AN OPTIMIZATION MODEL FOR THE YARD ALLOCATION PROBLEM

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ABSTRACT

Port terminals play an active role on supply chain performance as intermodal interfaces, and efficient cargo handling plays a key role in reducing global transportation costs while providing a good service level. At the port terminal, import containers are unloaded from the ship and are temporarily stored at the yard to be later dispatched to external trucks. Also, previous to the arrival of a ship, export containers are received from external trucks and storaged at the yard while they are loaded to the ship. In this work we address the problem to allocate storage space of the port yard to import and export containers. We present a mathematical formulation of the problem in which the aim is to control operation times of yard cranes based on the minimization of distance between containers of the same type. We present a preliminar experimentation with instance generated based on data provided by a Container terminal.

KEYWORDS . Yard Management, Port operations, Storage space allocation.

Main Area: Logistics & Transport

1. Introduction

The globalization of trade has increased the significance of international logistics issues, and it calls for integrated supply chains that can efficiently distribute products and services to the global markets, demanding more agility and value added services. A key element on the whole port supply chain performance is the port terminal efficiency, with an active role as intermodal interfaces (Rodrigue & Notteboom, 2009). Efficient cargo handling has become crucial in order to port terminals to compete and reduce global transportation costs.

At the port terminal, import containers are unloaded from ships and also should be temporarily stored at the yard of the terminal until they are dispatched on external trucks. The yard of the terminal also stores the export containers that are received from external trucks or rail, previous to the arrival of the ship in which they should be loaded and exported. Import and export container operations are different. Export containers are usually transported to the terminal by carriers during a time window prior to the ship arrival. In some particular cases, containers may be received at any time. Arrival of export containers is usually random, unless the terminal operates under an appointment system. Import containers on the other hand, arrive at predicable times based on the stowage plan, but may be delivered either randomly or defined by the terminal if it operates under an appointment system. The arrangement of containers within the yard clearly influences the operational continuity of the quay cranes, and then, the operational efficiency of the port terminal. In this paper, we consider the problem of assignining storage space to import and export containers at the yard, so as the productivity of the quay cranes may be enhanced.

Several authors have addressed related problems to assign storage space to containers at a yard. For instance, Kozan and Preston (1999) determined optimal storage strategies and container handling schedules of yard cranes. Kim and Kim (1999) addressed the problem of allocating yard space for import containers in order to minimize re-handles, and Kim et al. (2000) determined the storage location of export containers at the yard, developing a dynamic programming model, with the aim of minimizing the relocation movements. Kim and Park (2003) discuss the allocation of storage space for outbound containers, providing a heuristic approach to solve the problem.

Zhang et al. (2003) formulated the storage space allocation problem (SSAP), which is the problem that we are considering in this work, with some variations. The authors solve the model as a two stage problem in which they first determine the number of containers to place at each block and then defining the exact location of the containers of each ship, while minimizing the total distance traveled. Bazzazi et al. (2009) extended previous model in order to consider different types of containers, but considering only inbound containers unloaded from the vessels, and they proposed a genetic algorithm to solve the problem. In our research we consider both inbound and outbound containers that arrive at the terminal, and we also consider different types of containers, which are segregated according to common characteristics, as port destination, corresponding ship, type of container (refer, dry, etc), among other factors. Our model also differs in that we consider are aiming to improve productivity of the quay cranes by assigning storage space as close as possible to containers of the same segregation in order to avoid unnecesary moves of the yard equipment within the yard and enhancing in this way the continuous flow of containers to the quay cranes.

The remainder of the manuscript is organized as follows. Section 2 presents the problem description. Section 3 presents the mathematical formulation. Section 4 presents the results of the numerical application. Conclusions and managerial insights as well as recommendations for future research are given in section 5.

2. Problem Description.

We consider the problem of assigning storage space to import and export contianers at the yard of a Terminal, which is refereed as the yard allocation problem. This problem consists of assigning block spaces at the yard to containers arriving to the terminal (import and export), with the aim of obtaining a better space utilization of the yard, minimizing vessels handling time and maximizing the throughput of the terminal (productivity).

