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ORIGINAL ARTICLE

Applying expert knowledge to containership stowage planning: an empirical study

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Abstract Several maritime accidents have been caused recently by inappropriate stowage planning of cargo ships, specifically large containerships. This study focuses on improving stowage planning to increase navigational safety. Whereas most previous studies have only considered the position of containers in a ship, the stowage planning developed here considers container positions both onboard and at the terminal. The role of navigational safety requirements—such as metacentric height, trim, heel, bending moment, torsional moment, draft and adherence to International Maritime Dangerous Goods code—code has also been largely absent from previous studies. Therefore, our study proposes stowage planning methods that meet the above safety requirements. An empirical stowage planning study, applied to five containerships of an international shipping company, is presented. The five cases illustrate the effectiveness of the stowage planning methods developed in this paper.

Keywords Stowage planning · Containership · Maritime logistics · Transportation economics · Expert knowledge

1 Introduction

Containerization is one of the most important transportation methods in international trade and approximately 90% of all non-bulk cargo is carried by containerships (Delgado et al. 2012). With the size and sophistication of new containerships,

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it is becoming very important for liner shipping companies to be able to quickly and efficiently load and unload containers. This saves money on charter rates and port fees, increasing the turnover of the ship. Stowage planning of a containership involves determining the optimal positioning of to-be-stowed containers and it is a complex optimization process, comprising economic, locational and safety decisions.

When loading a ship, both the final positions of the containers onboard and their initial locations in the container yard must be considered. The containers to be loaded may be located randomly around the terminal. Thus, the yard crane location must be optimized to obtain the shortest transport paths and loading time. This is the locational aspect of stowage planning. The safety aspect of stowage planning requires the finished stowage plan to meet navigational safety requirements including metacentric height (*GM*), trim, heel, bending moment, torsional moment and draft. The separation requirements indicated by the International Maritime Dangerous Goods (IMDGs) code must also be respected. Meeting these requirements ensures that the containership can navigate safely from the loading to the discharging port.

Developments in the maximum size of containerships have been spectacular. In 2016, the largest containerships ever—with a capacity of 22,000 TEUs—were delivered to Maersk Line (UNCTAD 2017). Increases in ship capacity, however, have made stowage planning more complex. The operational efficiency and cost effectiveness of container terminals depend on having an appropriate container moving plan in place—known as a “stowage plan” or “master bay plan” (Sciomachen and Tanfani 2007; Dubrovsky et al. 2002). Therefore, one of the most important procedures in stowage planning is to minimize the number of unnecessary movements, called re-shifts (rehandles or over-stowage).

Stowage planning is not only relevant to stowage planners working for shipping companies, but also to the planners at container terminals who are involved in loading, unloading and storing thousands of containers each day (Monaco et al. 2014). Terminal operators involved in stowage planning (i.e. terminal planners) strive to offer highly efficient services to calling ships, via efficient management of terminal resources such as berths, gantry cranes, yard spaces and equipment. Due to the inherent difficulty of the underlying planning problems, operating a container terminal is often complex, involving some uncertainty.

Terminal planners employ a step-by-step approach when planning for a ship’s arrival, which begins with the allocation of a berth and continues with the assignment of gantry cranes and reservation of terminal space for the storage of containers. If necessary, terminal planners may rearrange the cargohandling sequence, as the arrival time of the vessel approaches.

The efficiency of cargohandling depends on the quality of terminal operations, as terminal operators are responsible for carrying out the shipping company’s cargohandling instructions. The presence of a good storage plan at a terminal has a significant positive impact on a containership’s cargohandling operations. When terminal operators participate in the stowage planning process, terminal operating costs are reduced and cargohandling efficiency is enhanced.

Few previous studies have discussed the safety issues involved in stowage planning. To fill gap in the literature, this paper addresses both the safety issues involved in stowage planning *and* the inter-dependent relationship between terminal storage operations and containership cargohandling operations.

2 Literature review

Previous studies on stowage planning can be grouped into four categories based on area of focus: mathematical programming methods, minimizing rehandles, computer-aided systems and joint planning of ship *and* terminal.

A number of earlier studies have developed stowage planning systems using mathematical programming models (Botter and Brinati 1992; Avriel and Penn 1993; Chen et al. 1995; Imai et al. 2002). However, over-simplified hypotheses have rendered these models unsuitable for practical stowage planning operations (Sciomachen and Tanfani 2007). Ambrosino et al. (2009) considered containership stability and determined stowage plans by using a Tabu Search meta-heuristic approach. Delgado et al. (2012) presented constraint programming (CP) and integer programming (IP) models for stowing a set of containers in a single bay section. Their stowage planning focused on the container stowage problem for below-deck locations (CSPBDLs) and they found that both CP and IP models could quickly solve the problem. The authors thus suggested that future research should extend the CSPBDL model to include on-deck locations and special containers including out-of-gauge, pallet-wide and dangerous cargo containers.

Other studies on stowage planning have dealt with the problem of minimizing the number of rehandles. Avriel et al. (1998) introduced a 0–1 IP model that considers all containers to have the same features and focuses on minimizing container rehandles. Dubrovsky et al. (2002) developed a stowage planning model for minimizing the number of container movements while taking into account some ship stability constraints. Yan et al. (2005) applied mathematical programming to develop an optimal stowage planning system with uncertain demand. Ding and Chou (2015) developed a heuristic algorithm that can generate stowage plans with a reasonable number of shifts. This algorithm could be extended to deal with more complex stowage planning problems, such as additional weight constraints (e.g. a heavier container cannot be stacked on a lighter one), mixture constraints (e.g. when different sizes of containers are stacked together) or balance constraints.

In addition, some scholars have developed computer-aided stowage planning systems. Chou (1993) used *knowledge-base*—a concept used in data mining and knowledge discovery, see Qin et al. (2018)—to stowage planning of containerships. The application of artificial intelligence to cargo stowage planning has also been explored (Wilson and Roach 2000).

Few studies have considered jointly stowage planning onboard ship *and* at yard. Sciomachen and Tanfani (2007) proposed a 3D stowage planning approach for evaluating how stowage plans can influence terminal performance. However, while their approach produced stowage plans that minimized total loading time and allowed for the efficient use of terminal equipment, it did not consider the ship safety constraints mentioned above.

Monaco et al. (2014) presented a binary integer model for solving stowage planning problems. The model considered container position onboard, position in the yard, maximum permissible weight of each stack, cargohandling time, and cargohandling equipment. Araujo et al. (2016) proposed a hybrid method Pareto clustering search (PCS) for solving container stowage problems. Their computational results showed that PCS provides better solutions to the container stowage planning problem than previous approaches.

Most of the above studies (and more) have focused on 20- or 40-ft containers, and few have discussed special containers such as out-of-gauge, pallet-wide or dangerous cargo containers. Moreover, most studies have only examined the position of containers onboard and ignored their storage location in the container yard. In addition, few stowage planning studies have considered navigational safety issues encountered while cargohandling. This paper develops an expert stowage planning system that accounts for special containers, the positions of containers both at the container yard and in the ship, and navigational safety requirements.

3 Procedures for stowage planning

Stowage planning is a highly complex task requiring complete information on the containers to be loaded or unloaded and the vessel carrying them. Stowage planning usually requires the input of experts or planners with extensive working experience at terminal yards or onboard containerships. In general, the stowage planning of a containership consists of two main phases: pre-stowage planning and final stowage planning (Steenken et al. 2004; Alvarez 2006; Monaco et al. 2014). Pre-stowage planning is carried out by planners at the head office of the shipping company. These planners have access to complete information on all containers to be loaded and unloaded at each port of call on a shipping route.

Final stowage planning is undertaken by terminal planners who focus only on the containers to be loaded and unloaded at their own terminal. Final stowage planning involves determining the sequence of cargohandling, and assigning the required gantry cranes and yard equipment. The detailed procedures involved in pre-stowage and final stowage planning are outlined below.

3.1 Pre-stowage planning

There are five steps involved in the pre-stowage planning process (Fig. 1).

