A Heuristic Algorithm for Generating Stowage Plans

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Abstract. An enormous number of containers are stowed on the vessels every week with different goods. Thus, stowage plans are required for loading containers onto containerships at container terminals. For a simulation purpose, stowage plans need to be generated with limited information on containers and the generated stowage plans should be as similar as possible to real corresponding stowage plan. The limited information includes the number of containers of different sizes and with different ports of destination, which are obtained from the existing real historical data. For the generation of the stowage plans, containers with different attributes should be allocated to slots onboard containership. This paper introduces a heuristic algorithm for generating stowage plans in multiple vessel bays. It is discussed about how to analyze information about previous stowage plans to obtain number of expected containers for each bay and appropriate PODs. Moreover, after generating the stowage plan using this study, the evaluation of generated stowage plans from the viewpoint of the historical data using a similarity index is also presented.

Keywords: container terminal, stowage plan, heuristic algorithm, ship operation

1. INTRODUCTION

A stowage plan is a job order document that assigns containers with a specific set of attributes to a set of slots onto a ship. Simultaneously, this plan significantly affects the operating cost of a shipping line or a terminal. Delgado et al. (2012a) noted that the purpose of the stowage planning is for reducing the duration of staying of vessels at ports and, as a consequence, the ship operation cost at the ports. That is, the stowage planning also affects various performance measures of not only the corresponding shipping company, but also the corresponding terminal operator (Monaco et al., 2014). Currently, the stowage planning is mostly carried out by human stowage planners, whose experience are used to generate the stowage plans. The stowage plans have to cover vessels of various sizes from the relatively small 350 TEUs (Twenty Foot Equivalent Unit) to ten thousand TEUs vessels. Nowadays, a large container ship requires thousands of container movements including the loading, discharging, or re-positioning of containers within the vessel.

Wilson and Roach (2000) described a stowage arrangement for slots within a ship on deck and in hold; longitudinal (along the length of the ship) and latitudinal (along the width of the ship) sections. Positions of slots are partitioned into ‘hatches’ and ‘bays’, which are segments of physical slots considering basic sight view of a standard containership and illustrated in Figure 1.

