Dangerous Goods Container Allocation in Ship Stowage Planning

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Keywords: Dangerous Goods, Ship Stowage Problem, Stowage Planning, Bay Assignment, Slot Assignment.

Abstract: Ship stowage problem is difficult to solve due to the complex conditions from real-world business. For Dangerous Goods (DG) containers, IMDG code mandates the different types of DG must follow the minimum segregation on vessel and in container yard. In addition, DG containers must meet ship requirements and in-house rules from port and ship owners. However, there is a lack of research on stowage planning including DG containers. In this paper, we suggest a novel method to assign DG to integrate the existing stowage planning model. The proposed method is divided into two parts respectively for bay assignment problem and slot assignment problem. The bay assignment model separates DG containers into segregation level groups based on standard IMDG segregation table and assigns different group of containers into bays according to specific ship structure. The slot assignment model is a search-based heuristic model which able to recommend possible slot for a new coming DG container according to assigned container distribution and segregation rules between the new coming DG class and the existed ones. An empirical evaluation on a real-world dataset obtained from a shipping company demonstrates the effectiveness of our method.

1 INTRODUCTION

1.1 Background

Container shipping has always been an extremely important resource-intensive industry. Under the shackles of trade protectionism, the growth rate of global trade has declined significantly. The global container shipping trade volume is highly correlated with the world economy. Because the global economic and trade situation is not optimistic, the global container shipping trade has declined slightly in 2018. However, annual container shipping volume is 201 million TEUs, and the annual growth rate has dropped to 4.5% (shashi kallada, 2015).

Ship stowage problem is a well-recognized difficult problem that involves in terminal side, vessel side and cargo owner side. The optimization of the ship stowage problem plays a key role in increasing the profit of shipping companies. Stowage plans are used to maximize the economy of shipping and safety on board as shown in Figure 1 and Figure 2. Since the ship stowage problem is NP-hard problem, the complexity will be exponentially growing with the increase of container amount under traditional algorithm, which makes it very hard to implement in real business condition.

Figure 1: Unsuccessful stowage plan causes severe accident.

Typically, there are several container types; general container (GP), dangerous goods (DG), refrigerated container (REF) and abnormal sized container (OOG) for a loading list in a specific ship stowage plan, as shown in Table 1.

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Lei, H. and Ok, M.
Dangerous Goods Container Allocation in Ship Stowage Planning.
DOI: 10.5220/0009160602410246
In *Proceedings of the 9th International Conference on Operations Research and Enterprise Systems (ICORES 2020)*, pages 241-246
ISBN: 978-989-758-396-4; ISSN: 2184-4372

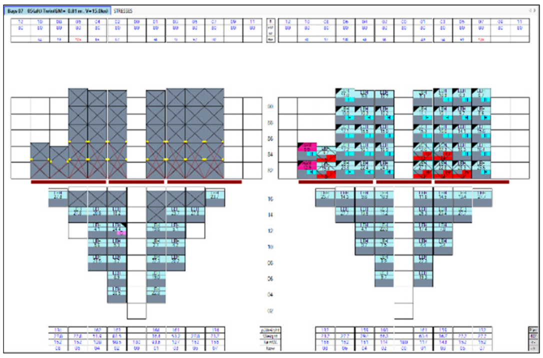

Figure 2: An example for ship stowage plan.

Table 1: An example of the distribution for container types.

Container Type	Distribution
GP-non DG	94.3%
REF	3.3%
GP-DG	1.3%
OOG	1.1%

Except for general container, other types of container are under different special treatment and conditions. As for dangerous goods, they are articles or substances which capable of posing a risk to health, safety, property, or the environment when transported by air. To ensure the safe transport of dangerous goods by air, requirements are set in place for both shippers, freight forwarders and air operators. These Classes and divisions have characteristic danger labels (aka warning diamonds) as shown in Figure 3.

Figure 3: Dangerous Goods Classification.