3.1.1 Receive the general stowage plan for the vessel

First, the planners of the carrier receive the vessel's general stowage plan when the ship has departed from the last port. The general stowage plan indicates how many containers are to be discharged at the next port, thus allowing a quick recalculation

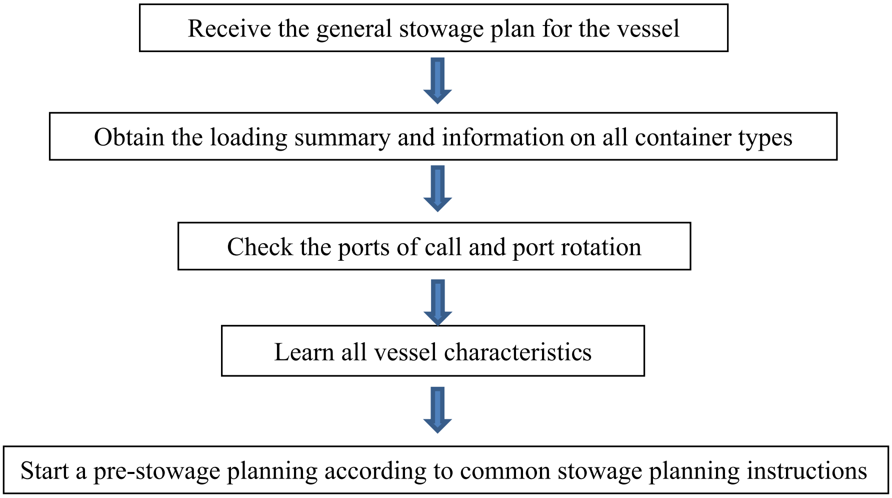


Fig. 1 Flowchart showing the steps involved in pre-stowage planning

of the number of empty spaces there will be, for loading the containers waiting at that port.

3.1.2 Obtain the loading summary and information on all container types

Containers are usually classified on attributes such as dimensions (20-, 40-, 45-ft, high cube or over size), weight (light, medium or heavy), nature of cargo (dangerous, perishable), special type (reefer, open-top) and port of destination. Terminal planners must obtain the loading summary, loading list, reefer containers list, dangerous containers list and special cargo list from the shipping company planners.

3.1.3 Check the ports of call and port rotation

Stowage planners always aim to maximize vessel capacity utilization: the number of containers loaded and the freight income received. They also strive to minimize the number of onboard container rehandles. These two objectives are often in conflict. For example, consider the following situation: at a given port (P_A), a rehandle occurs when a container destined for the next port (P_B) must be temporarily unloaded and then reloaded in a different position, so that additional P_A containers can be discharged. When planners load more containers, to maximize vessel capacity utilization and freight income, more container rehandles shall most likely be necessary. On the other hand, if fewer containers are loaded, so as to avoid rehandles, the shipping company receives less freight and associated income. Thus, stowage planners must *check* the ports of call by reviewing the pre-stowage plan and the rotation of ports of call.[1]

3.1.4 Learn all vessel characteristics

It is important for a planner to know all characteristics of a vessel (e.g. weight constraints such as maximum stack weight, and the positions of common, dangerous and reefer containers). The position of a container in a vessel is determined by its three coordinates: bay, row and tier, representing the longitudinal, transverse and vertical positions, respectively. The cargo hold of a vessel is divided sequentially into several bays, from bow to stern, and each bay is divided by a hatch cover into an on-deck and a below-deck section. Each stack of containers has a weight and height limit, and stack cells are divided into two slots: fore and aft. Some slots—known as reefer slots—have outlets to provide electricity to containers that require refrigeration. Others are not appropriate for stowing dangerous containers. Regarding container weights, an empty 20-ft container weighs about 2.5 tons and its maximum loading weight is approximately 28 tons.

3.1.5 Start a pre-stowage plan according to common stowage planning instructions

Common stowage planning instructions are as follows (Sciomachen and Tanfani 2007; Ambrosino et al. 2009):

- Containers of the same class are to be stowed together, or in adjacent slots, to minimize total cargohandling time.
- A 45-foot container is usually loaded on deck.
- Open-top containers are usually loaded on the top on-deck tier.
- Two 20-foot containers cannot be stacked on top of a 40-foot container, but a 40-foot container can be stacked on top of two 20-foot containers.
- The loading of a dangerous container must obey separation requirements according to the IMDG code associated with the cargo.

Dangerous cargo is divided into nine categories: explosives, gases, flammable liquids, flammable solids, oxidizing substances and organic peroxides, toxic and infectious substances, radioactive material, corrosive substances and miscellaneous dangerous substances. The four levels of separation given by IMDG code are (1) away from, (2) separated from, (3) separated by a complete compartment or fold from and (4) separated by an intervening complete compartment or hold from (IMO 2016). An example of separation instructions according to IMDG code is shown in Fig. 2.

[1] *Checking* in this context refers to containers with the farthest destinations being loaded at the lowest positions inside the ship. Different notations or colours on the stowage plan usually represent different container discharging ports.

CLASS	1.1 1.2	1.3 1.6	1.4	2	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	4	2	2	4	4	4	4	4	4	2	4	2	4	X
1.3, 1.6	*	*	*	4	4	2	2	4	3	3	4	4	4	2	4	2	2	X
1.4	*	*	*	2	2	1	1	2	2	2	2	2	2	X	4	2	2	X
2	4	4	2	X	X	X	X	2	1	2	X	2	2	X	4	2	1	X
2.1	4	4	2	X	X	X	X	2	1	2	X	2	2	X	4	2	1	X
2.2	2	2	1	X	X	X	X	1	X	1	X	X	1	X	2	1	X	X
2.3	2	2	1	X	X	X	X	2	X	2	X	X	2	X	2	1	X	X
3	4	4	2	2	2	1	2	X	X	2	1	2	2	X	3	2	X	X
4.1	4	3	2	1	1	X	X	X	X	1	X	1	2	X	3	2	1	X
4.2	4	3	2	2	2	1	2	2	1	X	1	2	2	1	3	2	1	X
	4	4	2	X	X	X	X	1	X	1	X	2	2	X	2	2	1	X
5.1	4	4	2	2	2	X	X	2	1	2	2	X	2	1	3	1	2	X
5.2	4	4	2	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	X	1	X	1	1	X	1	X	X	X
6.2	4	4	4	4	4	2	2	3	3	3	2	3	3	1	X	3	3	X
7	2	2	2	2	2	1	1	2	2	2	2	1	2	X	3	X	2	X
8	4	2	2	1	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

Fig. 2 An example of separation instructions by IMDG code

The planners at the shipping company's head office carry out pre-stowage planning using CASP software, which is used by several major shipping companies. Figure 3 shows an example of an initial pre-stowage plan.

3.2 Final stowage planning

There are six procedures involved in final stowage planning (Fig. 4).

3.2.1 Assign gantry cranes to the vessel according to the pre-stowage plan

First, terminal planners at the loading port assign gantry cranes to the vessel based on the pre-stowage plan (Fig. 3). Their aim is to equalize as much as possible the number of containers that each gantry crane will handle.

3.2.2 Obtain the terminal yard plan and determine the number of containers to be loaded

Once the terminal yard plan is received and the number of containers to be loaded is known, terminal planners identify the positions of reefer, dangerous and special containers to be loaded. Then, using CASP software, terminal planners calculate the *GM*, trim, heel, bending moment, torsional moment and draft values of the fully loaded containers. Based on these calculations, the initial pre-stowage plan may be changed substantially and an adjusted pre-stowage plan generated.

