Design and application of reuse stage algorithm of case-based reasoning method on container stowage planning

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Abstract. Stowage planning is a container arrangement planning activity on container ships. The Case-Based Reasoning method can solve the newest stowage plan cases by taking a stowage plan case that has the highest similarity and has been resolved in the past as a reference for arranging. The Case-Based Reasoning method has four-stage, there are Retrieve, Reuse, Revise, Retain. The Reuse stage is to adapt the Container Loading List so that it is arranged to resemble the case that was taken at the Retrieve stage. Algorithms for the Reuse stage of the Case-Based Reasoning Method has been designed and obtained the Container Loading List Adaptation, Fill-Blank, Adding the Remaining Container, Trim Optimization, and GM Optimization Functions. The functions can be implemented in software design and automatically or manually arranged the containers based on Casebase. Hence, users make the new stowage plans easier and faster. Based on the results of software testing, the difference between LCB and LCG is less than 1% LBP so that the Trim was fulfilled, and GM obtained a positive value so that the ship was in a stable condition.

1. Introduction
Stowage planning is a container arrangement planning activity on container ships. Stowage planning has a long history in its development. That is because stowage planning is very necessary to keep the ships in a stable condition and minimize operational costs used for container loading and unloading activities[1]. If the container is not placed in the right places and not following the condition of the ship, it will be a risk of some problems such as damaged goods in containers, the ship suffered a slope because of unstable, or even worse the ship could sink[2].

Until now the stowage planning problem is still not supported by the existence of computerized assistance in its resolution, so the stowage planner has to do his jobs manually to solve each different case in the problem of container stowage planning[3]. Stowage planner also experience obstacles in making decisions, such as setting the priority of container placement when the ship will stop at several ports, placing containers containing dangerous goods, keeping the ship in stable condition and in the process of arranging the container to be moved as minimal as possible so as to reduce the operational costs of loading and unloading containers. Stowage planning is a complex problem caused by uncertainty and different case conditions. Stowage planner resolves every container stowage planning case based on assumptions and experiences that have been experienced in similar cases that have been resolved[4].

Case-Based Reasoning Method is one of the Methods in an expert system that can be used to solve stowage planning problems. Case-Based Reasoning Method can solve the latest stowage planning case by taking the stowage planning case which has the highest similarity and has been resolved in the past
as a reference[1]. Case-Based Reasoning Method has four stages, there are Retrieve, Reuse, Revise, and Retain. Retrieve is to take back the case that has the highest level of similarity and has been resolved in the past, and provide solutions to the Reuse stage. Reuse is to adapt the Container Loading List so that it is arranged to resemble the case taken at the Retrieve stage. Revise is reviewing the results of the container stowage plan that has been obtained at the Reuse stage to be a solution to a new problem, the Revise stage is a conditional stage that may or may not be done (as needed). Retain is storing the latest cases that have been resolved into a database and will be used to solve subsequent problems[5].

In the research by Harwanto N.A. in 2011, "Development of a Case-Based Stowage Planning System Module Prototype for Semi-automatic Container Stowage on Ships", the prototype of the stowage planning system module uses Case-Based Reasoning Method to solve the stowage planning case[4]. However, the prototype only implements the Retrieve stage in the Case-Based Reasoning Method. Whereas the Reuse, Revise and Retain stages are still solved manually on the prototype. Based on previous research, the authors are interested in developing the research by applying the Reuse stage to the container stowage planning system with the Case-Based Reasoning Method to complete the prototype that was made beforehand so that the container stowage planning can be done automatically.

2. Preliminaries
2.1. Case-Based Reasoning Method
Case-Based Reasoning Method is one of the methods in an expert system that can be used to solve stowage planning problems. Case-Based Reasoning method can solve the latest stowage planning case by taking the case of stowage planning that has the highest similarity and has been resolved in the past as a reference[1]. Case-Based Reasoning Method has four stages, there are Retrieve, Reuse, Revise, and Retain. Retrieve is to take back the case that has the highest level of similarity and has been resolved in the past, and provide solutions to the Reuse stage. Reuse is to adapt the Container Loading List so that it is arranged to resemble the case taken at the Retrieve stage. Revise is reviewing the results of the container stowage plan that has been obtained at the Reuse stage to be a solution to a new problem, the Revise stage is a conditional stage that may or may not be done (as needed). Retain is storing the latest cases that have been resolved into a database and will be used to solve subsequent problems[5]. In the Case-Based Reasoning Method, the more data stored in the database of cases it will be the better the results and if the cases data stored in the database-less then the result will be unsatisfactory. The flowchart diagram of the Case-Based Reasoning Method can be illustrated as in Figure 1.

