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Integrated Scheduling Optimization of Two-Way Channel Ships Entering and Leaving Ports and Tugboat Distribution

Shiqian Jiang*

Dalian Maritime University, Dalian 116026, Liaoning Province, China

****Corresponding author:*** Shiqian Jiang, suntieyuan@cmhk.com

Abstract: According to the passage rules of ships in the bidirectional channel, the realistic conditions of the limited number of tugboats in the port are taken into account. This paper studies the problems faced in the integrated scheduling optimization in terms of ship arrival and departure and tugboat allocation in two-way channel. A mixed integer programming model with minimum waiting time was established, and a heuristic algorithm was designed to solve the problem. Experimental results show that the model and algorithm in this paper can effectively solve such problems and provide support for port management.

Keywords: Port management; Ship dispatching; Two-way channel; Tug distribution

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1. Introduction

In recent years, in order to reasonably expand the waterway to improve the passage capacity and alleviate the problem of increasingly congested port, many ports at home and abroad have changed the waterway from one-way to two-way. Compared with the one-way channel, the two-way channel can immensely improve the channel flow, with the goal of having ships entering and leaving the port simultaneously without interfering with each other. However, while the efficiency of two-way channel ships' import port is higher, the limited tugboat resources need to be rationally distributed.

Numerous research have been done on waterway traffic direction conversion. For example, Zhang et al. [1] proposed the idea of switching between single and bidirectional waterways according to conditions, established a ship dispatching optimization model with the minimum total dispatching time and waiting time as the objective, and conducted safety test on the designed model. Some scholars also based their research on the service rules of two-way waterway. For example, Zheng et al. [2] studied the bidirectional channel ship scheduling problem considering service rules such as rules regarding night voyage, ship type, and dangerous goods vessel. A branch cutting algorithm was then designed to solve the problem, and the effectiveness of the algorithm was proven through comparative experiments. Wang et al. [3] took the 100,000-ton waterway in Dagang Port area of Tianjin as the research object and studied the adaptability of one-way and two-way navigation. Tao [4] studied the bidirectional navigation of large ships in the waterway of Zhanjiang Port. Weng et al. [5] studied two-way navigation problems based on a simulated waterway. Liang et al. [6] evaluated the two-way navigation risk of the inbound and outbound channel of Fangchenggang based on the fuzzy analytic hierarchy process.

At the same time, a wide range of studies were also done on the tugboat scheduling [7]. Zheng et al. [8]

studied the tugboat configuration and scheduling under the compound channel, considered the inner and outer tugboat berthing bases, established the tugboat scheduling model with the goal of the lowest total cost of tugboat fuel consumption, and solved the model with genetic algorithm. Xie Lan [9] studied joint berths and tugs scheduling and came out with a model involving three operations of berthing, unberthing and shifting, and considered the realistic demand of tugs returning to the base after a certain working period. Li et al. [10] considered the uncertainty of some parameters, established a fuzzy programming model for tugboat scheduling with the goal of minimizing the total fuel cost of tugboat, and designed a whale-genetic hybrid algorithm to solve the problem.

The aforementioned studies involve the analysis of the waterway or tug operation process from various aspects. However, those research are done from the perspective of a single operation, or the research of joint scheduling problem, but none involves the combination of the type of channel and tugboat scheduling. With the increase of inbound and outbound ship flow in the bidirectional waterway, the operation coordination between the waterway and the tug can effectively improve the operation efficiency. Therefore, it is of practical significance to study the integrated scheduling optimization of inbound and outbound ship and tug allocation in the bidirectional waterway.

2. Problem description

Under normal circumstances, in the process of ships entering and leaving the port in the two-way channel, the flow of ships entering and leaving the port is relatively independent. However, in some cases, two wide-bodied ships cannot meet in the channel and a larger ship can overtake a smaller ship if it is safe to do so. Incoming vessels shall be assisted by tugboats to berth at designated berths after sailing to the channel gate. Outbound vessels shall be assisted by tugboats to berth and sail to the channel gate before leaving the port. In order to improve the passage efficiency of the waterway and reduce the waiting time for ships entering and leaving the port, it is necessary to formulate the order of ships entering and leaving the port and the arrangement scheme of tugs within the working cycle according to the number of tugs and the type of vessels entering and leaving the port.

