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Impact of Yard Organisation on the Master Bay Planning Problem

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In this paper we analyse the impact of the yard organisation on container stowing operations. We deal with the Master Bay Plan problem (MBPP), that consists in stowing containers of different types into available locations on a containership; the aim is to minimise the berthing time in such a way that structural and operational constraints, related to both the containers and the ship, are satisfied. In particular, we study how the total stowage time changes due to possible reloading operations, when different picking sequences are considered. We use a binary linear programming model for MBPP that has been recently proposed in literature considering two main scenarios. First, we assume to have all containers ready to be loaded on board in the quay independently of their stack position in the yard. In this case, we solve MBPP as it is having as objective function just the minimisation of the loading time. Then, we take into account the yard constraints following the directions of the planning office, which makes the bay plans according to the stocking area requirements and the picking list for the containers to be loaded. In the third case, we present a procedure that enables us to consider different lot arrivals and opportunely relax some constraints. Moreover, we assume that the containers are stored in the yard into different stacks on the basis of their size, destination and weight, depending on the storage strategy chosen by the yard managers. We evaluate alternative yard storage strategies with real size stowage plans of a containership located at a maritime terminal in Genoa. The results show that, when we look for the berthing time minimisation, it is quite important to think about the optimisation of the flow of containers from the yard to the quay.
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INTRODUCTION AND LITERATURE REVIEW

A maritime terminal is a basic node in the intermodal goods transportation network; for this reason, the company that manages the terminal has to optimise the flow of containers that passes through it and all related handling operations in order to achieve the maximum overall productivity, expressed in terms of some economic indicators, such as hourly container handling operations or berthing time.

The flow of containers can be considered as split into import and export ones. The import flow starts with the ship unloadings and continues with either transhipments or storage of containers in the yard for their successive departure by trucks or trains. The export flow concerns the loading of containers on board of the ships after having received and stored them in the yard.

In the yard, different handling operations are performed, depending on the above flows. In particular, export containers are stacked when they are unloaded from trucks or trains. Quay cranes unload import containers from the docked ships, while straddle carriers move the containers in the yard for their storage. An opposite process involves the picking of containers from the yard for their departure; in fact, shuttle trucks receive containers from the yard cranes and move them either to the proper quay for their loading on board ships or to the trains or trucks for their departure. Considering that most of the terminal operations originate from or are destined to the yard, it is evident that the yard plays a central role and impacts the productivity of the terminal.

Storing containers in the yard and scheduling the containerships' loading or unloading operations are correlated problems in maritime terminals. Container handling operations consist of different inter-dependent activities and for this reason, as it has been already mentioned, it is important to investigate the relationship between these terminal sub-system components and the management of each part of the *terminal system* (Atkins, 1991; Chen, 1999).

Many researchers tried to address these problems, but only some aspects of the handling operations have been approached, without considering the terminal as a complex system consisting of several integrated and correlated components. A more general view of the problem can be found in Gambardella *et al* (1998) and Hayuth *et al* (1994), where the authors present simulation models as support systems for testing the goodness of the management policies related to the transportation chains in intermodal container terminals. An interesting recent review of similar problems is given in Vis and de Koster (2003), where the authors give a classification of the decision problems that arise at container terminals and the related solution approaches.

In this paper, we deal with the Master Bay Plan problem (MBPP), that consists of determining how to stow a set C of m containers of different types into a set, say L, of n available locations on a containership with respect to some structural and operational constraints (Ambrosino and Sciomachen, 1998; Ambrosino *et al*, 2002).

We assume that the handling operations are performed by yard cranes that could work in parallel if different portions of the ship, in terms of bays, are considered. Moreover, we assume that the ship starts its journey in the port for which we are studying the problem and successively visits a given number of other ports where only unloading operations are allowed.

MBPP is one of the problems that has to be solved daily by an operator that manages a container terminal. The operator has to specify the stowage of containers together with their picking sequence in the yard.

The stowage of a containership involves multiple constraints. It is necessary to preserve goods during navigation, optimise the usage of the available space, prevent damages to the containership, its crew and equipment, and to guarantee the ship stability. These are key factors that have to be taken into account in simulating loading operations (Imai *et al*, 2002). Moreover, there is the need for getting the best economic results from the handling operations, that is to minimise the berthing time of the containership at the terminal (Drewry Shipping Consultants, 1998; Peters, 2001; Silberholz *et al*, 1991; Thomas, 1989).

