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Stowage Planning System for Ferry Ro-Ro Ships Using Particle Swarm Optimization Method

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Abstract— Stowage planning involves distributing cargo on board a ship, including quantity, weight, and destination details. It consists of collecting cargo manifest data, planning cargo location on decks, and calculating stability until the vessel is declared safe for sailing. Finding the ideal solution to real-world situations in this stowage planning problem is challenging and frequently requires a very long computing period. The Particle Swarm Optimization (PSO) algorithm is one of the evolutionary algorithms known for its efficient performance. PSO has been extended to complex optimization problems due to its fast convergence and easy implementation. In this study, the Particle Swarm Optimization (PSO) method is implemented to automate stowage arrangements on ships considering three factors (width, length, and weight of the vehicle). This system was evaluated with KMP Legundi vehicle manifest data and four load cases of 12 different vehicle types that can be loaded on Ferry / Ro-Ro Ships. It provides complete vehicle layouts and allows interactive changes for stowage planners, ensuring speed and accuracy in arranging ship cargo.

Keywords—Stowage Planning; Particle Swarm Optimization Method; Load Optimization

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I. INTRODUCTION

Stowage planning activity is a plan that shows the distribution of all cargo placed on board for a journey with cargo details such as quantity, weight, and port of discharge (destination). A stowage plan can be interpreted as a complete storage diagram or plan showing what objects or cargo have been loaded and the storage location in each hold, compartment between decks, or other spaces on the ship, including deck rooms. The stowage planning activity is an initial process that relevant stakeholders must carry out before making a voyage. This process includes several works, such as collecting cargo manifest data, planning cargo location on decks of ferries/ro-ro ships, or Bay, Row, Tier on container ships, and calculating its stability until the vessel is declared safe for sailing [1]–[7].

Ferry / Ro-Ro (Roll on - Roll off) vessels are one of the most successful multi-purpose vessels currently operating. The flexibility and ability to take advantage of a lot of space on board to load various types of vehicles and also passengers make this type of ship very popular and widely used on shipping routes around the world, especially in countries that have geographical forms of islands [4], [8]–[10]. A stern characterizes these vessels, and in some models, the bow or side hatches may provide access to the vehicle decks located above the waterline but below the upper decks. Access on board can be supplied through ramp floors or lifts that lead from the decks of these vehicles to the upper decks or holds below [11]. However, in the cargo planning process on ro-ro ships, there are still problems encountered. On this type of ship, the challenge is efficiently utilizing and maximizing deck space. The arrangement and location of vehicles with heterogeneous kinds and sizes on ro-ro ships depend on space constraints, such as deck height, ramp doors on the deck, fire safety evacuation route requirements, etc. [12]. By carrying out cargo arrangement planning, followed by proper stability calculations like this, the utility and safety of the ship's journey can be maximized before the ship leaves the dock.

The stowage planning task is one of the most crucial steps in the shipping business. Improving the quality of ship stability and its safety requires careful planning and calculation. Because effective stowage planning can increase the transportation system's efficiency [13]. Currently, most of the planning processes for arranging cargo on most shipping lines around the world are still carried out by humans in the stowage planner department, which is done manually. Because this process is still done manually by experts, the quality of the resulting stowage planning results, including operational costs, as well as the safety and stability of the ship, is very dependent on the experience of the stowage planner who must go through years of training and experience with the arrangement of cargo on board [14].

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Research on auto stowage that had been carried out applied the optimization algorithm. The approach to solving optimization problems is divided into two groups, namely: heuristic [15]–[24] and exact algorithm [25], [26]. Some of the other approaches were proposed by [27], which focus on the use of CBR-based methods to plan stowage on container ships semi-automatically by utilizing previous problems to be subsequently adapted to solving new problems by the system by providing solutions in similar cases by returning kind information. In addition, research conducted by [13] mentions several examples and the application of several methods in their applications to optimize the planning process assisted by auto stowage. In [28] focuses on applying genetic algorithms using two strategies, namely Master Bay Planning and Slot Planning. This study's Stowage Plan Generator (SPG) combines optimization problems: finding the best solution out of all possible explanations by optimizing several sub-functions. The Stowage plan resulting from the SPG can be processed or rearranged manually by the user. The system developed in [14], consists of 3 main modules: the generator stowage plan, the stability module, and the loading optimization module. One of the optimizations carried out in the stability module is to reduce the amount of ballast needed by the ship so that besides the arrangement of cargo on deck to be more optimal, it also reduces shipping costs due to the efficiency generated due to the reduced amount of water in the ballast tanks used on each trip. In tests conducted by researchers, this system efficiently produced good storage plans with an average time of 2 minutes per plan versus 2 hours per plan when done manually. However, in this study, the system has not been able to consider ballast adjustments and other stability issues, such as bending moment and torque.