![Figure 1. Flowchart of Case-Based Reasoning Method [5].](image)

2.2. Bay-Row-Tier Coordinate Concept
The Bay-Row-Tier coordinate concept is used to facilitate the visualization of the container stowage planning process. The Bay-Row-Tier concept follows a numerical coordinate system related to length, width, and height. The concept of Bay-Row-Tier coordinates is shown in Figure 2. According to this
principle, Bay is the container in the transverse direction, the Row is the elongated direction and the Tier is the vertical layer[6].

![Figure 2. Bay-Row-Tier Coordinate Concept [6].](image)

2.3. Stable, Unstable and Neutral Conditions

The review of a ship's stability is influenced by three main points, there are the ship's center of gravity ($G$), the ship's floating-point ($B$) and the ship's metacentric point ($M$). Point $G$ is the center of weight of the ship which is affected by ship construction. Point $B$ is the buoyancy pressure point of the volume of water displaced by a part of the ship that is immersed in water. Points $G$, $B$, and $M$ can be illustrated in Figure 3 below.

![Figure 3. G, B, and M Point [7].](image)

The transverse metacentric height is the distance between the transverse metacentric point ($M_T$) and the ship's center of gravity ($G_0$). The $G_0M_T$ value is one of the criteria to assess the stability and comfort of a ship. If the $MT$ point is above $G_0$ then the height of the metacenter is positive, and if the $MT$ is below $G_0$ then the height of the metacenter is negative[8]. In determining the height of the metacenter used the relationship between $KM_T$ and $KG_{0}$, namely:

$$G_0M_T = KM_T - KG_0 \quad (1)$$

Based on the position of the center of gravity, there are three conditions namely stable, unstable and neutral.

2.3.1. Stable Condition. When point $G$ is below point $M$, in this condition $GM$ is positive and the ship is in stable condition. The low $G$ point is due to the heavy load at the bottom of the ship. So that in this condition the ship has an enforcement moment when subject to external forces.

2.3.2. Unstable Condition. When point $G$ is above point $M$, in this condition $GM$ is negative and the ship is in unstable condition. Point $G$ that is too high is caused by too much heavy load on the top of the ship. So that in this condition the ship does not have an enforcement moment when subject to external forces.
2.3.3. Neutral Condition. When point $G$ coincides with point $M$, in this condition $GM$ is zero and the ship is in neutral condition. The high $G$ point is caused by too much heavy load on the top of the ship. If the ship is subjected to force from the outside, then the ship will remain tilted at the same sloping angle [7].

2.4. Trim

Trim is defined as the difference between the draft at the bow of the ship ($D_F$) and the draft at the stern of the ship ($D_A$).

$$\text{Trim} = \frac{BG \times \text{displacement}}{MTc \times 1000}$$

Or it can be written with

$$\text{Trim} = D_F - D_A$$

Where

$$D_F = \text{draft} + \left(\frac{\text{trim} \times (LBP - LCF)}{LBP}\right) \text{and} \ D_A = \text{draft} - \left(\frac{\text{trim} \times LCF}{LBP}\right)$$

Negative results indicate stern trim occurs. In general, it can be divided into three conditions that can be experienced by ships, namely:

a. Evenkeel, when the bow draft of the ship is the same as the stern draft of the ship.

b. Trim by stern, when the bow draft of the ship is smaller than the stern draft of the ship.

c. Trim by bow, when the bow draft of the ship is greater than the stern draft of the ship[8].

Illustration of ship trimming is illustrated in Figure 4 on transverse ship conditions.

![Trim Illustration](image)

**Figure 4.** Trim Illustration [7].

Trim values of the ship are met if the difference between the Longitudinal Center of Buoyancy (LCB) and the Longitudinal Center of Gravity (LCG) values is not more than 1% Longitudinal Between Perpendicular (LBP) of the ship[8].

