OPTIMAL DOCK BLOCK ARRANGEMENT CONSIDERING SUBSEQUENT SHIPS SOLVED BY GENETIC ALGORITHM

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Abstract
This paper presents an idea of making dock block arrangement for a series of ships by minimizing dock dry up times and block numbers. When ship moves out, dock is pumped dry to enable block arrangement for the next ship. However, this dry up operation can be removed if the block plan in the previous docking is properly arranged and covers the requirements of the next docking. The methodology described in this paper is based on the assumption that blocks are allowed to be adjusted when ship sits on them. The blocks are assumed all of uniform size, material and spacing, and the ship is assumed infinitely stiff, so beam theory can be applied on force calculation. The model is solved by genetic algorithm. The above idea is finally verified by a testing case.

Keywords: dock block arrangement, genetic algorithm, multi-objective, optimization

1. INTRODUCTION
Ships have to go for docking periodically during its service life. When a ship is to be docked, the dry dock is flooded, and the gate opened. After the ship is brought in, positioned properly, the gate is closed and the dock is pumped dry, bringing the ship gradually to rest on supporting keel and side blocks. Usually, after existing docking ship sail out and before the next ship sail in, docks have to be pumped dry one more time in the interval for dock blocks arrangement. This additional dry and flood operation is considered a waste since it may be moved out through careful planning. In this paper, a method is thereby proposed which takes into account the subsequent ships to make optimal dock block arrangement for a series of ships.

The method proposed here is based on genetic algorithm (GA). Previously Chen has done a preliminary research on this problem using GA in Chen et al. (2012), where dock floor space is meshed and blocks are placed on the intersection points, a binary GA chromosome structure is designed, in which “1” indicates existence of block and “0” indicates no block. However, since the location of ship on the dock floor is free, this mesh model has difficulty in catching the available positioning locations for blocks in all docking cases. So in this paper, a different approach is presented. Rather than using a mesh model fixed to the dock floor, a model variable with ship bottom area is proposed. To simplify the problem, uniform spacing is assumed for blocks. The blocks may be omitted in some instances to allow clearance for drilling moon-pool, thruster, sonar domes or other appendages that hang below the hull or to allow access for repairing that area of the keel. Also a block allocation plan should satisfy a couple of loading criteria. Block movements are allowed when the ship sit on these blocks. This assumption is supported by the appearance of movable blocks. In order to avoid additional dock dry up, it is required the following ship use the current block plan directly. The block arrangement procedure adopted in this paper is then described as following: the docking ship rests on the block plan inherited from the docking ahead. During its repair time, the block plan is adjusted to cover the requirements of docking behind. If block plan cannot be adjusted, then dock dry up operation after docking ship moves out is unavoidable, by which block plan can be refreshed for incoming ship. Aforementioned procedure iterates over each docking. Optimization target is multi-objective. One objective is to find block plans with the minimum dry up times. Another is to minimize the number of blocks. Since the view is holistic, this may result in a block plan not optimum for one particular docking, but it must be optimal for a series of dockings.

Docking analysis has attracted attention from many researchers. But most of them discussing the problem from a structural analysis view, for example Cheng et al. (1995), (2004), Su (2007). Their work focuses on designing an optimal positioning and stiffness allocation of docking blocks for one ship docking. Different from previous work, this paper attempts to solve the problem from a more holistic view with multi-objectives. This work will be part of the scheduling model the authors are developing. The whole system will provide a feasible optimization solution with the shortest total service time to the docking arrangement for a series of ships.

This paper first presents a mathematical model for minimization of total dock dry up times and block numbers. Emphasis is placed on investigating the possibility of block plan adjustment. The paper then proposes a GA method for solving the model. Finally, the whole idea is verified by a testing case.

2. THEORY AND FORMULATION

2.1. Problem Description

As mentioned above, one objective of the model is to minimize dock dry up times. To save from additional dock dry up, the block positioning plan should be carefully planned that it can cover the needs from both current docking and its next docking. By this block arrangement, the incoming ship can rest on previous block plan directly. The iteration continues until block arrangement unable to cover the following docking. Then dock dry up operation is activated for total block plan refreshment.

Below figure shows the block arrangement procedure in diagram. It can be seen from the diagram that to minimize dock dry up times effort can be taken on investigating the possibility of block plan adjustment.