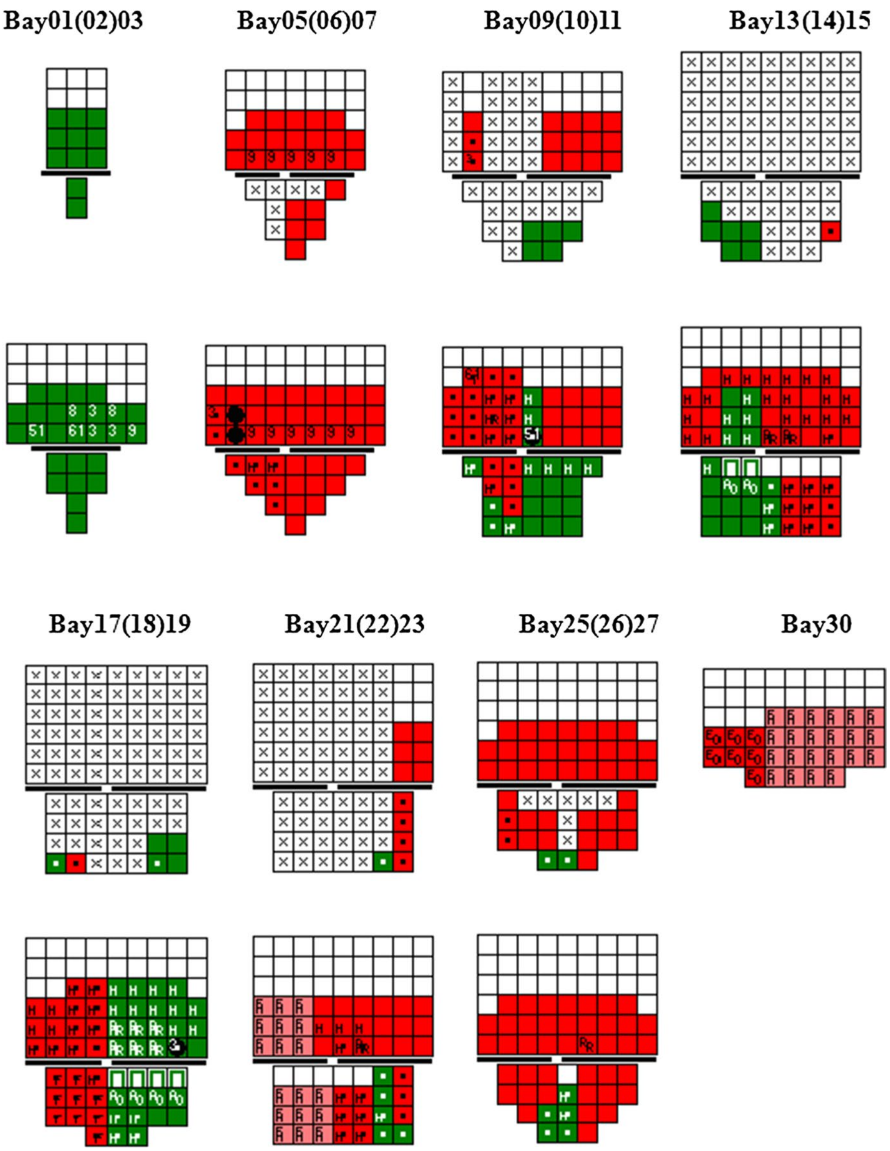


Fig. 3 An example of an initial pre-stowage plan

3.2.3 Stow containers according to the adjusted pre-stowage plan

Containers are loaded into the vessel according to the sequence specified in the adjusted pre-stowage plan. At this stage, the goal is to minimize the number of containers that will need to be rehandled in the vessel or at the yard. The crane split must be appropriate to avoid crowding of the cargohandling equipment.

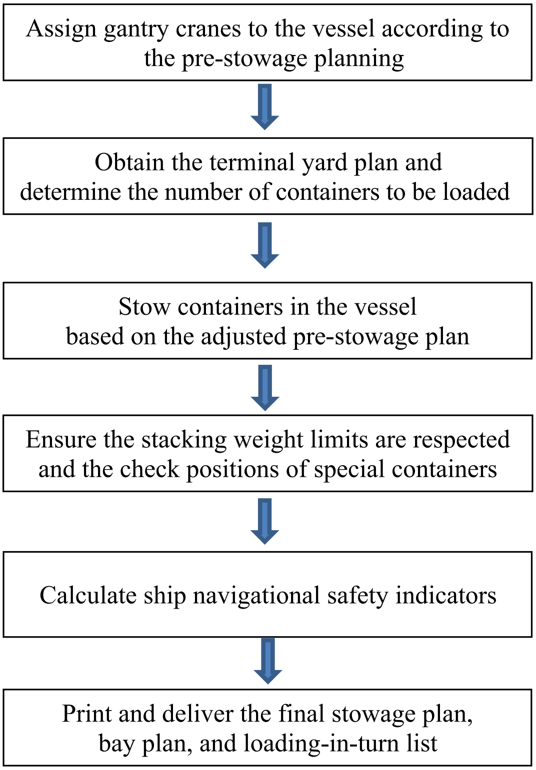


Fig. 4 Flowchart showing the steps involved in final stowage planning

3.2.4 Ensure stacking weight limits are observed and check positions of special containers

Terminal planners must ensure that the weight of containers to be stowed respects the stacking weight limit, and double check the positions of reefer and dangerous containers. Once this is complete, the number of containers to be re-stowed at the container yard can be calculated.

3.2.5 Calculate ship navigational safety indicators

Terminal planners note the bunker oil, fresh water and ballast water levels of the ship. They then re-calculate the *GM*, trim, heel, bending moment, torsional moment and draft values of the loaded ship. Each of these values must meet the requirements for safe ship navigation, and if there are problems, stowage adjustments are made at this point. Once all navigational safety requirements are met, the adjusted pre-stowage plan becomes the final stowage plan (Fig. 5 shows an example of a final stowage plan).

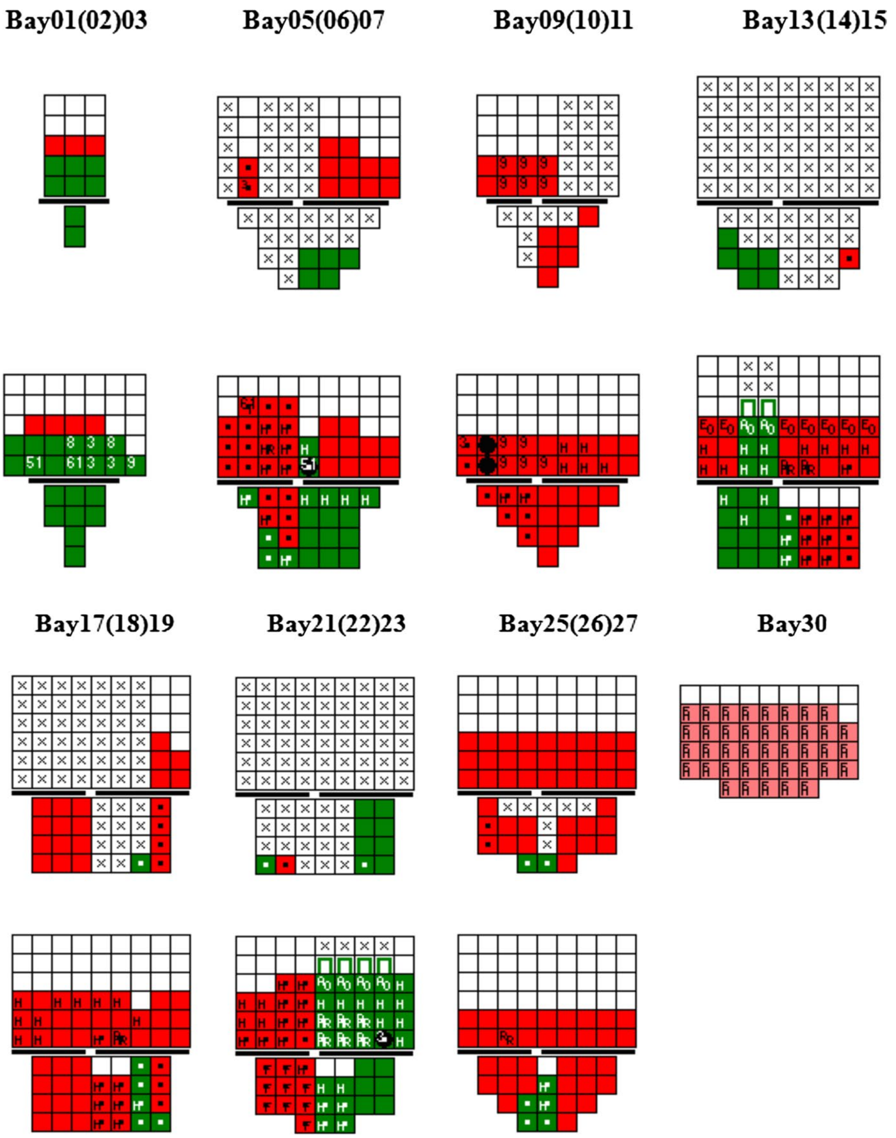


Fig. 5 An example of a final stowage plan

3.2.6 Print and deliver the final stowage plan, bay plan and loading-in-turn list

The last step in the final stowage planning procedure is to print the final stowage plan, bay plan and loading-in-turn list, and deliver copies to the relevant individuals: the deck officer of the containership, the tallyman, the container yard operator and any other relevant operators.