3. Results and Discussions

3.1. Software Specification and Modelling

3.1.1. Functional Requirements.

a. Software developed using MV. Sinar Jambi as a case study.

b. The system can arrange containers in the Container Loading List based on Casebase automatically.

c. The system can provide the three best container stowage plan recommendations.

d. The system can visualize the results of the container stowage plan.

e. The system can calculate ship stability.

f. The system can display the results of the calculation of ship stability.

g. The system can do the arrangement of containers manually so that users are given the flexibility to adjust the container stowage plan.

h. The system can find out the location of containers on ships.
3.1.2. Use Case Diagram. Use case diagram is a diagram that explains the interaction that occurs in a system with system users. Use case diagram from this system can be seen in Figure 5.

![Use Case Diagram](image)

**Figure 5. Use Case Diagram of The System.**

3.1.3. Activity Diagram. Activity diagrams can be used to explain the workflow or activity of a system. The following system activity diagram is presented in Figure 6.

![Activity Diagram](image)

**Figure 6. Activity Diagram of The System.**

3.1.4. Block Diagram of Reuse Stage. The process interpretation of the system designed can be considered in the block diagram of Figure 7.

![Block Diagram](image)

**Figure 7. Block Diagram of Reuse Stage.**

3.1.5. Container Loading List Adaptation Algorithm. The Container Loading List Adaptation Algorithm aims to adapt the Container Loading List to be a container stowage plan similar to Casebase. Here is the Container Loading List Adaptation Algorithm.

**Input:** Unloaded Container List List and Casebase results of The Retrieve Stage.

**Step 1.** For all container locations in the Casebase, do Steps 2-5.

**Step 2.** Check the weight class of each container in The Casebase.

**Step 3.** For all container locations in the Container Loading List, do Steps 4-5.
Step 4. Look for containers in the Container Loading List that have the same weight class as Step 2.
Step 5. Place the container in Step 4 into the processing system according to the location of the container in Step 2.
Output: Container Loading List stowage plan that corresponds to the container stowage plan in Casebase based on container weight class.

3.1.6. **Fill-Blank Algorithm.** This fill-blank algorithm will solve the problem when the number of containers of a weight class in the Container Loading List is less than the Casebase. Here is The Fill-Blank Algorithm.

**Input:** Container Loading List stowage plan that correspond to the container stowage plan in Casebase based on container weight class.

Step 1. For all container locations in the processing system, do Steps 2-4.
Step 2. Find the location of empty containers in the processing system that results in the arrangement of floating containers.
Step 3. Look for containers to fill the empty container locations in Step 2.
Step 4. Move the container in Step 3 to the location of the container in Step 2.
Output: No arrangement of floating Container Loading List.

3.1.7. **The Algorithm for Adding Remaining Containers.** The Algorithm for Adding Remaining Containers will solve the problem when the number of containers in a Container Loading List is more than in Casebase. Here is an Algorithm for Adding Remaining Containers.

**Input:** arrangement Container Loading List is not floating and Container Loading List which is not arranged.

Step 1. For all containers in The Container Loading List which is not arranged in the processing system, do Step 2.
Step 2. Insert the container obtained in Step 1 into the processing system according to the container weight class.
Output: Container Loading List has been arranged completely.

3.1.8. **Trim Optimization Algorithm.** This Trim Optimization Algorithm aims to optimize container stowage plan in the processing system that has loaded all containers in the Container Loading List to get the smallest trim possible when the difference between the Longitudinal Center of Buoyancy and the Longitudinal Center of Gravity is no more than 1% Length Between Perpendicular of the ship. Here is The Trim Optimization Algorithm.

**Input:** Container Loading List has been arranged completely.

Step 1. Check the condition of the ship. When the ship has a bow trim then do Steps 2-4, when the ship has a stern trim then do Steps 5-7.
Step 2. Look for heavy containers on the bow of the ship.
Step 3. Look for lighter containers at the stern of the ship.
Step 4. Swap the location of the container between Step 2 and the container in Step 3.
Step 5. Look for heavy containers on the stern of the ship.
Step 6. Look for lighter containers on the bow of the ship.
Step 7. Switch the location of the container between Step 5 and the container in Step 6.
Step 8. When LCB-LCG <1% LBP then the process stops. When LCB-LCG> 1% LBP then return to Step 1.
Output: Container Loading List stowage plan that has the smallest trim possible (When LCB-LCG <1% LBP).

