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A Proactive-reactive Approach for Dynamic Hybrid Berth Allocation Problem Considering Vessels Arrival Delay

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***Abstract*—Dynamic Berth Allocation Problem (DBAP) is an essential problem in container terminal operations. Most studies focus on discrete or continuous berths in DBAP. However, affected by the geographical conditions, the mixture of discrete and continuous berths which are called hybrid berths often appear in real port container terminals. Moreover, the arrival time of vessels is often fluctuant due to the influence of environmental factors. To solve such a Dynamic Hybrid Berth Allocation Problem (DHBAP) under vessels' arrival delay, this study develops a proactive-reactive approach. Specifically, we establish a mixed-integer programming model with a buffer as the proactive strategy to obtain a baseline schedule. Then, we propose a hybrid berth reactive strategy (HBRS) to adjust the baseline schedule for vessels that are delayed. To get a better solution in a short time, a genetic algorithm is designed. We verify the effectiveness of the proposed HBRS by comparing it with the most commonly used right-shift strategy. Experimental results show that the longer the buffer is, the better the robustness of the model is, but the total time of the vessel in terminals will also increase. Compared with the right-shift strategy, the proposed HBRS can obtain an allocation plan with similar robustness in a shorter total time of the vessel in terminals.**

Keywords—dynamic berth allocation, delayed vessel arrival time, hybrid berth, proactive-reactive approach, genetic algorithm

I. INTRODUCTION

With the rapid development of maritime transportation, ports play an increasingly important role as a node of international maritime and land transportation networks, and berths are essential resources of ports. A berth is a position in a port where a vessel can stop and perform loading and unloading operations. Making a reasonable berth allocation plan is significant for improving the operating efficiency and the service level of port terminals.

The problem of berth allocation is aimed to allocate berthing time and position for vessels arriving at the port in the future rationally to achieve the optimization of one or more objectives. Akio Imai et al. [1] divided the berth allocation problem into static berth allocation problems and dynamic berth allocation problems. If all the vessels have already arrived in the port, the problem is identified as a static berth allocation problem. Alternatively, if not all vessels have arrived in the port but the arrival time or time window is known, the problem will be classified as a dynamic berth allocation problem. In realistic situations, the berth allocation plan of a port needs to be made in advance. Therefore, most studies focus on dynamic berth allocation problems.

According to the types of berths, the dynamic berth allocation problem can be classified into two categories: Dynamic Discrete Berths Allocation Problem (DDBAP) and Dynamic Continuous Berths Allocation Problem (DCBAP). Discrete berths refer to a port with a fixed number of berths, and only one vessel can be berthed at each berth [2]. If the berths and vessels are analogized to processing units and jobs, the DDBAP can be regarded as a parallel machine scheduling problem, where each job has only one operation [3]. Under the current situation of scarce berth resources in *Japan*, Imai et al. [1] studied the problem of dynamic berth allocation in public berth systems. They established a linear programming model for discrete berths and proposed a heuristic algorithm to obtain an operation sequence for vessel berthing. Zheng et al. [4] considered the influence of tides on vessel berthing and the dynamic movement of quay cranes when developing the mathematical model and optimized the total operation time of all vessels within a cycle.

Different from discrete berths, in DCBAP, vessels can berth at any position on the coastline of a terminal. However, the sum lengths of vessels and the safe distance among them must be less than the length of the coastline. In the DCBAP, Lee et al. [5] represented the allocation plan of continuous berth in the time-space diagram and proposed a covetous stochastic self-adaptive search algorithm to ascertain the subsequent vessel's placement. Hao et al. [6] comprehensively considered the scheduling optimization problem of berths and quay cranes and established a collaborative scheduling model for them. Shi et al. [7] considered that different container vessels have different draught requirements. Taking continuous berths as research objects, they constructed an integrated optimization model for continuous berth assignment and quay crane allocation considering tidal effects.