Programming (MIP) to contribute to a better management

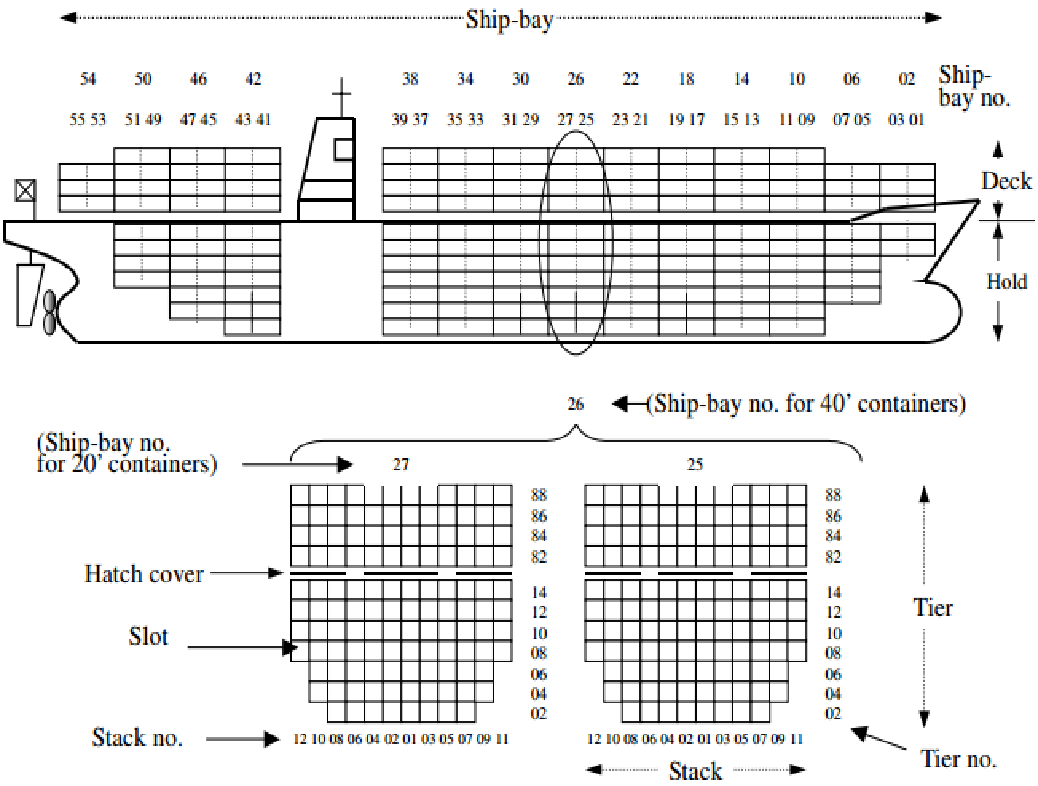

Figure 1: An example of structure ship-bays of a vessel.

Shipping lines and researchers have studied on the problems related to the container stowage planning since the 1970s. Mostly, the existing researches proposed various heuristic algorithms for constructing stowage plans. The sizes of the container loading problem will depend on the capacity and the number of containers to be loaded onto a containership at each port. Thus, even for a medium sized containership, the stowage planning problem becomes nontrivial because of the large number of decision variables. Furthermore, the problem has been proven to be NP-hard, in which it is unlikely to guarantee an optimal solution in a reasonable processing time. As a result, many researchers attempted to develop heuristic methodology approach to provide feasible solutions to the stowage planning problem.

Øvstebø at el. (2011) constructed a mathematical model, which is solved by both a standard MIP solver and a specially designed heuristic method, to be used to optimize the stowage plan (considering decisions such as which cargoes to carry, how many vehicles to carry from each cargo, and how to stow the vehicles carried during the voyage) when operating a fleet of RoRo ships.

Moura et al. (2012) presented a mathematical formulation model, which used also a Mixed Integer Programming (MIP) to contribute to a better management of small fleets of containerships in order to reduce transportation time and delivering costs transportation time and delivering costs. Ding and Mabel (2015) generated stowage plans with a reasonable number of shifts of containers by developing a heuristic algorithm.

Ambrosino et al. (2015) also used an exact MIP model for the Multi-Port Master Bay Plan Problem (MP-MBPP) to find good solutions for multi port stowage planning in a short amount of time and including the model into an effective tool that can help the liner planner during the entire trip of the ship. Araújo et al. (2016) proposed a hybrid Pareto Clustering Search (PCS) method to solve the CLPP (The 3D Container ship Loading Plan Problem) and obtain a good approximation to the Pareto Front. It is combination of metaheuristics and local search heuristics in PCS, and the intensification is performed only in promising regions. The computational numerical results are presented to show that PCS provides better solutions for the CLPP than a mono-objective Simulated Annealing solution.

In addition, there were more other studies with using various optimization search algorithms such as branch and bound search (Wilson and Roach, 2000; Sciomachen and Tanfani, 2003), greedy algorithm approach by Kang and

Kim, (2002), tree search scheme (Kang and Kim, 2002; Zhang et al., 2005), which have been used for a dynamic slot-assignment solution in the stowage planning problem. However, the complexities and the efficiencies of these heuristic algorithms still need to be identified and these issues were illustrated by Zhang et al. (2008), and Delgado et al. (2012b) in extensive literature reviews.

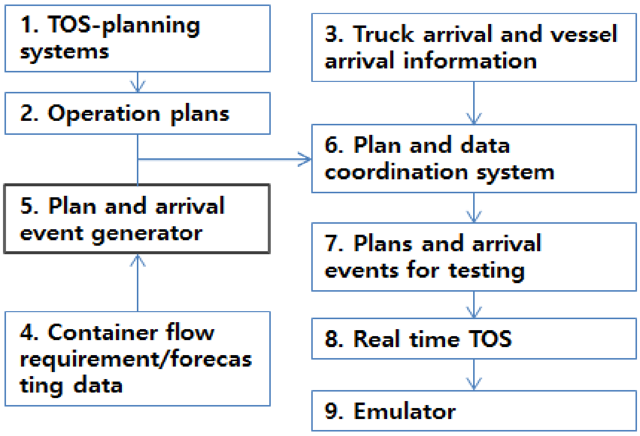

Figure 2: Evaluation of operation plans by using simulation.

