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Study on Vessel Slot Planning Problem in Stowage Process of Outbound Containers

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Abstract: In this study, the vessel slot planning problem for outbound containers is discussed which is crucial in the process of stowage planning in a container terminal. By carefully studying the operational flow of vessel stowage and practicing in related departments, a decision problem for slot planning is proposed and a mathematical programming model is formulated. The distribution of export containers in yard bays is taken into account, together with bearing capacity and specially-assigned cells in the vessel, to reduce the interference in the same slot during the process of container retrieval from the storage yard. Numerical tests are carried out and their results show the effectiveness and feasibility of the model. The application of the proposed theory provides a practical significance to improve loading efficiency.

Key words: Stowage planning, vessel slot planning, bearing capacity, loading efficiency

INTRODUCTION

With the acceleration of economic globalization, the rapid growth of containerized cargos gradually asks for an efficient shipping transportation network.

For loading plans in container terminals, the related containership agent usually delivers a stowage plan to the terminal operating company several days before ship's arrival for the reference of port operators.

During the loading period, each slot is assigned with a container group which is identified by the port of destination and the container size. A vessel slot can be filled with any container as long as the container group planned for that slot is the same as the required container group.

Stowage planning and container loading problem discussed in this study is a NP-hard problem which is widely recognized in the previous literature.

Haghani *et al.* (2001) developed a heuristic algorithm to solve the vessel stowage planning problem with the aim of minimizing container handling cost which is related to unloading re-handle issues. Ambrosino *et al.* (2004) addressed a stowage planning problem which is aimed to minimize the total stowage planning time where more practical constraints are taken into consideration. They assigned vessel slots to containers with the same destination in order to avoid unproductive work. Kim *et al.* (2004) delivered a loading planning problem with an objective to arrange container stacks appropriately on board in light of smooth quay crane

operation and proper container retrieval sequence from the storage yard. They developed a beam search algorithm for this problem. Wang *et al.* (2008) presented a heuristic algorithm based on a tertiary tree model to handle the Container Loading Problem (CLP) with weakly heterogeneous boxes. A dynamic space decomposition method was developed based on a tertiary tree structure which is aimed at partitioning the remaining container space.

More recently, Lee *et al.* (2010) presented a heuristic method for an optimized working plan to retrieve all the containers from a given yard according to a given order. The goal was to minimize the number of container movements, as well as the crane's working time. A binary integer program was generated to reduce the length of the sequence and the movement sequence was iterated to reduce the crane's working time. Woo *et al.* (2011) addressed a method for determining the size of storage space for outbound containers. The concept of the reservation space was introduced for locating the containers of the same group. Various rules were proposed for determining the optimal reservation sizes. Che *et al.* (2011) addressed the multiple container loading problem. The objective was to load products with various types into the containers which is intended to minimize the total cost. Ren *et al.* (2011) studied the container loading problem, in which the shipment priority was considered. A tree search method was presented based on a greedy heuristic algorithm. And the method of space splitting and merging was also inserted into the algorithm.

Park *et al.* (2011) proposed an online search algorithm which dynamically adjusted and optimized a stacking policy. It could be applied for determining the stacking positions. Delgado *et al.* (2012) conducted the research on the slot planning problem. A Constraint Programming and Integer Programming model was presented for stowing a set of containers in a single bay section. Two Constraint Programming and Integer Programming models were developed to solve the problem optimally. Salido *et al.* (2012) presented a decision support system to manage container stacking problem, berth allocation problem and quay crane assignment problem. Junqueira *et al.* (2012) presented mixed integer linear programming models for the container loading problem where the vertical and horizontal stability of the cargo and the load bearing strength of the cargo (including fragility) were considered. Chen *et al.* (2012) addressed the assignment problem of storage locations for outbound containers. The problem was solved by a mixed integer programming model and a hybrid sequence stacking algorithm was applied to analyze the proposed model. Bortfeldt and Wascher (2013) gave a review of the state-of-the-art in the field of container loading. They identified factors which practically need to be considered when dealing with container loading problems and analyzed whether and how the factors were represented in methods for the solution of such problems. Lim *et al.* (2013) considered a single container loading problem with practical constraints. An integrated heuristic solution approach was proposed that combined a GRASP wall-building algorithm with linear integer programming models.

