MATHEMATICAL MODEL TO OPTIMIZE LAND EMPTY CONTAINER MOVEMENTS

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ABSTRACT

Empty container logistics is one of the most relevant costs for shipping companies. Thus, efficient empty container management is a key issue in the maritime business. This article analyzes the problem from the local maritime agent point of view, which controls and manages land container logistics. Specifically, it is presented a mathematical model to optimize land empty container movements among shippers, consignees, terminals and depots, along with minimizing storage costs. The mathematical model is defined, tested with real data and solved by using CPLEX. Obtained results confirm the benefits of implementing this kind of models. Finally, future research lines in empty container logistics are identified.

Keywords: empty container logistics, mathematical model, optimization

1. INTRODUCTION

Maritime container traffic has been growing very fast during the last 15 years with steady annual growth rates of over 10%, achieving a global port traffic throughoutput in 2007 of around 500 million TEUs.
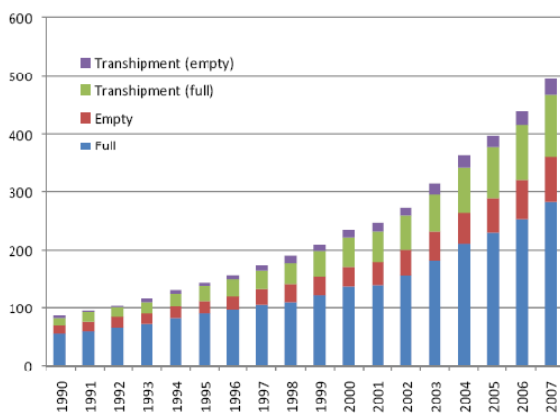

Figure 1: Evolution of world port container traffic

In order to meet this traffic there is a fleet of container ships with capacity for around 10 million

TEUs and a maritime container fleet of around 25 million TEUs, which is owned by shipping and leasing companies. Concerning the type of maritime containers used in all these operations, there is a big variety of equipment (standard, highcube, reefers, platforms, etc.), but standard 20 and 40 foot dry cargo containers are almost 90% of the total fleet.

Container logistics has to do with efficient container fleet management minimizing transport costs and maximizing containers use. Empty container logistics deals with the movements, storage and distribution of empty containers, process which starts once the container is emptied at consignee facilities, and ends once the empty container is positioned to be loaded again at the next shipper facilities.
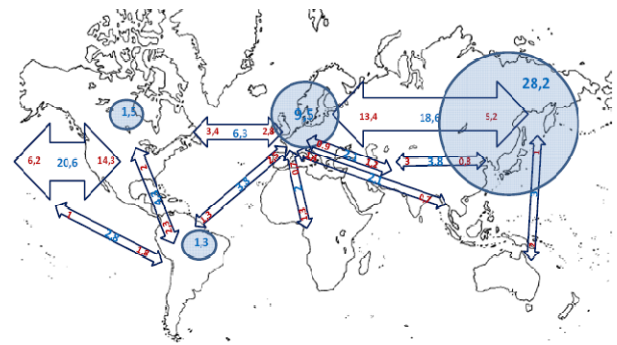

Figure 2: Main container traffic routes

The analysis of main world container traffics shows important eastbound/westbound differences at main trade routes. This way, shipping companies accumulate a large number of unnecessary empty containers at several import-dominant ports (mainly in Europe and USA) which need to be repositioned to different export-dominant ports (mainly in Asia) where they are required (Li et al, 2006).

Empty container incidence at main trade routes exceeds 21% of total traffic (Dekker, 2008), and containers spend more than a half of his life stocked or being transported empty to be repositioned (Crinks, 2000). All this makes empty container logistics one of

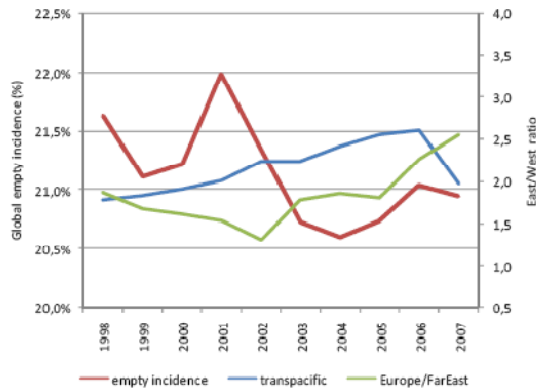the most relevant costs for shipping companies (Wang et al, 2007).