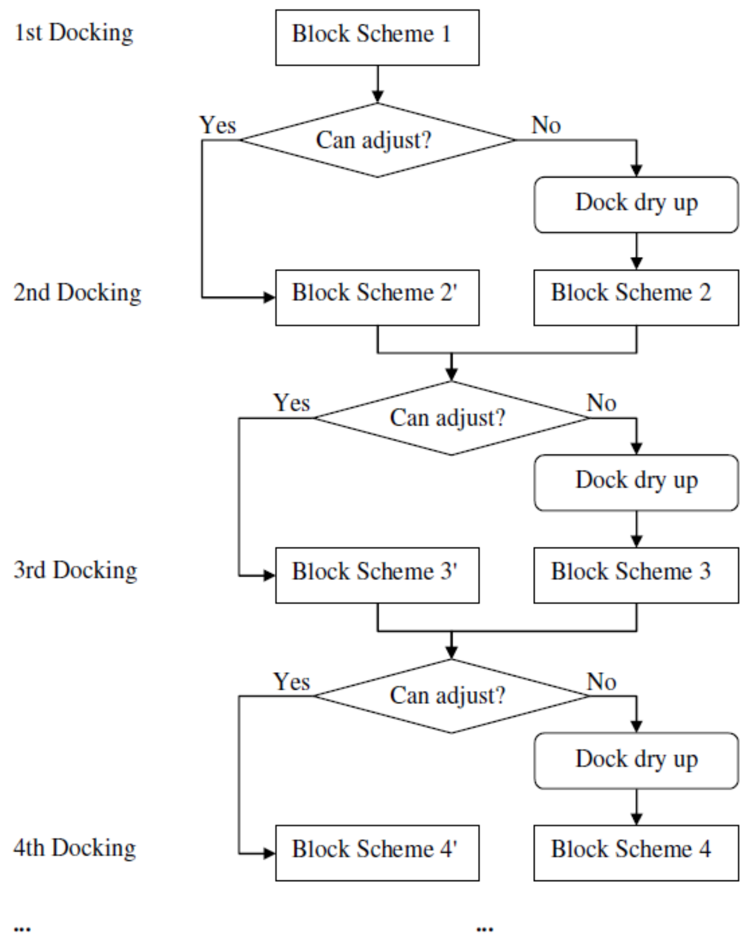


Figure 1 Block arrangement procedure diagram

A typical block plan is shown in Figure 2. The most common plan is a row of keel blocks in the centerline with a row or several rows of side blocks on each side.

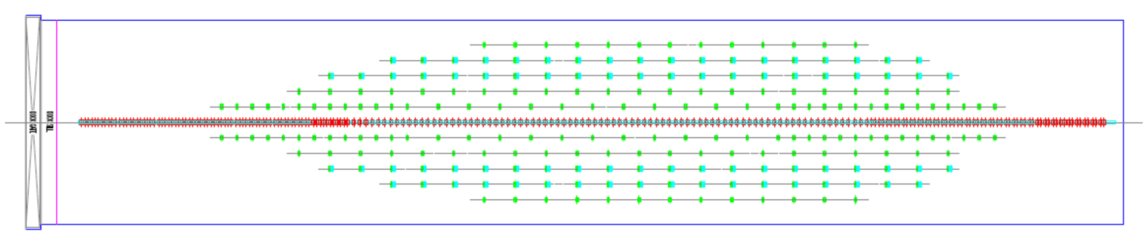


Figure 2 Typical block plan

In practice, ship's docking manual will give a guide block plan which has been approved by Ship Classification Society already. These guide plans are adopted here and give several guide lines along which blocks are evenly placed. See Figure 3.

