Intelligent scheduling technology for tugboat operations

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Abstract: As an important tool for non-powered vessels or large vessels to complete the scheduling work such as berthing, moving and disembarking, port tugs directly affect whether each vessel can enter the berth in time for loading and unloading operations. Therefore, tugboat scheduling is crucial to the normal operation of the port. The article will analyze the current domestic and foreign research on tugboat scheduling, analyze the algorithms and innovations, and consider a tugboat scheduling scheme suitable for this port area by taking a domestic port as an example.

Keywords: port tugboats, scheduling scheme, berth allocation

1 INTRODUCTION

The resource dispatching of port cargo mainly relies on tugboat dispatching and terminal loading and unloading operations and car transportation, while the development of the port relies largely on the efficiency of ship entry and exit, berthing and ship cargo loading and unloading, before which the first thing the ship needs is the assistance of the port pilotage system. Ship berthing is the primary condition for this series of normal operations, and this responsibility is assumed by port tugboats. Providing efficient tugboat scheduling solutions for incoming ships not only improves port revenue but also reduces tugboat operating costs. As tug and ship berthing will not change much in the short term, it belongs to the long-term investment of the whole port, which has a profound impact on the development of port shipping and the improvement of operation efficiency.

2 CURRENT STATUS OF DOMESTIC AND INTERNATIONAL RESEARCH

2.1 Berth allocation problem

The study for berth scheduling is generally referred to as the berth allocation problem, specifically the provision of berthing plans for these vessels within a given planning cycle based on the relevant information provided to the terminal by the upcoming vessels, the main information in the plan being the specific berthing location and berthing time of the vessel

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upon arrival [1].

According to the different berth distribution methods of actual operation berth allocation is mainly divided into discrete type and continuous type. Among them, discrete type means that a ship cannot cross multiple berths when berthing, but can only be in the position space limited by a certain berth [2]. In this scheduling method, the type of the ship, the water depth of the berth and the shape of the port shoreline do not restrict the smooth berthing of the arriving ship. Continuous berth scheduling means that the ship calls across multiple berths directly according to the physical location marked on the chart or shoreline [3]. Continuous berth scheduling is more flexible and requires a high level of port shoreline.

Berth scheduling can also be divided into static and dynamic depending on the arrival time of vessels and the time of berth allocation. Static berth scheduling means that all vessels to be scheduled for operation have already arrived at the port at the time of berth allocation and will be considered for allocation to the next operation time slot, while dynamic means that there are still vessels that have not arrived at the time of berth allocation but will arrive at some point in the allocation time slot [4].

Yantao Zhang [5] established a mathematical model of port berth scheduling with the objective of shortest total ship time in port, and obtained the optimal solution of the model based on genetic algorithm. Li [6] designed a nonlinear planning berth scheduling model using GATS algorithm for the advantage of model solving algorithm. Zhang Jindong [7] proposed an optimization algorithm for the problem of poor robustness of terminal berth optimization. Shaowen Sun [8] et al. took the tidal motion factor into consideration, summarized the tidal motion law, and used it as a basis to establish a model for minimizing the total ship time in port. Huang [9] et al. established a mathematical model on berth scheduling and introduced an improved particle swarm optimization algorithm to solve the optimal scheduling problem. Xu Ya [10] et al. proposed a class of coordinated berth scheduling problems for multiple container terminals at different locations in the port, established a corresponding mixed integer programming model, and designed a hybrid simulated annealing algorithm HSA combining heuristic strategy and simulated annealing mechanism to solve the problem.

Kim and Moon [11] developed a mixed-integer linear programming model to solve the berth scheduling problem and used a simulated annealing algorithm to solve the near-optimal solution of the berth scheduling problem. monaco and Sammarra[12] considered two types of berth assignment problems: the discrete case and the continuous case, proposed a new solution formulation, and designed a Lagrangian heuristic algorithm. Arango and Cortés [13] et al. presented a dynamic berth assignment problem for continuous terminals, proposed a mathematical model with the objective of minimizing the distance moved by forklifts and quay cranes for each vessel's container handling operation, and developed a heuristic program based on a genetic algorithm to solve the corresponding mixed integer problem.

2.2 Tugboat scheduling problem

By scheduling is meant the allocation of scarce resources required for various tasks that need to be completed at a certain time, with the aim of optimizing one or more objectives [14]-[15]. Scheduling can be divided into deterministic and uncertain scheduling depending on the environment under study, the environmental factors to which it is subjected, and the effects of uncertainty or randomness, and the scheduling problem can be divided into single-level scheduling and multi-level scheduling depending on the characteristics of the object under study [16].

For ship scheduling, it can be divided into two ways: plan scheduling and real-time scheduling, among which, plan scheduling means to make comprehensive planning for sea routes, ports of ships' routes and cargo volume before cargo is shipped, and to make ship's voyage plan, cargo specification and periodical schedule, etc.; real-time scheduling means to use AIS system and satellite navigation data to schedule ships that are carrying out cargo transportation work. Through flexible ship scheduling to adapt to the unexpected situation of shipping process. As an important tool for non-powered ships or large ships to complete berthing, moving and disembarking, port tugboats directly affect whether each ship can enter the berth for loading and unloading in time. Therefore, the dispatching of tugs is crucial to the normal operation of the port.