Figure 3: Empty container incidence

Two different levels can be defined when talking about empty container logistics: The international level and the local or regional level (Boile et al, 2008).

The former has to do with the movement of empty containers at global scale to reverse the imbalance problem at main world commercial axes. This is managed directly by shipping companies at global level.

The later deals with the land movement of empty containers between port terminals, empty container depots, consignees and shippers facilities. Local maritime agents, who are responsible of containers fleet management at their influence area, manage these kind movements.

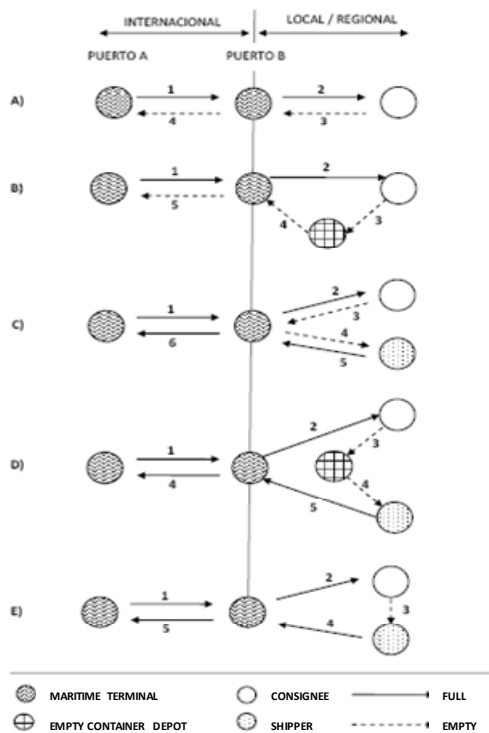Figure 4 shows the different container movement patterns that can be found.

Figure 4: Container movement patterns

The first pattern presented (A) matches with the typical "**empty reposition"** operation. It could be an Asian import container which reaches a European port (movement 1), after this, the container is moved to the importer facilities to be unloaded (movement 2) and, once emptied, it is transported again to the port terminal (movement 3) to be repositioned or sent back to Asia empty (movement 4), in order to start a new cycle.

Pattern B is also an empty reposition operation. The difference is that the empty container is stocked in an empty container depot before being sent it back to the port terminal to be loaded in a ship for repositioning.

Next patterns C, D are known as "**match back**" operations, where an export load allows avoiding the empty maritime transport to reposition the container. The difference between C and D is the place where the container is stocked before being re-used in an export operation (port terminal for C, and empty container depot for D).

Finally, pattern E is a match back operation where the container once unloaded at importer facility (consignee) is moved directly to the shipper facility (exporter) to be loaded again. This operation is also known as "**street-turn**" but it has a lot of difficulties to be carried out:

- It needs an import and export operation coinciding at the same time, type of container, shipping company and place
- It needs also the coincidence of the road transport operator for complementary import and export operations
- Most of the times containers need intermediate operations after a cycle to be reused (brushing, cleaning, repairing, etc.)

The mathematical model presented next, deals with the local or regional level of empty container logistics which is managed by local maritime agents. Specifically it tries to serve as decision support system to make easier the fleet management minimizing transport and storage costs.

2. PROBLEM DEFINITION

Before defining the mathematical model to support empty containers management from the local maritime agent point of view, it is necessary to know the problem and to identify which are maritime agent decisions concerning empty containers management and movements. In order to achieve this knowledge lots of interviews and working sessions have been performed with different maritime agents and empty container depots operating at the Port of Valencia. Thus, it has been developed a deep analysis of the procedures and tools maritime agents use to manage their containers fleet.