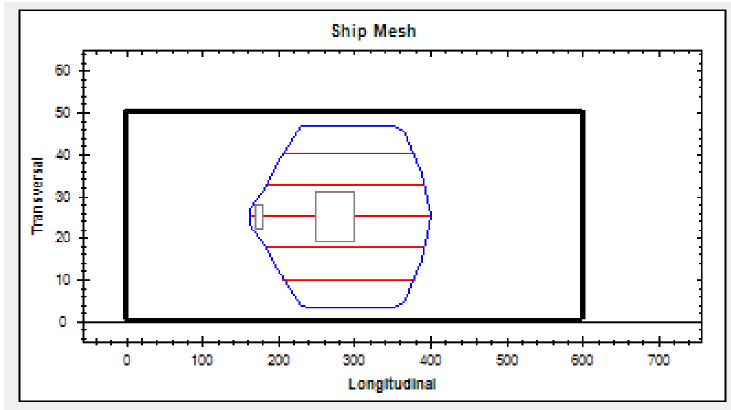
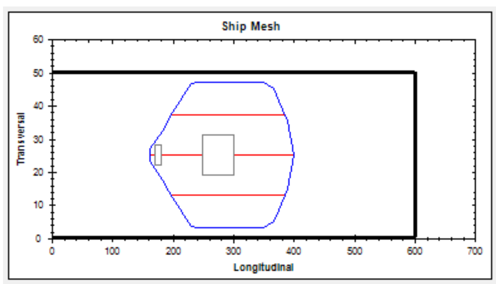
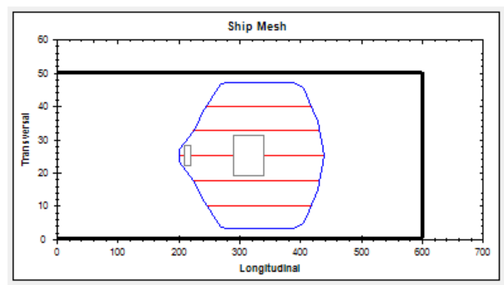


Figure 3 Block guide lines

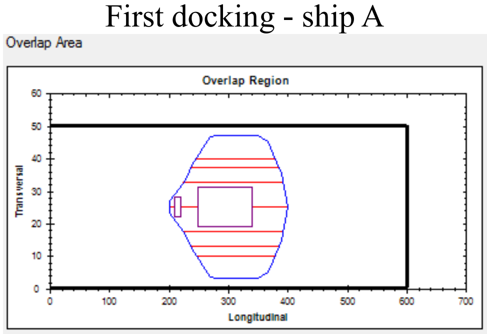
A block plan shared by two consecutive dockings should incorporate both omitted areas and at the same time satisfy both loading requirements. Since incoming docking follows its guide block line plan, then overlap region should incorporate this guide block line plan as well in current docking. See Figure 4.



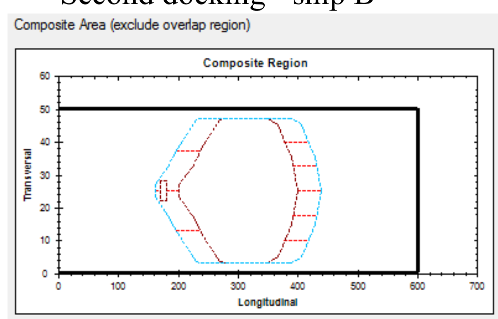
First docking - ship A



Second docking - ship B



Overlap area



Composite area (exclude overlap)

Figure 4 Overlap and composite

Because the blocks are assumed all of uniform size, material and spacing, and the ship is assumed infinitely stiff, then beam theory can be applied to calculate the force. Loading on the block line is trapezoidal shaped. The beam theory method is elaborated in the next section.

