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RE-MARSHALING EXPORT CONTAINERS IN PORT CONTAINER TERMINALS

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ABSTRACT

In order to speed up the loading operation of export containers onto a ship, the re-marshaling operation is an usual practice in port container terminals. It is assumed that the current yard map for containers is available and a desirable bay layout is provided. A methodology is proposed to convert the current bay layout into the desirable layout by moving the fewest possible number of containers and in the shortest possible travel distance. The problem is decomposed into three sub-problems such as the bay matching, the move planning, and the task sequencing. The bay matching is to match a specific current bay with a bay configuration in the target layout. In the move planning stage, the number of containers to be moved from a specific bay to another is determined. The completion time of the re-marshaling operation is minimized by sequencing the moving tasks in the final stage. A mathematical model is suggested for each sub-problem. A numerical example is provided to illustrate the solution procedure.

KEYWORDS

Re-marshaling; container port terminal; export containers; traveling salesman problem; dynamic programming.

INTRODUCTION

In this paper, it is tried to reduce the turn-around time of container ships in port container terminals. The turn-around time of each ship implies the sum of times for waiting, berthing, unloading, loading, and departing. One of important factors that effect the efficiency of the loading operation is the storage location of export containers in the marshaling yard. If containers are stacked in the same order of loading, it will speed up the loading operation [2, 3]. Since the detailed information about the order of loading is not available when containers start to arrive at the yard, the layout of containers is not ideal from the viewpoint of the load planner who sequences the loading operation. In this case, the re-marshaling operation is planned to convert the current layout into an ideal layout. The re-marshaling operation is usually performed just before a full amount of space is allocated to the corresponding container vessel.

Suppose that the ideal layout of containers for a vessel is as in Table 1. A container group in Table 1 implies a collection of containers of a same size to be loaded onto the same vessel and unloaded at the same destination port. In Table 1, target bay configurations imply that a bay should have only 23 containers of group C and another bay should have 12 containers of group A and 10 containers of group B, and so on. Note that since containers of a same group tend to be loaded successively, it is an usual practice that containers of more than two groups are not stacked in a same bay together. However, since containers arrive at random points of time and the full yard space is not allocated at the early stage of the container arrivals, the actual distribution of containers may be far from the ideal layout. The problem in this paper is how to move efficiently containers to change the current layout of containers (Table 2) into the ideal one (Table 1) which we call the target layout in this paper. The problem may be decomposed into two following sub-problems:

Table 1. An example of the target layout

Target bay-configuration number	Container group					Total
	A	B	C	D	E	
1	0	0	23	0	0	23
2	12	10	0	0	0	22
3	0	14	0	0	8	22
4	24	0	0	0	0	24
5	0	0	0	24	0	24
6	0	0	0	15	7	22
Total	36	24	23	39	15	137

Table 2. An example of the current layout

Bay number	Container group						Total
	A	B	C	D	E	others	
01	0	9	0	0	0	4	13
02	5	0	6	0	0	0	11
04	6	2	0	7	0	0	15
06	0	0	5	0	15	0	20
07	2	0	0	14	0	0	16
10	8	4	0	0	0	0	12
11	0	4	2	0	0	0	6
12	10	0	0	8	0	0	18
15	0	0	5	7	0	0	12
16	0	0	5	3	0	2	10
Total	31	19	23	39	15	6	133

(1) **Bay matching and move planning problem**: In order to convert the current layout into the target layout, we have to match each current bay with a specific bay configuration in the target layout. Once the final configuration of each bay is determined, we have to determine how many containers to be moved from a bay that has surplus containers of a group to a bay that requires additional containers of the same group.
(2) **Sequencing the moving tasks**: The moving tasks have to be sequenced in a way of minimizing the total travel time of transfer cranes.

BAY MATCHING AND MOVE PLANNING PROBLEM

The overall solution procedure is as follows:
Firstly, the bay matching problem is solved using the dynamic programming. Based on the result of the bay matching problem, the move planning is done using the transportation problem technique. Considering that two transfer cranes can not perform handling operations simultaneously within a specific distance from each other, the transportation problem may result in a solution that causes interference between transfer cranes (TC). Then, the corresponding matching subset of bays that cause the interference is appended to the list of the prohibited matching. Next, the bay matching problem is solved again with the constraint that the matching in the list of the prohibited matching should not be in the solution. The above procedure is repeated until the move planning results in a feasible solution.