The motivation of this study is to develop a simulation model which will be used for evaluation of an operation plan in container terminals. This is also specialized as the purpose of this study when generating the stowage plan.

The purpose of generating stowage of containers on the vessel will help stowage planners at the terminal estimate data processing time for the next operations. As shown in Figure 2, TOS-planning system will have operation plans, which are conducted and scheduled by the generator for plan and arrival event is based on relevant necessary container flow order/forecasting data. Therefore, they can build the plan and data coordination system that store information of truck and vessel arrival for testing to recognize these plans and arrival events before calculating the accuracy real time TOS (Terminal Operation System) for completion time of an operation plan. Finally, deploy an emulator engine is as indispensable summary process for evaluation of operation plans.

Hence, in this study, a heuristic algorithm is proposed for generating stowage plans, which include characteristics of the slots (row, tier, bay) of each bay. Figure 3 illustrates a generated stowage plan for one ship-bay, which gives its position relative to the cross section of the containership. There are 10 rows to be counted as the vertical section of the corresponding ship-bay, and its position related to the horizontal section of the corresponding ship-bay will have number of tiers equal to 7. For each location is addressed by (row, tier) of this bay is allocated by number of containers, each container has specific information such as type of POD, source port, shipper, container type, height and weight of the container.

With the main contribution of this study are as follows:

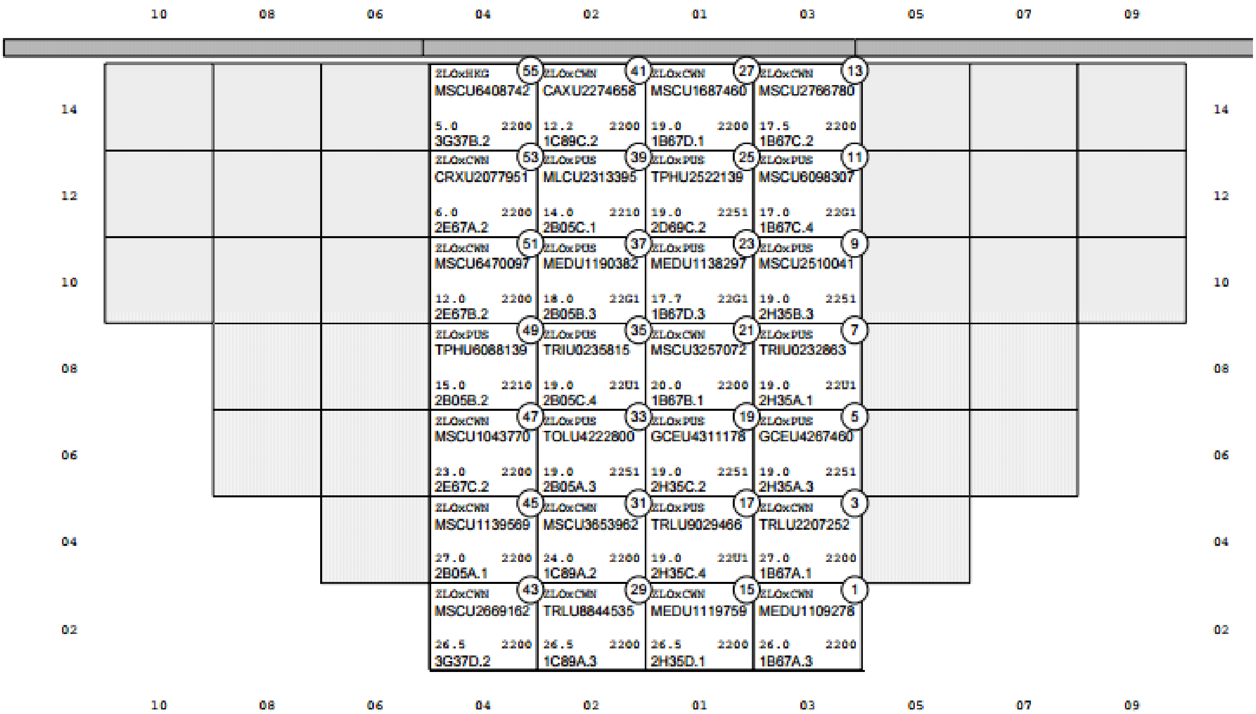

Figure 3: An illustrative stowage plan.

this study analyzes real data and proposes a method for generating stowage plans, which will be used as an input to the real time simulation.