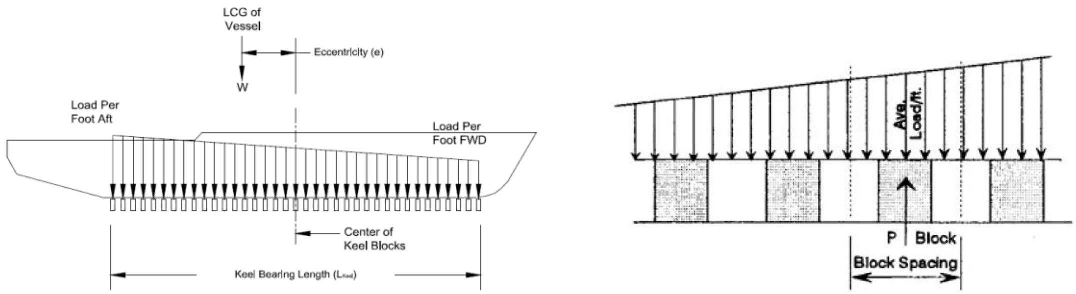


Figure 5 Loading shape

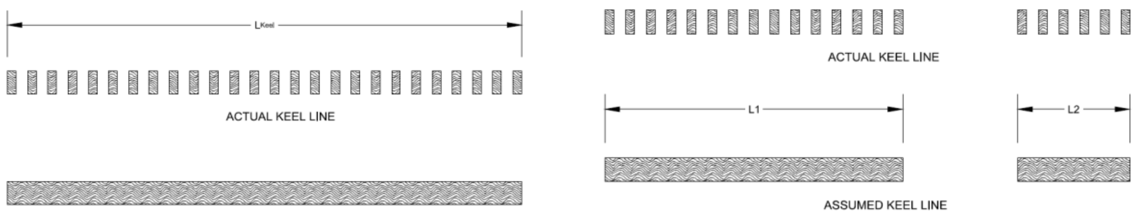


Figure 6 Keel line representation

2.2. Block Loading Analysis

Assumptions made:

- ✓ blocks are all of uniform size, materials, and spacing;
- ✓ the ship is infinitely stiff;
- ✓ 100% ship weight goes into the keel blocks;
- ✓ 15% ship weight taken by side blocks, and further scaled 200% to take into environmental load.

2.2.1. Constraints for keel blocks

Because the ship is a rigid structure whose keel is a straight line that cannot deflect very much in the distance between keel blocks, the loading along the keel line results in a trapezoidal shape, and the load on any one block is equal to the portion of the trapezoidal load directly over that block, see Figure 5. Only when the longitudinal center of gravity of the ship (LCG) is located directly over the center of keel line can the loading be rectangular in shape. Furthermore, for a keel line with regularly spaced blocks and no large gaps, the keel line can be assumed to be one continuous beam with, see Figure 6. If blocks are omitted, gaps are created in the keel line, or if a varying width keel, then one continuous beam is divided into several segments. Using the trapezoidal loading equation, refer to Dock Master Training Manual (2005), the load per meter along the keel can be calculated to insure the dock's rated load per meter is not exceeded. The pattern of keel blocks hereby can be determined.

STEP 1. The center of all blocks must be calculated first. This is done by multiplying the area of each rectangle by its distance from any arbitrary point, adding these values together, and dividing by the total area of blocks.

STEP 2. Next, the moment of inertia of all rectangles about the center of block area must be calculated.

STEP 3.

$$I = b \times h^3 / 12 + A \times d^2$$

where:

b = Base of the rectangle or width of the block, can be assumed 1 if all block widths are constant

h = Height of the rectangle or length of the block line segment

A = Area of the rectangle

d = Distance the center of the rectangle is from the axis being investigated (center of block area in this case)

STEP 4. The eccentricity (e) need to be calculated, which is the distance between longitudinal center of gravity of the vessel (LCG) and the center of the keel bearing area.

STEP 5. The distance (c) from the center of block area to the point being investigated. Points calculated are usually the ends of each rectangle.

STEP 6. Plug into the eccentrically loaded column equation and obtain the values of the trapezoid at the ends of the block segments:

$$\text{Load at the end of the block segments} = W / A \pm W \times e \times c / I$$

Max load on the block = load per meter × block spacing

STEP 7. Check max load on the block < block load capacity?

2.2.2. Constraints for side blocks

The actual portion of the ship' weight which the side blocks take is dependent on many factors. The US Navy's Ships' Technical Manual S9086-7G-STM-010 Chapter 997 "Docking Instructions and Routine Work in Dry Dock" arbitrarily assumes 15% of the ship's weight is taken by the side blocks. This means side blocks on one side of the ship take 7.5% of the ship's total weight. The allowable load for each side block is based on the bearing area of the timber cap against the hull multiplied by the pressure that is allowed on the timber cap. Thus, the number of side blocks can be calculated. Formula is given as below:

Allowable load per block = bearing area × proportional limit

Number of side blocks required = total load on side blocks / allowable load per block

where:

For example, if Timber cap is Douglas Fir then with proportional limit 800 psi.

The position of the side blocks must fall under a strength point in the ship (usually a longitudinal girder) and over a strength point in the dock (usually a transverse frame).

2.2.3. Constraints for all blocks

The total number of blocks used should provide enough timber bearing area against the hull to limit the maximum bearing stress to 2.145 MN/m^2 or less. This insures the hull will not have excessive loads that could damage it. This can be checked by dividing the ship's docking weight by total bearing area of all blocks (keel and side).

