
500	50	25
600	50	25
700	60	30
800	64	32
900	90	45
1000	100	50
1100	80	40
1200	120	60
1300	130	65
1400	140	70
1500	150	75
1600	144	72
1700	160	80
1800	180	90
1900	190	95
2000	200	100

Time Window = 24 Hours, 50 % accompanied for all RoRo volumes
Inventory := 40%
Truck Capacity := 2 TEU
Train Capacity := 4 TEU

TEU	**Trucks**	**Train**
0	**0**	**0**
100	3	2
200	10	5
300	13	7
400	40	20
500	50	25
600	30	15
700	35	18
800	64	32
900	90	45
1000	100	50
1100	55	28
1200	120	60
1300	130	65
1400	140	70
1500	150	75
1600	160	80
1700	170	85
1800	180	90
1900	183	92
2000	190	95

Time Window = 48 Hours, 50 % accompanied for all RoRo volumes
Inventory := 40%
Truck Capacity := 2 TEU
Train Capacity := 4 TEU

Table 4 Estimated numbers of trucks and train capacity (based on TEU volumes)

Output Analysis

From tables 2 &3, the number of equipments varies with the number and type of ships used, since the equipments are selected to serve the ships. Changing the time window for handling changes the number of equipments selected since the workload estimate for equipments depends on their performances calculated in moves per unit hour. The model handles a wide range of issues, and as such, model output can be analyzed in several different ways depending on particular aspects of interest. Some analysis of interest, for example could include the following;

- **A Change at TEU 1100**

Tables 2 & 3 shows that at 1100 TEU capacity point, there is a significant change in the type of vessel and equipments used. Such a situation can be difficult to handle if it hasn't been pre-aimed because investments at 1100 TEU level are shown to be less efficient at 1200 TEU level as can be seen from the results. By tuning model parameters to meet conditions at 1100 TEU capacity level, from the present TEU handling capacity, it can be possible to estimate the required investment rate in order to handle such changes. E.g. suppose the present handling volume is 200 TEU, then setting constraints at 1100 TEU volume, and running the model, results indelicate that an increase investment be made on

RoRo vessels and yard vehicles. Such information can help the port to make reasonable trade offs that avoids future decision problems.

- **Choice of Vessel Versus TEU Volume**

From tables 2 & 3 LoLo vessels can be seen to be less efficient for capacities below 500 TEU compared to RoRo vessels. This is reasonable since LoLo vessels have huge capacities which shall be underutilized if used for TEU capacities less than 500. Above 500 TEU, it is possible to use both LoLo and RoRo but, LoLo will be more efficient than RoRo since about 70 % of the scenarios from 500 TEU upwards makes use of LoLo. However, the time window is a limit to the type of LoLo especially in relation to capacity. LoLo vessels with capacities more than a 1000 TEU can be difficult to serve a SSS system within a 48 hour handling time window. The variation of choice of vessel versus capacity can be shown using a simple bar chart (figures 6 & 7)

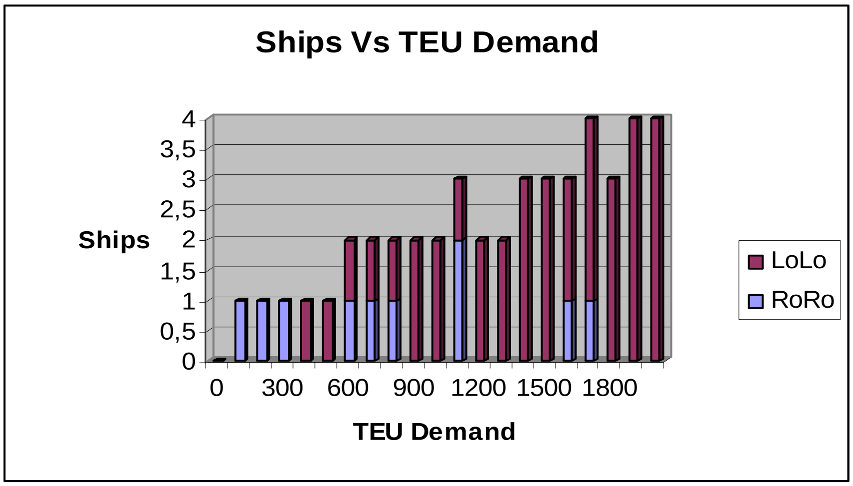

Figure 6 Variation in number of ships with TEU demand for a 24 Hour Handling Time Window