4 Empirical Study

In this section, we present five stowage planning case studies taken from actual ships operated by an international shipping company. All case studies describe the solutions, found and carried out by the terminal planners of Kaohsiung Port, while checking different navigational safety calculations in the initial pre-stowage plans received from the carrier. Each case study focuses on a different navigational safety indicator. The indicators considered are *GM*, trim, heel, bending moment and torsional moment.

4.1 Case 1: Metacentric height (*GM*)

Metacentric height (*GM*) refers to the vertical distance between the ship's centre of gravity (*G*) and its initial transverse metacentre (*M*). This is a very important indicator to consider when loading. It is the responsibility of the officer in charge of loading the ship to ensure that the vessel's *GM* value respects safety requirements. In general, *GM* should not be less than 0.15 m (International Maritime Organization, IMO 2002). The acceptable range of safe *GM* values for a containership is usually 0.9–1.3 m.

Figure 6 shows the initial pre-stowage plan of ship A as prepared by the shipping company. The Kaohsiung Port terminal planners found that, based on the initial pre-stowage plan, the ship's *GM* was 2.07 m. Obviously, this was too high to warrant departure from Kaohsiung, and terminal planners had to make adjustments. After reviewing the plan, planners determined that the problem was caused by the presence of too many heavy containers loaded below deck. The best way to solve this *GM* problem is to move some heavy containers above deck. After doing this, the *GM* of the vessel was reduced to 1.24 m, which falls in the safe range of 0.9–1.3 m. Figure 7 shows the final stowage plan, which reflects the movement of heavy containers above deck.

4.2 Case 2: Trim

Trim refers to the difference between the forward and aft draughts. A ship is said to be on an even keel when the forward and aft draughts are equal. Trim is also a very important consideration when loading a vessel. Usually, a small trim by stern is desirable as most ships are expected to handle better in a seaway in this condition. Trim by bow should be avoided (Rhodes 2003; Derrett 2006).

Figure 8 shows the initial pre-stowage plan for containership B. Based on this plan, the Kaohsiung terminal planners found that the trim of this vessel was 0.71 m by bow. The optimal trim value for the safe operation of this kind of containership is about 1 m by stern. The trim of ship B was apparently unsafe and needed to be changed to permit departure from Kaohsiung. Thus, the terminal planners had to adjust the initial pre-stowage plan. While checking the plan, planners found that too many heavy containers were located in the bow of

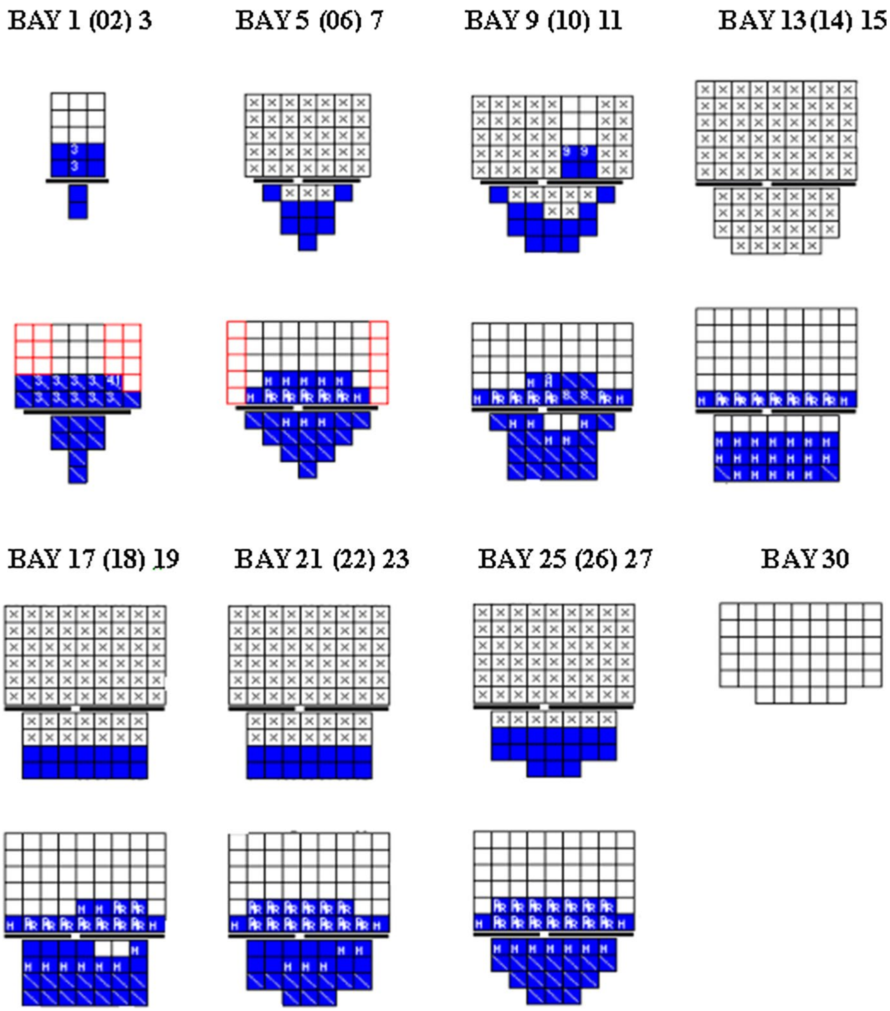


Fig. 6 The initial pre-stowage plan for ship A

the ship and that too many special containers were located toward the stern. In addition, the tanks at the bow were to be filled with a large quantity of bunker oil. These factors resulted in the trim by bow. As Pezzoli and Franza (2000) indicate, ballast water has a significant impact on the trim, heel and navigational safety of a ship. The best way to solve this *trim by bow* problem is to move some heavy containers to the stern, and to drain some ballast water from the bow of the ship. After making these changes, the trim was 0.41 m by stern, which falls within the acceptable range for safe navigation. The final stowage plan for ship B is shown in Fig. 9.