2.3. Modeling

To summarize, the problem is formulated into procedure described as below:

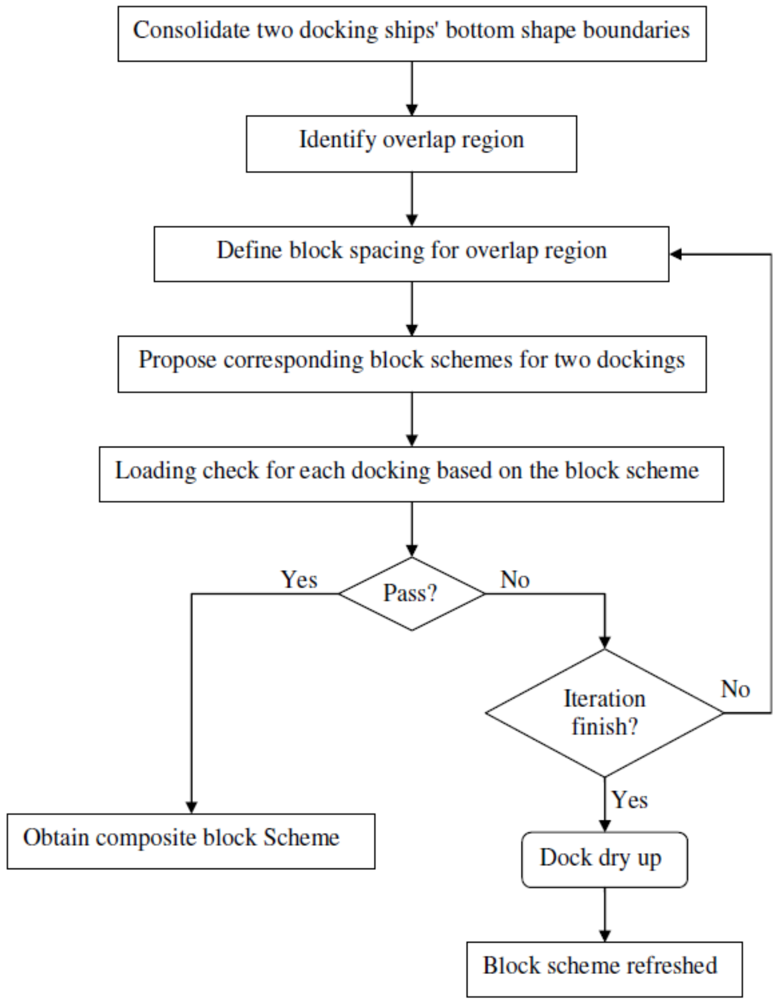


Figure 7 Problem formulation

2.4. Genetic Algorithm

GA is used to find near-optimal solution to the model aforementioned. Integer chromosome is used to represent the block plan. Chromosome size is the number of guide block lines, and its gene represents the block spacing on each block line. Since blocks are assumed all of uniform spacing, and locations of block lines are known, then from the chromosome a whole block plan can be reproduced.

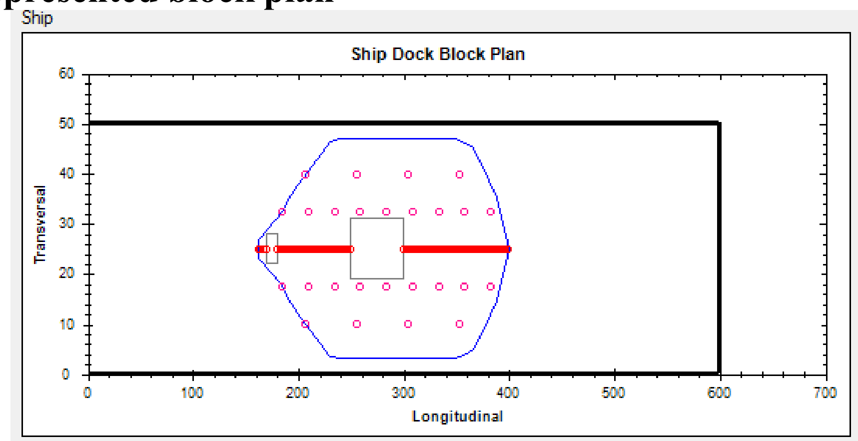
2.4.1. GA Chromosome

0	-1	K1	-2	S1	S2	-1	K2	-2	S1	S2	0	-1	K3	-2	S1	S2	S3

Figure 8 Chromosome sample

Above gives a chromosome representing multiple ships docking case of two consecutive dockings. In the first docking there are two ships, and the second is one. “0” is the separator of dockings, “-1” is the separator of ships, and “-2” is the separator of keel blocks and side blocks. “K” and “S” are the spacing of keel blocks and side blocks, respectively. Because blocks are always placed below girders and here the ship’s girders are assumed evenly distributed, then the block spacing can be represented by a multiple of girder spacing. These multiples are stored as genes in the chromosome.