3.1.9. **GM Optimization Algorithm.** This GM optimization algorithm aims to optimize the container stowage plan of the processing system to get a positive GM, so the ship can be said to be in stable condition. Here is the GM optimization algorithm.

**Input:** Container Loading List has been arranged completely.
Step 1. For Step 2-4, do as many as the number of tier-1.
Step 2. For each bay, check the weight of the container on each row and tier.
Step 3. Compare the weight of the containers in Step 1 with the containers located above the containers Step 1.
Step 4. If the container for Step 1 is lighter than the container located above the container for Step 1, the location will be swapped between those 2 containers.
Output: Container Loading List stowage plan that has positive GM values.

3.2. Testing and Analysis
3.2.1. Data Testing. The process of testing will be done using the following data.
1. Casebase with a capacity of 244 TEUs as in Table 1, with the value of stability Trim = -0.014086086943565787; $D_A = 2.6935989059293397$; $D_F = 2.6795128189857738$; $D_M = 2.686558624575567$; and GM = 5,40925062236966.

| Container Weight Class | The Number of Containers (TEUs) |
|------------------------|---------------------------------|
| 20ft heavy (>20 tons)  | 51                              |
| 20ft medium (10-20 tons)| 111                             |
| 20ft light (<10 tons)  | 30                              |
| 40ft heavy (>20 tons)  | 12                              |
| 40ft medium (10-20 tons)| 40                              |
| 40ft light (<10 tons)  | 0                               |
| **Total**              | **244**                         |

2. Container Loading List with a capacity of 231 TEUs as in Table 2.

| Container Weight Class | The Number of Containers (TEUs) |
|------------------------|---------------------------------|
| 20ft heavy (>20 tons)  | 46                              |
| 20ft medium (10-20 tons)| 102                             |
| 20ft light (<10 tons)  | 31                              |
| 40ft heavy (>20 tons)  | 12                              |
| 40ft medium (10-20 tons)| 38                              |
| 40ft light (<10 tons)  | 2                               |
| **Total**              | **231**                         |

3.2.2. Testing Process. The process of testing the arrangement of container Container Loading List automatically arranged based on Casebase as in Figure 8 below.
Figure 8. (a) The Testing Process of Automatically Arrangement Containers in Bay 1 and 3, (b) The Testing Process of Automatically Arrangement Containers in Bay 7 and 9.

3.2.3. Analysis of Testing Process. The testing process has been carried out on Casebase with a capacity of 244 TEUs and a Container Loading List with a capacity of 231 TEUs. The results obtained with the arrangement of stability data in Table 3 and the results of the analysis as follows.

Table 3. Stability Data of Stowage Plan

| Stability  | Casebase | Plan 1     | Plan 2     | Plan 3     | Plan 4 (manual) |
|------------|----------|------------|------------|------------|----------------|
| Trim       | -0.014086| -0.00134690| -0.00134690| -0.34564941| -0.34861904    |
| D_A        | 2.6935989| 2.49946355 | 2.49946355 | 2.66533469 | 2.66676534    |
| D_F        | 2.6795128| 2.49811644 | 2.49811644 | 2.31968528 | 2.31814630    |
| D_M        | 2.6865558| 2.49879009 | 2.49879009 | 2.49250999 | 2.49245582    |
| GM         | 5.4092506| 6.55949422 | 6.52766768 | 6.63830279 | 6.60647625    |
| LCG-LCB    | -0.032227| -0.00325258| -0.00325258| -0.83469318| -0.84186440   |

1. Based on the stability data in Table 3, Trims and GMs have been obtained in container stowage plan 1, container stowage plan 2, and container stowage plan 3. Where The Trim and GM of the three structuring results have met the requirements. Trim of the three results of the arrangement is eligible because the difference between the Longitudinal Center of Gravity (LCG) and the Longitudinal Center of Buoyancy (LCB) of the three structuring results is less than 1% of the Length Between Perpendicular (LBP) of the ship, which is 0.84573. GM of the three results of the arrangement is eligible because GM of the three results of the arrangement is positive so that the ship is in a stable condition.

2. Users can choose to arrange containers in the Container Loading List automatically or manually.

3. Users can select containers in the results of the stowage plan or in the casebase, and the location of the row-bay-tier of the selected container will be displayed making it easier for users to find out the location of the container on the ship.