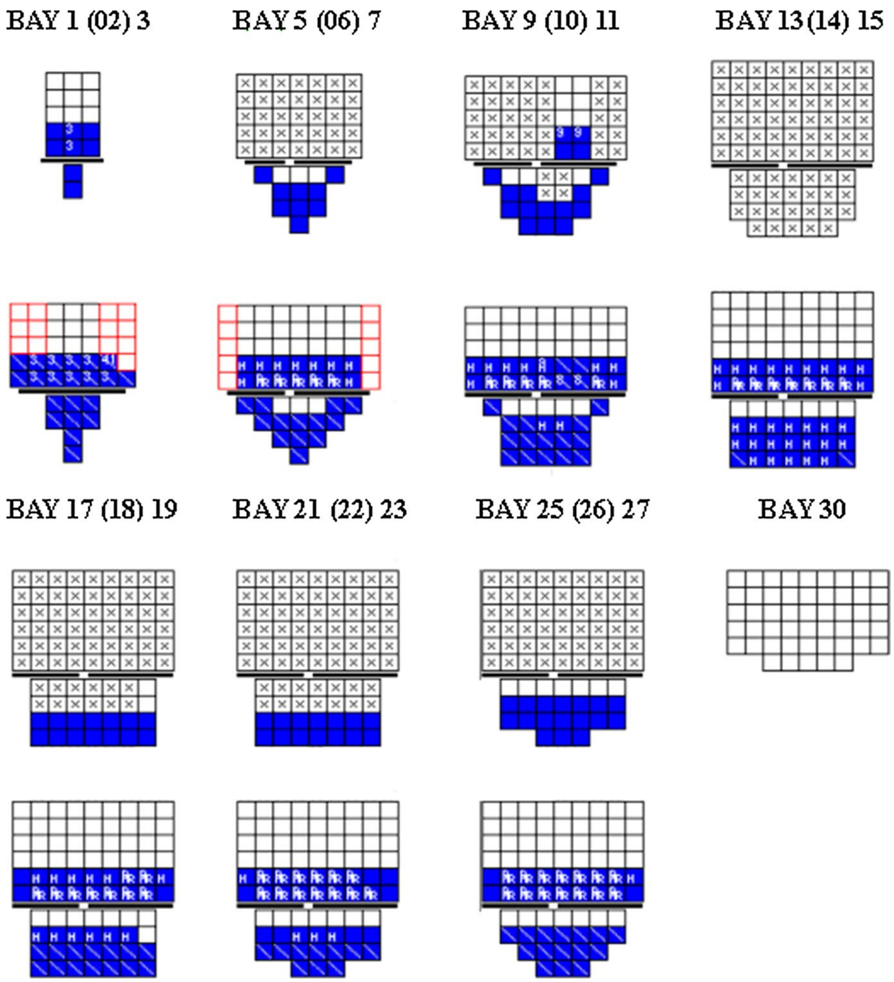


Fig. 7 The final stowage plan for ship A

4.3 Case 3: Heel

Heel and *list* are terms used to describe a ship that is leaning either to port or starboard due to the weight distribution of its cargo, or that it has been forcibly inclined by external forces such as wind or waves. The angle of list describes how much a ship is heeling to one side or the other. If a ship is upright (i.e. the angle of list is zero after loading), this is the most safe condition to navigate a seaway (Rhodes 2003; Derrett 2006).

Figure 10 shows the initial pre-stowage plan for ship C. The terminal planners found that the *GM*, trim and heel of this containership were 0.37 m, 0.34 m trim by bow and 39.2° to starboard, respectively. These values clearly show that the pre-stowage plan is problematic and the ship cannot depart from Kaohsiung until

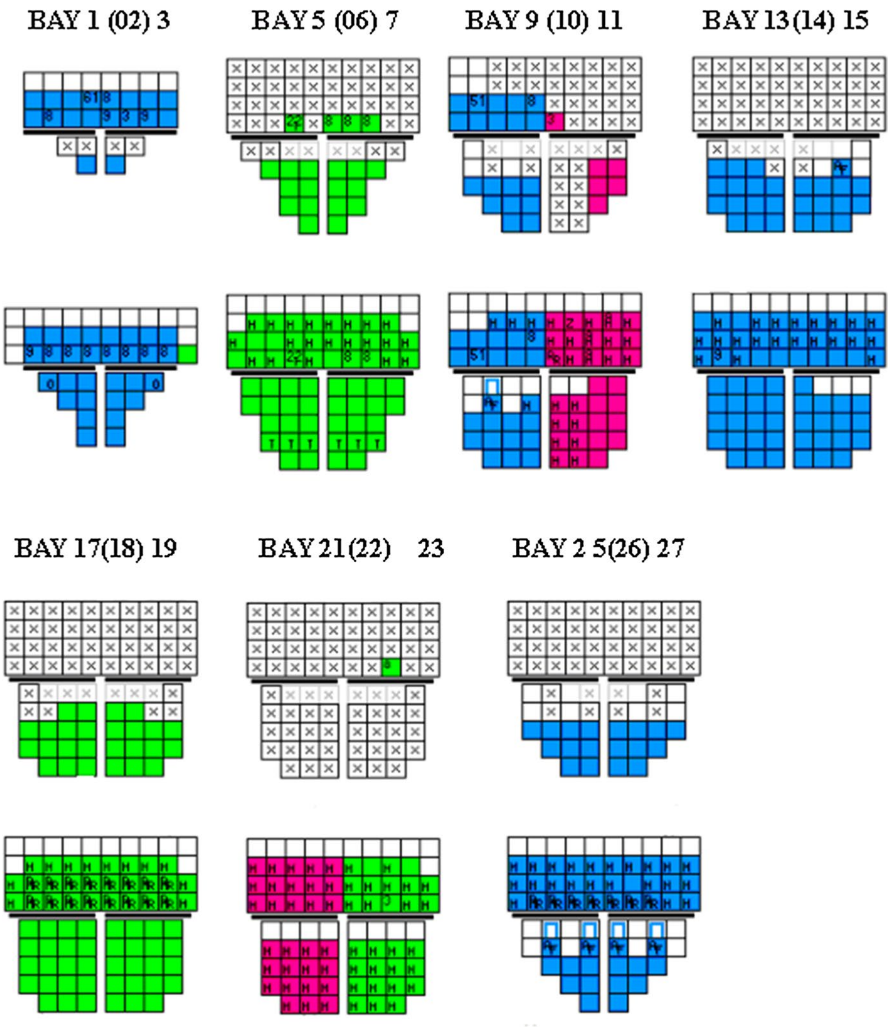


Fig. 8 The initial pre-stowage plan for ship B

the terminal planners have adjusted it (thus rendering it a final stowage plan). Thus, they firstly moved some heavy containers from above to below deck to fix the *GM* problem. Second, to address the trim by bow problem, some heavy containers were moved from the bow to the stern of the ship. Third, some heavy containers were moved from starboard to port side, and ballast water was added to the port side to eliminate the *heel to starboard* problem. As a result of this final stowage planning process, the *GM*, trim and heel values were improved to 0.99 m, 0.57 m trim by stern and heel 0.0°, all of which fall within safe ranges. The final stowage plan is shown in Fig. 11.