In a ship stowage plan, dangerous goods are defined based on UN number, IMO Class, packing group and flashpoint found in safety data sheet. Vessels carrying excessive amount of DG may be restricted to berth locations, which is why ship owners must be careful when they plan to locate dangerous goods containers somewhere. Therefore, despite the small proportion of DG in the loading list, the constraints on the risk of DG are very strict.

The stowage planning studied so far focused on optimal slotting of only GP and REF. However, the planning without considering DG is hard to be applied in practical business since the insertion of DG after the planning will affect the performance and constraints, which will lead an unsuccessful plan. In this paper, we first suggest an effective framework to integrate DG model into the existing MIP model. In the following, we suggest new methods for two DG module; bay constraints of DG and slot assignment of DG.

1.2 Related Work

Ship stowage problem is a topic of interest in industrial engineering recent twenty years. Researchers usually divide this problem into two parts: bay assignment problem and slot assignment problem. Algorithms including mathematical programming, search-based heuristics and rule-based heuristics have been applied to solving this problem.

For bay assignment problem, it's formulated as a set of integer programs and solved by a heuristic algorithm that employed a general procedure of the transportation simplex method by Kang and Kim.

Wilson and Roach mentioned that the container stowage problem concerns a multi-port journey container placement problem. Anna Sciomachen et al. tried to minimize the total loading time and allow an efficient use of the quay equipment by using a rule-based heuristics model considering size, weight of the containers and operational and security constraints which are related to the weight distribution on the ship. Pasino et al. added stack weight and height limits and other stacking rules to minimize over-stowage and free as many stacks as possible. Daniela Ambrosino et al. provided a 0/1 linear programming model by using exchange algorithm and decomposition approach.

However, due to its high complexity and variable rules for different ships and shipping companies, not much research work has been done in this area for dangerous goods container allocation problem. In this paper, we suggest a framework with 3 modules including the existing MIP model and the methods to assign DG into bays and slots satisfying IMDG segregation rules and ship requirement.

2 PROPOSED METHOD

2.1 Problem Definition

As dangerous goods can cause tremendous danger to people, property and the environment, it is crucial handling them in a safe and compliant manner to minimize the risks that they may have upon in the field.

The requirements for the storage and handling of dangerous goods can be found in the Australian Standards. The Australian Standards are documents that outline the best practices for the storage and handling of dangerous goods in the workplace. Each dangerous goods class poses different risks upon the workplace and therefore Standards Australia have developed a different standard for each dangerous goods class. Incompatible dangerous goods should not be transported or stored together to avoid possible reactions between the dangerous goods or reduce the hazards of any accidental leakage or spillage. For incompatible materials, shared transportation or storage may still be allowed if the materials are separated from each other by a minimum distance. Figure 4 represents the dangerous goods segregation table which shows the segregation levels among all the DG classes.

Segregation Table – IMDG Code 37-14

Class	1.1, 1.2, 1.5	1.3, 1.6	1.4	2.1	2.2	2.3	3	4.1	4.2	4.3	5.1	5.2	6.1	6.2	7	8	9
1.1, 1.2, 1.5	*	*	*	4	2	2	4	4	4	4	4	4	2	4	2	4	X
1.3, 1.6	*	*	*	4	2	2	4	3	3	4	4	4	2	4	2	2	X
1.4	*	*	*	2	1	1	2	2	2	2	2	2	X	4	2	2	X
2.1	4	4	2	X	X	X	2	1	2	2	2	2	X	4	2	1	X
2.2	2	2	1	X	X	X	1	X	1	X	X	1	X	2	1	X	X
2.3	2	2	1	X	X	X	2	X	2	X	X	2	X	2	1	X	X
3	4	4	2	2	1	2	X	X	2	2	2	2	X	3	2	X	X
4.1	4	3	2	1	X	X	X	X	1	X	1	2	X	3	2	1	X
4.2	4	3	2	2	1	2	2	1	X	1	2	2	1	3	2	1	X
4.3	4	4	2	2	X	X	2	X	1	X	2	2	X	2	2	1	X
5.1	4	4	2	2	X	X	2	1	2	2	X	2	1	3	1	2	X
5.2	4	4	2	2	1	2	2	2	2	2	2	X	1	3	2	2	X
6.1	2	2	X	X	X	X	X	X	1	X	1	1	X	1	X	X	X
6.2	4	4	4	4	2	2	3	3	3	2	3	3	1	X	3	3	X
7	2	2	2	2	1	1	2	2	2	2	1	2	X	3	X	2	X
8	4	2	2	1	X	X	X	1	1	1	2	2	X	3	2	X	X
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X Refer Column 16b of DGL
1. "Away from" (May be loaded in the same container, see 7.3.4)
2. "Separated from"
3. "Separated by a complete compartment or hold from"
4. "Separated longitudinally by an intervening complete compartment or hold from"
* see 7.2.7.1.4