All parts of this paper are organized as follows. Section 2 describes a clear definition of the stowage planning problem of a containership including factors to be considered for the construction. Next, Section 3 provides the main heuristic algorithm together with an explanation illustrating in detail on how the algorithm works. Section 4 analyzes the performance of the algorithm. Finally, section 5 will provide concluding remarks.

2. CHARACTERISTICS OF STOWAGE PLANS

In modern container transport, a container vessel usually carries containers on a fixed cyclical route, and it typically serves a sequence of ports. Each container has attributes such as weight, height, length, and destination port where it has to be unloaded (POD).

The cargo space in a container vessel is divided into sub-sections, which are called bays. Each bay of a vessel consists of over- and under-deck stacks of slots divided by a hatch cover. The view of the basic structure of standard ship-bays is illustrated in Figure 1. A containership contains a number of bays with increased bay numbers from bow to stern. Considering a specific type of container storage capacity of each bay, each 20 foot (20ft) bay is numbered with an odd number, e.g bay 01, 03, 05, 07, e.g, whereas two adjacent odd bays conventionally form one even bay, for the stowage of 40 foot containers, such as bay no. 06 = bay no. 05 + bay no. 07, and this description is also introduced in Figure 1. In this study, a combination of three defined constituents (bay no. 05, bay no. 06, and bay no. 07) is called as a cluster of bays.

Each slot is addressed by three following identifiers:

- Bay, which means the compartments as a part of a container vessel of 20 ft or 40 ft size.
- Row, which is the position (slot) where the container is placed across the width of the container vessel.
- Tier, which indicates the level where a container is placed – basically how high a container is stacked on the deck or in the hold. This gives its position involved in the horizontal section of the corresponding bay.

For the third index, the tiers in the hold are numbered from the bottom of the containership to the hatch cover with even number, e.g tier 02, 04, 06, while on the above deck from the hatch cover to the top of the containership, the tier numbers are 82, 84, 86 as mentioned in Figure 1.

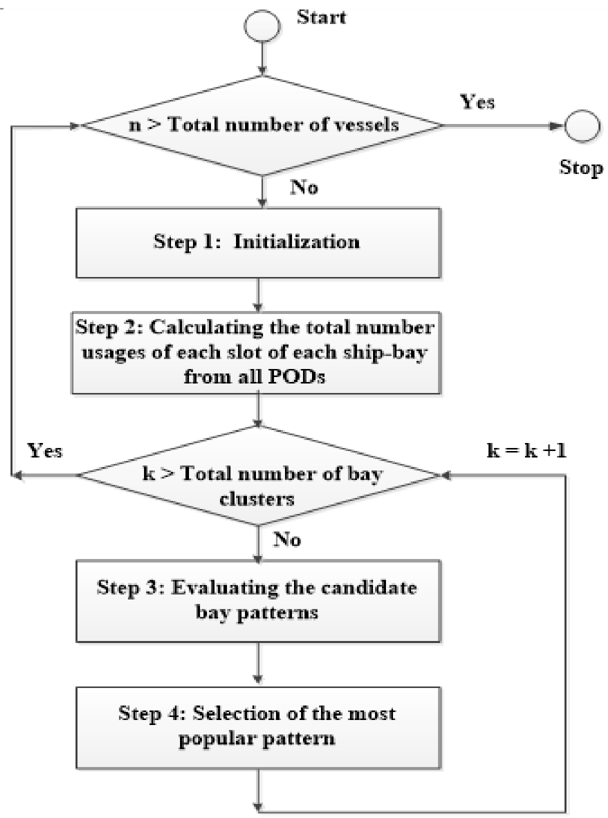

Figure 4: Procedure to generate the stowage plans.