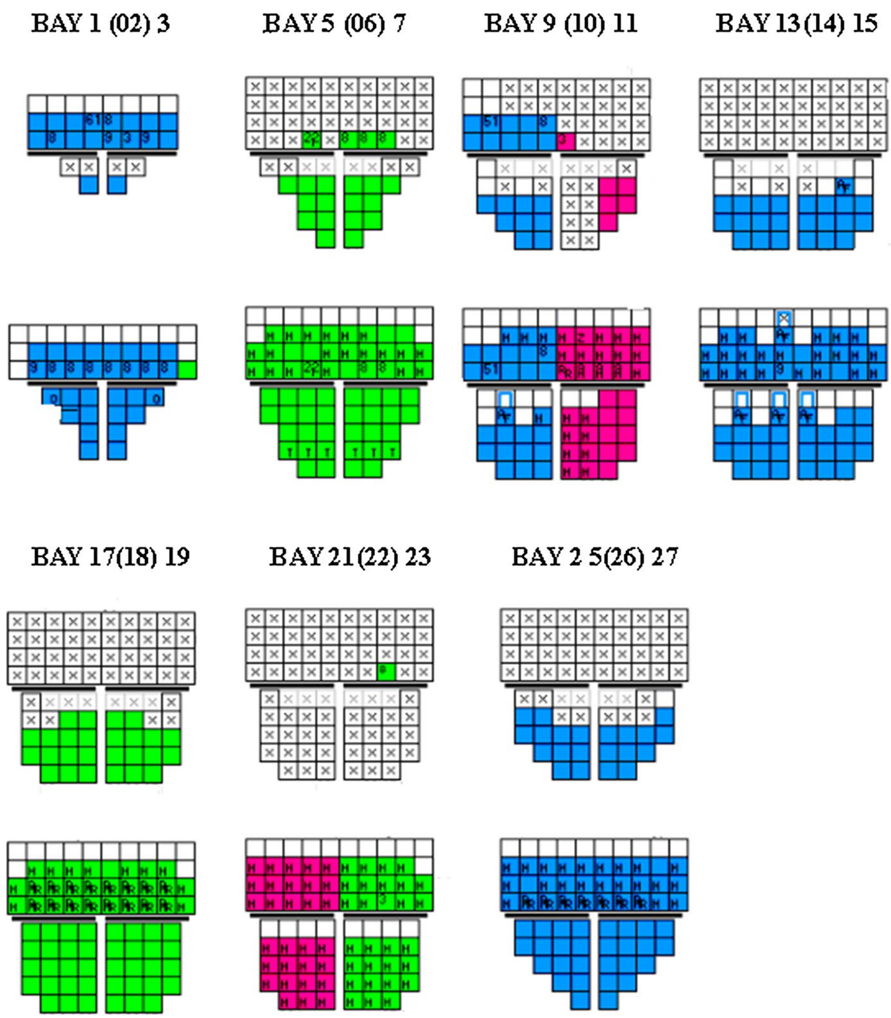


Fig. 9 The final stowage plan for ship B

4.4 Case 4: Bending moment

Hogging or *sagging* is caused by bending moment (as shown in Fig. 12) and both significantly affect the navigational safety of a ship. Hogging results when too many containers are to be loaded on both the bow and stern, or when both bow and stern ballast tanks are filled. Sagging is caused when too many containers are to be loaded in the middle part of a vessel.

When examining the initial pre-stowage plan of ship D, the terminal planners found that *GM* and heel were 1.67 m and 10.9° to port, respectively. While these values were within the acceptable ranges, the ship's trim was 3.51 m by stern, rendering it navigationally unsafe. Figure 13 shows that the bending moment

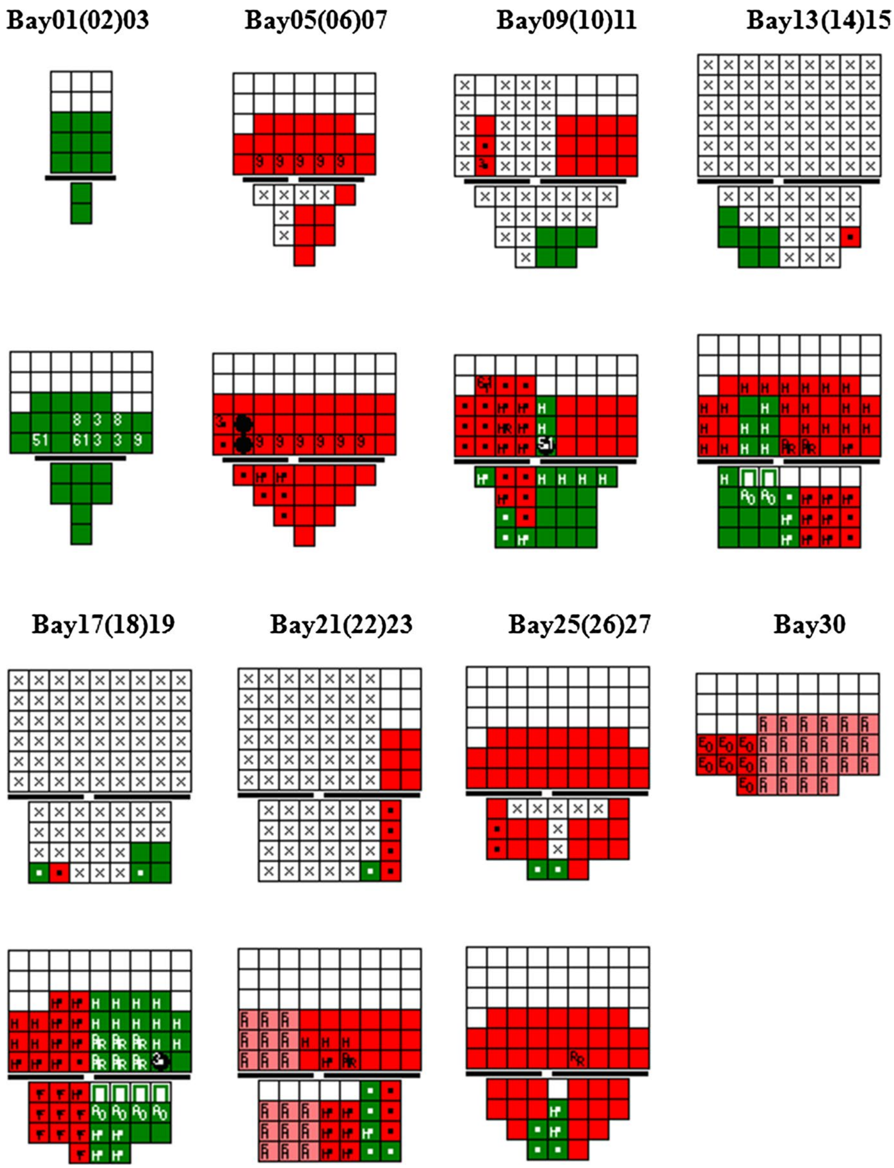


Fig. 10 The initial pre-stowage plan for ship C

curve was outside the safe range, and thus terminal planners had to make changes to the initial pre-stowage plan. First, they decided to move the containers in the vessel as shown in Fig. 14, but the bending moment still fell outside of the safe range. Then, they emptied the stern ballast water to improve the hogging and trim by stern problems. Finally, the starboard side ballast at the middle of the ship was filled with water to improve the heel to port problem. After making

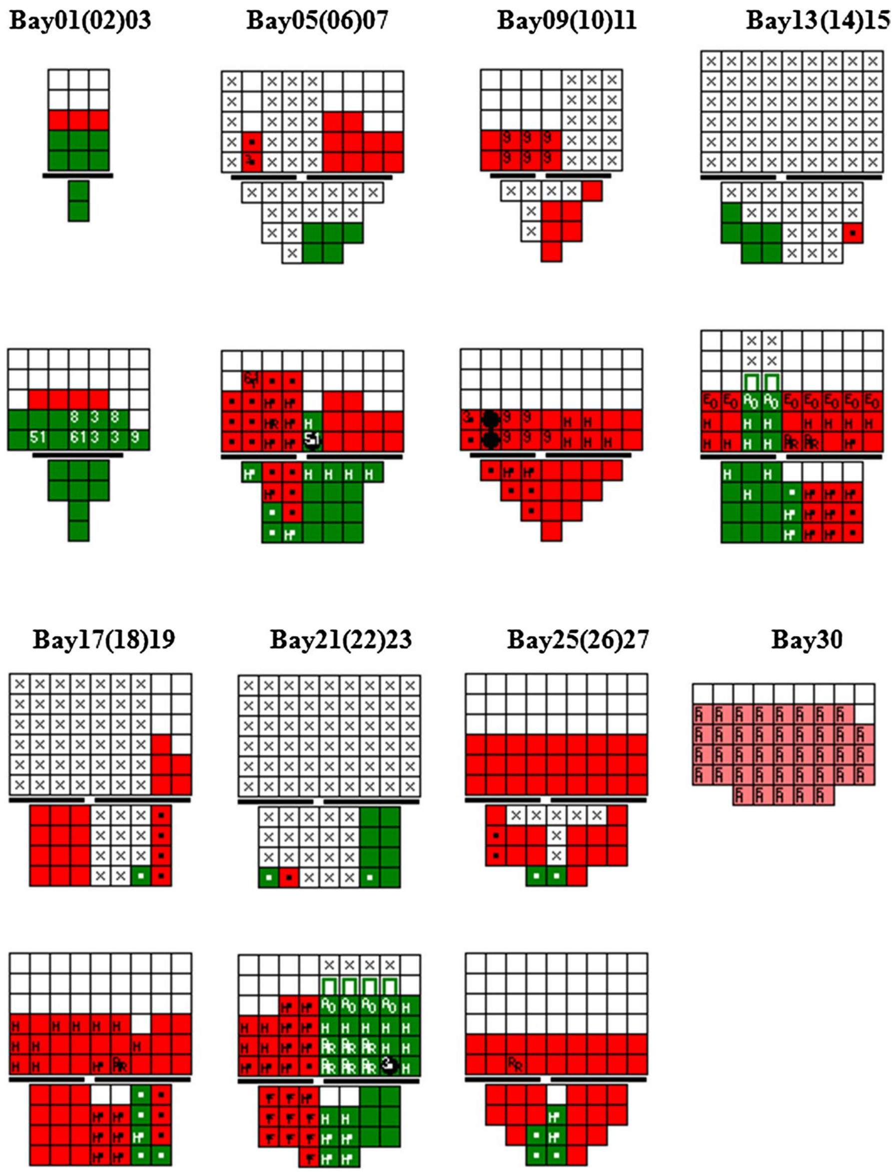


Fig. 11 The final stowage plan for ship C

these changes, the bending moment curve fell within a safe range (Fig. 15). In the final stowage plan, the *GM*, trim and heel were 1.63 m, 1.79 m by stern and 0.4° portside, respectively.