So far, the algorithm's efficiency in making stowage plans has constantly been improved by cutting or reducing the search space. [29] examines the test optimization problem, including the RSM and SB SSM models. Random sample model (RSM) and sequential sample model (SSM) are used in analyzing issues, as well as how to make the constraint evaluation process efficient. The results of this alternative strategy show that the efficiency is close to optimal, with an average speed of 2.74 times better in the payload management evaluation tool. Solving the stowage planning problem using the mathematical model in [24] makes it impossible to calculate the lower limit within 1 hour. The application of the Adaptive Large Neighborhood Search (ALNS) method to stowage planning is based on the principle of "destroying" and "reconstructing" existing solutions. The semi-automatic approach uses the Lowest Horizontal Line (LHL) algorithm to create a Roll-on/Roll-off (Ro-Ro) ship stowage plan [12]. The test is carried out by comparing the results made by the semi-automatic system with the load case tests previously made by the Lloyd's Register class. By using an accurate deck model and optimized Lowest Horizontal Line algorithm, a more realistic stowage plan can be generated by this system.

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This study aims to implement the Particle Swarm Optimization method in automating stowage arrangements in the deck space layout on ships based on existing manifest data in ferry / ro-ro ship cargo. The Particle Swarm Optimization method is an algorithm inspired by biological activity and behavior in nature, based on the behavior of groups and the cooperation of flocks of birds and schools of fish to take advantage of the experiences of all other members [30]. This method was first developed by James Kennedy, a social psychologist, and Russell Eberhart, an electrical engineer, in 1995 [31]. The Particle Swarm Optimization (PSO) algorithm is one of the evolutionary algorithms known for its efficient performance. PSO has been extended to complex optimization problems due to its fast convergence and easy implementation. This method can help solve problems in optimizing population-based space filling. By using this system, it is hoped that the user can minimize the total time needed from the existing old system, both for shipping companies and for port managers, without compromising the stability and safety factors of the ship.

II. RESEARCH METHOD

A. Data & Material

This research is focused on implementing an automation arrangement, where the stowage planning of cargo in the form of vehicles on the deck will be carried out automatically, with the object used in this research being the ro-ro/ferry ship "KMP Legundi," which is operated directly by PT ASDP Indonesia Ferry (Persero) on the Merak – Bakauheni crossing route. The general arrangement of the ships have three decks with the dimensional data of the available particulars as follows are Length Over All (LOA)=109,4 meters, Length of Water Line (LWL)=103,168 meters, Length of Perpendicular (LPP)=99,2 meters, Breadth (B)=18,965 meters, Height (H)=5,6 meters, *Draft*=4,1 meters, *Gross Tonnage*=5556 Tons and *Lightweight* (LWT)=3014,848 Tons. The particle swarm optimization algorithm trial was only carried out on Deck 2, which has the most significant dimensions compared to the others, as shown in Figure 1. Deck 2 is the vehicle deck located amidships. This deck can be used as a place for large commercial vehicles such as trucks and buses because apart from having a deck height of up to 4,5 meters, this deck also has direct access to the ramp door, which is the access for vehicles in and out via a standard wharf. Deck 2 has dimensions of 96,714 meters in length and 16,168 meters in width. Several types of vehicles to be used in the optimization simulation can be seen in Table 1.

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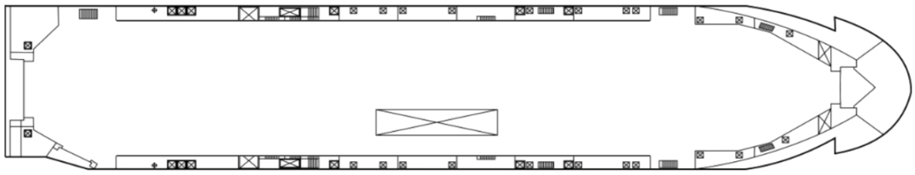