4. The user can swap locations between two containers on the results of the arrangement, and the stability of the results of the new stowage plan will automatically be performed and the results of these calculations will be displayed in The ‘Calculation Table’.

5. The user can choose the Stowage Plan that will be displayed in the illustration. Which is container stowage plan 1, container stowage plan 2, container stowage plan 3, and container stowage plan manual.

6. Users can find out the results of the visualization of the stowage plan on Casebase making it easier for users to do the arrangement manually.
7. Users can find out the results of the calculation of the stability of the ship in the 'Calculation Table' making it easier for users to find out the stability of the ship.
8. Users can find out the container data currently being loaded in The 'Container Data' Table.
9. Users can delete the results of the container stowage plan and stability calculations of Casebase and Container Loading Lists.
10. The software is executed using a computer with an Intel Core i5 processor and Random Access Memory 4 Giga-Byte. And it takes 3 seconds of computing time to arrange a 231 TEUs Container Loading List and 2 seconds to arrange a 136 TEUs Container Loading List.
11. Based on Table 3, arranging containers automatically results in better stowage plan and requires a shorter time than arranging containers manually.

4. Conclusion
Based on testing results and analysis of testing results, it can be concluded.
1. An algorithm has been designed for the Reuse stage of the Case-Based Reasoning Method and we get the Container Loading List Adaptation, Fill-Blank, Adding Remaining Containers, Trim Optimization, and GM Optimization Functions. The functions can be implemented in software design and automatically or manually arranged the containers based on Casebase.
2. A good container stowage plan is obtained because the Trim and GM have met the requirements. Trim is fulfilled when the difference between the Longitudinal Center of Buoyancy (LCB) and the Longitudinal Center of Gravity (LCG) value is not more than 1% Length Between Perpendicular (LBP) of the ship, which is 0.84573. GM is met when GM is positive, so the ship can be said to be in stable condition.

5. References
[1] Nugroho S 2005 CASESTOW: Recycling of Past Stowage Plans in 1st International Conference on Operations and Supply Chain Management (Bali, Indonesia)
[2] Nugroho S 2004 Case-based Stowage Planning for Container Ships in International Logistics Congress 2004 (Izmir, Turkey: Dokuz Eylul University Publications) pp 609-618
[3] Nugroho S 2005 Case-based Stowage Planning System in Maritime Engineering and Ports III vol 80, ed Olivella J, Trebbia C, and Macet R (Southampton: Wessex Institute of Technology Press)
[4] Harwanto N A 2011 Pengembangan Prototipe Modul Sistem Perencanaan Stowage Berdasarkan Kasus Untuk Penataan Semi-otomatis Peti Kemas pada Kapal Thesis Mathematics Department, Institut Teknologi Sepuluh Nopember (Surabaya)
[5] Riesback C K and Schank R C 1989 Inside Case-based Reasoning Lawrence Erlbaum Associates, Inc.
[6] Wilson I D, Roach P A and Ware J A 2001 Container Stowage Pre-planning: Using Search to Generate Solutions, a Case Study Knowledge-Based Systems pp 137-145.
[7] Jahar R 2018 Studi Pengaruh Kondisi Inisial Terhadap Operasi Peluncuran Struktur Jacket Thesis Naval Architecture Department, Institut Teknologi Sepuluh Nopember (Surabaya)
[8] Lewis E Principle of Naval Architecture Second Revision vol II (Jersey City: The Society of Naval Architecture and Marine Engineers)
[9] Leake D 1996 Case-Based Reasoning: Experiences, Lessons and Future Directions Chapter CBR in Context: The Present and the Future (Massachusetts: AAAI Press/MIT Press) pp 3-30
[10] Kolodner J and Leake D 1996 Case-Based Reasoning: Experiences, Lessons and Future Directions Chapter A Tutorial Introduction to Case-Based Reasoning (Massachusetts: AAAI Press/MIT Press) pp 31-66
[11] Imai A, Nishimura E and Sasaki K 2002 The Containership Loading Problem International Journal of Maritime Economics pp 126-148
[12] Ambrosino D, Sciomachen A, and Tanfani E 2004 Stowing a containership: the master bay plan problem. Transportation Research Part A