2.4.2. Represented block plan



0	-1	3	-2	31	61	31	61

Figure 9 Represented block plan

All the blocking plans are referred to the stern reference point (SRP) which is the aftermost point on the ship. The block is placed starting from the SRP to forward.

2.4.3. Fitness Function

There are two objectives in this problem: 1) minimize dock dry up times, and 2) minimize dock number. The performance of the chromosome is evaluated by their ranking in each objective.

Table 1 Represented matrix based on objective function

Objective	Ranking				Represented sequence
	1	2	...	N	
Obj(1)	X11	X12	…	X1N	X1
Obj(2)	X21	X22	…	X2N	X2
…	…	…	…	…	

Obj(n)	Xn1	Xn2	…	XnN	Xn

For each chromosome, its fitness value is calculated by below formula:

$$E_i(X_j) = \begin{cases} \left(N - R_i(X_j)\right)^2 & R_i(X_j) > 1 \\ kN^2 & R_i(X_j) = 1 \end{cases} \quad i=1,2,\ldots,n$$

$$E(X_j) = \sum_{i=1}^{n} E_i(X_j),\ j=1,2,\ldots,n$$

Where:
n = total number of objectives
N = total number of individuals
Xj = the jth individual
Ri = the ranking in Obj(i)
Ei = the fitness in Obj(i)

For the last generation, the result individual is selected by sorting first objective firstly. If some individuals have the same objective value, they are sorted by the second objective.

2.4.4. The Constraint Handling Method

In the calculating process, the individual may be infeasible solution because of the violation of constraints. The constraint handling method in this paper is that of the literature Su (2007). This method searches the solution space of the problem through the admixture crossover of feasible and infeasible solutions, and does the selection and operation on feasible and infeasible populations, respectively.

2.4.5. Population Initialization

The feasible solution population and infeasible solution population are generated randomly.

2.4.6. GA Operators

- Selection

Selection operator combines the roulette wheel selection and the elite strategy. The individuals in the current population are copied to the new population according to the probability that is proportional to their fitness. The individual with higher fitness value gets more chance to survive. And mating pool (where parents are selected from) is selected in the same probability method.

- Crossover

The crossover operator is the primary search, which determines the global search capability of GA. The parents are selected based on below probability formula:

$$P_c = \begin{cases} \dfrac{k_1(f_{max} - f')}{(f_{max} - f_{avg})} & f' \geq f_{avg} \\ k_2 & f' < f_{avg} \end{cases}$$

Where:
Fmax = the maximum fitness value in the group;
Favg = the average fitness value in the group;
f' = the maximum fitness value of the parents;
k1,k2 is a number between [0,1]

It should be noted that crossover is performed on the ship level, which means the part of genes in the individual representing block arrangement for one ship is crossover with the part of genes in the same location of another individual.

- Mutation

The mutation operator is an assistant method of generating new individuals, which determines the local search capability of GA. The parents are selected based on below probability formula:

$$P_m = \begin{cases} \dfrac{k_3(f_{max} - f)}{(f_{max} - f_{avg})} & f \geq f_{avg} \\ k_4 & f < f_{avg} \end{cases}$$

Where:
f = the fitness value of the parent;
k3,k4 is a number between [0,1].

The mutation approach in this paper is that genes of individuals are randomly generated.

2.4.7. GA Procedure

STEP 1. Initialization, set GA parameters. According to constraints, divide the initial population into the feasible population popf and the infeasible population popinf.

STEP 2. Operate the crossover and the mutation on the feasible population and the infeasible population.

STEP 3. According to the constraints, divide the new population after crossover and mutation, into the feasible population popf and the infeasible population popinf.

STEP 4. Selection. According to the fitness of the individual, select N1 individuals which are good enough to form new feasible population from the old population to the new population; so is the new infeasible population that has N2 individuals.