Fig 1. General Arrangement of the 2nd deck of KMP Legundi

Table 1. Vehicle Data

Voyage Name: LC 2				
Class VI B (Business Vehicles 7-10 meters)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
2	9,0	2,3	3,2	4,0
Class VII (Business Vehicles 10-12 meters)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
26	12,0	2,5	3,3	3,0
Voyage Name: LC 1 LIGHT LOADED VEHICLE				
Class IV A (Cars <=5 meters)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
100	4,8	1,8	1,4	1,5
Voyage Name: LC 3 BREAKING THE LINE				
Class V B (5 - 7 meters Commercial Vehicles)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
42	7,0	2,2	2,5	2,5
Class IV A (Cars <=5 meters)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
12	4,8	1,8	1,4	1,5
Class VI B (Business Vehicles 7-10 meters)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
24	9,0	2,3	3,2	4,0
Voyage Name: LC 4 FITS LINE				
Class VI B (Business Vehicles 7-10 meters)				
Number	***Length (m)***	***Width (m)***	***Height (m)***	***Weight (t)***
54	7,0	2,2	2,5	2,5

B. Stowage Planning System

In general, the stowage planning system that proposed involves such processes described in Figure 2. The loading list contain data that can later be used to support the auto stowage module, such as deck structure and design, ship parameter data from general particulars, as well as examples of cargo manifest lists.

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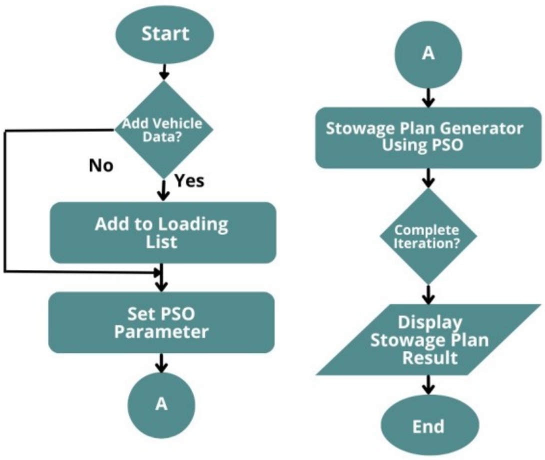

Fig 2. Flowchart of Stowage Planning System

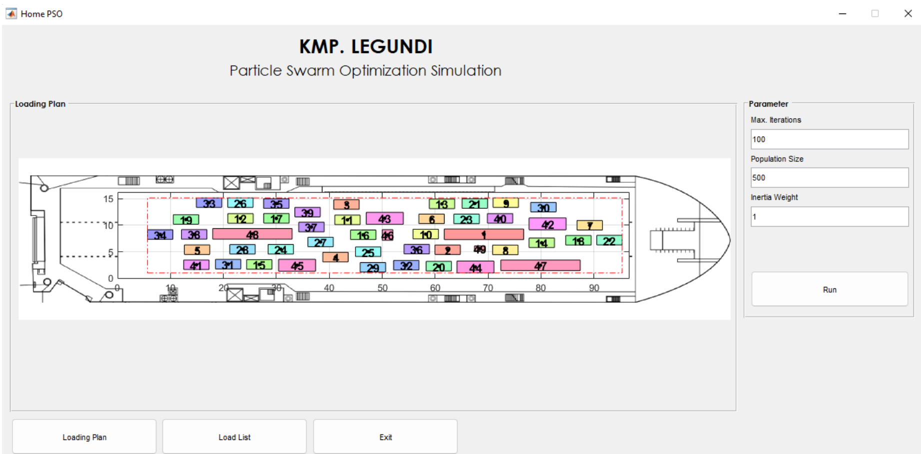

Fig 3. Start page of the stowage planning system application

When the user runs the application, the first page to be found is the start page or the loading plan page as shown in Figure 3. This start page is the work area as well as the main points in implementing this method, where there is a loading plan section that will display the process and the results of the arrangement of the ship's cargo on the general deck arrangement section.

The PSO parameters are determined as the initial initialization of the data, consisting of *max-iteration*, *population size*, and *inertia weight*. *Max-iteration* is a parameter that indicates how many iterations or iterations will be carried out. *Population size* measures the number of group members that will be initialized to contain several particles. *Inertia weight* controls the impact of the change in velocity exerted by the particles.

