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Berth Allocation Optimization based on Genetic Algorithm

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Abstract

The main task of berth allocation is to make reasonable use of port berths and reduce the total service time and operation cost. In this paper, an improved heuristic algorithm model based on genetic algorithm is proposed for comprehensive planning of ship sequencing and berth allocation in one-way channel. The berth allocation and berth rate are verified and calculated through simulation. Compared with the traditional algorithm, the optimal operating cost can be calculated faster.

Keywords

GA; Heuristic Algorithm; Berth Allocation.

1. Introduction

Berth allocation is the starting point of port operation and management. It is very important to solve the problem of port allocation (BAP). After anticipating the vessel's arrival plan and stowage plan, the port will make a berthing plan and operation plan for the vessel. When the vessel arrives at the port, it will dock at the anchorage until it gets the permission of the VTS Center to hoard the anchor, the vessel will sail through the channel to the corresponding berth, and complete the loading or unloading operation here; When a ship makes an application for leaving the port, the port will send the ship's name, berthing location and other information to the VTS center for examination and approval. Only after the ship gets the notice of leaving the port can it sail out of the port through the channel [1]. It can be seen that channel and berth have a great impact on the efficiency of port operation.

Berth allocation is divided into static allocation and dynamic allocation. Static allocation means that all vessels are already in port when berth allocation is planned, while dynamic allocation is not required. Dynamic continuous berth allocation means that ships do not dock at the anchorage at the beginning of the planned period, but arrive at the port dynamically during the planned period, and the ship's prow can choose any position along the shoreline to dock [2]. A port usually consists of several bay basins where ships in different quay berths share a one-way passage. Therefore, it is necessary to determine berth allocation of different terminals at the same time. The berth is generally matched with some container areas in the rear yard of the port, that is, ships berthed at this berth load and unload cargo through the above container areas, thus generating preferred berths. If the berthing position of a ship deviates from the preferred berth, the distance between the ship and the storage area will be increased, resulting in an increase in port operation cost, which is called berth deviation cost.

Most existing studies on BAP have ignored the influence of one-way channel. However, one-way channel exists in many real ports, such as Jingtang Port (China) and Guangzhou Port (China) [3]. In this paper, we focus on single-channel berth allocation and cost minimization, and use heuristic algorithm to optimize ship entry and exit plan to make port operation more efficient. Ting Ching Jung developed a Mixed Integer Programming (MIP) model for BAP to minimize the total waiting time and processing time for all ships[4]. Wu studied the integrated optimization of berth allocation and ship inbound and outbound scheduling in one-way channel through precise branch pricing algorithm

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[5]. Arthur Kramer proposed two novel formulas, namely time index formula and arc flow formula, to solve DBAP effectively[6].

2. Mathematical model

2.1 Assumptions

In this model, the following assumptions are introduced:

(a) The wharf is divided into several berths, each berth can serve one ship at a time, regardless of the size of the ship;

(b) No physical or technical restrictions (e.g. water depth)

(c) After berthing, it will remain in place until all necessary container handling is completed;

(d) The ship's handling time (i.e. the time to complete the unloading and loading of containers) is commensurate with its handling capacity and depends on the berth allocated;

2.2 Mathematical models

In developing a mathematical model for ship scheduling optimization, we define the symbols as follows:

Table 1. Parameter definitions

Notations	Meaning
i∈N={1,…N}	N is the total number of vessels to be scheduled; i is the vessel identifier
Li	The length of vessel i
vi	The average speed of vessel i travelling in the port
tai	The time vessel i applies for scheduling
tsi	The time vessel i starts the schedule
tc1i	The time vessel i approaches the channel
tc2i	The time vessel i departs the channel
di	The distance for vessel i to travel from its anchorage to the channel opening
si	The distance for vessel i to sail from its berth to the end point of the channel
cl	The length of the channel
kim	Vessel i is going to be served at berth m; kim=1, if berth m is available at present; kim=0, otherwise
IOi	Indicates the direction of the vessel i travel; IOi=1 if vessel i is entering the port; IOi=0, otherwise
M	A sufficiently large constant

The mathematical model for vessel scheduling optimization is formulated as follows:

$$\text{Minimize } \sum_{i=1}^{N}(ts_i - ta_i) \tag{1}$$

$$t_{gap\,0(i)} = 6 * \frac{L_i}{V_i} \tag{2}$$

$$t_{gap\,1(i)} = 6 * \max(L_i, L_j)/V_i \tag{3}$$

$$ts_i \geq ta_i + IO_i * (1 - k_{im}) * M \tag{4}$$

$$tc\,1_i = ts_i + IO_i * (d_i/v_i) + (1 - IO_i) * (s_i/v_i) \tag{5}$$

$$tc\,2_i = tc\,1_i + \frac{cl}{v_i} \tag{6}$$

$$\begin{cases} tc\,1_i \geq tc\,1_j + t_{gap\,0} \\ v_i \leq v_j \end{cases} \tag{7}$$

$$tc\,1_i \geq tc\,2_j + t_{gap\,1} \tag{8}$$

$$ts_i + \frac{(DB_i - DB_j)}{v_i} \geq tc\,2_j + \frac{s_j}{v_j} + t_{gap\,1} \tag{9}$$

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$$ts_i \geq tc2_j + DB_i/v_j + t_{gap\,1} \tag{10}$$

Function (1) minimizes the total waiting time for the schedule.