The analysis result has arisen that well defined procedures are implemented. These procedures allow in most of the cases updated information and control of the equipment (containers), but there is a lack of operating

tools to support decisions in order to minimize movements, storing and transport costs.

The mathematical model developed aims to support maritime agent decisions around container movements to achieve reduced costs for containers fleet management. It is important to remark that only daily operational decisions are being considered, being out of the scope other strategic decisions such as the selection of the container terminals and empty container depots to work with. These kinds of decisions are considered as a given input to the problem which is here addressed.

The daily operational decisions of the local maritime agent concerning empty container logistics are the following:

- Selection of empty container provider (from different terminals and empty depots) for every export operation. (This is needed to fill up the transport order)

- Selection of empty container final destination for every import operation. (This is needed to fill up the transport order)

- Selection and distribution of container movements among different storage places (terminals and empty depots)

And the main objectives to determine all these decisions are the following:

- Ensuring empty container at their disposal to attend export operations

- Maximizing ships capacity

- Minimizing empty container land movements or transport

- Minimizing empty container storage costs

- Minimizing empty container stock at port terminals in order to reduce their congestion and improve their productivity

Taking all these decisions and objectives into account, next comments will be considered when formulating the model:

- The objective of ensuring empty container availability could be guarantee by establishing a set of minimum stocks by type of container depending on demand forecasts

- Maximizing ships capacity could be approached by estimating the optimum number of empty containers to be loaded, having into account: Ship load situation at arrival, ship loading and unloading forecasts, specific instructions of the shipping company. To simplify the model the number of empty containers to be loaded in a ship could be considered as a given input data which is established at a higher level by the shipping company

- The minimization of empty container land movements would be achieved by selecting proper terminal and depots to provide empty containers at every export operation and to storage empty containers after every import

operation. This should also reduce the need of empty containers movements between different storage facilities.

- The objective of minimizing empty containers stock at port terminals could be contradictory to the previous one, but a rational solution could be achieved by limiting the maximum number of days for an empty container at port terminals

- Minimization of transport costs is directly related to minimization of empty container land movements and total cost minimization (transport costs along with storage costs) could be the objective function of the mathematical model to be developed

Looking again through the problem definition the input data to the problem would be:

- Ship or line-services arrival forecasts: Date of arrival at port, ship load situation at arrival, loading/unloading forecasted movements, etc.

- Empty container stock situation by type of container at different storage facilities

- Export and import forecasted operations related to ships or line-services involved

- Storage costs of empty container at different terminals and depots. (These costs could be dependent on the number of days containers are stocked)

- Transport costs of moving containers between shippers, consignees and storage facilities

- Type of containers master file

- Storage facilities (terminals and depots) master file

- Consignees and shippers master file

3. MATHEMATICAL MODEL

The problem of allocating storage facility to every empty container supply or demand operation can be modeled as a typical transport problem (Network Flow Problem) to look for optimal solutions giving response to daily operational decisions of local maritime agents which have been discussed above.

Next, the model formulation is presented. (In order to simplify notation and understanding constant storage costs have been considered):

Index

c= 1,2,…, C	Consignees
s= 1, 2, …, S	Shippers
d= 1,2, …, D	Empty container Depots
j=1,2,…., J	Port Terminal
t=1,2,…, T	Time periods
r=1,2,…,R	Container types

Demand / Supply Data

L_{tsr} — Number of type r empty containers to provide to shipper s at t time period

U_{tcr} — Number of type r empty containers supplied by consignee c at t time period

R_{tjr} — Number of type r empty containers to unload at terminal j at t time period

O_{tjr} — Number of type r empty containers to load at terminal j at t time period