Limited/Excepted Quantities

- No Segregation applicable between LQ/EQ packages and other dangerous goods
- Same Outer packaging for LQ, see 3.4.4.1
- Same Outer packaging for EQ, see 3.5.8.2

Figure 4: Segregation table.

Another requirement we need to consider is ship requirement which indicates which DG class can be located underdeck or on deck according to the property of a certain ship that is applied in addition to the general segregation rule. Table 2 shows an example of DG requirement for a ship where x means 'NOT PERMITTED' and P means 'PACKED GOODS PERMITTED'.

Table 2: An example of ship requirement for DG.

Bay / Class	Underdeck			On deck	
	1,3-5	2	6	1-6	8
1.1	x	P	x	P	P
1.4	P	P	P	P	P
2.3	x	x	x	P	P

2.2 Model Framework

Our proposed framework includes mainly two part; (1) Bay constraints generation and (2) Available slot generation. As mentioned in Section 1, our goal is providing DG information to the existing model. Therefore, DG constraints reflecting bay-related regulation is conveyed to the any MIP model, and then any slotting model will obtain the feasible slots for a given DG container. Figure 5 describes the relationship between two frameworks and the flows between modules. In Figure 5(a), we apply the ship requirement into each bay structure, which is explained in section 2.3. Based on the total available slots per each class of DG, we generate constraints for the MIP model from segregation table in section 2.4. Final module calculates all the possible slots out of available slots for a given DG container from the slotting algorithm.

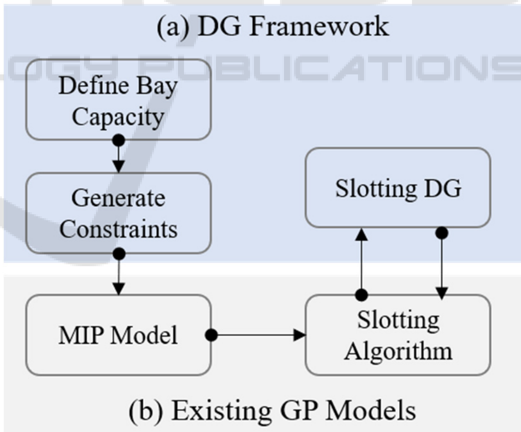

Figure 5: Model Framework.

2.3 Bay Capacity for DG

For a certain ship, each bay has its own structure that indicates the number of slots available. Due to the special requirement of ship in Table 2, we need to limit the number of available slots per each bay and each DG class. Since DG class is given by a container list, this module only calculates available slots for the given DG. The result of this module is used to define a DG feasible region for the next step, generating DG constraints.