The yard is organized into blocks, which are divided into BAys, ROws and TIers (BAROTI system). Bays give the position of the containers relative to the cross section of the yard. Rows give the position of the containers relative to the vertical section of the corresponding bay and tiers gives the position related to the horizontal section of the bay. Storage space is defined as bays of the blocks assigned to containers, and the exact location of each container is not defined (which is addressed in the container stacking problem, commonly by heuristic rules).

Export and import containers are usually segregated according to common characteristics. The segregation of containers is defined according to the policies defined by the Container Terminal. In this article we consider the particular case of a Chilean Terminal, in which containers are segregated according to the following factors:

- Type of container: dry, reefer or IMO (dangerous cargo).
- Length (20 or 40 feet) and type of container: high cubed, general cargo, flat rack, tank, open top, etc.
- State: full or empty container.
- Weight: low, medium, high.
- Import/Export container.
- Service (ship) in which the container will be loaded.
- Port of destiny.

Particularly, the case that we consider segregate export containers with more detail, because containers have to be loaded according to the stowage plan and equilibrium of the ship should be considered. For the case of the import contianers, given that most of the containers are dispatched directly to external trucks within the following 48 hours in which they are unloaded from the ship, according to the sequence of the stowage plan, the main characteristic considered to segregate them are the type and lenght of the container, as well as the ship.

3. Mathematical Formulation.

In this section we present the mathematical formulation proposed. The following parameters are defined:

$S = \{1 \ldots I\}$: Set of containers groups or segregation. Each segregation groups containers with the same characteristics, as those described in section 2.

B : Set of blocks at the container yard.

T : Set of the discrete time periods (planning horizon).

$CR \subseteq S$: Subset of containers of type reefer.

$CI \subseteq S$: Subset of containers of type IMO (dangerous cargo).

$C40 \subseteq S$: Subset of containers of 40 feet length.

$Exp \subseteq S$: Subset of containers of export type.

$Imp \subseteq S$: Subset of containers of import type.

$BR \subseteq B$: Subset of bays habilitated for reefer containers.

$BI \subseteq B$: Subset of bays designated to store IMO containers.

$CapB_j$: Capacity of each bay of block *j* to store containers.

$CapIMO_j$: Capacity to store IMO containers of each bay of block *j*. For this, capacity is reduced for the security restrictions of the ISPS code (if IMO containers are stored, because those blocks can be used for IMO and general cargo).

$CantB_j$ *:* Number of bays contained in block *j*.

O_i^t : Number of containers of type *i* arriving the terminal during period *t* (either from external trucks or from a ship).

D_i^t : Number of containers of type *i* leaving the terminal during period *t* (either loaded to a ship or dispatched to external trucks).

r_t : Number of hours of period *t*.

K : represents the capacity in terms of distance traveled by the yard trucks in the terminal port per hour, which is defined as a function of the average speed of the trucks times the number of available trucks at the terminal per hour.

The following decision variables are defined:

x_{ij}^t : Number of containers of type *i* stored at block *j* during the period *t*.

NB_{ij}^t : Number of bays of block *j* assigned to containers type *i* during the period *t*.

FS_{ij}^t : Number of export/import containers of type *i* loaded to a ship from block *j* in period *t* or dispatched to external trucks from block *j* in period *t* (containers that get out from yard).

FE_{ij}^t : Number of export/import containers of type *i* received from external trucks and placed into block *j* in period *t*, or unloaded from a ship and placed at block *j* in period *t* (containers that get into the yard).

$$ye_{ij}^t = \begin{cases} 1 \text{ if containers of type } i \text{ are assigned to block } j \text{ during period } t \\ 0 \text{ otherwise} \end{cases}$$

$$u_{ijl}^t = \begin{cases} 1 & \text{whether if containers of type } i \text{ are assigned to block } j \text{ and block } l \text{ during period } t \\ & \text{or if containers of type } i \text{ are assigned to block } l \text{ in period } t\text{-1 and also containers} \\ & \text{of type } i \text{ are assigned to block } j \text{ in period } t \\ 0 & \text{otherwise} \end{cases}$$

Accordingly, the mathematical formulation is as follows:

$$\text{Min} \left\{ \sum_{t \in T} \sum_{i \in S} \sum_{j \in B} \sum_{l \in B} u_{ijl}^{t} \cdot d_{jl} \right\} \qquad (1)$$