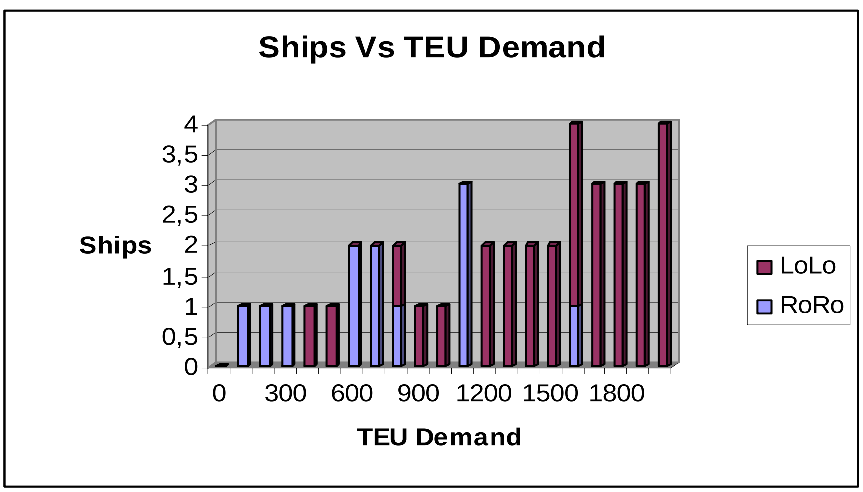

Figure 7 Variation in number of ships with TEU demand for a 48 hour handling time window

- **Choice of Vessel Versus Number of Yard Vehicles**

When ever a RoRo ship is used for transportation, about 50% of the cargo is treated as accompanied for the above outputs. This means that the units are equipped with drivers to drive them out of the ship without the need for any handling. Consequently fewer types of equipment are used in RoRo operations than LoLo (shown in figure 8).

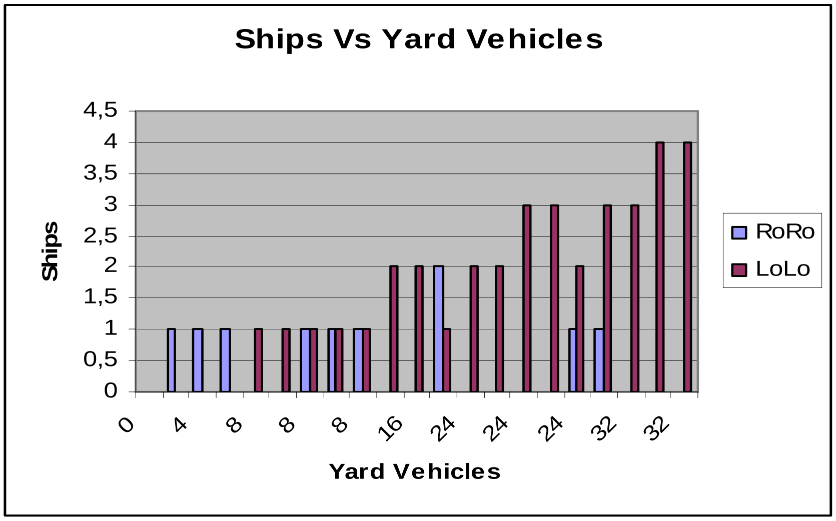

Figure 8 Variation in number and type of ships with yard vehicles

- **Effect of Handling Time Window**

Increasing the time window from 24 to 48 reduces the number of equipments. This is because equipments are selected with respect to the total number of TEU moves required to complete handling. The TEU moves depend on the performance value of the equipments, calculated in moves per hour. As such, if the time window is increased then, less equipment shall be needed to handle the same amount of TEU than within a short time window. For the vessels the time window determines the choice of vessel from the required time to load/unload a vessel. The following figure (figure 9) shows how the number of yard vehicles varies for a 24 hour handling time window, compared to a 48 hour handling time window for the same TEU volume