In summary, few research works have been carried out in the field of stowage planning, especially in the vessel slot planning problem. And this is the research area of this study. The related assignment principles will be carefully taken into account.

PROBLEM DEFINITION

With the fast development of computer technology and ever-growing demand for container transportation and handling efficiency, modern management information systems for vessel stowage have been widely adopted and applied in container terminals all around the world.

Stowage planning is an important link in loading operations at the terminals which refers to a detailed plan concerned with the assignment of containers to be loaded onto a vessel. In the past, the container stowage was fulfilled by the Captain of a containership. Nowadays the port operators must determine the stowing sequence

according to information and constraints given by shipping companies and operational rules set by port authority. The stowage planning is decomposed into pre-stowage and actual stowage. Pre-stowage means the vessel bay allocation for a certain number of containers. The actual stowage planning is regarded as the process of assigning a container to a specific cell in the vessel bay.

The pre-stowage phase for the actual stowage contains two aspects. The first stage is to gather all documents about container loading and then carefully check related information. In this section, containers listed on manifest with customs clearance will be eventually stowed and therefore information on manifest and CLP (Container Load Plan) should be examined to avoid human errors. And moreover, port operators are required to make arrangements considering the position of export containers in storage yard to reduce container reshuffling, thus ensuring a reasonable loading sequence and handling efficiency. The second phase is to formulate pre-stowing plans which secure meaningful reference for loading operations along the quayside. Note that containers of special types are stowed into specially assigned location and their priority is higher than that of GP containers.

Several rules are accepted for storage space planning. The first principle is that containers of the same group should be located as close as to each other. The second principle is that the interference between yard cranes must be avoided during the vessel stowage operation. The third principle is that yard bays that are planned to a containership should be located as near as possible to the vessel's berthing position.

The stowage problem discussed in this paper refers to space allocation for export containers in a containership. Ship's stowage plan has to consider significant factors, such as container type, port of discharging, ship stability, bearing capacity, turnaround time, draft and etc.

The vessel stowage plan must be made in accordance with the restrictions enforced in retrieving containers from stacks in storage yard. Note that each container can only be loaded into a cell in a ship's hold or on the deck. In order to ensure a fast and smooth loading operation and reduce container reshuffles in the following ports of discharging, vessel stowage must satisfy a standard and orderly operational process.

The process of stowage planning generally comprises of five steps (Fig. 1).

Firstly, export containers of a vessel are classified into groups according to pre-stowing information

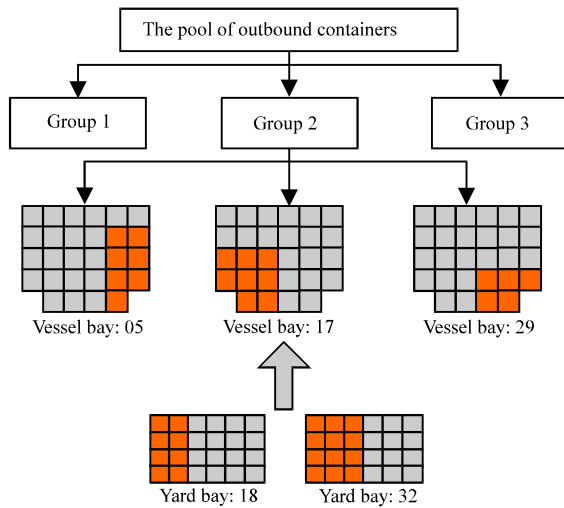


Fig. 1: A schematic diagram of stowage planning

provided by maritime companies, such as discharging ports, container sizes and shapes. A complex stowage process can be divided into multiple parts which helps to simplify the problem. Secondly, for each container group, multiple vessel bays are determined to provide a certain number of adjacent cells to hold containers of the same group. The relation between container groups and vessel bays is generated. Thirdly, containers from strings in yard bays are retrieved and stowed into cell sections of a vessel bay (bay-filling) according to the pre-stowing plan made by shipping companies and the export container distribution in the yard which is intended to manage the partitioning of yard operations and the movement of yard cranes. Fourthly, on the basis of the bay-filling result, a group of containers from yard bays are stowed into a single slot of the vessel bay. As such, the concept of slot planning is proposed and it will be mentioned in detail later on. Finally, the detailed stowing sequence of each container is figured out and the relation between a vessel cell and a container is established.