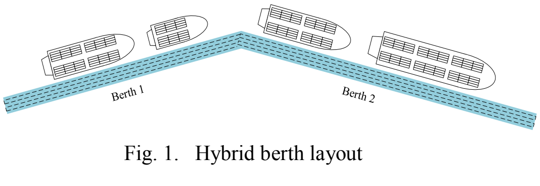

Fig. 1. Hybrid berth layout

In many realistic ports, such as *Dalian* Port, *Fuzhou* Port, *Guangzhou* Port, et al., berths are not only discrete or continuous but also hybrid berths containing both discrete and continuous characteristics. As shown in Fig.1, the berthing line of a hybrid berth is an irregular shape containing several straight lines, each of which can be regarded as a continuous

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berth [8]. Therefore, a hybrid berth consists of multiple independent continuous berths. Compared with the DDBAP, the DHBAP needs to consider the operation sequence of vessels after selecting the berth for vessel operation. Compared with the DCBAP, when a vessel arrives at a port, the vessel needs to choose a suitable berth for berthing. Therefore, different from traditional DBAP, the DHBAP has some new features where hybrid berths have both discrete and continuous characteristics. However, the current researches related with BAP only establish mathematical models for discrete and continuous berths respectively, so it is necessary to establish a mathematical model for hybrid berths.

At present, there are few studies on hybrid berths. Among them, Sun et al. [8] studied the vessel berthing mode and quay crane allocation strategy under the hybrid berth system. They designed three berthing modes and three allocation strategies and used Monte Carlo simulation technology to conduct simulation experiments to compare the effects of different modes and strategies. De et al. [9] studied the dynamic allocation problem of hybrid berths in large-scale real environments based on actual ports. They regarded hybrid berths as continuous berths. Considering the waiting time of vessels caused by unavailable berths and quay cranes, they established a mixed integer linear programming model and proposed a chemical reaction optimization algorithm to solve the model. Wang et al. [10] studied the allocation problem of retractable-parallel hybrid berths under the condition of scarce shore resources. They established a berth allocation model and designed a fast Non-dominated Sorting Genetic Algorithm with elite strategy (NSGA-II) to obtain a better allocation strategy. However, these studies did not consider the uncertain factors of vessel arrival times [11] and simply analogized hybrid berths as continuous berths, ignoring their characteristics of discrete berths.

In the actual process of vessel arrival, due to uncertain factors such as weather and vessel anchoring, the actual arrival time of vessels often deviates from the estimated arrival time [12]. Especially when vessels are delayed, the formulated baseline allocation will be greatly affected. The approaches for solving these uncertain factors in berth allocation problems include proactive and reactive strategies [13]. Proactive strategies mainly generate a pre-scheduling or pre-allocation plan with robustness using strategy. Zhen et al. [14] studied the berth allocation problem under uncertain vessel arrival time and operation time by adding a certain degree of uncertain expectation to the baseline allocation. Reactive strategies mainly modify the original scheduling or allocation plan or even reschedule when encountering uncertain events. For example, Umang et al. [15] designed a recovery plan for real-time adjustment of the baseline schedule when uncertain scenarios occur. The use of either the proactive strategies or the reactive strategies alone cannot handle all uncertainties. To get the best of the two strategies, Tan et al. [16] used a proactive-reactive approach to study the BAP for continuous berths.

Therefore, we study the DHBAP considering the arrival delay of vessels and design a proactive-reactive approach for dealing with the uncertainty. In conclusion, the main contributions of this study are three aspects: (1) the dynamic scheduling problem of hybrid berths under vessels' arrival delay is researched; (2) a proactive-reactive approach which contains a two-stage mixed-integer programming model with buffer strategy and a reactive reallocation strategy for hybrid berths is proposed; (3) a genetic algorithm has been designed to solve the model for large-scale vessels.

The rest of the paper is organized as follows. In section II, we describe the problem and establish a mathematical model for it, and propose a reactive strategy suitable for hybrid berths. In section III, a genetic algorithm for DHBAP is designed. The results and discussion of the experiment are presented in section IV. Finally, section V summarizes the main work of this paper.

II. MODEL FORMULATION

A. Problem Description

The hybrid berth allocation problem under vessels arrival delay can be divided into two stages: (1) baseline allocation in which the port terminal formulates a berth allocation plan according to the estimated arrival time of vessels; (2) reactive strategy in which the terminal will adjust the baseline allocation to address the disturbance caused by vessels arrival delay during the implementation of the baseline allocation.

When formulating the baseline schedule for hybrid berths, considering that hybrid berths have both discrete and continuous characteristics, the proper berth will be first assigned to vessels based on the condition that the length of the vessel is less than the length of the berth. Then, vessels assigned to the same berth are scheduled for berthing position and time using the method of continuous berth allocation.