2.4 DG Constraints for MIP

Following Section 2.3, we suggest an algorithm to determine how many DG containers can be located at each DG feasible region per bay for a given DG list. In addition, we decide the minimum bay interval when the distance should be longer than the size of feasible region. From the loading list provided by shipping company, it is easy to find dangerous goods class of each container converted by UN number. What needs to be emphasized is, there could be several UN numbers in one DG container due to the mixture of different types of hazardous cargo. So that when we think about the allocation of DG containers, it is necessary to concern all DG classes packages in one container. Here is an example about how to search segregation level from the segregation table and DG container data.

Example 1

UN 1263, Class 3
UN 1944, Class 4.1

1. *Column 16b of above both UN Numbers does not contain any segregation codes*
2. *Intersecting column between classes 3 and 4.1 in segregation table shows "x"*

Conclusion = Both may be packed in same container or stowed together.
In pre-processing, we will create segregation level 3,4 matrix A:

$$A = \begin{bmatrix} 0 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 2 & \cdots & 1 \end{bmatrix}$$

For every element A_{ij}(for $\forall i \in I, \forall j \in J$) of matrix A, we have

$$A_{ij} = \begin{cases} 0 & segregation\ level\ 0{,}1{,}2 \\ 1 & segregation\ level\ 4 \\ 2 & segregation\ level\ 3 \end{cases}$$

Then we can use two functions to separate segregation level class pairs. After filtering and separating all DG groups, we will come up with mathematical constraints generated automatically for each segregation level group. Together with general container allocating constraints and stability validation constraints, we're able to generate a table with container type, container DG class, bay number and number of this containers which can assigned into this bay.

2.5 Slot Assignment of DG

For slot assignment model, it works like a black box in which an automated calculating program inside. When the main program of general slot assignment model finds that next coming container is DG container, it will call the DG slot assignment model with input data of the coming container and exist DG containers in same bay and adjacent bays. Detailed input and output have been showed below.

For DG slot assignment model, the input is:
1. block/bay structure: discrete integer points group in coordinate (r, t)
   $B_i = \{(a_1, b_1), (a_2, b_2), \ldots, (a_r, b_t)\}$
2. vessel structure $V = \{B_i, B_{i+4}, B_{i+8}, \ldots\}$
3. exist DG container slot location (a_m, b_m), with DG category C_d^p (p: POD, d: dangerous good class)
4. new DG container with category C_d^p(p: POD, d: dangerous good class)

Output is:
Possible slot for this new coming DG container $(a_n, b_n)\ n \in min(r, t)$
After DG slot assignment model return the possible slots for this new coming DG container, the main slot assignment model will find overlapping parts of the feasible domain and assign this DG container in the domain randomly.

3 EXPERIMENTAL RESULT

To validate the performance of our algorithms, we used a real-world container list from a shipping company in Singapore and ship information for a ship with 13686 TEUs. Table 3 shows the DG feasible region on each bay.

Table 3: DG feasible region.

Bay Number	Rows	Tiers
01	8	8
02	9	9
03	7	8
04	6	9
05	8	10

The loading list can be summarized as Table 4 using a mapping table from IMDG code to numeric class code; 1 to 17 according to the same distance group.

Table 4: Loading List.

DG class	Number of Containers	POD
1	5	Singapore
2	4	Singapore
5	8	Singapore
8	2	Singapore
16	6	Singapore

1. Get all DG classes with POD: Singapore from loading list:
   [1, 2, 5, 8, 16]
2. Find all distance level pairs from DG class:
   {[1, 5, 0], [1, 8, 1], [1, 16, 1], [2, 1, 0],
   [2, 2, 0], …}
3. Filter segregation level 3 pairs:
   [2, 8, 1]
4. Find segregation level 4 pairs:
   {[1, 8, 1], [1, 16, 1]}
5. Get constraints for all segregation pairs. Final output of constraints showed in table 5:

Table 5: Bay Assignment Output.