In short, the problems in this paper can be described as follows: In a fixed period, in a ports with a two way channel, with known loading and unloading time of vessels in the port and the time of arrival of vessels outside the port. In the two-way channel, without considering situations like overtaking and ships encountering each other, and the number of available tugboats is fixed, the optimization goal is to minimize the waiting time for ships entering and leaving the port, the order of ships entering and leaving the port and the scheme of tugboat configuration are given.

3. Mathematic model

3.1. Model assumptions

(i) Passage conditions are not affected by tides; (ii) the arrival time of the incoming ship and the departure time of the outgoing ship are known; (iii) large line up at the passageway, but overtaking is not allowed; (iv) the ship waits at the anchorage before entering the port, and the ship waits at the berth before leaving the port; (v) the fuel used and quantity of the tug are fixed, and the tug does not break down; (vi) the tugboat are situated at the target wharf after assisting in the port entry operation and at the channel gate after assisting in the port exit operation.

3.2. Symbol description

3.2.1. Parameter

I is the assembly of incoming and outgoing ships within the planning period; G is the collection of tugs available in port; K is the collection of docks in the port. One dock contains multiple berths, and the distance between docks is $D_{KK'}$; T is the set of time periods within the planning period; t_{safe} is the safe interval between two vessels entering and leaving the port continuously within the channel; t_{ai} is the estimated arrival time of ship i; t_{di} is the estimated time of departure of ship i; v_i is the speed of ship i and v0 is the speed of tugboat. d1 is the distance from the ship from the outer anchorage to the channel mouth; d_2 is the distance the ship passes in the channel; d_{3i} *i*s the distance between ship *i* from the channel entrance to the wharf where the pre-berthing berth is located; t_{0i} is the loading and unloading operation time of ship *i* at the corresponding berth; If ship *i* is a large ship, *Ai* is 1, otherwise it is 0. The number of tugs required by ship *i* is C_i.

3.2.2. Variate

When tugboat *g* is idle in time period *n*, U_{gn} is 1, otherwise it is 0. When the tugboat *g* is idle, the dock is *k*, then λ_{gk} is 1, otherwise it is 0. The waiting time of ship *i* in anchorage is t_{1i}; the waiting time of ship i at the gate is t2i; the waiting time of ship i at berth is t_{3i}, and the waiting time of ship *i* at gate is $t4_i$. If the incoming ship *i* enters the port during the period *n*, the value of x_{in} is 1, and the value of x_{in} is 0; if the outbound ship i is in the outbound condition of time period *n*, then yin is 1; otherwise, 0; if tugboat *g* is assigned to ship *i* to assist in port entry and exit at time period *n*, χ_{ing} is 1, otherwise it is 0.

3.3. Model establishment

$$MinZ = \sum_{i \in I} t1_i + t2_i + t3_i + t4_i \tag{1}$$

$$\sum_{n \in T} x_{in} \le 1, \forall i \in I, \tag{2}$$

$$\sum_{n \in T} y_{in} \le 1, \forall i \in I, \tag{3}$$

$$\sum_{n \in T} x_{in} + y_{in} \ge 1, \forall i \in I, \tag{4}$$

$$t_{ai} + t1_i = nx_{in}, \forall i \in I, \forall n \in T, \tag{5}$$

$$t_{di} + t3_i + t4_i = ny_{in}, \forall i \in I, \forall n \in T, \tag{6}$$

$$t_{di} = nx_{in} + t1_i + t2_i + \frac{d2 + d3 + d3_i}{v_i} + t_{0i}, \forall i \in I, \forall n \in T, \tag{7}$$

$$\sum_{n \in T} nx_{in} - \sum_{n \in T} nx_{jn} \ge t_{safe}, \forall i \in I, \forall j \in I, \forall n \in T, \tag{8}$$

$$\sum_{n \in T} ny_{in} - \sum_{n \in T} ny_{jn} \ge t_{safe}, \forall i \in I, \forall j \in I, \forall n \in T, \tag{9}$$