Using the data in Table 1 and Table 2, the solution of the bay matching problem is obtained as (02, 10, 01, 12, 07, 04) for target bay-configuration 1-6 at the first iteration and the number of the containers to be moved is 69. Based on the results of the bay matching problem, the transportation problem for each container group is constructed. Note that two TCs can not work simultaneously at bays that are too close from each other (in a distance shorter than two bay-length in this paper). When we solve the transportation problem, a big value, M, is assigned to the entry in the cost matrix corresponding to the movement which causes the interference between two transfer cranes. Table 3 illustrates the cost parameters and the optimal solution of the move planning problem for container group B for a given solution of the bay matching problem. The c_{ij} represents the distance from bay i to j while x_{ij} represents the optimal number of containers that should be moved from bay i to j. Note that $x_{11,10}$ is positive while $c_{11,10}$= M. Thus, this solution cannot be implemented considering the physical interference between TCs. In this case, it is tried to solve the bay matching problem one more time after adding the current solution of the bay matching problem to the list of prohibited matching. Then, the solutions in the list of prohibited matching will be excluded from the further consideration. This necessity to add a constraint is the reason why the well-known Hungarian method [6] is not used in solving the bay matching problem.

Table 3. An example of infeasible movements for container group B

From	To				Total
	01		10		
	c_{ij}	x_{ij}	c_{ij}	x_{ij}	
01	0	9	9	0	9
04	3	0	6	2	2
10	9	0	0	4	4
11	10	0	M	4	4
Dummy	0	5	0	0	5
Total	14		10		24

Table 4. The final result of the move planning for container group B

From	To				Total
	10		11		
	c_{ij}	x_{ij}	c_{ij}	x_{ij}	
01	9	6	10	3	9
04	6	0	7	2	2
10	0	4	M	0	4
11	M	0	0	4	4
Dummy	0	0	0	5	5
Total	10		14		24

Using the iterative procedure for the bay matching and the move planning problem, the final solution of the example is found to be (02, 10, 11, 12, 07, 03) and the number of containers to be moved is 74. For container group B, the result of the move planning is shown in Table 4.

In Table 5, the moving tasks for all the container groups are summarized which will be used as the input data to the task sequencing problem.

Table 5. The list of moving tasks

n_i	a_i	b_i	q_i	n_i	a_i	b_i	q_i	n_i	a_i	b_i	q_i	n_i	a_i	b_i	q_i
1	02	10	4	6	01	11	3	11	16	02	5	16	16	06	3
2	02	12	1	7	04	11	2	12	04	07	7	17	06	11	8
3	04	12	6	8	06	02	5	13	12	07	3				
4	07	12	2	9	11	02	2	14	12	06	5				
5	01	10	6	10	15	02	5	15	15	06	7				

n_i : task number, a_i : source bay, b_i : destination bay, q_i : number of containers to be moved.

TASK SEQUENCING PROBLEM

In this stage, the moving tasks have to be sequenced in a way to minimize the total travel time of container handling equipment. Note that some moving tasks may not be carried out before enough spaces become available at the destination bays. This problem can be defined as a Traveling Salesman Problem with precedence constraints where the precedence relationship can not be expressed by an explicit relationship between tasks but can be expressed in the form of a condition to be satisfied [1, 4, 5]. The condition is that the space at the destination bay should be available before a moving task begins. The availability of the space for a task depends on the preceding tasks, which will be performed before the corresponding task. The solution of sequencing moving tasks is summarized in Table 6 for the example. The minimum completion time for the re-marshaling operation is 107 time units and the optimal task sequence is (12, 8, 5, 1, 6, 9, 2, 7, 14, 17, 4, 13, 15, 16,11, 10, 3).

Table 5. The summary of sequencing moving tasks for the example

Sequence number	Task Number	TC number at source	TC number at destination	u_{ij}	Completion time of task	Sequence number	Task Number	TC number at source	TC number at destination	u_{ij}	completion time of task
1	12	1	2	2	7	10	17	1	2	2	60
2	8	2	1	5	14	11	4	1	2	1	64
3	5	1	2	1	25	12	13	2	1	3	68
4	1	1	2	2	30	13	15	2	1	1	78
5	6	1	2	1	35	14	16	2	1	5	82
6	9	2	1	1	38	15	11	2	1	1	92
7	2	1	2	2	40	16	10	2	1	3	98
8	7	1	2	2	44	17	3	1	2		107
9	14	2	1	1	51						

* u_{ij} : the changeover time of transfer cranes to perform task *j* after task *i*

CONCLUSION

In this paper, it is discussed how to re-marshal export containers in port container terminals. The problem is decomposed into two stages. In the first stage, the bay matching problem and the move planning problem are solved simultaneously. The task sequencing problem is solved in the second stage. Both the bay matching problem and the task sequencing problem are formulated by the dynamic programming while the move planning is approached by the transportation problem technique. Since all the sub-problems are solved by mathematical programming techniques, it took a considerable computational time to solve each sub-problem, especially for the task sequencing problem. Heuristic techniques need to be developed for the efficient calculation.

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