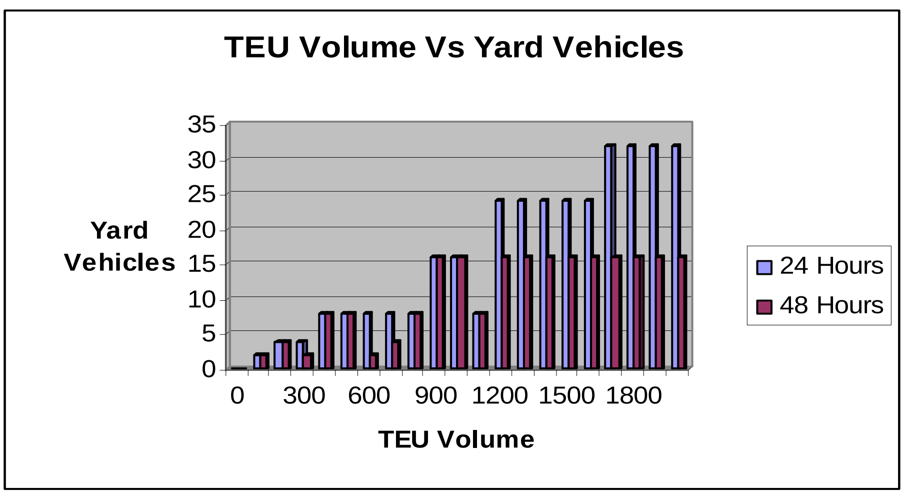

Figure 9 Variation in number of yard vehicles with TEU Volume for different handling time windows

- **Cumulative use of Equipments**

If the port invest on given equipment, the equipment remains useful over a given period of time according to the depreciation period associated to the equipment. Therefore it is possible to use the same equipment at different TEU demand capacity levels within the depreciation period. Such a situation can be accommodate into the model or analyzed from the output i.e. the required set of equipments for the next 100 TEU capacity scenario is calculated taking into consideration the existing equipments. As an example, results from the 24 hour scenario (table 7-2) for investments in Quay crane, Fork lifts and yard vehicles, taking accounts of the already existing investments are shown on figure 10 below;

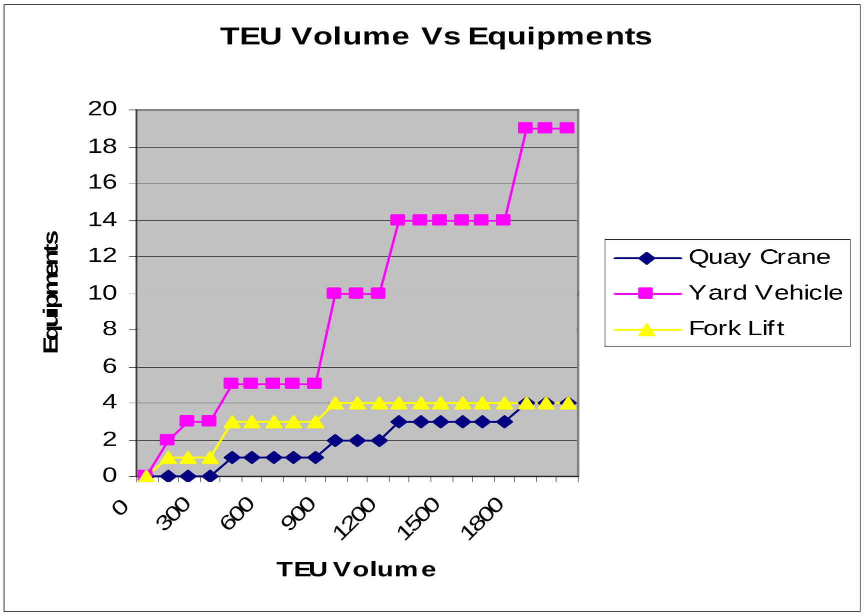

Figure 10 Cumulative reuse of equipments fork lift, yard vehicles and quay crane (from table2)

For ships the depreciation period is usually very long (hundred of years), and a similar analysis is presented in figure 11 below:

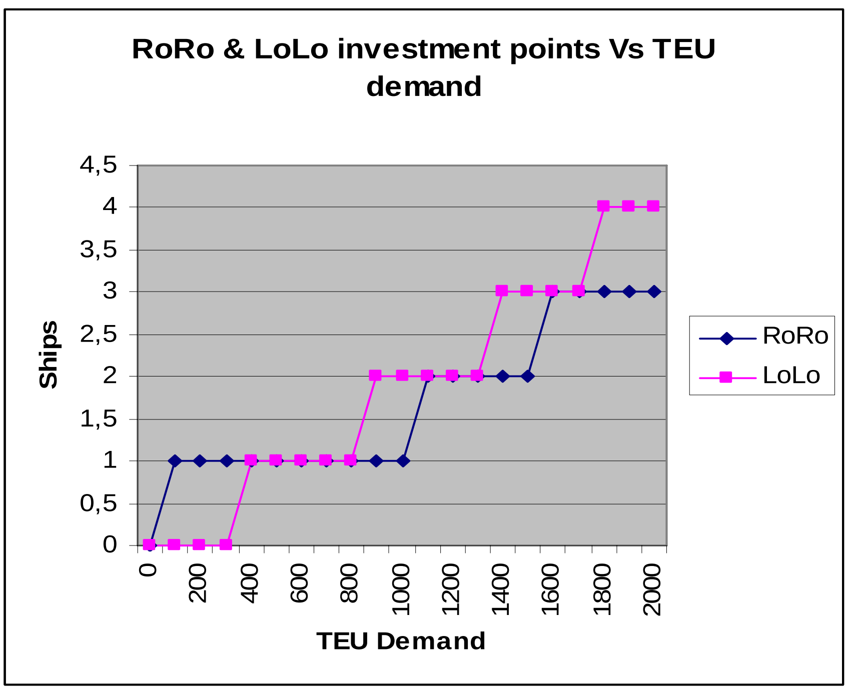

Figure 11 Investment points in ships with TEU demand (from table 2)

The changes indicate the point at which to invest or negotiate for a new vessel and helps in making a choice between LoLo or RoRo solutions.

- **Variation of Total Cost with TEU Volume**

Analyzing how the total cost varies with TEU demand can enable the port to determine the appropriate pricing strategy to attain a given investment point from the present capacity point. E.g. suppose the port is at capacity level 400 TEU/day and forecast a need for an investment in order to be able to handle TEU demand 800 /day, then from the variation of total cost per TEU, it is possible to determine a benchmark for the appropriate cost/price per TEU to attain investments at demand level 800 TEU/day after a certain period of time. Figure 12 below illustrates the variation of total cost per TEU demand.

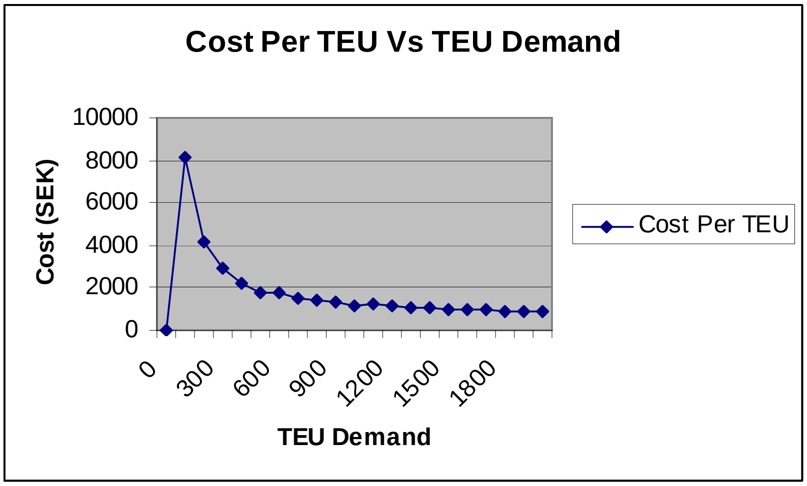

Figure 12 Variation of total cost per TEU (from table3)

- **TEU Volume Vs Truck and Train Capacity.**

Estimating the truck and train capacity is important to adjust the ratio of TEU volume distributed between truck and train, or estimate the facilities to invest on in order to offer an intermodal service. This can help balance the TEU volume distribution so that congestion can be managed.