As shown in Fig. 1, the vessel contains three container groups and containers from group 2 are classified into three vessel bays. Totally there are eight containers in bay 05, seven containers in bay 17 and five containers in bay 29. And two yard bays are scheduled to release containers (eight containers in bay 18 and twelve containers in bay 32).

This study mainly focuses on the slot planning in vessel stowage (Fig. 2). It can be composed of the following three steps:

- Select a target area in a vessel bay. The entire vessel bay may be partitioned into two or more sections due

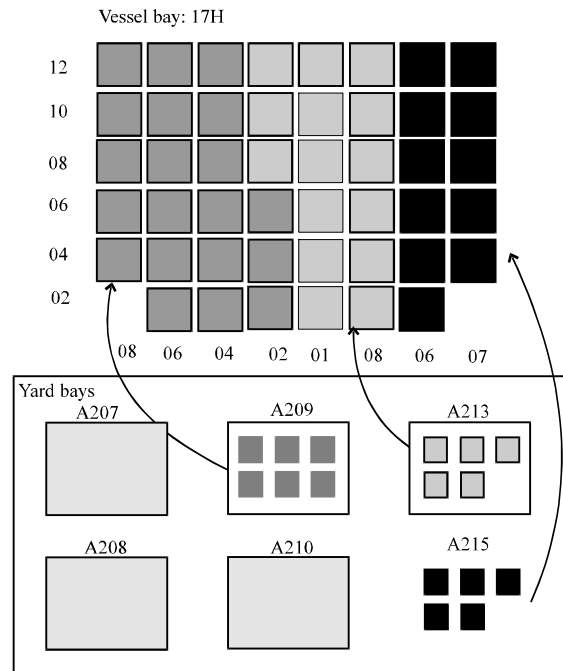


Fig. 2: Illustration of vessel slot planning

to the hatch cover in order to avoid the container reposition in the storage yard

- Search and choose a container group to obtain the number of blocks and container distribution in each block and yard bays
- Stow the selected containers to the slots of a vessel bay section. Note that the loading sequence is very important for the future vessel loading operation

The major decision-making of vessel slot planning is to assign an entire slot of the given vessel bay to the containers waiting for allocation. Note that the containers stowed into a slot should be picked up from the same yard bay or adjacent bays. This is aimed at increasing the position intensiveness of containers and eliminating the unnecessary movement of yard cranes. What's more, the number of stowing containers cannot be larger than the number of cells in a vessel slot and the total weight of each slot should not exceed the bearing capacity with the purpose of balancing weight distribution of a vessel bay, thus effectively improving the stowage quality.

MODEL FORMULATION

Notations

Dimensions:

C : The set of export containers waiting for stowage allocation, indexed by c

S : The set of the slots of planned vessel bay, indexed by s
W : The set of yard bays for export containers, indexed by w

Parameters:

p : Indicates the yard bay for a specific container it is 1 if container c is from yard bay w , 0 otherwise
z : Indicates the weight of container c
n : Indicates the number of stowing container in slot s
a : Indicates the bearing capacity of vessel slot s
h : Indicates the type t of container c
g : Indicates the number of cells in vessel slot s , where containers with type t are stowed

Decision variables:

X : Indicates the slot allocation for container c it is 1 if container c is assigned to vessel slot s, 0 otherwise
D : The auxiliary variable it is 1 if vessel slot s holds the container from yard bay w, 0 otherwise
T_obj : The objective function

Constraints

Constraints 1: In the process of vessel stowage planning, the volume capacity of each slot in a vessel bay should be measured and the number of containers cannot exceed this capacity. The constraint is defined as follow:

$$\sum X_c^s \leq n_s \quad (1)$$

The left term of the constraint is a zero-one matrix where the parameter X is summed with regard to container c. And the right term refers to the allowed number of stowing containers in slot s.

Constraints 2: The bearing capacity of each slot means the allowable gross weight of a slot and the total weight of containers in a single slot must be taken into account. The constraint is shown as follow:

$$\sum X_c^s * z_c \leq a_s \quad (2)$$

For the left term, is a two-dimensional matrix that expresses the weight of container in vessel slot s and then compute the summation in terms of container . The right term defines the bearing capacity of vessel slot s.