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C. Particle Swarm Optimization Algorithm

The Particle Swarm Optimization method is an artificial intelligence method based on coordinates. Population generation is the next step in the initialization process in this algorithm, where the process of creating a random solution aims to generate the initial position or coordinates and the initial velocity of each particle. These particles will be distributed randomly as in (1) but are still limited according to the variables that have been previously determined. This is inseparable from the goal so that processes running on the PSO algorithm can perform searches quickly and optimally.

$$\begin{aligned} sol1.xhat &= [xhat_1, xhat_2, \dots, xhat_{\mathrm{n}}] \\ sol1.yhat &= [yhat_1, yhat_2, \dots, yhat_{\mathrm{n}}] \\ sol1.rhat &= [rhat_1, rhat_2, \dots, rhat_{\mathrm{n}}] \end{aligned} \quad (1)$$

Where *n* is the number of objects (in this case, the number of vehicles arranged on the ship's deck), *sol1.xhat* is an object in the solution that contains a vector representing the *x* coordinate, *sol1.yhat* is an object in solution that contains a vector representing the *y*-coordinate and *sol1.rhat* is a vector representing some values associated with the object.

Velocity updates affect the process of moving the direction and position of particles in the population. The process is carried out by calculating the existing variables, such as *pBest* as the best result obtained in the swarm, and *gBest*, which is the best fitness of the entire swarm. [32] explain that for the development and improvement of the PSO algorithm, many researchers add the inertial weight *w* to the first part of the velocity update formula, using (2).

$$v_i^d(t+1) = wv_i^d(t) + c_1 r_1 \left(pBest_i^d - x_i^d\right) + c_2 r_2 \left(gBest^d - x_i^d\right) \quad (2)$$

Where $v_i^d(t+1)$ is a variable for the new position of the particle. *w* for inertia weight. $v_i^d(t)$ for the position of the particle from its previous location. *pBest* for the best fitness value for each particle. *gBest* is the best fitness value of all existing particles. $c_1 c_2$ is the coefficient of particle acceleration. $r_1 r_2$ is a random value from the interval 0 to 1.

The steps of the PSO algorithm applied to the stowage planning system are as follows:

```
Step 1. Create Model with input variable: vehicle_width (xhat),
         vehicle_length(yhat) and vehicle_weight(rhat) using (1)
Step 2. Define Cost Function
Step 3. Define Initial PSO Parameters: Maximum Number of Iterations (MaxIt),
         Population Size (nPop), Inertia Weight(w), Inertia Weight Damping
         Ratio (wdamp=1), Personal Learning Coefficient (c1=0.7), Global
         Learning Coefficient (c2=1.5)
Step 4. Repeat until Population Size (nPop) do
        Step 5. Initialize Position
        Step 6. Initialize Velocity
        Step 7. Evaluation Cost Function
```