We analyse the impact of the yard organisation on the stowage of containers in terms of unfruitful container movements. Our aim is to minimise unproductiveness together with the berthing time of containerships at the terminal due to loading operations.

When dealing with MBPP, the terminal should operate in order to reach the highest possible system productivity, while satisfying all safety constraints during both loading and sailing. In fact, due to the high cost related to the total time spent by a ship in a terminal, all maritime companies refer to productivity indicators for choosing the routes of their ships and the sequence of harbours to visit.

Decision support systems, heuristics, genetic algorithms, analytical, and stochastic models have been suggested as very interesting approaches for solving problems that unfortunately have only some commonalties with MBPP and are mainly devoted to the loading problem (Avriel and Penn, 1993; Bischoff and Ratcliff, 1995; Bortfeldt and Gehring, 2001; Chen *et al*, 1995; Davies and Bischoff, 1999; Wilson and Roach, 2000).

The main constraints of MBPP have been extensively discussed in Ambrosino and Sciomachen (1998), while in Ambrosino *et al* (2002) a 0–1 Linear Programming Model for MBPP is proposed. In the present work, the above Linear Programming model is used for loading containers on board on the basis of their arrival's sequence, thus evaluating the best yard organisation policy.

Interesting problems related to the organisation of the stacking area have been considered in Kim *et al* (1998, 2000), Preston and Kozan (2001), and Taleb-Ibrahimi *et al* (1993).

In the next section of the paper, we describe the present problem and give our referring 0–1 Linear Programming model. Successively, the main management policies related to the yard are discussed. Then, our method for analysing such yard management policies is given together with a procedure for considering different lot arrivals of containers. In the last section, we give some computational results aimed at evaluating the performance of different strategies for the picking operations. Finally, some conclusions, comments, and outlines for future work are presented.

MASTER BAY PLAN PROBLEM

MBPP is really complicated due to its combinatorial nature; moreover, when solving it we have to consider:

- the structure of the containership;
- the characteristics of the containers waiting for loading (in terms of both quantity and type);
- the destination of the containers and the ships itinerary in order to avoid expensive shifting during the loading and unloading operations;
- the weight distribution in the different parts of the ship (ie hold or upper deck) in accordance with the structure of the ship (tonnage, draft, trim, stability, equilibrium);
- the possible presence of dangerous goods to load; and
- the position of the containers in the yard in order to be able to consider the whole terminal system for a global productivity maximisation.

Note that information related to the structure of the ship is reported in the profile of the ship, while information related to containers to be loaded and their characteristics is in the booking, that is the document sent by the maritime agencies to the terminal. Other useful information is provided by the ship coordinator; in particular, he provides a complete guide to the stowage containing both general instructions defining, for example, the available locations for containers having different destinations, and specific constraints for the location of reefers, hazardous, and oversized containers. Finally, the container position in the yard useful for defining the picking list arises from sophisticated information systems of the terminal.

We consider here the standard sizes of a container, namely 20 and 40 feet in length with a cross-section of 8×8 feet. Moreover, in what follows we will refer to the container system expressed in terms of TEUs (twenty-foot Equivalent Units); that is a TEU is 8 feet wide, 8 feet high and 20 feet long, and a 40 feet container is equivalent to two TEUs.

Before presenting our referring 0/1 Linear Programming model for the problem described above, let us note that each location $l \in L$ is identified by indices i,j,k, related to its bay, row, and tier address, respectively; in particular, the bay index gives its position related to the cross-section of the ship (counted from bow to stern and split into even and odd bays, and anterior and posterior bays), the row index gives its position related to the vertical section of the corresponding bay (counted from the centre to outside and split into right and left side row), and the tier index gives its position related to the horizontal section of the corresponding bay (counted from the bottom to the top).

Let us introduce the following notation:

Q_{max}: maximum weight capacity of the ship;

$Q1$: maximum weight tolerance of each transversal section;

$Q2$: maximum weight tolerance of each horizontal section;

W_c: weight of container c;

D_c: destination of container c; and

t_{lc}: time required for stowing container c in location l.