Equation (2) indicates the minimum pursuit time interval for vessel i and vessel j when they are travelling in the same direction (the time is equal to s distance six times longer than the length of vessel i divided by the speed of vessel i).

Equation (3) indicates the minimum pursuit time interval for vessel i and vessel j when they are travelling in the opposite direction (the time is equal to a distance six times longer than the longer of the vessel i and vessel j lengths divided by the speed of vessel i).

Constraints (4) ensure that every vessels must be scheduled after their applications, and if the vessel is entering the port, the berth must be available.

Equation (5) indicates the time vessel i approaching channel equals the time vessel i starts the schedule plus the time it travels from its current position to the channel; if vessel i is entering the port, its travelling distance is di; otherwise, it is si.

Equation (6) indicates the time vessel i departing channel equals the time vessel i approaches the channel plus the time it passes through the channel.

Constraint (7) ensures that the time between vessel i approaching the channel and vessel j approaching the channel is at least a time interval of tgap0(i) if they are travelling in the same direction; in addition, the speed of vessel i should not exceed that of vessel j.

Constraint (8) ensures that the time between vessel i approaching the channel and vessel j departing the channel is at least a time interval of tgap1(i) if vessel i is entering the port while vessel j is travelling in the opposite direction.

Constraint (9) ensures that the time between when vessel i arrives at the berth where vessel j had been served and the time vessel j arrives at its berth must be at least a time interval of tgap1(i) if vessel i is departing the port while vessel j is travelling in the opposite direction and the berth where vessel i is going to be served is farther than the berth where vessel j had been served.

Constraint (10) ensures the time between when vessel i starts the schedule and the time vessel j arrives at the berth where vessel i is going to be served is at least a time interval of tgap1(i) if vessel i is departing port while vessel j is travelling in the opposite direction and the berth where vessel i is going to be served is nearer than the berth where vessel j had been served.

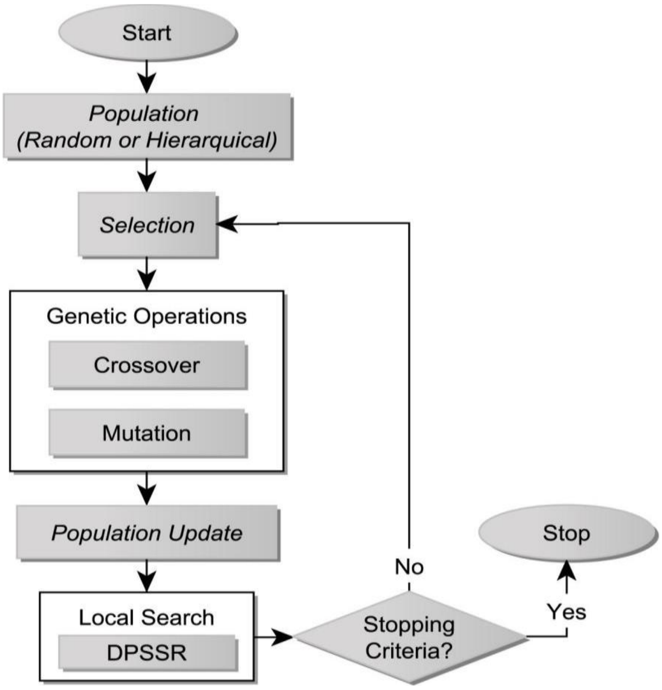

Figure 1. Optimization algorithm flow

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3. Algorithm design

In order to effectively solve the BAP problem and quickly and reasonably allocate berths, Figure 1 shows the process of heuristic algorithm. Next, we will briefly introduce the specific process.

3.1 Integer coding and initial population

Chromosome elements are coded as integers. Chromosome can be represented as the position of ships on the dock. Suppose there are N ships, numbered 1-N, allele 0 represents the transition from one berth to another, and other alleles represent ships. Take 19 ships berthed to 5 ports as an example (Table 1). 3.9.12 Three ships were arranged in one berth, 1.8.11.18.19 in another berth, and so on, 19 ships were allocated to 5 ports.

3 9 12 0 1 8 11 18 19 0 2 7 15 0 4 14 0 6 5 10 13 17 16

3.2 Fitness selection

The fitness of each individual in genetic algorithm is used to evaluate the quality of each individual, so as to determine the size of its genetic opportunity. The higher the fitness is, the better the individual is, whereas the smaller the fitness is, the worse the individual is. According to the fitness of the size of the individual selection, to ensure that individuals with good adaptability have more opportunities to reproduce, so that the excellent characteristics can be inherited. In the case, the objective function is always taken as a non-negative value, and the maximum value of the function is the target, so the objective function value can be directly used as the individual fitness. Therefore, the smaller the objective function value, the higher the fitness value. Therefore, the fitness function is as follows:

Fitness=1/(1+exp(y(x)/1000000))   Y (x) is the value of the target function

3.3 Selecting crossover and variation

Choose using the roulette wheel selection method. Roulette selection method is to calculate the probability of each individual appearing in the offspring according to the fitness value of the individual, and according to this probability, randomly select individuals to form the offspring population. The starting point of the roulette selection strategy is that the higher the fitness score, the greater the probability that an individual will be selected.