Constraints 3: An important factor in vessel stowage should be considered, namely the vessel cells for special containers. The quantity of special containers cannot exceed the volume limit for special ones in each slot. The constraint can be expressed as follow:

$$\sum X_c^s * h_c^t \leq g_s^t \quad (3)$$

The left term of the constraint is the summation of a zero-one matrix as to container c to obtain the amount of special containers in slot s. The right term of the constraint denotes the capacity limit of special containers in slot s.

Constraints 4: Note that a container can only be moved towards a vessel slot. If two or more slots are planned to hold the container c, the clash may occur. It is defined by the following equation:

$$\sum X_c^s = 1 \quad (4)$$

Objective: The programming model is aimed to optimize the container concentration level in a single vessel slot. In other words, the containers are planned to be retrieved from the same yard bay to one slot as far as possible (Fig. 3).

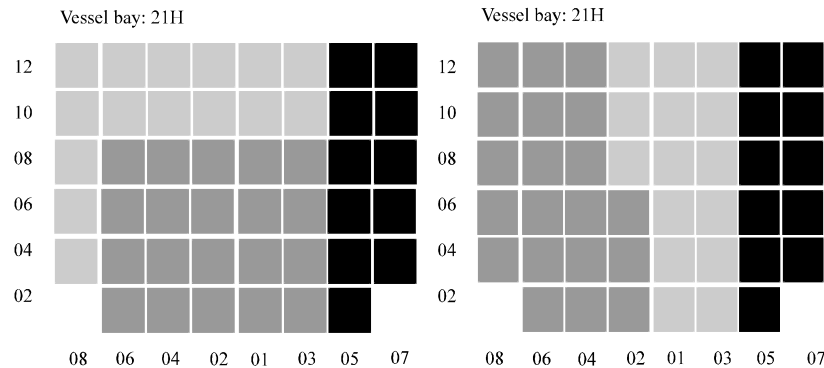


Fig. 3. An outline showing container concentration in a vessel bay

As is shown in Fig. 3, different colors represent three different bays in the storage yard and there are two vessel slot planning results for bay 21H (H denotes the “hold”). It is obvious that the right option is much better than the left option for the fact that only slot 02 involves outbound containers from two yard bays in the right one and the concentration degree of ship stowage is more reasonable. The objective function is written in the following equation:

$$T_obj = \sum [If \sum (X_c^s * p_c^w) > 0, 1, 0] \quad (5)$$

Linear transformation: It can be observed that this objective expression is a non-linear equation. For solution, logical judgment must be performed and its computational efficiency is far lower than that of the linear equation. As such, the concept of linear transformation is applied and an auxiliary decision variable D is introduced to form an auxiliary constraint. The constraint is expressed as follow:

$$[\sum (X_c^s * p_c^w)] \div 100 \leq D_s^w \quad (6)$$

Due to the fact that the amount of containers in a slot must be far smaller than 100, the number divided by 100 can lead to the result between 0 and 1. Accordingly, the objective function can be revised as follow which is a minimization problem:

$$\min : T_obj = \sum D_s^w \quad (7)$$

The objective of the model is to minimize the yard bay number of a vessel slot. The entire model is summarized as follows.

Objective function:

$$\min : T_obj = \sum [If \sum (X_c^s * p_c^w) > 0, 1, 0] \quad (8)$$

Subject to:

$$\sum X_c^s \leq n_s \quad \forall s \quad (9)$$

$$\sum X_c^s * Z_c \leq a_s \quad \forall s \quad (10)$$

$$\sum X_c^s * h_c^t \leq g_s^t \quad \forall s, t \quad (11)$$

$$\sum X_c^s = 1 \quad \forall c \quad (12)$$

$$[\sum (X_c^s * p_c^w)] \div 100 \leq D_s^w \quad \forall s, w \quad (13)$$

Constraint (9) defines the number of containers cannot exceed the volume capacity of each slot in a vessel bay. Constraint (10) ensures that the total weight of containers in a single slot should be controlled within the allowed bearing capacity of a slot. By constraint (11), the quantity of special containers cannot exceed the vessel cell limit for special containers in each slot. Constraint (12) makes sure that one container can only be transported into a vessel slot. In constraint (13), yard bays are computed in each slot.

NUMERICAL EXPERIMENTS

In this section, the numerical experiments are performed by a personal computer with duo CPU @ 1.8 GHz and 1 GB RAM. The vessel slot planning is studied by using the actual data. A single objective programming model is solved through the application of CPLEX 10.0. And moreover, the experimental tests with different sizes are carried out to evaluate the effectiveness and reliability of the proposed problem.