We assume as decision variable the following binary variable x_{lc} such that:

$$x_{lc} = \begin{cases} 1 & \text{if a container } c \text{ is stowed in location } l \\ 0 & \text{otherwise} \end{cases}$$

The model in a mathematical programming language formalism (MPL Modeling System, 2000) is the following:

Model MBPP

$$\text{MIN T} = \text{Total} - \text{Stowage time} := \sum_{l} \sum_{c} t_{lc} x_{lc} \tag{1}$$

Subject to

Selection constraint

$$\sum_{l} \sum_{c} x_{lc} = m \tag{2}$$

Assignment constraint [*for every container c*]

$$\sum_{l} x_{lc} \leq 1 \tag{3}$$

Assignment constraint [for every location l]

$$\sum_c x_{lc} \leq 1 \tag{4}$$

Capacity constraint

$$\sum_l \sum_c W_c x_{lc} < Q_{max} \tag{5}$$

Size constraints [for every bay i = even_bay, every row j, every tier k]

$$\sum_c x_{i+1jkc} + \sum_c x_{ijkc} \leq 1 \tag{6}$$

$$\sum_c x_{i-1jkc} + \sum_c x_{ijkc} \leq 1 \tag{7}$$

$$\sum_c x_{i+1jk+1c} + \sum_c x_{ijkc} \leq 1 \tag{8}$$

$$\sum_c x_{i-1jk+1c} + \sum_c x_{ijkc} \leq 1 \tag{9}$$

Weight constraint 1 [for every bay i = odd_bay, every row j, every tier k]

$$\sum_{c=20\_\mathrm{feet}} W_c x_{ijkc} + \sum_{c=20\_\mathrm{feet}} W_c x_{ijk+1c} + \sum_{c=20\_\mathrm{feet}} W_c x_{ijk-1c} \leq \mathrm{MF} \tag{10}$$

Weight constraint 2 [for every bay i = even_bay, every row j, every tier k]

$$\sum_{c=40\_\mathrm{feet}} W_c x_{ijkc} + \sum_{c=40\_\mathrm{feet}} W_c x_{ijk+1c} + \sum_{c=40\_\mathrm{feet}} W_c x_{ijk-1c} \leq \mathrm{MF} \tag{11}$$

Weight constraint 3 [for every bay i, every row j, every tier k]

$$\sum_c W_c x_{ijkc} \geq \sum_c W_c x_{ijk+1c} \tag{12}$$

Cross equilibrium constraint:

$$-\mathrm{Q1} < \sum_{i,j=\mathrm{left\_side},k} \sum_c W_c x_{ijkc} - \sum_{i,j=\mathrm{right\_side},k} \sum_c W_c x_{ijkc} < \mathrm{Q1} \tag{13}$$

Horizontal equilibrium constraint:

$$-\mathrm{Q2} < \sum_{i=\mathrm{anterior\_bay},j,k} \sum_{c} W_c x_{ijkc} - \sum_{i=\mathrm{posterior\_bay},j,k} \sum_{c} W_c x_{ijkc} < \mathrm{Q2} \qquad (14)$$

Destination constraint [for every bay i, every row j, every tier k]

$$\sum_{c} D_c x_{ijkc} \geq \sum_{c} D_c x_{ijk+1c} \qquad (15)$$

$$\text{Binary variable X} \qquad (16)$$

Objective function 1 minimises the total stowage time given by the sum of the times required for loading all containers in their assigned locations. Constraint 2 establishes that all containers (m) have to be loaded.

The assignment constraints 3 and 4 assign a container to only one location and store in each location at most one container. The capacity constraint 5 forces the total weight of the containers to be stowed to be no greater than the maximum capacity (Q_{max}) of the ship.

The constraints related to the structure of the ship are split into size and weight constraints. In particular, 40 feet containers require two contiguous locations of 20 feet, and for the numerical cells' system chosen by the maritime company that holds the ship, they can be located only in even bays; consequently, those locations in the same row and tier corresponding to two odd bays are not anymore available for stowing 20 feet containers; then, we can set to zero the variables related to the locations in odd bays for 40 feet containers 6–7. 20 feet containers can be located both in even and odd bays but not above 40 feet containers, as it is imposed by constraints 8 and 9.

Weight constraints 10 and 11 impose that the weight of a stack of 20 or 40 feet containers cannot exceed a given amount of tons, say MT and MF, respectively; for instance, in all cases considered in this paper stacks of three 20 and 40 feet containers are considered with MT = 45 and MF = 66 tons. Constraint 12 imposes that the weight of a container located in a tier cannot be greater than the weight of a container located on the next tier in the same row and bay.