Fig.2 shows a baseline allocation plan of a hybrid berth composed of two continuous berths under the condition of eight vessels. The horizontal axis of the figure represents time in hours, and the vertical axis represents positions in meters on a continuous berth. Each rectangle shown in Fig.2 represents a vessel, with the length of the left side representing its length and the length of the bottom representing its handling time. The horizontal coordinate corresponding to the left side represents the start time of vessel operation, and the vertical coordinate corresponding to the bottom represents its berthing position.

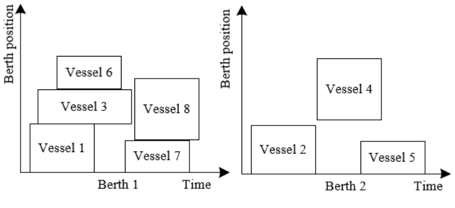


Fig. 2. A baseline allocation plan for hybrid berths

B. Mathmatic Model with Proactive Strategy of Hybrid Berth

1) Model Assumptions

In actual ports, berth allocation problems are complex due to many uncertainties that affect the allocation plan. To simplify the problem, the assumptions of this problem are as follows:

- All berths can meet the draft depth of all vessels.

- The berthing position in the berth is based on the bow of the vessel.
- The estimated arrival time and handling time of the vessel are known.
- The time for docking and undocking is included in the vessel's handling time.
- No shift operation occurs after the vessel moors.
- The vessel can only moor after it arrives.

2) *Parameters and Variable Definitions*

a) Sets and Indices

- V: Set of vessels, $V=\{1,2,\ldots,v\}$;
- B: Set of berths, $B=\{1,2,\ldots,b\}$;
- i, j: The index for vessels, $i \neq j$, $i, j \in V$;
- k: The index for berths, $k \in B$;

b) Parameters

- v_i: The length of vessel i, $i \in V$;
- e_i: The estimated arrival time of vessel i, $i \in V$;
- a_i: The actual arrival time of vessel i, $i \in V$;
- b_k: The length of berth k, $k \in B$;
- T: The length of buffer time added in the allocation plan;
- M: A very large positive number;
- h_i: The handling time of vessel i, $i \in V$;

c) Decision Variables

- l_i: The berthing position of vessel i, $i \in V$;
- s_i: The start handling time of vessel i, $i \in V$;
- d_i: The departure time of vessel i, $i \in V$;
- α_{ij}: 1, if the departure time of vessel i is earlier than the start handling time of vessel j; 0, otherwise, $i, j \in V$;
- β_{ij}: 1, if vessels i and j are handled at the same time in the same berth and vessel m to the below of vessel n, 0 otherwise, $i, j \in V$;
- δ_{ki}: 1, if vessel i is berthed in berth k; 0, otherwise, $i \in V$, $k \in B$.

3) *Model Description*

To handle uncertain factors such as the uncertainty of vessels' arrival times which affect the implementation of berth allocation plans and improve the robustness of the baseline schedule, this paper adopts a buffer strategy as a proactive strategy to establish a mixed-integer programming model for the hybrid berth allocation problem.

$$min\, F = \sum\nolimits_{i \in V} \left(d_i - e_i\right) \tag{1}$$

$$\sum\nolimits_{k \in B} \delta_{ki} = 1, \forall i \in V \tag{2}$$

$$s_i - e_i \ge 0, \forall i \in V \tag{3}$$

$$d_i = s_i + h_i + T, \forall i \in V \tag{4}$$

$$l_i + v_i \le \sum\nolimits_{k \in B} \left(\delta_{ki} * b_k\right), \forall i \in V \tag{5}$$

$$s_j - d_i - M * \left(\alpha_{ij} - 1\right) \ge 0, \forall i, j \in V \tag{6}$$

$$l_j - l_i - v_i - M * \left(\beta_{ij} - 1\right) \ge 0, \forall i, j \in V \tag{7}$$

$$\alpha_{ij} + \alpha_{ji} + \beta_{ij} + \beta_{ji} \ge \delta_{ki} + \delta_{kj} - 1, \forall i, j \in V, \forall k \in B \tag{8}$$

$$\alpha_{ij} + \alpha_{ji} \le 1, \forall i, j \in V \tag{9}$$

$$\beta_{ij} + \beta_{ji} \le 1, \forall i, j \in V \tag{10}$$

$$s_i, h_i, e_i, d_i, l_i \ge 0, \forall i \in V \tag{11}$$

$$\alpha_{ij}, \beta_{ij}, \delta_{ki} \in \{0,1\}, \forall i, j \in V, \forall k \in B \tag{12}$$