3. GENERATING STOWAGE PLANS

Stowage plan generation is the process of allocating containers to the slot locations of a container vessel. The objective of this study is to propose a method for generating stowage plans of containers which will be loaded into the slots of each bay on a ship. A heuristic to allocate containers of different sizes and with different POD (port of destination) into slots of bays in a ship is proposed. At first, a container vessel profile, which contains information related to the number of bays to be used, the number of containers to be loaded in each bay for each POD, needs to be estimated. Secondly, detail loading pattern for each bay is to be generated. A good pattern is the one which resembles the previous patterns.

The following steps are used to describe the main concepts in the heuristic algorithm of this study. The overall procedure of the algorithm is also introduced in Figure 4. The proposed heuristic algorithm is presented as follows:

Step 1. Initialization

This step collects information on the number of PODs, ship-bays, rows, tiers, and containers to be allocated to the designated containership. Raw input data which were used for the analysis, are illustrated in Table 1.

Step 2. (Calculating the total number usages of each slot of each ship-bay from all PODs) Figures 5(a), 5(b) show the frequency of container occupations of ship-bay 1

Table 1: Raw input data for each vessel.

Container ID	Vessel Name	Calling Year	Calling Sequence	Bay	Row	Tier	POD
ContS1	VS1	2014	CS1	1	1	2	POD1
ContS2	VS1	2014	CS2	2	2	4	POD2
…	…	…	…	…	…	…	…
ContS21	VS2	2014	CSS21	1	1	4	PODS1
ContS22	VS2	2014	CSS22	2	2	6	PODS2
…	…	…	…	…	…	…	…
ContSN1	VSN	2014	CSSN1	1	1	6	PODN1
ContSN2	VSN	2014	CSSN2	2	2	8	PODN2

For POD 1

Ship Bay 1	Tier No.										
	92	0	0	0	0	0	0	0	0	0	0
	90	0	0	0	0	0	0	0	0	0	0
	88	0	0	0	0	0	0	0	0	0	0
	86	0	0	0	0	0	0	0	0	0	0
	84	0	0	0	0	0	0	0	0	0	0
	82	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0
	6	**1**	**1**	**1**	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0
	2	**1**	**1**	**1**	0	0	0	0	0	0	0
	Row No.	1	2	3	4	5	6	7	8	9	10

(a) The frequency of container occupation of ship bay 1 with calling sequence CS1.

For POD 1

Ship Bay 1											
	92	0	0	0	0	0	0	0	0	0	0
	90	0	0	0	0	0	0	0	0	0	0
	88	0	0	0	0	0	0	0	0	0	0
	86	0	0	0	0	0	0	0	0	0	0
	84	0	0	0	0	0	0	0	0	0	0
	82	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0
	6	**1**	**1**	0	0	0	0	0	0	0	0
	4	**1**	**1**	0	0	0	0	0	0	0	0
	2	**1**	**1**	0	0	0	0	0	0	0	0
		1	2	3	4	5	6	7	8	9	10

(b) The frequency of container occupation of ship bay 1 with calling sequence CS2.

Check Table

Ship Bay 1											
	92	0	0	0	0	0	0	0	0	0	0
	90	0	0	0	0	0	0	0	0	0	0
	88	0	0	0	0	0	0	0	0	0	0
	86	0	0	0	0	0	0	0	0	0	0
	84	0	0	0	0	0	0	0	0	0	0
	82	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0
	6	**2**	**2**	**1**	0	0	0	0	0	0	0
	4	**1**	**1**	0	0	0	0	0	0	0	0
	2	**2**	**2**	**1**	0	0	0	0	0	0	0
		1	2	3	4	5	6	7	8	9	10

(c) The frequency of container occupation of ship bay 1 with all corresponding calling sequences.