Liu, C.X. [17] et al. used a rolling time series method to construct a dynamic dispatching model of tugs based on a time window-based rolling dispatching strategy with the objective of minimizing tugs as well as maximizing operation time for ports with one-way channels and based on real-time changing vessel dynamics. Although the study does not consider the problem of berth allocation for ships in the port, the tugboats will depart in time while waiting for berths to become available due to the real-time based on the ship's motion status, which reduces the tugboat's idling distance even if berths are missing.

Liangcai Dong [18] et al.. solved the mathematical model of tugboat dynamic scheduling by analyzing the process and characteristics of port tugboat operations, using an improved particle swarm optimization algorithm based on dynamic genetic operators (introducing elite sets). Han Xiaole [19] et al. a hybrid algorithm based on simulated annealing with forbidden depth local search for solving the discrete berth scheduling problem in the case of dynamic ship arrival. He achieved improved operational efficiency and port service satisfaction in the model.

Chou [20] et al., scholars in Taiwan, analyzed the data of merchant ships entering and leaving the port of Kaohsiung and applied the condition analysis related to the concept of towage fee differentiation to study the relationship between towage operations and tug revenue under various conditions. A feasible solution to improve the port congestion problem and increase the efficiency of towage operations using the Delphi method was proposed. Lin [21] et al. developed an optimal scheduling model for ship entry and exit using a one-way traffic channel to effectively avoid ship collisions caused by ships waiting to berth in and out of the port in congested waters. Lan Xie [22] proposed an improved particle swarm optimization algorithm to study the cooperative optimization of tugboats and discrete berths, and used a multi-objective optimization algorithm to solve the problem of minimizing the ship's time in port, as well as the problem of minimizing the operation cost.

Braganzae [23] et al. proposed a control method for positioning an undriven vessel by multiple autonomous tugboats. A scheme for scheduling tugboats by rational allocation of tug thrust is proposed. Lee Seung-Min [24] et al. proposed a method for dynamic motion analysis, calculation and optimization of control data based on surface vessels to improve the efficiency of tugboat scheduling.

2.3 Problems

Currently, in the actual operation of ports, berth allocation and tugboat scheduling are mostly made up manually by experienced employees, which is especially lacking in science when there are more vessels arriving in ports, generating more consumption and reducing economic efficiency. And in the theoretical research, most scholars study berth scheduling or tug scheduling separately. However, if only tug scheduling is considered, if there is no berth available after tugboat pilotage, it will lead to chaotic and disorderly port traffic, and then lead to marine environment pollution, which is not conducive to the sustainable development of the port. If only the scheduling of berth is considered, if the tugboat does not pilot the arriving vessel to the free berth in time, then the berth must wait for the vessel to load and unload; or if the tugboat does not tow the vessel out of the berth in time after the vessel has finished loading and unloading at the berth, the next vessel at the berth will not be able to load and unload, which will lead to the waste of berth resources, longer time for the vessel to stay in port, and lower customer satisfaction.

3 PORT TUG SCHEDULING OPTIMIZATION SCHEME THINKING

Based on the above review of domestic and foreign tugboat scheduling research, a tugboat scheduling scheme is proposed for the new port of Dalian Port in China. Dalian Port, as the largest trade port in northeast China, has superior natural geographic conditions and is the cargo distribution hub of Liaodong Peninsula and Bohai Rim region, an important port at the eastern end of the Eurasian Continental Bridge, and an advantageous port to promote the construction of "One Belt and One Road" and the deep integration of regional economic development and opening[25]. Dalian Port New Port is located at the northeast foot of Dagushan Mountain at the south end of Liaodong Peninsula, southwest of Dayao Bay on the Yellow Sea coast (crude oil products, chemicals) has two large crude oil terminals of 450,000 tons and 300,000 tons, LNG terminal, 450,000 tons bulk cargo terminal with a total of five large ship berths, now provides including oil products, liquid chemicals terminal, professional LNG terminal, bulk cargo terminal. As an emerging port area in Dalian Port in recent years, the capacity of the new port area for oversized tankers and bulk carriers has outstanding contribution in the whole port operation. The article will take five berths in the new port area of Dalian Port as an example and consider the scientific and economic tug scheduling scheme.

Table 1. Main data of port tugboat

Horsepower (hp)	1200	3800	4200	4800	5200	6500	7200
Dagang tug base	1	1	3	3	4	1	0
Dayao Bay tug base	0	1	2	1	0	1	4

3.1 Berth allocation model

Assume the following constraints on the model.

(1) The model assumes that only the inbound and outbound tug scheduling of vessels to be inbound is studied.

(2) all vessels arriving in the port during the planning period have arrived at the port anchorage and are waiting, and no other vessels are considered to come to the terminal for operation during the planning period (this assumption limits the model to a static scheduling model).