According to the parameters in the mathematical model, the data employed in this case study includes information about a slot in a vessel bay and related export containers. The details are listed in Fig. 4, Table 1, 2 and 3.

As illustrated in Fig. 4, the grey-colored sections means that the cells are reserved for export containers from two yard bays (A315 and A209) in the stowage planning.

From all above mentioned tables, slot plans satisfy all the constraints in the model. The summation of the total number of yard bays is seven which is content with the minimization objective function. The final stowage result

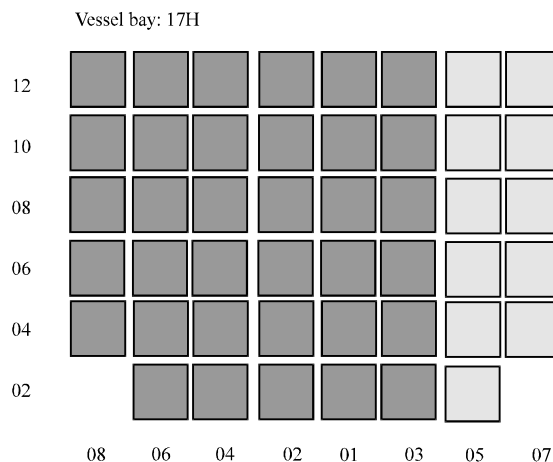


Fig. 4: A diagram of the selected slot

Table 1: List of slot information

Slot No.	Bearing capacity (ton)	Cells No.	Special cells
17H01	180	6	3 (HC)
17H02	180	6	3 (HC)
17H03	180	6	
17H04	180	6	
17H06	180	6	
17H08	150	5	5 (RF)

Note that “HC” stands for the high cube container and “RF” denotes the reefer container

Table 2: List of outbound containers (A315)

Bay	Container No.	No.	Weight (t)	Special flag
A315	FSCU7317130	1	21	HC
	FSCU7317131	2	23	HC
	FSCU7317132	3	21	GP
	FSCU7317134	4	26	GP
	FSCU7317133	5	22	GP
	FSCU7317135	6	23	GP
	FSCU7317148	7	29	GP
	FSCU7317147	8	20	RF
	FSCU7317145	9	27	GP
	TGHU2467104	10	24	HC
	TGHU2469205	11	24	GP
	TGHU2980703	12	23	GP
	TGHU2470504	13	27	RF

Table 3: List of outbound containers (A209)

Bay	Container No.	No.	Weight (t)	Special flag
A209	INBU3494124	14	21	GP
	INBU3494134	15	25	GP
	INBU3494117	16	24	GP
	INBU3494133	17	25	GP
	INBU3494125	18	26	GP
	INBU3494137	19	24	GP
	INBU3494120	20	22	GP
	INBU3494123	21	25	GP
	INBU3494118	22	27	GP
	INBU3494151	23	21	GP
	INBU3494253	24	24	GP
	INBU3494257	25	22	GP
	INBU3494266	26	26	GP
	INBU3494147	27	28	HC
	INBU3494263	28	23	HC
	INBU3494251	29	25	RF
	INBU3494121	30	25	RF

Note that “HC” stands for the high cube container, “GP” means the general purpose container and “RF” denotes the reefer container. The numerical results of the proposed model are listed in Table 4, 5, 6, 7, 8 and 9. Note that the term “No.” is related to all export containers which have been described in Table 3

Table 4: List of export containers (17H01)

Slot	No.	Gross weight	Bay No.	No. of yard bays
17H01	17	149	A209	1
	19		A209	
	20		A209	
	22		A209	
	27		A209	
	28		A209	

Table 5: List of export containers (17H02)

Slot	No.	Gross weight	Bay No.	No. of yard bays
17H02	1	124	A315	1
	2		A315	
	7		A315	
	9		A315	
	10		A315	

Table 6: List of export containers (17H03)

Slot	No.	Gross weight	Bay No.	No. of yard bays
17H03	3	139	A315	1
	4		A315	
	5		A315	
	6		A315	
	11		A315	
	12		A315	

Table 7: List of export containers (17H04)

Slot	No.	Gross weight	Bay no.	No. of yard bays
17H04	16	118	A209	1
	18		A209	
	21		A209	
	23		A209	
	25		A209	