STEP 5. Judge whether the iteration reaches the stopping condition? NO: go to step 1; YES: terminate procedures.

3. NUMERICAL EXAMPLES

A simple case is conducted to verify the feasibility of above illustrated theory. The code can be written in C#. The testing case is described as below:

➢ Model data

Table 2 Dock information

Length (m)	Breadth (m)	Max allowable load per square meter (ton)
450	60	200

Table 3 Scheduling

Time window	1	2	3
Ship index	1	2	3,4

Table 4 Ship information

Ship index	Bottom boundary length	Bottom boundary breadth	Dock weight	LCG[1]	Bow position in the dock[2] (x, y)	Longitudinal girder spacing (lbhd)	Transversal girder spacing (tbhd)
	(m)	(m)	(ton)	(m)	(m, m)	(m)	(m)
1	200	32	14500	90	(420, 30)	2.5	3.6
2	300	40	20000	130	(400, 30)	2.5	3.6
3	200	30	15000	100	(220, 30)	2.5	3.6
4	200	32	14500	90	(440, 30)	2.5	3.6

[1] reference point is at ship stern
[2] reference point is at the left-lowest point of the plan view of the dock

For simplicity, ships are represented by rectangles, and their block line interval is all 2×tbhd.

Table 5 Block information

	Length (m)	Breadth (m)	Max Allowed Load (ton)
Keel Block	1	1.7	240
Side Block	0.8	1.5	120

➢ Result from C# code

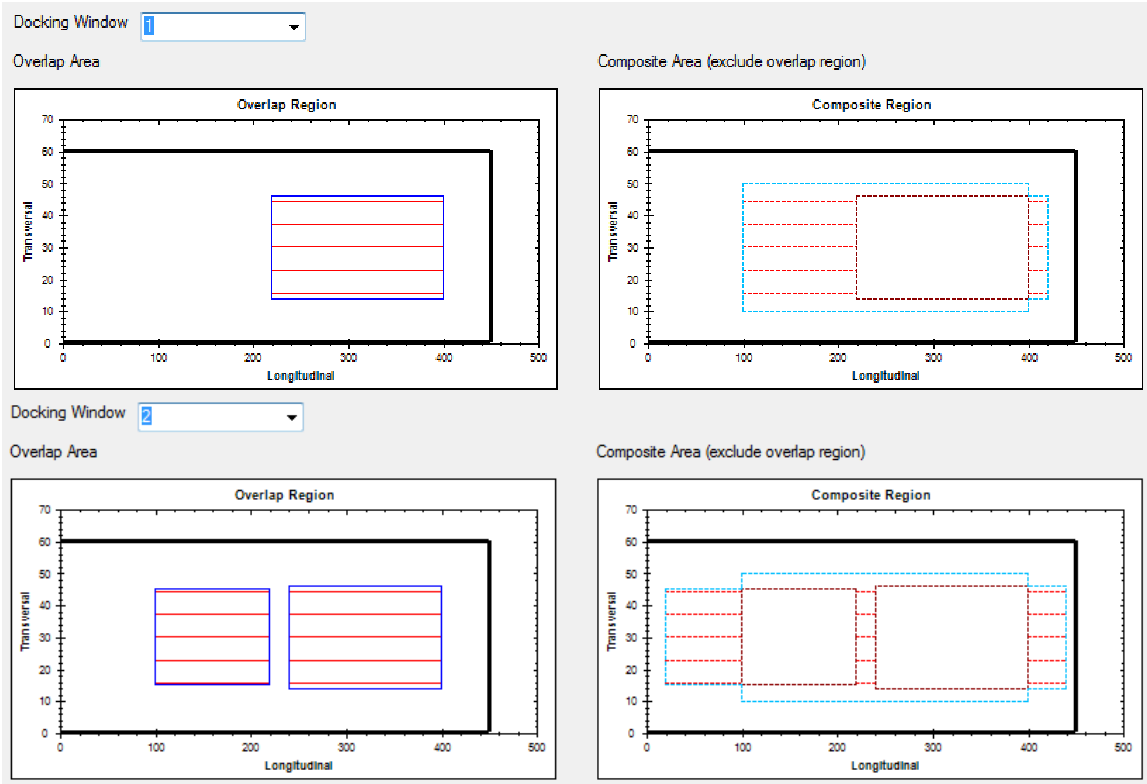


Figure 10 Overlap and composite for docking 1 and docking 2

Feasible population size = 50, infeasible population size = 20, elitist bias = 0.5, crossover rate = 0.8, mutation rate = 0.3, generation = 100.