For POD 1

Calling Sequence No. \ Ship Bay No.	1	2	3	…	13	14	15	…	34	35
CS1	6	40	17	…	0	0	0	…	55	4
CS2	0	0	0	…	0	0	0	…	0	0
CS3	0	0	0	…	0	0	0	…	0	0
CS4	0	0	0	…	0	0	0	…	0	0
…	…	…	…	…	…	…	…	…	…	…
CS11	0	0	0	…	22	192	18	…	0	0
CS12	0	42	8	…	30	323	30	…	0	0
CS21	0	0	0	…	0	0	0	…	0	0
CS22	0	0	0	…	0	0	0	…	46	4
CS23	0	0	0	…	12	321	12	…	0	0
CS24	0	0	0	…	0	380	0	…	0	0
CS25	1	2	3	…	0	0	0	…	0	0

(d) The total number of usages across all the slots in each ship bay with the corresponding calling sequences.

Figure 5: Frequency of container occupation in each ship-bay with the corresponding sequence.

with the corresponding calling sequences CS1, CS2 for POD1. Then, the tables are added across the all the calling sequence to obtain the "Check Table" illustrated in Figure 5(c). Then, we calculate the total number of usages across all the slots in each bay with the corresponding calling sequence, which is a numeric value in the entry of (calling sequence no., bay no.) in Figure 5(d). We calculate these values for all the combinations of ship-bay and POD.

Step 3. (Evaluating the candidate bay patterns)

Figure 6 shows the number of usages of slots in each ship-bay across all the PODs, and also counts the total number of usages (TP) of slots across all the ship-bays and PODs for each calling sequence. The maximum total number of usages (TPs) is written in bold, which will be used for generating forecasting stowage plan later. Refer to Figure 6. Assume that the number of required bay clusters = (the number of ship-bays of each containership designated)/3 = 27/3 = 9. The bay cluster (13, 14, 15) is selected as the first one to assign a pattern, because TP value of this ship-bay is the largest (4289). After assigning a pattern to the bay cluster (13, 14, 15), the process will be repeated for bay clusters in the decreasing order of TP value until all the required number of bay clusters are assigned with patterns.

Ship-Bay No.

Calling Sequence No.

	1	2	3	…	13	14	15	…	35
CS1	6	40	17	…	20	53	24	…	4
CS2	2	10	8	…	0	0	0	…	0
CS3	0	0	0	…	20	118	20	…	17
CS4	0	0	0	…	55	115	55	…	17
...	...	...	...	...	...	...	...	...	...
CS21	34	112	64	…	83	223	82	…	17
CS22	53	48	89	…	100	236	102	…	4
CS23	2	60	28	…	12	321	12	…	11
CS24	30	107	69	…	0	380	0	…	7
CS25	57	50	93	…	53	136	53	…	27
TP	427	1439	1041	…	931	**4289**	934		266

TP = the total number of usages of slots across all the PODs and calling sequences.

Figure 6: Number of usages of slots across all PODs.

Step 4. (Selection of the most popular pattern)

This step selects a pattern from a call sequence with the maximum value of the evaluation function, which is expressed as:

$$T = \alpha.A + \beta.B + \gamma.C \qquad (1)$$

For the evaluation of the first term A, the ratio of the popularity of each pattern from each calling sequence and bay to the maximal popularity among patterns for the bay is calculated The popularity of a pattern is evaluated by adding the value in the check table corresponding to every slot used in a specific pattern.

For evaluating the second term B, the ratio of the number of containers included in a pattern divided by the number of containers to be allocated to the corresponding bay will be used. The second term represents the similarity of the size of the pattern to the number of containers to be allocated to the corresponding bay. The third term C is evaluated by the total number of containers, which can be allocated to the corresponding bay considering POD, divided by the total number of containers in the pattern. The third term represents how much the pattern fits the required number of containers for each POD in the bay. The pattern with the largest value of T will be selected. Figure 7(a), (b), and (c) shows values of term A, term B, term C in mathematical equation (1) for scale coefficients $\alpha = 0.2$; $\beta = 0.4$; and $\gamma = 0.4$, respectively. Table 2 shows the final evaluation value, T, of patterns collected from stowage plans in previous calling sequences.

4. NUMERICAL EXPERIMENTS

The numerical tests were performed to examine the effectiveness of the proposed heuristic algorithm. It was programmed by using Java and executed in an Intel ® core (TM) i-7-6700 CPU 3.40 GHz with 32 GB RAM.