1.1 Sensitivity Analysis

As part of the validation process of a model, it sensitivity can be studied by varying parameter values and constraints and significant effects of such changes monitored to draw conclusions about the behavior of the model. Validation of the proposed ILP model was done mainly by following the operational Research Process (L. Radon 2000) in which we obtain data from the real world, run the model, and compare the output with known practical solutions. The proposed model parameters were adjusted to suit the present practical scenario for the case study and results were quite similar to the practical case. A summary of some sensitivity analysis for the model is shown on the table below (Table 5);

Test	**Effect**	**Conclusion**
Decreasing the time window to 6 hours	Increase use of RoRo ships for small capacities	Large capacity ships (LoLo), cannot be served within smaller time windows.
Increase in Time window to 60 hours	Increase use of LoLo ships for bigger capacities	A larger time window is suitable to serve larger ships
Increasing demand to 4000 TEU, time window 48 hours	Increase in number of equipments. The pattern from 0 to 2000 remains averagely the same for RoRo plus more LoLo ships from 2000 to 4000	The solution seems to be symmetric since all conditions were maintained.
Change in Container Yard capacity (CYC)	Increase in CYC increases the use of yard vehicles and non-stacking equipments and decrease in yard increase the use of stacking equipments	Increase yard will lead to use of non stacking equipments with less cost relative to stacking equipments and vice versa.
Relaxing the constraint on	Use of small capacity LoLo ships from	A sequential service where possible

simultaneously serving LoLo vessels within 48 hours	800 TEUs upward. The total cost is reduced	may be cost effective than a simultaneous service because investments in equipments may be more costly than labor
Limiting facilities to a maximum of 1 berth and 2 ramp, 48 hours, 2000 TEU	Increase total cost, 1 LoLo vessel and 2 RoRo vessels at 2000 TEU	Multiple RoRo solution at high capacity is more costly compared to LoLo solution.
Relaxing integer requirement, time window 48 hours	Model is solved with fractional values. For some scenarios the cost reduction is quite significant as much as 39% for scenario with TEU volume 1800	Depending on the penalty that will be incurred some equipments may not be suitable to invest on at certain demand levels

Table 5 Analysis of model sensitivity

Conclusion

In order to meet European Union SSS requirements in delivering seamless intermodal solutions, it is absolutely necessary that port terminals and shippers consider cooperative strategies in order to minimize time and manage cost. An acceptable SSS solution will be one that serves time all across the entire transport chain from the shipper through the terminal and to the land transport, hence the need to study it as an integrated system. Integrated optimization models build into DSS will be useful in achieving such strategies. Applying modeling techniques to similar problem domains will provide us a good approach for expanding practical application areas in computer science, challenges presented by such systems will shape the evolution of research within computer science whereas successful applications will be an improvement to the real world. Further improvements can be made to the ILP model developed in this paper following the operational research process, and the model can be tailored to the needs of different port terminals at large.

In developing our ILP model we attempted to establish a methodology by which a complete decision support tool can be developed for a container terminal. The suggested methodology considers the integrated problem as made of sub problem models (yard, intermodal, yard discharge etc) all build into a single integrated optimization model through a number of operational research process (L. Radon 2000) iterations, until reasonable results are obtained.

Based on data obtained from the case study (ports of Karlshamn and Klaipeda), ILP Model results indicates that a LoLo vessel with a capacity between (500 and 1000 TEU) capable of completing a SSS voyage within 48 hours will be less costly than a RoRo that transports with multiple voyages or one voyage each for multiple RoRo vessels for TEU volumes greater than 1000. Under such circumstances the capacity advantage of a LoLo vessel will as well be extended to handling and all this shall together outwear the disadvantage associated with speed. The high cost of investment in quay crane will be recouped due to the scale economies in using LoLo system.

Finally further improvement will be to develop the different models to consider the different activities in a considerable depth and include more models such as stowage optimization, a demand forecast, berth allocation strategies etc. The model can further be developed to consider all variations in cargo since we assumed that all cargo is unitized and can be stacked where LoLo is the vessel of choice. Trailers, though unitized, cannot be stacked and will only be transported in a RoRo vessel.

Other optimization modeling approaches such as non-linear programming can be applied to solve this same problem and results compared. Performance of different algorithmic codes in solving the problem modeled in this paper can be compared by applying these algorithms and comparing results. If the operational research cycle is iterated several times the model can further be improved to a full DSS with a suitable interface.

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