Storage Capacity Data

I_{jr}^{max} — Upper limit of type r empty container stock at j terminal

$\hat{I}_{dr}^{max}$ — Upper limit of type r empty container stock at d depot

$\hat{I}_{dr}^{min}$ — Lower limit of type r empty container stock at d depot

Storage Costs Data

h_{jr} — Unit storage cost of type r empty containers at j terminal

h_{jr} — Unit storage cost of type r empty containers at d depot

Transport Cost Data

α_{cjr} — Unit transport cost of type r container from consignee c to terminal j

β_{cdr} — Unit transport cost of type r container from consignee c to depot d

γ_{jsr} — Unit transport cost of type r container from terminal j to shipper s

δ_{dsr} — Unit transport cost of type r container from depot d to shipper s

$\varepsilon_{jj'r}$ — Unit transport cost of type r container from terminal j to terminal j'

$\varphi_{dd'r}$ — Unit transport cost of type r container from depot d to depot d'

μ_{jdr} — Unit transport cost of type r container from terminal j to depot d

Initial Stock Data

I_{jr}^{0} — Initial type r container stock at terminal j

$\hat{I}_{dr}^{0}$ — Initial type r container stock at depot d

Variables

x_{cjr}^{t} — Number of type r containers supplied by consignee c at t time period and allocated to terminal j

z_{cdr}^{t} — Number of type r containers supplied by consignee c at t time period and allocated to depot d

y_{jsr}^{t} — Number of type r containers provided to shipper s from terminal j at time period t

w_{dsr}^{t} — Number of type r containers provided to shipper s from depot d at time period t

$v_{jj'r}^{t}$ — Number of type r containers moved from terminal j to terminal j' at time period t

$q_{dd'r}^{t}$ — Number of type r containers moved from depot d to depot d' at time period t

p_{jdr}^{t} — Number of type r containers moved from terminal j to depot d at time period t

f_{djr}^{t} — Number of type r containers moved from depot d to terminal j at time period t

I_{jr}^{t} — Number of stocked type r empty containers at terminal j and time period t

$\hat{I}_{dr}^{t}$ — Number of stocked type r empty containers at depot d and time period t
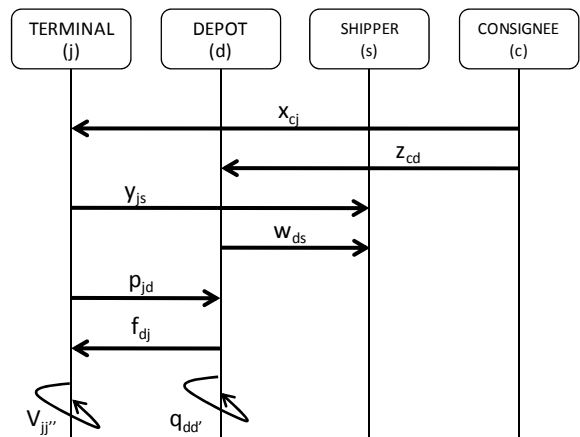

Figure 5: Decision variables associated to empty container movements

Model

$$
Mimize \sum_{t}\sum_{r}\left[\sum_{c}\sum_{j}\alpha_{cjr}x_{cjr}^{t} + \sum_{c}\sum_{d}\beta_{cdr}z_{cdr}^{t}\right] +
$$

$$
+ \sum_{t}\sum_{r}\left[\sum_{j}\sum_{s}\gamma_{jsr}y_{jsr}^{t} + \sum_{d}\sum_{s}\delta_{dsr}w_{dsr}^{t}\right] +
$$

$$
+ \sum_{t}\sum_{r}\left[\sum_{j}\varepsilon_{jj'r}v_{jj'r}^{t} + \sum_{d}\varphi_{dd'r}q_{dd'r}^{t}\right] +
$$

$$
+ \sum_{t}\sum_{r}\left[\sum_{j}\sum_{d}\mu_{jdr}p_{jdr}^{t} + \sum_{d}\sum_{j}\mu_{djr}f_{djr}^{t}\right] +
$$

$$
+ \sum_{t}\sum_{r}\left[\sum_{j}h_{jr}I_{jr}^{t} + \sum_{d}\hat{h}_{dr}\hat{I}_{dr}^{t}\right]
$$