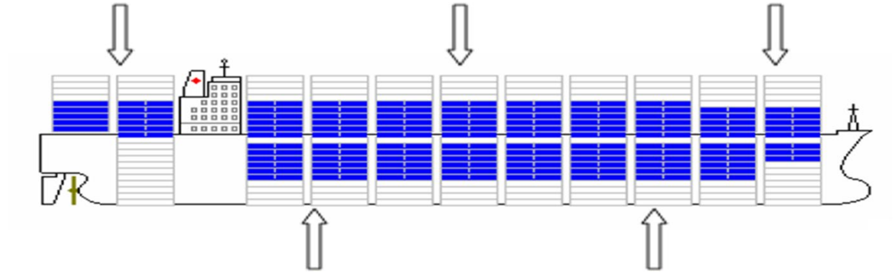


Fig. 12 Bending moment

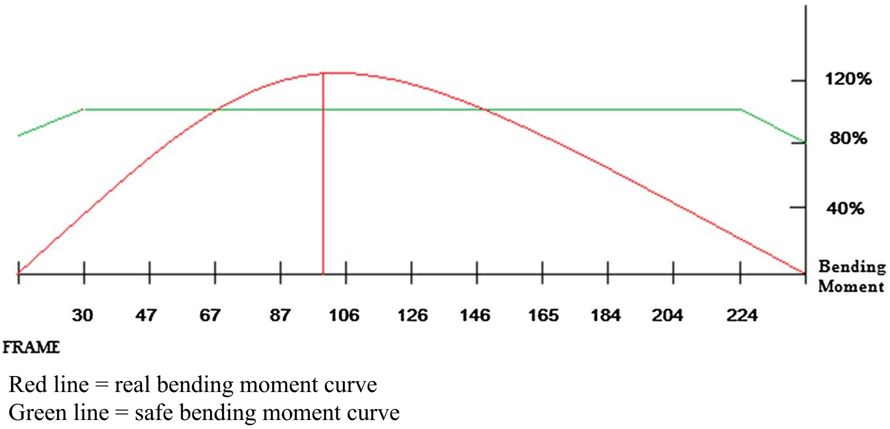


Fig. 13 The bending moment for the initial pre-stowage plan of ship D. (Color figure online)

4.5 Case 5: Torsional moment

Torsional moment (shown in Fig. 16) is caused by an imbalance in loading between the port and starboard sides of a vessel and it is of particular concern in large vessels. When terminal planners reviewed the initial pre-stowage plan of containership E, they calculated that its *GM* was 2.63 m, trim was 1.39 m by stern, heel was 0.6° to starboard and its torsional moment curve was outside the safe range (represented by the green line in Fig. 17). The torsional moment was caused by too many containers being loaded in the port side of cargo holds Nos. 2, 4, 7 and 8, and in the starboard side of cargo holds Nos. 6, 10 and 11.

The best way to solve this torsional moment problem was to change the initial pre-stowage plan so that there was a better balance between the number of containers to be loaded in the starboard and port sides of the ship. Firstly, the terminal planners decided to move all containers in cargo hold No. 9 to the starboard side of cargo hold No. 2. Secondly, some heavy containers in the port side of cargo hold No. 12 were moved to its starboard side. These movements solved

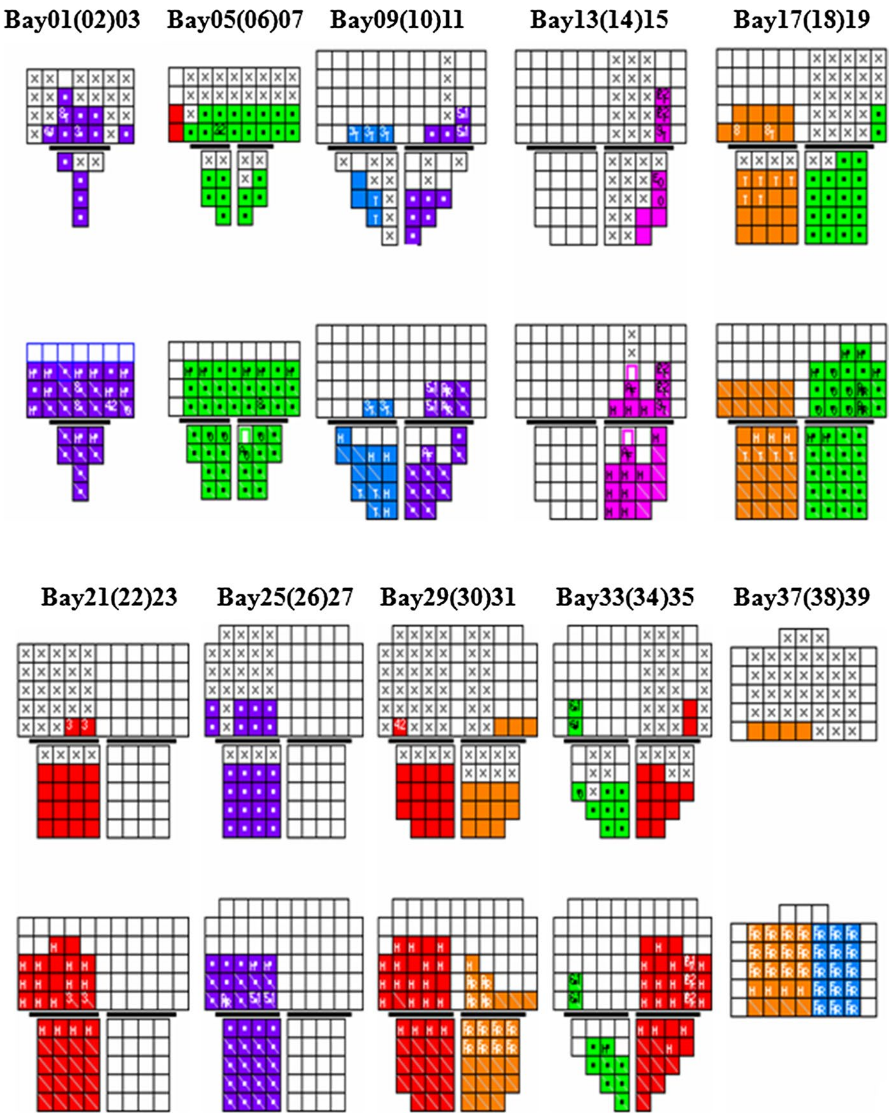


Fig. 14 The initial pre-stowage plan for ship D

the torsional moment problem (Fig. 18 shows the torsional moment curve within a safe range) but they caused another problem: ship E was heeling because too many containers were moved to its starboard side. To address the new problem, terminal planners emptied some ballast water on the starboard side. They then emptied the bottom ballast to reduce *GM*. After these adjustments, the final stowage plan (shown in Fig. 19) met all requirements of navigational safety.