The formula (1) represents the objective function, which minimizes the time that all vessels spend in container terminals. Constraint (2) indicates that a vessel must select one berth for operation. Constraint (3) limits the start operational time of vessel *i*. Constraint (4) indicates that the departure time of vessel *i* equals the sum of its start operational time and handling time. Constraint (5) defines the berthing position of a vessel. Constraints (6)-(10) represent conditions under which vessels do not collide with each other, whereas constraints (6) and (7) indicate that two vessels cannot overlap in their berthing times and positions. Constraint (8) indicates that when vessel *i* and vessel *j* are assigned to the same berth, regardless of the order of operations, two vessels must satisfy the condition that they do not overlap in their operation time or berthing position. Constraint (9) ensures that two vessels do not have a phenomenon where one vessel's departure time is earlier than another vessel's start time. Constraint (10) ensures the spatial order of two vessels. Constraints (11) and (12) limit the value of parameters.

C. *Reactive Reallocation Strategy of Hybrid Berth*

Due to the incorporation of buffer strategy within the mixed integer programming model, the baseline schedule derived from solving this model exhibits a notable degree of robust. In instance of vessels arrival delay, if the baseline schedule is capable of mitigating the disruption, the allocation of berths shall proceed in alignment with the baseline schedule. Conversely, if the baseline schedule is insufficient to counter the effects of such delays, it will be modified according to the preconceived reactive strategy.

In the allocation problem of discrete and continuous berths, the right-shift strategy (RSS) [17], which refers to delaying the berthing time of the vessel until the planned shoreline is available, is often used to adjust the baseline for vessels that are delayed. However, the RSS only adjusts the baseline of the berth that is pre-assigned to the vessel, without considering the characteristic of vessels being able to operate in different segments of hybrid berth. Therefore, a reactive strategy which suitable for hybrid berths (HBRS) is proposed. Fig.3 is the flow chart of the HBRS proposed in this paper.

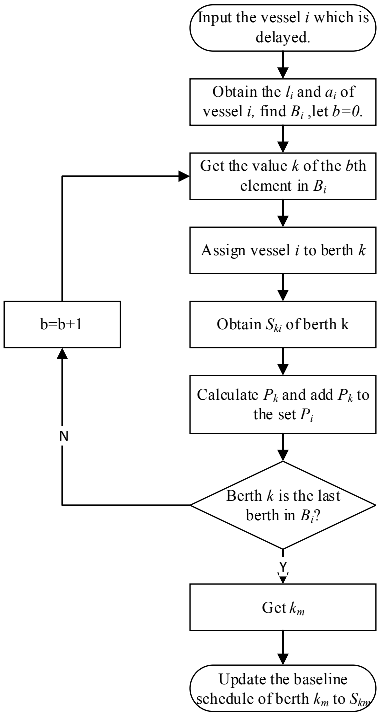


Fig. 3. The flow chart of the HBRS

The meaning of the symbols in Fig.3 and the specific steps of the HBRS are as follows:

- Step 1: Input the vessel *i* which is delayed.
- Step 2: Obtain the length l_i and actual arrival time a_i of vessel *i*.
- Step 3: Find the set of berths $B_i=\{k|\ b_k>=l_i,\ k\in B\}$, which are suitable for vessel *i* to operate, and let the B_i's element serial number b=0.
- Step 4: Get the value *k* of the b^{th} element in B_i which is the serial number of berth, and obtain the baseline schedule of berth *k*.
- Step 5: Insert vessel *i* into the baseline schedule according to a_i, and obtain the scheduling plan S_{ki} of the vessels which operate after the arrival of vessel *i*.
- Step 6: Calculate the deviation value P_k between S_{ki} and the baseline schedule, and add P_k to the deviation value set P_i of vessel *i*.
- Step 7: If berth *k* is the last berth in B_i, go to step 8; otherwise, let $b=b+1$ and go to step 4.
- Step 8: Get the berth's serial number k_m corresponding to the minimum value in the set P_i, and update the baseline schedule of berth k_m to the scheduling plan after inserting vessel *i*.