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        Step 8. Update Personal Best
        Step 9. Update Global Best
Step 10. Repeat until Maximum Number of Iterations (MaxIt)
        Step 11. Repeat Until Population Size (nPop)
                Step 12. Motion on vehicle_width (xhat):
                                Update Velocity xhat using (2)
                                Apply Velocity Limits xhat
                                Update Position xhat
                                Velocity Mirror Effect xhat
                                Apply Position Limits xhat
                Step 13. Motion on vehicle_length(yhat):
                                Update Velocity yhat using (2)
                                Apply Velocity Limits yhat
                                Update Position yhat
                                Velocity Mirror Effect yhat
                                Apply Position Limits yhat
                Step 14. Motion on vehicle_weight(rhat):
                                Update Velocity rhat using (2)
                                Apply Velocity Limits rhat
                                Update Position rhat
                                Velocity Mirror Effect rhat
                                Apply Position Limits rhat
                Step 15. Evaluation Cost Function
                Step 16. Apply Mutation
                Step 17. Update Personal Best
                Step 18. Update Global Best
        Step 19. Apply Local Search (Improvement) to Global Best
```

III. RESULT AND DISCUSSION

Simulation of the arrangement of vehicles on the ship deck automatically is a testing process that is carried out based on several conditions or scenarios that resemble the actual conditions in the field with the addition of several influencing parameters, as shown in Table 2. This stage starts from the particle initialization process, creating a random set of solutions containing several particles in the form of vehicle manifest data and vector particle velocity. The location of the vehicles will be randomly distributed in a predetermined n swarm. The PSO algorithm will perform several iterative functions