Subject to

[1] $\sum_j x_{cjr}^t + \sum_d z_{cdr}^t = U_{tcr} \quad \forall t \, \forall c \, \forall r$

[2] $\sum_j y_{jsr}^t + \sum_d w_{dsr}^t = L_{tsr} \quad \forall t \, \forall s \, \forall r$

[3] $I_{jr}^t \le I_{jr}^{max} \quad \forall t \, \forall j \, \forall r$

[4] $\hat{I}_{dr}^{min} \le \hat{I}_{dr}^t \le \hat{I}_{dr}^{max} \quad \forall t \, \forall j \, \forall r$

[5] $I_{jr}^t = I_{jr}^{t-1} + R_{jr}^t - O_{jr}^t - \sum_s y_{jsr}^t - \sum_d p_{jdr}^t$
$\qquad - \sum_{j'} v_{jj'r}^t +$
$+ \sum_c x_{cjr}^t + \sum_d f_{djr}^t + \sum_{j'} v_{j'jr}^t \quad \forall t \, \forall j \, \forall r$

[6] $\hat{I}_{dr}^t = \hat{I}_{dr}^{t-1} - \sum_s w_{dsr}^t - \sum_j f_{djr}^t - \sum_{d'} q_{dd'r}^t +$
$+ \sum_c z_{cdr}^t + \sum_j p_{jdr}^t + \sum_{d'} q_{d'dr}^t \quad \forall t \, \forall d \, \forall r$

[1] The number of containers supplied from import operations match up with the number of containers sent from consignees to depots and terminals

[2] The number of containers provided for export operations match up with the number of containers sent from depots and terminals to shippers

[3] Empty container stock at terminals should be below the upper limit established

[4] Empty container stock at depots should be between the lower and the upper limits established

[5] Empty container stock update at container terminals

[6] Empty container stock update at empty container depots

4. RESULTS AND CONCLUSIONS

The model designed has been implemented in CPLEX for experimentation and result analysis. The model was firstly tested with different sets of random data and secondly with real data provided from a local maritime agent at the port of Valencia, which required the development of a database with the following information:

- Port terminals and empty container depots master files
- Shippers and consignees master files
- Type of containers master file
- Historic data of transport operations associated to different line services
- Ships arrival forecast
- Road transport costs information
- Storage costs information

Experiment results have shown us that an optimal solution to the problem is found rapidly. As it has been already stated, the model defined addresses a Transport Problem where all the decision variables are integer. The resulting Integer Programming problem (IP) can be successfully solved by using Linear Programming because all empty container supplies and demands *(L, U, R, O)* are also integer, and the optimal solution will have integer values for all the variables.

It is also interesting to remark that optimal solutions do not include movements between depots and terminals in most of the cases that have been tested, which looks logical due to the main objective of minimizing transport costs. This kind of movements only appear at the optimal solution if upper stock limits are going to be exceeded (in order to avoid it); if there are very high storage costs at any terminal or depot; or if there are punctual big demands of containers at a particular terminal.

The study presented provides a well structured approach to the empty container logistics problem, identifying different problems and basic lines to work in at different levels (optimizing sea movements, optimizing land movements, optimizing containers use, optimizing storage yards use, etc.), as well as different solutions or ideas to be developed and implemented (collaborative schemes, improved information systems, etc.) and the introduction to the use of mathematical models to face a particular empty container problem concerning surface transport and container equipment management by local maritime agents. Obtained results confirm the benefits of implementing this kind of models for operational decision making.

Finally, future research lines around empty container logistics can be pointed out, such as:

- Modeling empty container logistics introducing collaborative schemes among shipping lines
- Modeling container logistics and traffics introducing the "risk" concept
- Modeling international container traffic and different scenarios of container fleet composition
- Development of useful models to plan new infrastructures to support container logistics
- Development of new technologies to improve land use at container yards

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