The operation of creating a new individual by replacing two parent parts of the structure is called crossover. The crossover in this case is a two-point crossover,The crossover algorithm uses partial matching crossover.

The basic content of mutation operator is to change the gene value on some loci of individual string in the population in order to accelerate convergence and prevent premature convergence. Because the ship has a fixed real number code, so the mutation uses transposition mutation.

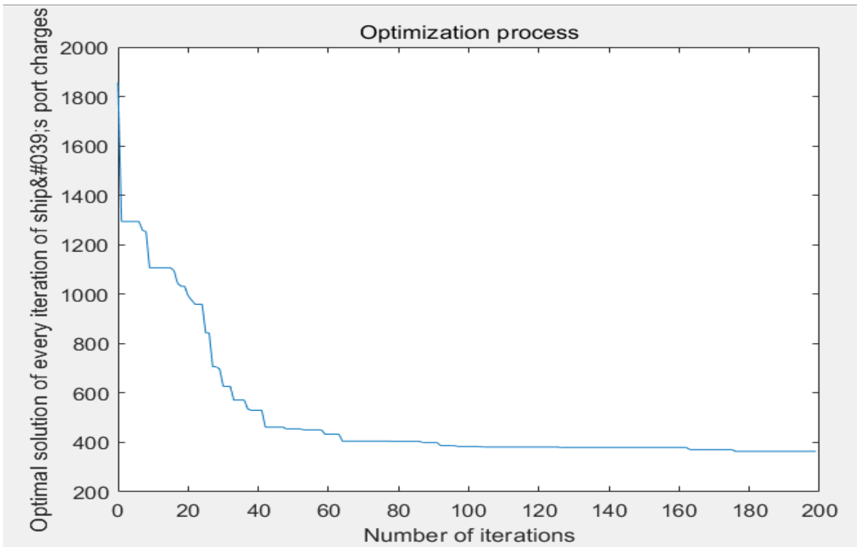

Figure 2. Simulation results of the algorithm

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4. Case study

There are many restrictions for the actual ship to enter and exit berths, so the model proposed this time cannot meet the actual situation. In this paper, the model and algorithm are verified by a simulation method, which simulates the one-way channel of Chinese ports. MATLAB was used for verification. In this case, 19 ships and 5 berths are used for simulation. The arrival time, loading and unloading time, deadweight tonnage and berthing rate of the ship have been determined. See Table 2.

Table 2. Ship Berth Plan

The ship number	Time of arrival	Loading and unloading time	Deadweight tonnage	Wait berth rate
1	0	25	41392	0.27
2	5.5	23.5	66557	0.43
3	16.5	20.5	67500	0.44
4	17.5	21	51335	0.33
5	18.7	42.8	70851	0.46
6	18	11.5	32706	0.21
7	23.5	23.2	69411	0.45
8	25.5	20	59850	0.39
9	38	13	18533	0.18
10	44	13.8	37248	0.24
11	50.3	25	68704	0.28
12	53	23.7	43546	0.33
13	62.3	24	97200	0.37
14	64	24	42940	0.41
15	71	24.7	68342	0.45
16	72.5	70	92160	0.49
17	73.5	34.3	82800	0.53
18	78.3	19	67840	0.58
19	80	22.5	41819	0.62

Group size:popsize=100;

Maximum genetic algebra:MAXGEN=200;

The ship number:vesselNum=19;

The berth number:berthNum=5;

Chromosome length:chromlength=Number of ships+The berth number-1;

Crossover probability:Pc=0.8;

Mutation probability:Pm=0.05;

Select probability:GGAP=0.9;

As shown in the figure 2, after 60 iterations of berth allocation optimized by heuristic algorithm, the optimal solution of ship's cost in port can be reached.

The optimal berth scheduling scheme is 6 8 0 4 9 11 18 15 0 2 7 12 0 13 10 14 19 0 5 13 17 16. The ship in port fee of the optimal solution is 334.0734

5. Conclusion

To establish single-channel ship sequencing and berth allocation, this paper adopts heuristic algorithm to carry out simulation. In the heuristic algorithm, real coding, selection, crossover and mutation are designed for iterative optimization, and numerical examples are simulated to verify the proposed model and algorithm. After calculation, a better solution can be obtained by comparing ship sequencing and berthing rate with first-come-first-served sequencing. However, the model still has a lot of room for improvement. The heuristic algorithm can be improved to achieve faster convergence, and the simulation should be combined with the specific berth conditions.

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