As shown in Table 3, it summarizes the assignment of a pattern to each ship-bay cluster. Each ship-bay cluster is assigned with a pattern, which is represented by the calling sequence. The number of containers accepted in each bay cluster may be different from the original number of containers in the selected pattern, because the required number at the corresponding bay cluster may be different from the number of containers of each POD in the pattern. For an illustrative example, the first ship-bay cluster (1, 2, 3) has the same call sequence (representing a pattern), POD type A, and the number of containers are assigned to the bay cluster (1, 2, 3) is 8, 15, 17, respectively.

	1	2	3	…	13	14	15	…	35
CS1	0.020	0.053	0.036	…	0.04	0.027	0.047	…	0.029
CS2	0	0	0.131	…	0	0	0	…	0
CS3	0.102	0.158	0.1312	…	0.04	0.062	0.039	…	0.125
…	…	…	…	…	…	…	…	…	…
CS23	0.007	0.080	0.060	…	0.024	0.168	0.023	…	0.0815
CS24	0.098	0.143	0.148	…	0	0.2	0	…	0.0519
CS25	0.187	0.066	0.2	…	0.106	0.071	0.103	…	0.2

(a) Value of term A in mathematical equation (1) for scale coefficient α

Calling Sequence No.

Cluster Bay No.

Ship Bay No.

	1	2	3	…	13	14	15	…	35
CS1		0.835		…		1.680		…	1.0545
CS2		1.144		…		1.284		…	1.2363
CS3		0.804		…		0.062		…	1.1636
…	…	…	…	…	…	…	…	…	…
CS23		1.317		…		0.168		…	0.8909
CS24		0.871		…		1.8462		…	0.9455
CS25		0.573		…		0.7548		…	0.2909

(b) Value of term B in mathematical equation (1) for scale coefficient β

Total proportion value of a bays cluster (13, 14, 15)

	1	2	3	…	13	14	15	…	35
CS1		1.7445		…		0.477		…	6.9741
CS2		0		…		0		…	1.2364
CS3		5.8545		…		1.935		…	26.9917
…	…	…	…	…	…	…	…	…	…
CS23		1.62		…		1.057		…	0.0815
CS24		6.874		…		5.383		…	0.0519
CS25		2.036		…		1.353		…	0.2

(c) Value of term C in mathematical equation (1) for scale coefficient γ

Figure 7: Value of terms A, B, C in mathematical equation (1).

Table 2: Values of the final evaluation, T.

Calling Sequence	Ship-Bay No.				
	Bay 1-3	…	Bay 13-15	…	Bay 33-35
CS1	6.537		2.384		26.597
CS2	3.042		1.473		27.149
CS3	2.893		1.963		11.551
…	…	…	…	….	…
CS23	2.408		1.97		19.412
CS24	7.565		6.358		48.083
CS25	2.563		1.884		1.952

Table 3: Assignment of a pattern to each ship-bay cluster.

Ship-Bay Cluster No.	Ship-Bay No.	Assigned pattern			
		Original Number of Containers in the Pattern	Call Sequence of the Pattern	PODs in the Pattern	Assigned Total Number of Containers
1	1	6	2399	A	8
	2	15	2399	A	15
	3	12	2399	A	17
2	5	10	497	A	14
	6	28	497	A	36
	7	14	497	A	18

3	9	14	2071	A, B	0
	10	37	2071	A, B	18
	11	14	2071	A, B	0
4	13	17	1705	A, C, D	44
	14	38	1705	A, C, D	49
	15	19	1705	A, C, D	8

5. CONCLUSIONS

In this research, we presented a method for generating stowage plans for the use during the simulation of operation plans. We proposed a heuristic approach to generate stowage plans by using stowage plan patterns collected from previous stowage plans. For selecting the best pattern, we proposed an evaluation function consisting of the term representing usage frequency of slots, the term representing the similarity of the number of required containers to be allocated, the size of the pattern, and the term representing the similarity of the pattern to the required number of containers for each POD. By using this heuristic, we generated stowage plans with very large containerships' data.

Furthermore, our next research direction for future work may be the intensive test of the proposed algorithm for many vessels for verifying the accuracy of the proposed algorithm and to reduce the computational time for generation of stowage plans.

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