Subject to:

$$x_{ij}^{t} \leq CapB_j \cdot NB_{ij}^{t} \qquad \forall i \in (S - CI),\ j \in B, t \in T \qquad (2)$$

$$x_{ij}^{t} \leq CapBIMO_j \cdot NB_{ij}^{t} \quad \forall i \in CI,\ j \in B, t \in T \qquad (3)$$

$$\sum_{i \in S - i \in C40} NB_{ij}^{t} + \sum_{i \in C40} 2 \cdot NB_{ij}^{t} \leq CantB_j \quad \forall j \in B, t \in T \qquad (4)$$

$$x_{ij}^{t} + FS_{ij}^{t} = x_{ij}^{t-1} + FE_{ij}^{t} \quad \forall i \in S,\ j \in B, t \in T \qquad (5)$$

$$\sum_{j} FS_{ij}^{t} = D_i^{t} \qquad \forall i \in S, t \in T \qquad (6)$$

$$\sum_{j} FE_{ij}^{t} = O_i^{t} \qquad \forall i \in S, t \in T \qquad (7)$$

$$\sum_{i \in CR} NB_{ij}^{t} = 0 \qquad \forall j \in (B - BR), t \qquad (8)$$

$$\sum_{i \in CI} NB_{ij}^{t} = 0 \qquad \forall j \in (B - BI), t \qquad (9)$$

$$FE_{ij}^{t} \leq ye_{ij}^{t} * (CapB_j * CantB_j) \qquad \forall i, j, t \qquad (10)$$

$$u_{ijl}^{t} \geq ye_{ij}^{t} + ye_{il}^{t-1} - 1 \qquad \forall i, j, l, t \qquad (11)$$

$$u_{ijl}^{t} \geq ye_{ij}^{t} + ye_{il}^{t} - 1 \qquad \forall i, j, l, t \qquad (12)$$

$$\frac{\sum_{j \in B} \left(\sum_{i \in EXPO} \left(d_{ij} \cdot FS_{ij}^{t} \right) + \sum_{i \in IMPO} \left(d_{ij} \cdot FE_{ij}^{t} \right) \right)}{r_t} \leq K \qquad \forall t \qquad (13)$$

$$x_{ij}^{t} \geq 0,\ NB_{ij}^{t} \geq 0, \text{integer},\ ye_{ij}^{t} \in \{0,1\};\ u_{ijl}^{t} \in \{0,1\}; \qquad \forall i, l \in S,\ j \in B, t \in T \qquad (14)$$

Equation (1) minimizes the sum of distances among locations within the yard (blocks) assigned to containers of the same segregation that enter to the yard at the same period, or at two consecutive periods. Constraints (2) guarantee that the number of containers of type *i* (excluding IMO containers) allocated into a block *j* should not exceed the capacity associated to the number of bays assigned to that type of container (assigned number bays times the capacity of the bays), and constraints (3) guarantee the same but for the IMO containers. Constraints (4) guarantee that all bays of the block *j* assigned to storage containers at period *t* observe the number of available bays of the block. Here we consider that bays assigned to 40' containers actually require two bays, while 20' containers require only one.

Equation (5) states the balance flow constraints for each bay of a block at the yard: the number of containers of type *i* stored at a bay in period *t*, should be equal to the containers previously stored in period *t*-1 plus the containers that are assigned to that location in period *t*, minus the containers that were retrieved and dispatched to external trucks, or loaded to a ship at period *t*. Constraints (6) states the balance flow constraints for incoming containers (import and export): the number of containers that enter to the yard should be equal to the number of containers of type *i* assigned to all blocks of the yard, for each period *t*, either from external trucks or from a ship. Constraints (7) states the balance flow constraints for outgoing containers (import and export): the number of containers that depart from the yard should be equal to the number of containers of type *i* leaving all blocks of the yard, for each period *t*, either loaded into a ship or dispatched on external trucks.

Constraints (8) establish that at any period, reefer containers cannot be assigned into blocks which are not able to store this type of containers and constraints (9) guarantee the same for the IMO containers. Constraints (10) allow to compute variables ye_{ij}^{t} (according to its definition) and also establish capacity constraints for the number of containers placed in the yard (defined by variables FE_{ij}^{t}). Constraints (11) and (12) allow to compute variables u_{ijl}^{t} according to its definition. Constraints (13) state the maximum distance traveled per hour by the internal trucks during loading and unloading operations. Constraints (14) are the no-negativity, integer and binary constraints.