Safety constraints are related to a balanced distribution of weights on the ship. In particular, after the loading operations, we have to verify different kinds of equilibrium: cross equilibrium, that is the weight on the right side of the ship must be equal, within a given tolerance ($Q1$), to the weight on the left side of the ship 13; horizontal equilibrium, that is the weight on the stern must be equal, within a given tolerance ($Q2$), to the weight on the bow 14.

Destination constraints 15 represent a general rule that suggests to load first those containers having as destination the final stop of the ship and last those containers that have to be unloaded first.

Finally, 16 is the definition of our binary decision variables.

MANAGEMENT POLICIES FOR THE YARD

The system for storage of containers in the yard is a very important link in the containers flow; consequently, from ineffective control and management of the storage operations may arise difficulties in transferring containers to sea and land interfaces.

With reference to the yard operations, it can be distinguished between export and import storage management. In particular, the *import storage management* involves the planning for receiving import containers from the quayside, housekeeping operations for the storage, stacking of the import containers, and finally delivery operations. The *export storage management* involves the planning for receiving export containers and the planning for their storage, stacking operations in accordance to their status (loading ship, destination ports, weight categories, and so on), and finally the planning of the export sequence of the containers together with their transfer to the quay for their loading on board. An accurate description of management in terminal operations is reported in Chen (1999).

Efficiency in export storage operations enables the terminal to achieve efficiency in loading operations, while an efficient stack of the unloaded containers permits an efficient delivery of them from the import yard to outside.

In what follows, we examine in detail the operations involved in the export storage system and, successively, we analyse their impact on loading operations.

Two main storage strategies are generally used in order to reach efficiency and effectiveness in terminal operations. These strategies are the following:

- *The pre-marshalling (PM) strategy*: export containers are assigned to a temporary storage area in accordance to their loading ship, or more generally their shipping line, as soon as they arrive at the terminal. When the shipping line sends the list of the containers to load on the containership, the yard manager defines, for the queuing containers, a storage plan in the PM area, usually assigned near the containership; then, containers are moved to this area, for instance 12 h before the ship arrival, waiting for loading. This strategy is mainly used for saving space in the yard, since according to it, and considering only few terms of the containers

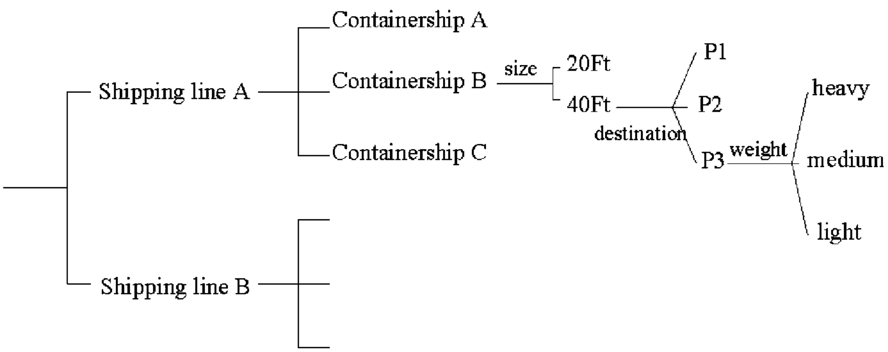

Figure 1: An example of the sequential information for containership bay plans

status, it is possible to store containers in higher stacks. The main drawback of this strategy is that a large number of moves might be required in the temporary area for preparing the PM one.

- *The sort and store strategy*: the storage of the export containers is planned on the basis of all information included in their status, that is shipping line, loading containership, destination port, size, and weight. A rolling plan is defined in order to maintain the storage condition in the yard; but some moves might be necessary due to mixed storage conditions sometimes occurring due to shortage of storage space or a change in some containers status. With respect to the previous strategy, this one permits fewer containers shifting before the arrival of the containership, but requires a more complex storage management system for taking into proper account all information of the status.

An example of the sequential information taken into account during the storage planning is reported in Figure 1.

In any case, the effectiveness of yard operations is related to the possibility of regulating the arrival of the export containers, while for loading operations the storage capacity for each ship and the number of yard cranes devoted to it are crucial points.