to find the best results by evaluating the fitness of the position of each particle. This initial iteration will continue until all the particles are used up and scattered in the workspace. It aims to find the best fitness of each swarm. The best result from that 1 group will be the personal best result (*pBest*). Furthermore, the PSO algorithm will look for the best particle from all existing *pBest* as the global best (*gBest*) results.

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Table 2. Setting PSO Parameter And Processing Time

Voyage Name	Number of particles	Swarms	Iterations	Processing Time (seconds)
LC 2	28	100	500	506,38
LC 2	28	50	500	501,99
LC 1 LIGHT LOADED VEHICLE	100	100	500	52202
LC 1 LIGHT LOADED VEHICLE	100	1	10	346,26
LC 3 BREAKING THE LINE	73	100	500	11628,10
LC 3 BREAKING THE LINE	73	50	500	4622,57
LC 4 FITS LINE	26	100	500	471,62
LC 4 FITS LINE	26	50	500	427,58

In the Load Case 2 (LC2) trial, the simulation process for arranging vehicle loads totaled 28 vehicles with two categories, namely class VI B (Vehicle Commerce 7-10 meters) and class VII (Vehicle Commerce 10-12 meters). With the iteration and swarm variables in 2 predefined scenarios, the results obtained until the iteration process stops take up to 8 minutes. The simulation result of this scenario is shown in Figure 4, with an iteration diagram of PSO in Figure 5. Figure 4 shows that the result with 50 swarms is better than 100 swarms. In the 100 swarms case, vehicles intersect with other cars (number 11). Based on the iteration diagram in Figure 5, it can also be seen that the scenario with swarm 50 has reached a fit condition when iterations are below 50, while the scenario with swarm 100 is still not convergent until the end of iteration 500.

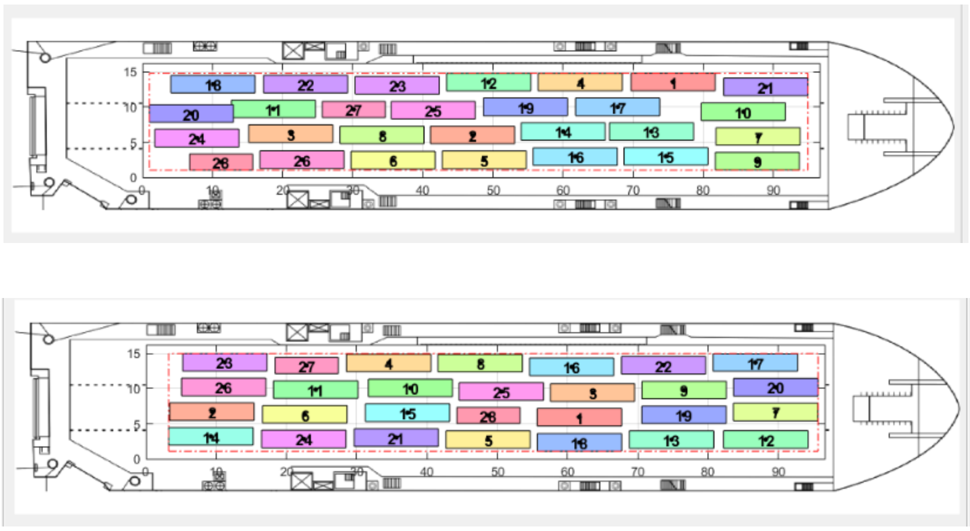

Fig 4. Test results for the LC 2 scenario on a load plan with 100 swarms and 50 swarms

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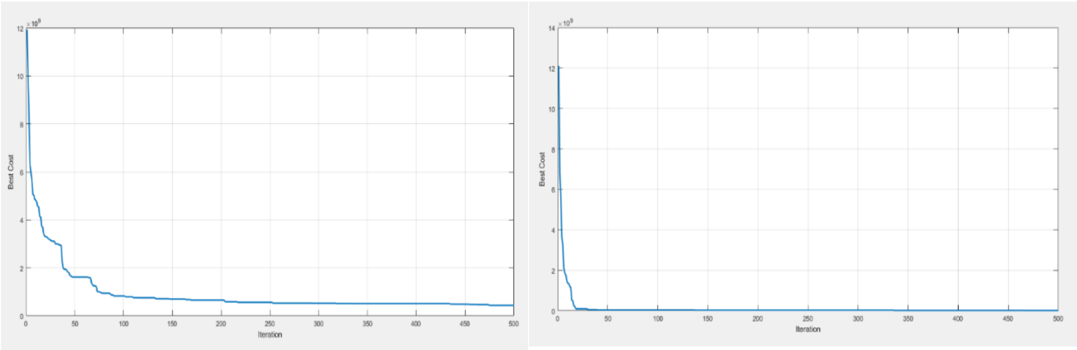

Fig 5. Iteration Diagram PSO for LC 2 Scenario with 100 Swarms And 50 Swarms