Table 8: List of export containers (17H06)

Slot	No.	Gross weight	Bay No.	No. of yard bays
17H06	14	72	A209	1
	15		A209	
	26		A209	

Table 9: List of export containers (17H08)

Slot	No.	Gross weight	Bay No.	No. of yard bays
17H08	8	121	A315	2
	13		A315	
	24		A209	
	29		A209	
	30		A209	

Table 10: Comparison of computational efficiency

Test No.	CTN No.	Slot No.	Variable No.	Solution time (msec)	CPU memory (M)
1	10	3	30	60	1.2
2	15	3	45	134	1.8
3	20	4	80	220	2.4
4	25	5	125	308	2.9
5	30	5	150	375	3.5
6	35	6	180	465	4.1
7	40	7	210	578	4.8
8	45	7	245	655	5.3
9	50	8	320	764	5.9
10	55	8	360	830	6.3
11	60	8	400	933	6.7
12	65	9	495	1020	7.1
13	70	9	540	1105	7.4
14	75	9	585	1198	7.6
15	80	9	630	1260	7.9
16	85	10	750	1318	8.1
17	90	10	800	1369	8.3
18	95	10	850	1410	8.4
19	100	10	900	1453	8.5
20	105	11	1045	1497	8.6
21	110	11	1100	1530	8.8
22	115	11	1155	1566	8.9
23	120	12	1320	1598	9.1
24	125	12	1380	1625	9.1
25	130	12	1440	1642	9.2

is specified in Fig. 5. The number in the square box stands for the serial number as shown in Table 2 and 3 (the third column).

To verify the effectiveness and reliability of the single-objective programming model, several experiments are conducted with various sizes. There are totally ten tests and the performance on computational efficiency is summarized in Table 10.

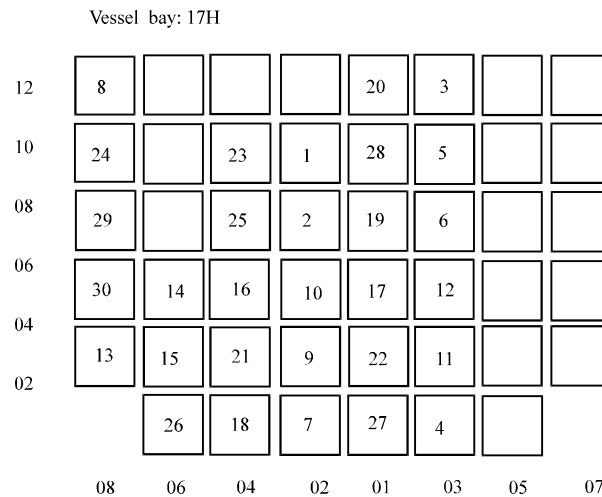


Fig. 5: An outline of the stowage result

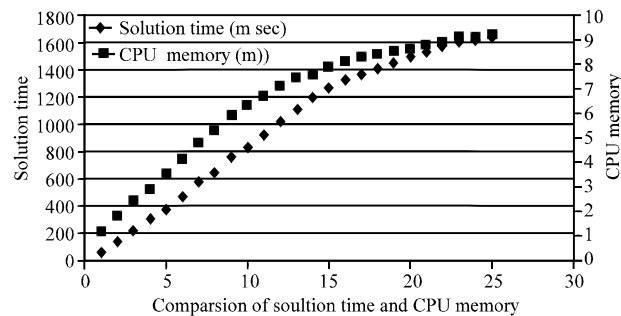


Fig. 6: An illustration showing comparison of solution time and CPU memory

It can be observed from the table and Fig. 6 that the computing time is very instant and well-desired. And the memory usage of each test is feasible. As a result it is quite acceptable to improve the efficiency during the process of slot planning.

CONCLUSION

In this study, the slot planning problem in the process of containership stowage planning is discussed. Several principles are considered and analyzed. The problem is illustrated by a single-objective programming model. Such constraints as capacity limit of a vessel slot are taken into consideration which is intended to optimize the efficiency and stowage quality of slot planning for outbound containers in container terminals.

Numerical tests are performed with 10 cases and then solved by CPLEX 10.0. The effectiveness and feasibility of the mathematical model is certified. The proposed model can also be helpful to motivate future researches in terms of related vessel stowage problems.

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