$$\sum_{i \in I} \sum_{g \in G} \chi_{ing} \le g_{\max}, \forall n \in T, \tag{10}$$

$$\sum_{i\in I}\sum_{n\in T}\chi_{ing} \le 1, \forall g \in G, \quad (11)$$

$$\sum_{i\in I}\sum_{g\in G}\chi_{ing} = C_i, \forall n \in T, \quad (12)$$

$$\sum_{n\in T} nx_{in} - n \le M(1-\chi_{ing}), \forall i \in I, \forall n \in T, \forall g \in G \quad (13)$$

$$n - \sum_{n\in T} nx_{in} - t_{1j} - \frac{d1+d2}{v_j} \le M(1-\chi_{ing}), \forall i \in I, \forall n \in T, \forall g \in G \quad (14)$$

$$\chi_{ing} - U_{gn} \le 0, \forall i \in I, \forall n \in T, \forall g \in G \quad (15)$$

$$t2_i \ge Max\sum_{i\in I}\chi_{ing}\lambda_{gk}\frac{D_{ko}}{v0}, \forall i \in I, \forall n \in T, \forall g \in G \quad (16)$$

$$t3_i \ge Max\sum_{i\in I}\chi_{ing}\lambda_{gk}\frac{D_{kk'}}{v0}, \forall i \in I, \forall n \in T, \forall g \in G \quad (17)$$

The objective function (1) is to find the minimum sum of the waiting time of all ships; constraints (2), (3) and (4) constraint that each ship can enter and leave the port no more than once; constraints (5) and (6) are used to limit the port entry and exit time of ships; constraint (7) represents the time of completion of the ship; constraints (8) and (9) indicate that a safe time interval needs to be maintained between the ships entering and leaving ports; constraints (10), (11) and (12) mean that the total number of tugs used in the same period shall not exceed the total number of tugs. Tugs can only assist one ship at a time, and the number of tugs assigned to each ship meets the requirements of the ship; constraint (13) and (14) indicate that the tugboat operation period is within the arrival and departure period of the ship; constraint (15) means that tugs can only be assigned to ships to assist in port entry and exit when they are idle; Constraints (16) and (17) indicates that the waiting time for the tugboat is the time when the last tugboat arrives at the operating dock.

4. Solution algorithm and example experiment

4.1. Solving algorithm

The structure of the model in this paper is relatively complex, so genetic algorithm is used to solve it. The main steps of genetic algorithm are as follows: generating the initial population, calculating the fitness of the population, screening the offspring, cross mutation and so on. The specific algorithm steps are shown in **Figure 1**.