In the LC 1 scenario, the simulation process for arranging vehicle loads totaling 100 vehicles with only 1 type of vehicle used, namely class IV A (cars <= 5 meters) or private vehicles. With the number of vehicles exceeding the deck load capacity, the iteration and swarm variables set in the first scenario, the results obtained until the iteration process stops take a very long duration. The iteration process of 500 times takes up to 14 hours. The simulation result of this scenario is shown in Figure 6, with an iteration diagram of PSO in Figure 7. With the same number of vehicles but using iteration and swarm variables different from the first scenario, the results obtained until the iteration process stops take 5 minutes. Using only one swarm has two impacts on the iteration process. The results of the cargo arrangement simulation in this test scenario are not as good as in the first test, but with 100 iterations, the process does not take more than 10 minutes for 100 vehicles to be arranged on the ship's deck.

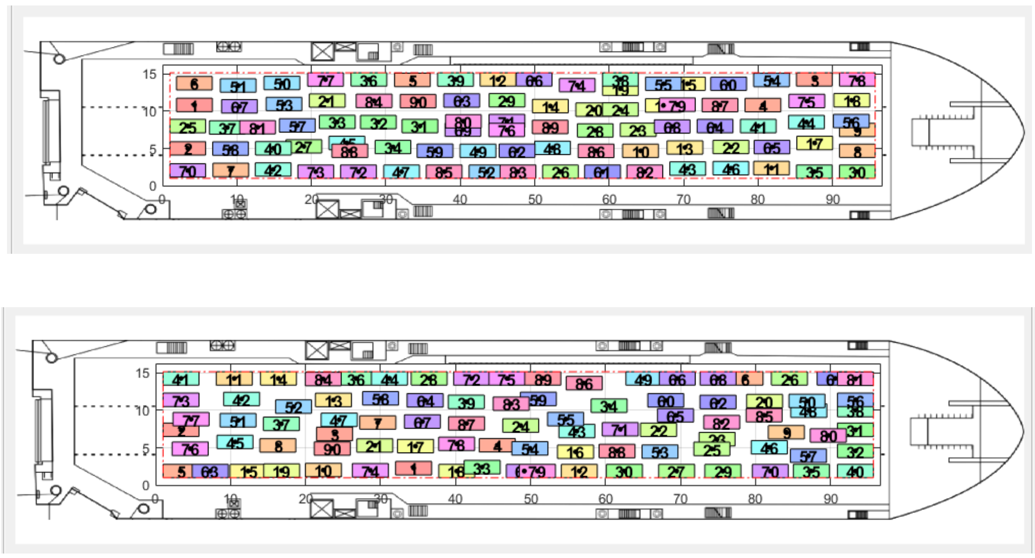

Fig 6. Test Results for the LC 1 Scenario on a Load Plan with 100 Swarms and One Swarm

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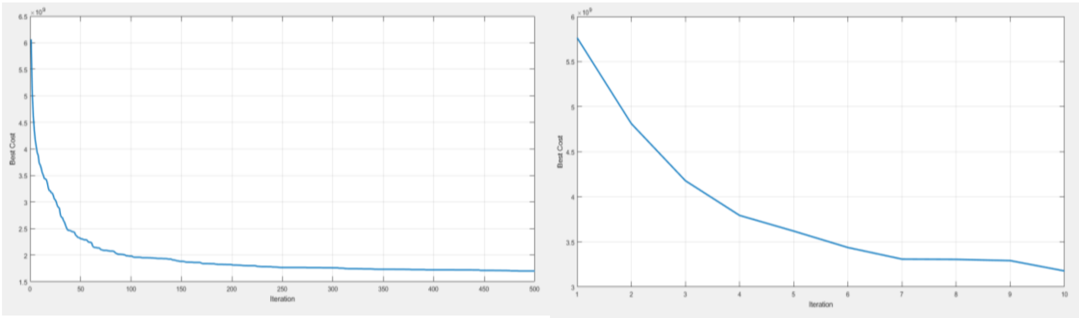

Fig 7. Iteration Diagram PSO for LC 1 Scenario with 100 Swarms and One Swarm

In this LC 3 scenario, the number of vehicles arranged on deck reaches 73 units. Almost the same as the previous scenario, which used the number of vehicles that exceeded the deck load capacity, except that this test used a more heterogeneous class of cars, namely class V B (Vehicle Commerce 5-7 meters), class IV A (Cars <= 5 meters), and class VI B (Vehicle Commerce 7-10 meters). As a result, with 500 iterations, this process takes up to 3 hours. The swarms are reduced to 50 with the same number of iterations. The iteration time results obtained in this process reached 77 minutes, which is very different from the previous test. The simulation result of this scenario is shown in Figure 8, with an iteration diagram of PSO in Figure 9.

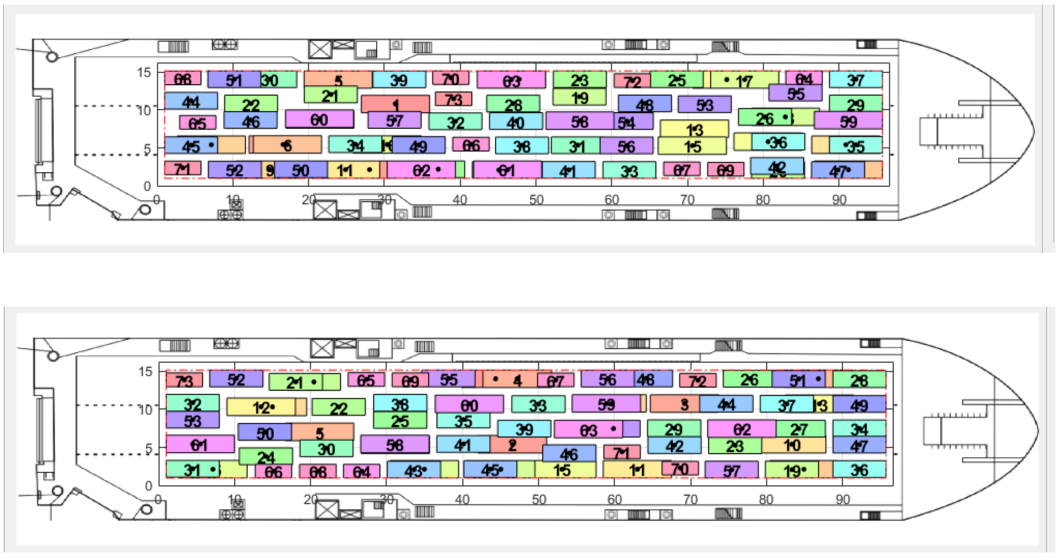

Fig 8. Test Results for the LC 3 Scenario on a Load Plan with 100 Swarms And 50 Swarms

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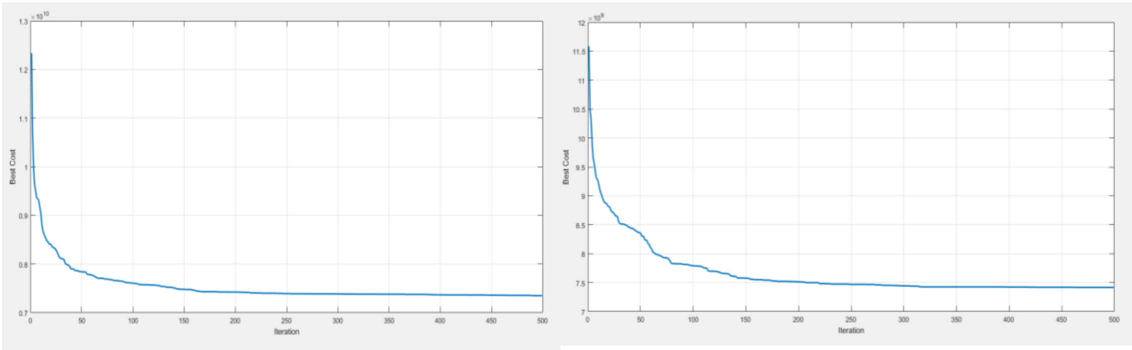