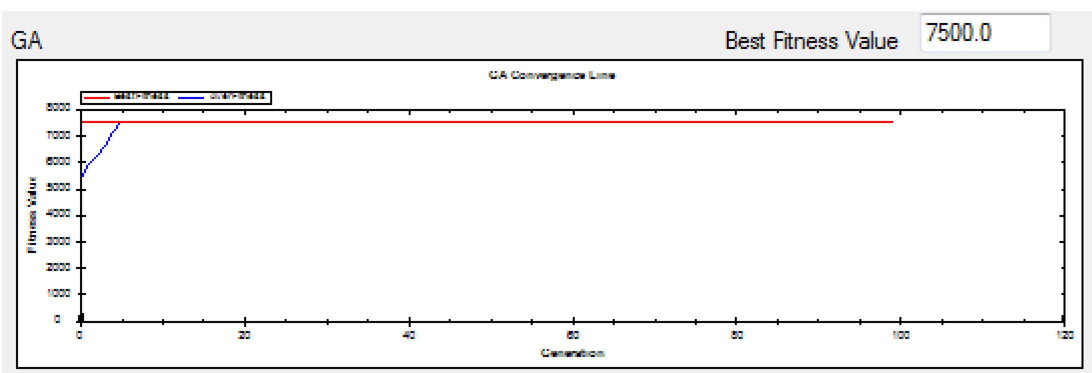


Figure 11 Lines of best fitness value and elitist average fitness value

Result Chromosome:

0	-1	1	-2	68	5	68	5	0	-1	1	-2	5	88	5	88
0	-1	1	-2	64	2	64	2	-1	1	-2	47	5	47	5	

Dock dry up times = 0

➢ Hand check

Table 6 Hand check result

	Single ship check						Composite plan check					
	Constraint 1		Constraint 2		Constraint 3		Constraint 1		Constraint 2		Constraint 3	
	GA	limit	GA	limit	GA	limit	GA	limit	GA	limit	GA	limit
Ship 1	235.625	240	38	37	121.85	200	235.625	240	60	37	103	200
Ship 2	233.325		54	50	148.15		233.325		93	50	115	
Ship 3	187.5		86	38	89.82		-	-	-	-	-	-
Ship 4	235.625		39	37	120.83		-	-	-	-	-	-

Constraint 1: Maximum load per keel block < limit
Constraint 2: Total side block number > limit
Constraint 3: Maximum load on dock floor per meter < limit

4. CONCLUSIONS

This paper gives an idea to find the optimum block arrangement for a series of dockings with multi-objectives to minimize dock dry up times and the block numbers. The problem of finding the minimum dock dry up times is converted to a problem of finding the available composite block arrangement for two consecutive dockings. Ship model is meshed by the distribution of its longitudinal and transversal girders. Keel blocks are placed under the keel line, which is the centerline of the ship model, while side blocks are placed under the cross points of longitudinal girder and transversal girders reflecting stronger points. Block pattern should satisfy strength constraints of ship, block and dock, thus separated into feasible solutions and infeasible solutions.

In our model, the girders are assumed evenly distributed, generating uniform mesh model. In addition, blocks all of uniform size, material and spacing, and ship assumed infinitely stiff, so simple beam theory can be applied for calculation of bearing load. Obviously, this generates the most simple block pattern with one keel blocks row in the center and several rows of side blocks scattered symmetrically along the centerline, and block spacing in each row is uniform. Of course, the model's complexity can be increased by relaxing above assumptions.

Since it is a NP-hard optimization problem, meta-heuristic method like genetic algorithm is used. GA is specially designed for this multi-objective problem which has constraints. Integer chromosome is proposed to reflect the block pattern. The fitness value of each chromosome is evaluated by its ranking in population. Solutions are divided into two sets of populations: feasible population and infeasible population. The admixture crossover of feasible and infeasible solutions is used for searches in the solution space of the problem.

Finally, a testing case is illustrated to elaborate the whole idea.

This work will be part of the scheduling model the authors are developing for docking arrangement for a series of ships. The whole system will provide a feasible optimization solution with the shortest total service time.

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