4. Numerical Results.

- **Computational Implementation**

The proposed model was solved based on a rolling horizon scheme which is a current practice of the terminal. For these matters, we consider 72 hours (3 days) with 12 non-homogeneous periods of time, with 2-2-4-4-4-8-8-8-8-8-8-8 hours each period so that less detail and more aggregated data are used for the last periods. Non-homogeneous periods are used given the variability on the operations and uncertainty on data, and hence, information is more precise on the first hours (shifts).

The rolling horizon scheme was implemented in Java and we used CPLEX 9.0 to solve the model instances. Once the first instance of the model is solved, the solution found is considered as input for the second instance within the rolling horizon scheme. Particularly, initial inventory within the yard is updated based on decisions involved in the first period of the first optimal solution. Additionally, information of arrivals of ships and external trucks is updated providing new demand parameters (O_i^t and D_i^t).

- **Instance generation**

A set of instances based on data provided by a Container Terminal was generated. The instances were defined based on a number of container segregations, input and output flows of containers to and from the yard, the total number of blocks of the yard and their related capacity. First, we classify the containers according to segregations as it was mentioned in section 2.

We generated an instance of 38 segregations of containers, based on data provided by the terminal. The yard terminal consists of 30 blocks, and an initial inventory of containers at the yard is considered, that correspond to those containers already at the port at the beginning of the planning horizon. Manhattan metric was used in order to estimate distance among the different blocks of containers and with respect to the quay, using a satellite map of the terminal, based on the coordinates of the center of each block. A static capacity of each bay within each block was determined, assuming a maximum height of the block (number of tiers) as 5. For IMO blocks, capacity was reduced by 80% when IMO containers are stacked on it, due to restrictions associated to dangerous cargo (mainly that containers cannot be stacked over an IMO container). When standard containers are stacked on IMO blocks, capacity is not reduced.

Capacity of the terminal related to internal trucks (meters per hour) is estimated as a function of the average round trip along the yard that trucks can perform. This capacity assumes that each truck can perform a number of round trips per hour, with an average distance traveled according to the layout of the terminal. The number of internal trucks is determined considering the total number of chassis that owns the terminal or is able to lease. Export container flows to enter the yard from the gate are determined based on a real sample of arrivals during a month of operation at the port terminal. The specific time of arrival for each container was determined based on a historical empirical distribution of data. For this set of segregations, the flows of containers to be loaded into ships were determined based on an average number of containers loaded per hour by the quay cranes, using as reference a random generated stowage plan, with the considerations of the Container Terminal: heavier containers should be loaded at the bottom of the hold of the ship, and in general containers of the same segregation are loaded consecutively. We also estimate the capacity of the yard cranes in order to move containers from and to the yard.

In order to generate a set of instances, we consider the base instance and vary the initial inventory and as well as the flows of containers (input and output) to and from the yard. We consider five levels of initial inventory (I) and also five levels of container flows (F). Hence an instance is refer as I1F1 which represents the initial inventory level 1 and flow of container level 1. In total we generated 25 instances.

- **Preliminar Results**

In this section we present the results of the preliminary experimentation that we performed. We solved the instances using CPLEX 9.0, including the alternatives for cuts that CPLEX has: Gomory cuts and Mixed Integer Rounding Cuts for the alternatives of including aggressive, moderate and automatic cuts options. We realized that the best alternative was to used Mixed Integer Rounding Cuts moderately and the automatic option. Table 1 presents the results found with the corresponding gap and time for both alternatives. As we can observe, there were several instances in which CPLEX could find the optimal solution (gap is zero), but there were others in which it was out of memory. We can also observe that MIP Cuts lead sometimes to better results in terms of the gap but required in general, more time.

Table Nº1. Preliminary Results.