EVALUATION METHOD OF TWO MAIN YARD POLICIES ON THE CONTAINER'S LOADING OPERATIONS

First, we analyse the problem in order to minimise the berthing time of the containership in the terminal, without considering those constraints that are related to the picking operations in the yard, that is employing a picking list for the best stowage of the containers according to what has been described in the previous section. In this case, we assume that the terminal applies the *PM strategy*, preparing the PM area in accordance with the list of containers as it is suggested by the optimal solution of the MBPP. Hence, we do not include now the cost, or time, related to the need of moving containers in the temporary area; therefore, we solve MBPP by using the three-phase heuristic algorithm proposed in Ambrosino *et al* (2002), having as objective function the minimisation of the total stowage time T as in 1, that is just the sum of the loading times given as input data required for handling the containers from the quay to their location on the ship, including both the time for lifting a container off the quay and the time for putting it into the assigned location.

As a second analysis, we evaluate the influence of the organisation of the yard and of picking operations on the berthing time of the ship in the terminal with the hypothesis that the terminal yard management applies a *sort and store strategy* (*SS*). In particular, we consider the case of containers being loaded on a ship according to a given sequence, and look for stowage plans for minimising the number of unproductive moves, or *shifts*, that is the number of containers that is necessary to move for unloading/loading other containers previously stowed; in fact, shifts strongly affect both time and cost of the handling operations. These unproductive moves or re-stowage operations are required for satisfying the structural and operational constraints of the ship.

In order to implement the sort and store strategy in MBPP, we consider arrival sequences of containers from the yard as constraints and minimise a new objective function value, denoted by τ, expressing the stowage time T, as in 1, plus a penalty P that includes the possible re-stowage time due to the need of moving an already stowed container for being able to load on board another one without violating any stowing constraint. More formally, τ is given by

$$\tau = T + P = \sum_{l} \sum_{c} t_{lc} x_{lc} + \sum_{l} \sum_{c} s_{lc} y_{lc} \qquad (17)$$

where T is exactly given by 1 and s_{lc} is the shifting time that counts for the time required for moving and putting again on board an already stowed container; y_{lc} is a binary variable such that $y_{lc} = 1$ if putting container c into location l requires to move an already stowed container, and $y_{lc} = 0$ otherwise, $\forall c \in C$, $\forall l \in L$.

Note that the sequence of containers reaching the quay is strongly affected by the storage policy followed by the yard. So, we analyse the sort and store strategy dealing with different sequences of containers that reflect different stacking hypotheses in the yard. In particular, we consider two cases, namely S_1

and S_2, where the storage of export containers is planned according to the following sequences of information status (Figure 1):

S_1: shipping line–loading vessel–weight;

S_2: shipping line–loading vessel–destination–weight.

Let us think of lot arrivals at the quay. If a container belongs to the first lot of containers reaching the quay, objective function 1 has to be minimised. Otherwise, objective function 17 holds since the already stowed containers have to be considered; in this last case, the so-called penalty variable y_{lc} plays the role of minimising the unproductive moves due to re-stowage operations. Putting as coefficient of y_{lc} the loading time s_{lc} as in 1, we get the effective total stowage time, which takes into account the possible empty moves.

In practice, when either sort and store strategy S_1 or S_2 is used, we solve model 1–16 by splitting C into n subsets, where n is the number of lot arrivals; that is we consider subsets $C_1, C_2, \ldots, C_n$, such that $C = \cup_{i=1\ldots n} C_i$ and $C_i \cap C_{i+1} = \emptyset$, for every $i = 1, \ldots, n-1$, and proceed as follows:

1. Solve model 1–16 considering L and C_1;
2. Let X_1 be the optimal solution obtained at step 1, that is $X_1 \subset X$ is the set of variables fixed to 1 (while variables belonging to subset $X \backslash X_1$ are set to 0), and L_{X_1} be the corresponding set of locations assigned to C_1; For ($i = 2$, $i \leq n$)
3. Solve model (2)–(16) considering L, C_i, and objective function 17 and execute the following steps: put $\Lambda = L \backslash L_{X_{i-1}}$ and $\Xi = X \backslash X_{i-1}$; add penalty variable y_{lc}, $\forall l \in \Lambda$, $\forall c \in C_i$; relax weight or destination constraints 12 or 15; add the constraints for defining the penalty variables;
4. If a weight or destination constraint is violated in some tier, then exchange $c \in C_i$ with $g \in C_{i-1}$; and
5. Let X_i be the optimal solution for $C_1, \ldots, C_i$, and L_{X_i} the corresponding set of locations assigned to $C_1, \ldots, C_i$.