(3) All vessels to be serviced use the principle of FCFS (first to arrive with higher priority) according to the order of arrival.

When there are more ships waiting for approaching at anchor or the channel is congested, the priority of ships can be adjusted according to the congestion. By adjusting the priority, the berthing and unberthing operations that have a higher possibility of not being completed on time can also be carried out earlier, so that the problem of operations not being completed on time due to unreasonable scheduling can be eliminated to the greatest extent.

3.2 Tugboat scheduling model

In general, the actual production operation of tugboats in China's coastal area follows 3 principles: the principle of shortest distance tugboat operation (focusing on how to quickly serve the next ship), the principle of first available tugboat (taking into account the operation of all tugboats), and the principle of uniform task volume of each tugboat (preventing driver fatigue and distributing income evenly). The tug scheduling model is established in order to achieve the minimum waiting time for tug, the minimum tug overflow horsepower, and the maximum tug economic efficiency.

Table 2. Assuming the parameters of the tug scheduling model.

K: Number of ships waiting	$MinS_i$: Minimum number of tugs required for ship i
i: entry operation vessel number , i={1, 2, 3...K}	R_{im} : The number of the mth tug assigned to the ship
j: operation phase (j=[1, 2] represents berthing, disembarkation)	T_{im} : The tug class assigned to the vessel
N_i : Number of tugs assigned to the ship	$Tmin_{im}$: the minimum class of tug assigned to the vessel
M: Total number of tugs in the two ports	$costT_{im}$: assign the amount spent by tug m to ship i
m: tug number, m = {1, 2, 3...M}	H_{im} : Time consumed by tug m to complete berthing of vessel i
Si: type of the ith ship	θ_1 , θ_2 , θ_3 are the weighting coefficients
Y_i : time vessel i waits for the tug	

$$f = Min\{\theta_1 \times f_1, \theta_2 \times f_2, \theta_3 \times f_3\} \quad (1)$$

$$f_1 = Min\sum_{i=1}^{k} Y_i \quad (2)$$

$$f_2 = Min\sum_{i=1}^{k}\sum_{m=1}^{N_i} costT_{im} \quad (3)$$

$$f_3 = Min\sum_{i=1}^{k}\sum_{m=1}^{N_i} T_{im} - Tmin_{im} \quad (4)$$

Subject to:

$$0 \le T_{im} - Tmin_{im} \le 2, 1 \le i \le K, 1 \le MinS_i \le N_i \ (5)$$

$$R_{im} - R_{ik} \ne 0, 1 \le i \le K, 1 \le m, k \le N_i \ (6)$$

$$H_{im} \ge 0, 1 \le k \le i, 1 \le m \le N_i, 1 \le t \le N_k \ (7)$$

Eq. (2) indicates the shortest operating time when the incoming vessel needs the assistance of a tug to berth, andY_i is the time that the incoming vessel waits for the arrival of the tug.

Eq. (3) indicates the minimum amount spent on tug-assisted approach required by all incoming vessels.

Eq. (4) represents the minimum spill horsepower of the tug serving the incoming vessel

Eq. (5) indicates that the tug provided for the incoming vessel satisfies the appropriate horsepower for the vessel-tug ratio, and if there is no minimum appropriate horsepower that satisfies the condition, when the horsepower overflows, it cannot exceed at most two levels of the tug horsepower required by the incoming vessel.

Eq. (6) indicates that tugs of the same number cannot be assigned to each incoming vessel at the same time.

Eq. (7) indicates that the incoming vessel, aided by the required tug, operates in a sequence that cannot be reversed.

Therefore, there are many constraints in the tugboat scheduling model, and there are many kinds of decision variables in the model, and the workload of problem solving is huge, so the optimal solution cannot be found using general mathematical planning methods, and intelligent algorithms must be used for optimization.

4 CONCLUSION

In view of the above analysis, the particle swarm algorithm can be used to optimize the tugboat scheduling in the new port area. The characteristics of this method are: compared with other intelligent algorithms, the parameter setting is simpler and easier to serve the actual application; however, the particle swarm algorithm is more suitable for the optimization of continuous-type problems, and since the problem is discrete, an improved particle swarm optimization algorithm is used. There are two key steps in the computational process of applying the algorithm.

1.Mapping each combination of tugs serving incoming vessels to the representation space

2.Convert the objective function in the tug scheduling model into an adaptation function

Step1: Tug class adaptation function

Step2: Tug scheduling conflict adaptation function

Step3: Tug utilization function, the higher the tug utilization rate, the lower the cost of tug scheduling. The tug utilization rate is expressed by the average tug utilization rate, i.e., the working time of all tugboats / the time of tugboats in port (including the waiting time for the task).

The laboratory's navigation simulator has a variety of tugboats and supporting detailed parameters and ship motion models, which can easily obtain the tugboat's horsepower data, operability, and fuel consumption models, providing complete data support for the model. The tugboat pilotage simulation in the simulator is more detailed and realistic to be able to provide simulation tests for this study.

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