Instance	Automatic		MIP Cuts moderately		Instance	Automatic		MIP Cuts moderately	
	Gap	Time	Gap	Time		Gap	Time	Gap	Time
I1F1	6.64%	587.98	1.82%	1089.07	I3F4	0.00%	372.39	1.82%	991.63
I1F2	0.00%	241.85	0.00%	462.48	I3F5	0.00%	261.57	0.00%	218.48
I1F3	0.00%	984.45	0.00%	361.47	I4F1	0.00%	738.24	0.00%	363.29
I1F4	0.00%	168.83	0.00%	402.76	I4F2	0.00%	496.78	0.00%	316.26
I1F5	0.00%	826.21	0.00%	1127.74	I4F3	0.00%	313.39	0.22%	7218.97
I2F1	3.33%	743.48	5.63%	887.28	I4F4	0.00%	769.14	0.00%	2085.36
I2F2	0.00%	1127.79	0.00%	999.26	I4F5	4.41%	724.47	0.00%	357.68
I2F3	0.46%	2382.88	0.00%	283.44	I5F1	0.00%	2533.43	0.00%	178.99
I2F4	11.27%	604.93	0.00%	356.49	I5F2	0.60%	1384.39	1.12%	792.45

I2F5	0.00%	358.41	6.52%	483.47	I5F3	0.00%	387.49	0.00%	598.59
I3F1	0.00%	778.58	0.00%	607.13	I5F4	1.59%	616.31	0.00%	351.28
I3F2	4.38%	724.93	0.00%	367.32	I5F5	0.00%	6811.07	2.32%	821.93
I3F3	0.17%	7232.03	0.00%	319.95					

With the implementation of the rolling horizon scheme, we observed that as long as the procedure is implemented, distance between containers of the same segregation and the usage of internal trucks (W) in terms of the distance traveled along the yard, tends to decrease, which means that as long as we implement the solution, results tend to improve and better usage of the internal trucks is obtained as it is shown in figure 1.

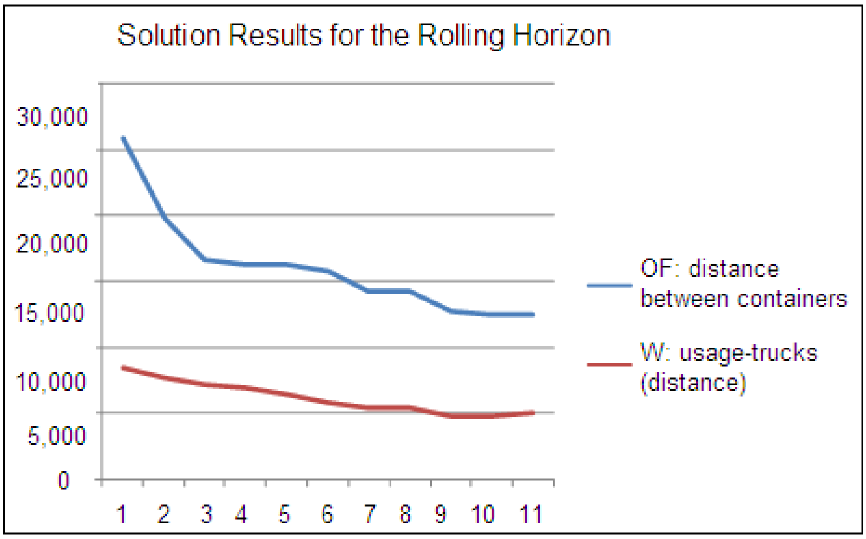

Figure Nº1. Rolling Horizon Implementation Results.

5. Conclusions and Further Research.

We have proposed mathematical models to support the planning decisions at the yard of a terminal: an optimization model in which the aim is to minimize distance between the movements from/to the yard and the quay. The objective is to guarantee a continuous flow of containers to and from the quay cranes to increase their productivity and hence, reduce the permanence time of the ships at the terminal. The models proposed aim to support the decisions of the yard planner of the terminal, and provide alternatives for the location of containers at the terminal. We include a preliminary experimentation using some alternatives of cuts with CPLEX 9.0.

We are currently working on a biobjective model of the problem, considering the parameter K as a second objective to optimize. We are also working on the design of a second level that may be integrated to the model proposed in which the exact location of containers should be defined, based on the minimization of potential rehandles of containers, mainly associated to export containers, due to the assignment of space to import containers is already solved because they are delivered to the external trucks following the sequence in which they were unloaded to the ship. We are also designing a solution methodology that may be implemented either based on mathematical programming approaches or heuristic approaches. As further research we propose to explore some other modeling structures, based on agents and fuzzy logic systems.

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