Fig 9. Iteration Diagram PSO for LC 3 Scenario with 100 Swarms And 50 Swarms

In the LC 4 scenario, the number of swarms that will be used is only 100, while the number of iterations is 500 times. The payload arranged in this simulation is homogeneous, with one class of vehicles being tested. With only 26 units of class VI B vehicles (7-10 meters commercial vehicles), the iteration process can be completed in 7 minutes. The same duration is also obtained when the test scenario uses the same number of iterations but with the swarms being reduced to only 50. The simulation result of this scenario is shown in Figure 10, with an iteration diagram of PSO in Figure 11.

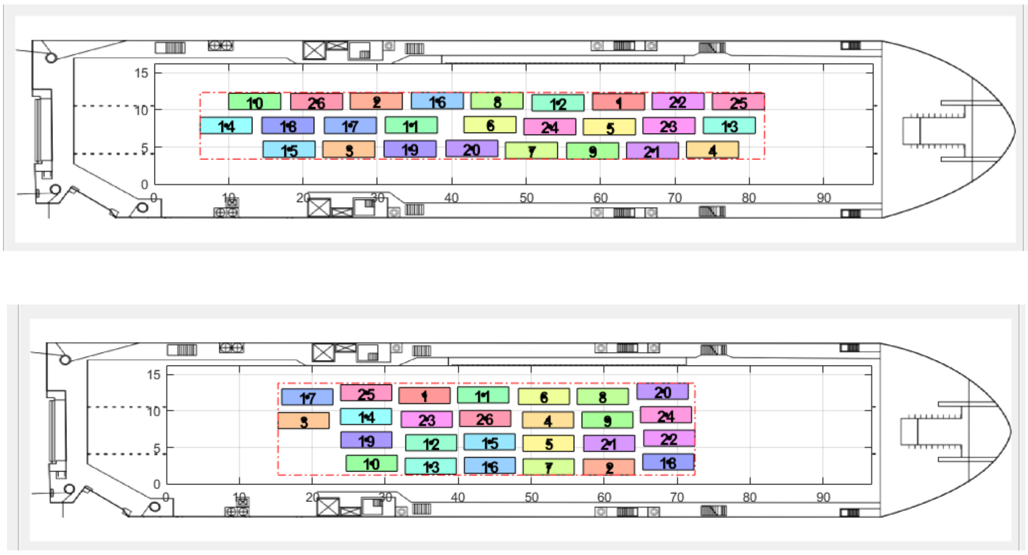

Fig 10. Test Results for the LC 4 Scenario on a Load Plan with 100 Swarms And 50 Swarms

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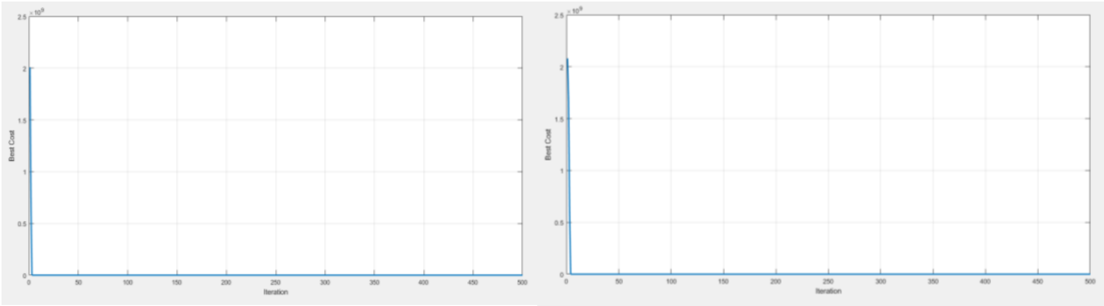

Fig 11. Iteration Diagram PSO for LC 4 Scenario with 100 Swarms And 50 Swarms

IV. CONCLUSION

This research develops software for stowage planning systems on Ro-Ro ships / Ferry by applying the Particle Swarm Optimization (PSO) method. This system was tested using KMP Legundi vehicle manifest data with four load cases of 12 types of vehicles that can be loaded on Ro-Ro ships / Ferry. This software is also equipped with a simulation of the application of stowage planning on the second Ro-Ro ships / Ferry deck, whose parameters can be set interactively by the user. The speed and accuracy of arranging the ship's cargo on the deck depend on the number and type of vehicles loaded and the predetermined number of swarms. This software system assists stowage planners in two ways: first, by providing complete Ro-Ro ships / Ferry deck vehicle layouts as a planning tool, and second, it allows planners to make changes when needed interactively. For further development, it is necessary to add functions and variables that can record the moment positions of LCG, VCG, and TCG based on the coordinate data obtained so that this system can also calculate whether the results of the cargo arrangement on the deck are safe.

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