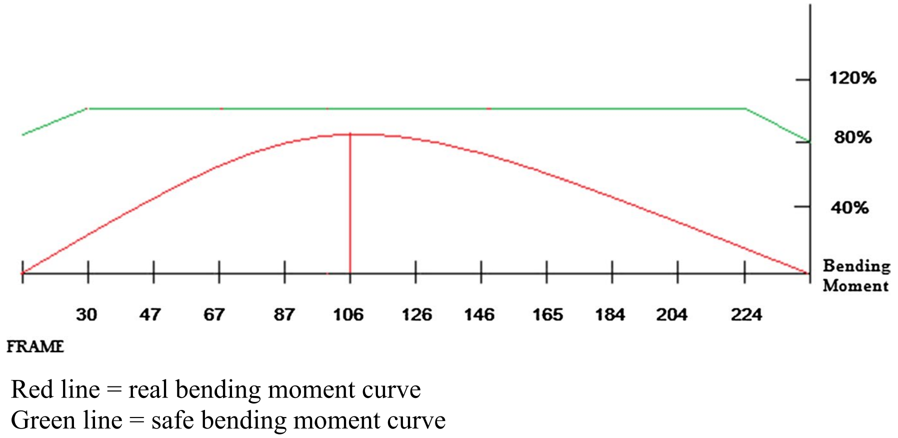


Fig. 15 The bending moment for the final stowage plan of ship D. (Color figure online)

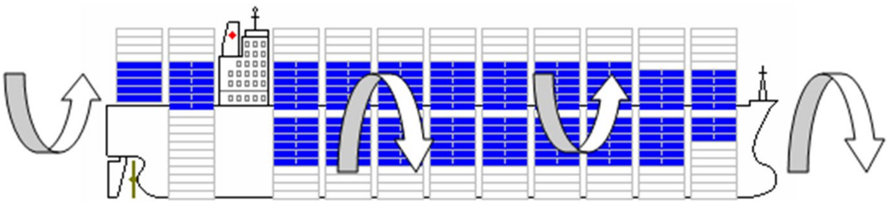


Fig. 16 Torsional moment

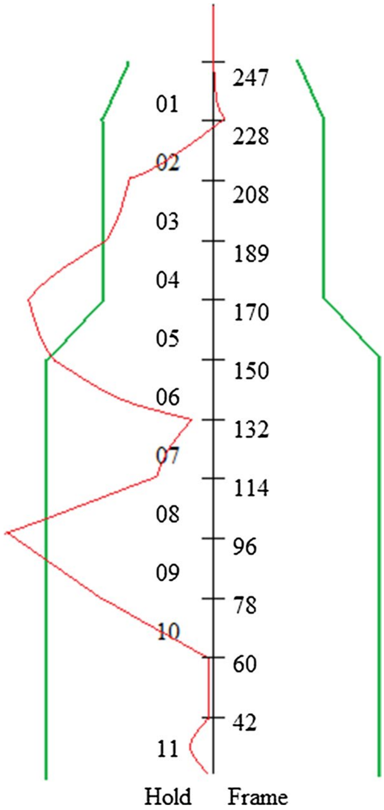
5 Conclusions

The main contributions of this study to the field of stowage planning are (a) a discussion and exposition of the most important stowage planning instructions, and (b) the introduction of faster solutions to stowage planning problems based on expert knowledge gained through extensive work experience. Stowage planners who lack considerable work experience often carry out the stowage planning by try and error, which wastes time.

In the past, most studies focused on either stowage planning of a containership, or stowage planning at a container terminal yard. Few studies have presented a combined analysis of the stowage planning process in both locations. Further, much of the previous literature has only considered common dry containers, without exploring the role of reefer, dangerous and special containers.

In addition, a focus on achieving optimal container positioning onboard a vessel has led many stowage planning studies to ignore aspects of navigational safety.

Fig. 17 Torsional moment curve for the initial pre-stowage plan of ship E. (Color figure online)

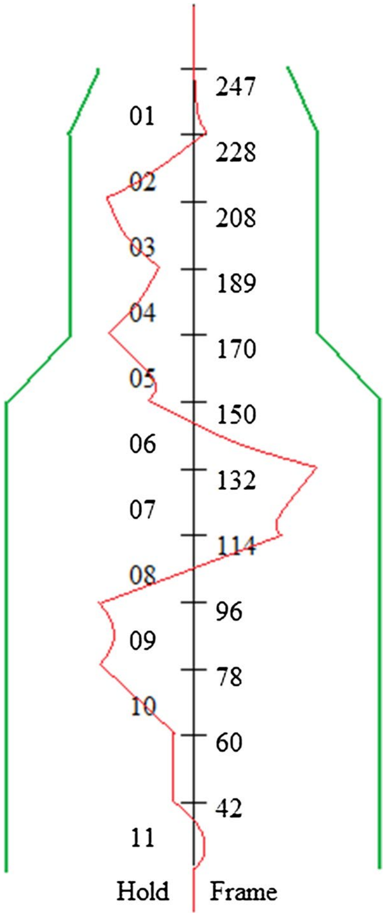


Red line = Actual torsional moment
Green line = Safe torsional moment

Our study addresses this gap by analysing *GM*, trim, heel, bending moment and torsional moment.

Finally, our study presents five empirical stowage planning cases, from an international shipping company, and introduces important stowage planning instructions from experts. The case study results show that stowage planning problems can be solved quickly and directly—rather than by trial and error—when stowage planning instructions and expert knowledge are taken into account. The stowage planning instructions and expert knowledge presented in this study can help stowage planners without extensive work experience in the field to complete planning procedures efficiently and with ease.

Fig. 18 Torsional moment curve for the final stowage plan of ship E. (Color figure online)



Red line = Actual torsional moment
Green line = Safe torsional moment

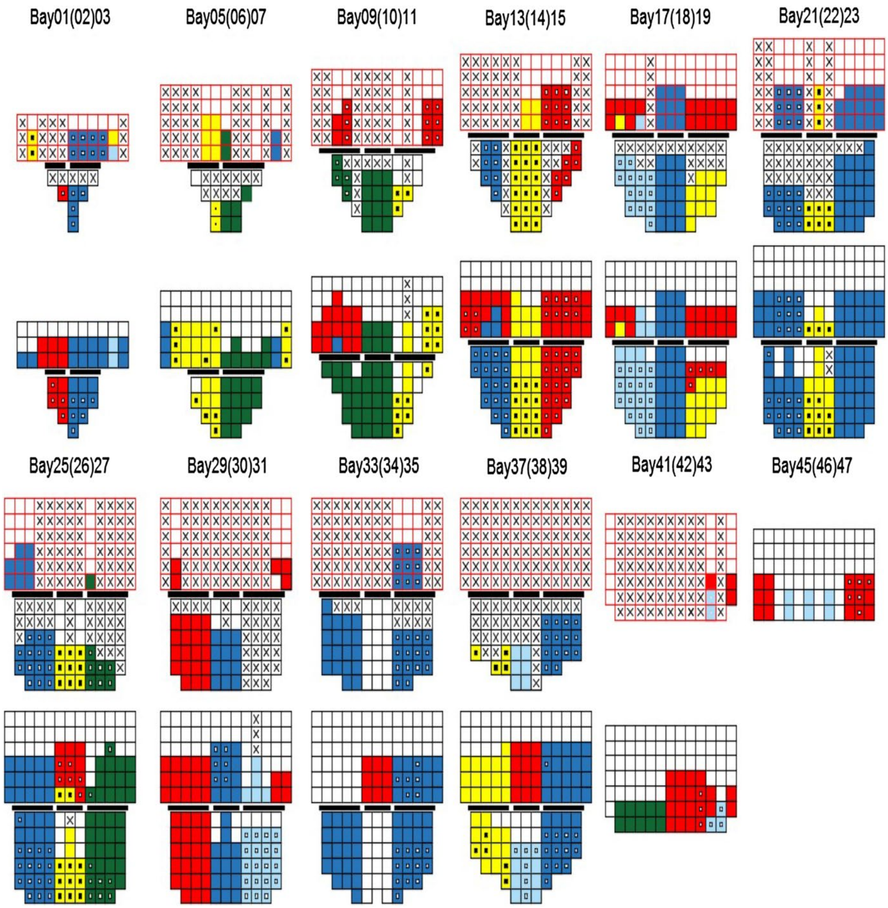


Fig. 19 The final stowage plan for ship E

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