DG class 1	DG class 2	Bay number	Inside Constraint
2	8	Bay 01	$m_{2i}^{p} + m_{8i}^{p} \leq 48$
1	5	Bay 01	$m_{2i}^{p} + m_{8i}^{p} \leq 56$
1	2	Bay 01	$m_{2i}^{p} + m_{1i}^{p} \leq 56$
2	2	Bay 02	$m_{2i}^{p} \leq 5$

For DG slot assignment model, we interpreted a small part of bay assignment data as an input.

Table 6: Slot Assignment Input.

DG Class	Assigned Bay	Number of Containers
1	Bay 01	5
2	Bay 01	4
5	Bay 01	8
8	Bay 02	2

By calling the DG assignment model for DG containers one by one, the output is showed below:

Table 7: Slot Assignment Output.

DG Class	Assigned Bay	Possible Slot
1	Bay 01	(1,2), (1,3), (2,2), …
2	Bay 01	(1,2), (2,3), (4,2), …
5	Bay 01	(3,1), (3,2), (3,3), …
8	Bay 02	(1,1), (1,3), (2,1), …

Using the result of Table 7, any slot assignment model will find overlapping parts of the feasible domain and assign DG containers one by one with other types of containers according to stacking rules.

In summary, From the result of Table 5, we can add the constraints into any MIP model to determine the number of containers in each position. After determining the number of containers, sequential allocation module for stacking containers finally fix the slot of containers out of the result of Table 7.

4 CONCLUSIONS

In this paper, we proposed a method to find feasible solutions for dangerous goods allocating problem in ship stowage planning. We used real-world data to do experiments and get in-house rules from ship companies. We successfully built a bay assignment model to separate DG containers into segregation level groups based on standard IMDG segregation table and completed an MIP model with constraints about hazardous containers to assign different groups of containers into bays according to specific ship structure. We made the slot assignment model as a function which can be called to recommend feasible slots for a given DG container according to assigned container distribution and segregation rules between the new coming DG class and the existing ones.

As a future work, we need to consider any in-house rule that applies only a specific port as user-defined input. In addition, unlike the standardized DGs discussed so far, there exist OOG-DG type of containers, which is difficult to handle since they have the property of both OOG and DG. We can use data mining technology to find patterns of special types of slotting inside the data based on the historical data from shipping companies.

REFERENCES

shashi kallada. June 3, 2015. Stowage and Segregation of Dangerous Goods on General Cargo Ships. IMDG Code Compliance Centre

J. G. Kang, Y. D. Kim. Stowage planning in maritime container transportation. *Journal of the Operational Research Society (2002) 53, 415¨C426.*

ID. Wilson and PA. Roach. Container stowage planning: a methodology for generating computerised solutions. *Journal of the Operational Research Society (2000)*.

Anna Sciomachen, Elena Tanfani. A 3D-BPP approach for optimizing stowage plans and terminal productivity. *European Journal of Operational Research (2005).*

Pacino, Dario, Jensen, Rune Møller. Fast Generation of Container Vessel Stowage Plans. *PhD Thesis (IT University of Copenhagen)*

Daniela Ambrosino, Anna Sciomachen, Elena Tanfani. A decomposition heuristic for the container ship stowage problem. *Journal of Heuristics (2013).*

APPENDIX

Appendix 1: part of Matrix A.

Matrix A

class	1.1,1.2,1.5	1.3,1.6	1.4	2.1	2.2	2.3	3	4.1	4.2
1.1,1.2,1.5	0	0	0	1	0	0	1	1	1
1.3,1.6	0	0	0	1	0	0	1	2	2
1.4	0	0	0	0	0	0	0	0	0
2.1	1	1	0	0	0	0	0	0	0
2.2	0	0	0	0	0	0	0	0	0
2.3	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0
4.1	1	2	0	0	0	0	0	0	0
4.2	1	2	0	0	0	0	0	0	0
4.3	1	1	0	0	0	0	0	0	0
5.1	1	1	0	0	0	0	0	0	0
5.2	1	1	0	0	0	0	0	0	0
6.1	0	0	0	0	0	0	0	0	0