Steps 1 and 2 are related to the solution of MBPP for the first group of containers. When the first lot of containers is stowed, we have to modify model MBPP in order to consider the set of locations assigned to C_1 that are no more available ($\Lambda = L \backslash L_{X1}$), and hence execute steps 3–5. We relax the weight and/or destination constraints 12 and/or 15 and add those for defining the penalty variables in order to add containers on board without violating the weight or destination constraints for safety and operational reasons. If a container is stowed on a lighter one (on a container that must be unloaded first), it is necessary to exchange them and hence to include for both containers the cost for unproductive moves (ie four container shifts) by fixing the corresponding penalty variable to one.

Note that possible violated constraints at step 4 could be either the weight or the destination one, depending on the strategy used, that is either S_1 or S_2.

COMPUTATIONAL RESULTS

Now, we present some preliminary results related to the solution of MBPP by model 1–16 that we use assuming the storage strategies for the yard discussed above.

For our performance evaluation, we consider a case study related to a 198 TEU containership, with 11 bays, four rows, and five tiers (three in the hold and two in the upper deck, respectively), that is a *client* of the maritime terminal in Genoa (Italy) with which we work.

We test the above rules looking for master bay plans referring to four cases, summarised in Table 1, that differ from each other in the number of containers to load, from 130 to 148, split into 20 and 40 feet, their size and weight, the number of ports to be visited, either two or three, and the number of TEUs to load on board.

As it has been already mentioned, we assume that the handling operations are performed by yard cranes, whose loading times are reported in Table 2. We can see from Table 2 that the difference of the values between two contiguous locations is of the order of 10 s and increases when we move from the quay side

Table 1: Input data of the case study instances

		Container								
		Size (ft)			Weight (tons)			Destination		
Instance	**TEUs**	**Tot**	**20**	**40**	**5–15**	**15–25**	**>25**	**P1**	**P2**	**P3**
1	170	130	90	40	56	46	28	55	75	0
2	175	130	85	45	58	45	27	62	68	0
3	185	140	95	45	60	50	30	50	40	50
4	188	148	108	40	62	53	33	50	40	48

Table 2: Loading times as function of the ship row and tier addresses

	Tier02	**Tier04**	**Tier06**	**Tier82**	**Tier84**
Row04	3′ 10″	3′	2′ 50″	2′ 40″	2′ 30″
Row02	3′	2′ 50″	2′ 40″	2′ 30″	2′ 20″
Row01	2′ 50″	2′ 40″	2′ 30″	2′ 20″	2′ 10″
Row03	2′ 40″	2′ 30″	2′ 20″	2′ 10″	2′

going to the bottom, since the locations become more difficult to be reached. In particular, loading times range from 2 min for the locations closest to the quay in the highest tiers to a maximum of 3 min and 10 s for the locations on the seaside in the lowest tiers. Note that these figures come from the terminal that has provided us the data of the containership reported in Table 1. However, any other linear function for the loading times that depends on the location where a container has to be put can be also properly used in (1) for our binary linear programming model.

Procedure Lot_MBPP, that in some sense is a first approach for an integrated view *yard-quay*, has been tested with some instances of the containership described in Table 1. As a first experiment, we have considered different arrival processes with regard to the number of containers per lot. Table 3 reports some preliminary results related to lot arrivals of 10 containers at a time of cases 1–4 given in Table 1. In particular, in Table 3 the reader can find a comparison between the stowage time (in minutes) related to *PM* and sort and store (*SS*) strategies. *Strategy* refers to the yard management policy under evaluation, that is *PM*, sort and store when storage criteria S_1 and S_2 are used for export containers, assuming that an optimal picking rule is followed as far as the yard operations are concerned (*SS-S*1) and (*SS-S*2). *Loading Time* and *Total Time* give the value (in minutes) of the objective functions 1 and 17 obtained by applying the corresponding strategy; since 17 is given by the sum of two terms, namely loading and penalty times, the contribution of the penalty time to the total one is specified in *Penalty Time (P)*. Finally, *Moves* gives the number of containers loaded per hour when the different strategies are used; this is a relevant performance index for the terminal.