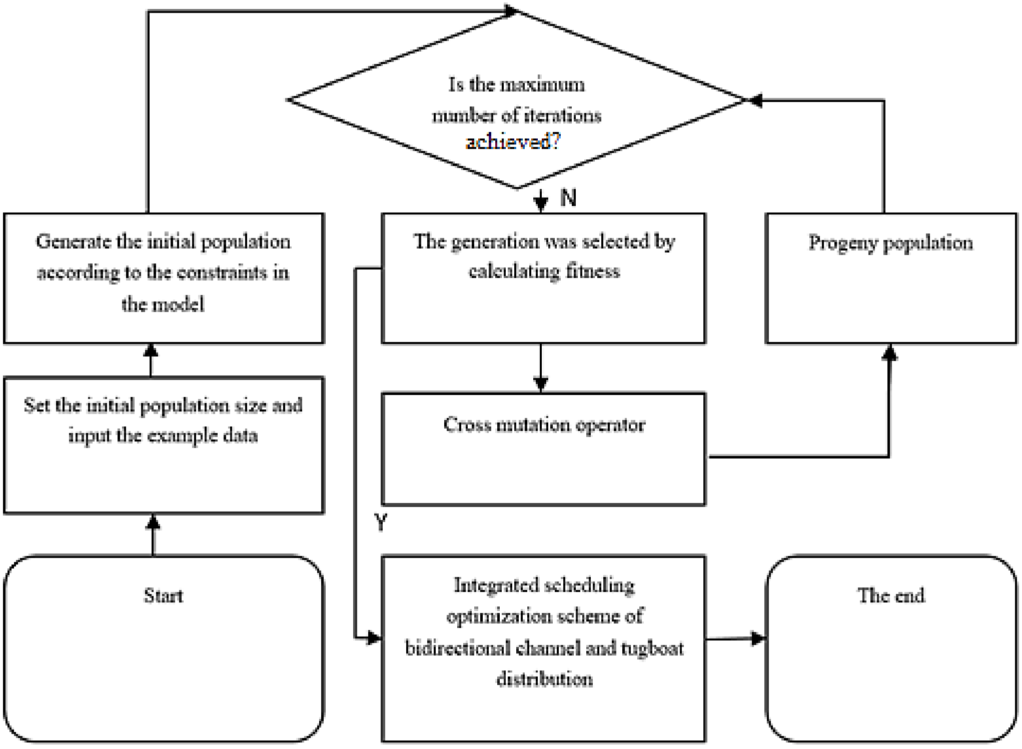

Figure 1. Algorithm flow chart

Coding structure: integer coding structure is adopted, each integer represents the ship number, and the sequence of the serial number is the order of the ship entering and leaving the port. According to the limitation of the number of tugs, the tugs that meet the requirements of its berth assistance are randomly assigned to the ship.

Decoding mode: The entry sequence of the ship can be known through the ship number, which contains the entry time and departure time of the ship, and the waiting time of the ship in the whole operation cycle can be calculated.

4.2. Example experiment

The incoming and outgoing information of 30 ships in a cycle is randomly generated, the algorithm parameters are initialized, the population is set as 30, and the number of iterations is 150. In this paper, Intel (R) Core (TM) i5-9300CPU@2.40GHz processor was used in the experiment, and MATLAB programming is used to solve the problem for 5 times on a PC with 16GB memory. The final result of the solution and the convergence process of the algorithm are shown in **Figure 2**.

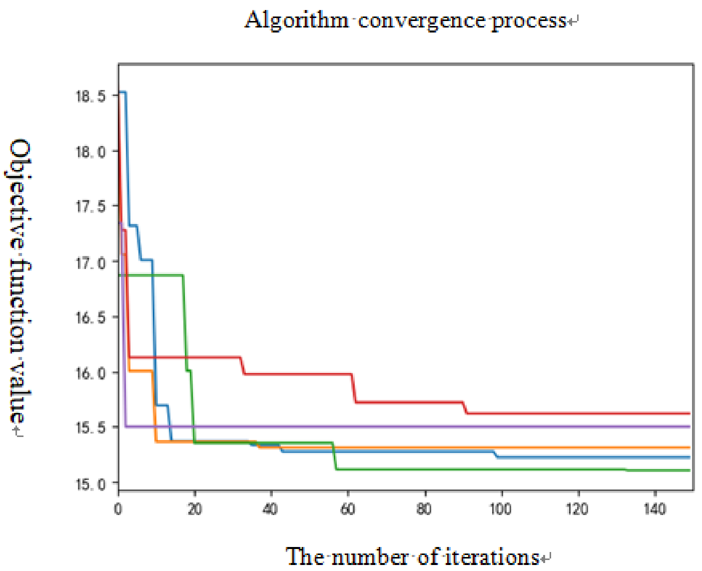

Figure 2. Algorithm solution results

5. Conclusion

As channel widened from a one-way passage to a two-way channel, vessel traffic further increase, tug operating pressure also will increase. Therefore, this paper studies the two-way waterway shipping scheduling and tug roads distribution integration problems, and established a mixed integer programming model through heuristic algorithm according to the characteristics of two-way waterways and tug limit. The feasibility of the algorithm was proven with an example, which shows that this model has theoretical value and practical significance.

In future studies, in addition to optimizing the waiting time, optimization objective conditions such as the total cost of integrated scheduling should also be considered to maximize the benefits of operators. In terms of uncertain factors, such as bad weather, ship failures and other events will disrupt the synergy between original channel scheduling scheme and the tugboat distribution scheme, and affect the stability of the port system. Therefore, in future studies, the influence of uncertain factors on the operation plan can be considered in designing a port.

Disclosure statement

The author declares no conflict of interest.

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