If a sort and store strategy is used, when comparing the total stowage time resulting from different stacking rules in the yard, it is possible to note that the

Table 3: Comparison of the stowage time for MBPP due to different yard management strategies

Instance	Strategy	Loading time (T)	Penalty time (P)	Total time (T+P)	Moves
	PM	302.6	—	302.6	25.77
1	SS S1	303.65	42.75	346.4	22.52
	SS S2	302.9	33.95	336.85	23.15
	PM	302.8	—	302.8	25.76
2	SS S1	303.96	42.79	346.75	22.49
	SS S2	303.24	34.25	337.49	23.11
	PM	324.5	—	324.5	25.88
3	SS S1	325.22	46.85	372.07	22.57
	SS S2	324.88	36.58	361.46	23.24
	PM	432.3	—	432.3	20.54
4	SS S1	433.2	62.32	495.52	17.92
	SS S2	432.52	48.91	481.43	18.44

less careful the storage plan is the higher the re-stowage time and *vice versa*: the re-stowage time using strategy S_2 is, in every considered case, lower than that in strategy S_1. We can observe that the yard storage management affects the re-stowage time, which represents about 10% of the total loading time in the case of S_2 and 12.5% in the case of S_1.

Moreover, the higher the number of containers loaded in the ship, the higher is the re-stowage time. Finally, using strategy S_1 the re-stowage time increases with the number of ports to be visited, while using strategy S_2 there is the opposite trend.

To further compare the analysed strategies, we graphically report their impact on the total stowage time in Figure 2, while the performance of the same strategies in terms of hourly container operations is drawn in Figure 3.

From these figures it can be easily noted that in the case of berthing time minimisation, the best strategy is the PM one; however, due to the high costs and the operational constraints resulting from having all containers ready at the quay, the PM strategy is almost impractical. It is hence quite important to think about the optimisation of the flow of containers from the yard to the quay in terms of strategy $S2$.

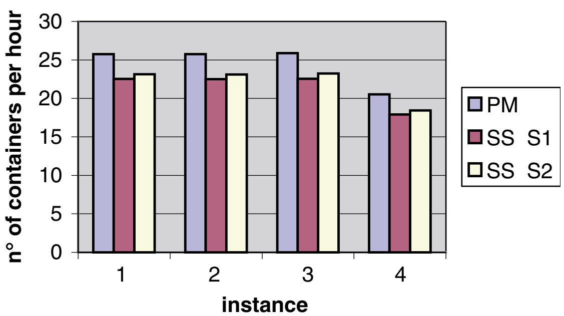

Figure 2: Impact of different storage strategies on hourly container operations

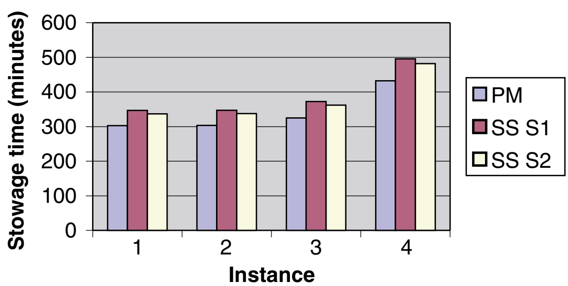

Figure 3: Impact of different storage strategies on the total stowage time

CONCLUDING REMARKS

In this paper, we have stressed the role of container terminals as basic nodes in the transportation network and the fact that major correlated problems concern storing containers in the yard and scheduling the containerships' loading and unloading operations.

Our aim is to minimise the berthing time of containerships due to loading/unloading operations; for this scope, we have briefly described the problem of stowing containers in a containership (MBPP) with respect to a set of structural and operational constraints. We have introduced a 0/1 Linear Programming model for addressing this problem.

We have solved MBPP in relation to different strategies applied by the terminal, that is the PM strategy and the sort and store one, with the aim of looking for an integrated view for both the export containers flows and the complex logistic process. The resolution approach for solving MBPP has been presented.

The approach presented here permits to evaluate the productivity of the terminal. For example, we can value it by comparing the number of containers moved per hour in the present operative scenario with those resulting by applying the proposed approach. We can identify the appropriate strategy to further improve the productivity of the loading operations (ie by adding new handling resources).

Presently, we have not included in our analysis the costs due to the yard operations. As a next step of our research, we would evaluate the *yard movement* costs.

Finally, we can conclude that if the major part of the revenue of a terminal is due to the loading/unloading operations, it is really important to manage these operations as well as possible in order to increase the profits.

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