III. SOLUTION ALGORITHM

Obtaining the baseline schedule of berths has been proven to be an NP-hard problem [18]. As the scale of vessels and berths increases, it is less possible for the computer to obtain the optimal solution within the effective computing time. Therefore, a Genetic Algorithm (GA) is employed to expedite the solution of the mixed-integer programming model, thus acquiring the baseline schedule efficiently.

A. Chromosome Coding

This paper adopts a two-layer coding method. The first layer of coding in the chromosome uses the order of the vessel's serial numbers to represent the vessel operation sequence on the berth, and the second layer represents the berth's serial number assigned to the vessel. As shown in Fig.4, the chromosome represents the allocation plan of 9 vessels in 3 berths, where the vessel's serial number that operates at berths 1 is 2, 3, 8, and 9. The vessel operation sequence is 8-9-3-2.

Vessel number	8	5	6	4	9	1	3	7	2
Berth number	1	3	2	2	1	3	1	2	1

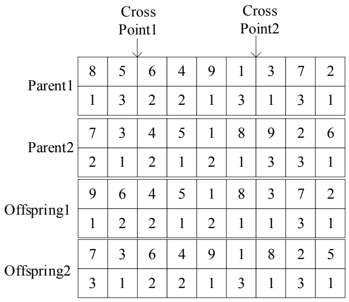
Fig. 4. Chromosome coding

B. Population and Selection

When formulating a hybrid-berth allocation plan, the port selects an appropriate berth based on the length of the vessel. If the length of the vessel is greater than the length of the selected berth, the plan is infeasible. Therefore, it is necessary to generate an initial population according to constraint (5). After generating the initial population, we use a tournament selection strategy for the selection operation.

C. Chromosome Crossover

This paper uses partial matching crossover for the first layer of genes in the chromosome. The specific operation is as follows. Firstly, two random numbers within the range of the chromosome length are generated to determine the crossover point. Then, the positions of the partial genes are exchanged between the crossover points. Finally, conflict detection is performed. The most important aspect of conflict detection is the establishment of a mapping relationship among genes. As shown in Fig.5 which is an example of the crossover operation, the mapping relationship between genes is 6-4-5 and 9-1-8. Consequently, when performing conflict detection, it is necessary to map gene 6 to gene 5 and gene 9 to gene 8 outside the two crossover points. The second layer of genes in the chromosome changes simultaneously with the corresponding first layer of genes.



Parent1	8	5	6	4	9	1	3	7	2
	1	3	2	2	1	3	1	3	1
Parent2	7	3	4	5	1	8	9	2	6
	2	1	2	1	2	1	3	3	1
Offspring1	9	6	4	5	1	8	3	7	2
	1	2	2	1	2	1	1	3	1
Offspring2	7	3	6	4	9	1	8	2	5
	3	1	2	2	1	3	1	3	1

Fig. 5. Chromosome crossover

D. Chromosome Mutation

For the first layer of genes, this paper uses the crossover mutation method. For the second layer of genes, the mutation operation steps are as follows. Firstly, the gene segment at the mutation point that is the vessel's serial number is selected. Then, a berth's serial number in the corresponding vessel's optional berth set is randomly selected to complete the mutation. Assuming that vessel 6 has berths 1 and 2 available and vessel 3 has berths 2 and 3 available. An example of chromosome mutation is shown in Fig.6.

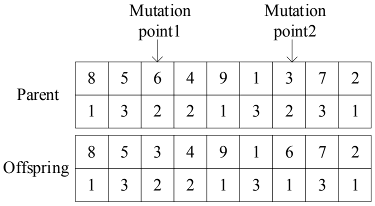


Fig. 6. Chromosome mutation

IV. COMPUTATIONAL EXPERIMENTS

The basic parameters of the GA are shown in Table I. All the computational procedures are implemented in Matlab 2018a by the personal computer with Intel(R) Core(TM) i5-12400 2.50 GHz and 16 GB of RAM.

TABLE I. PARAMETERS OF GA

Parameters	Value
Population size	100
Crossover probability	0.8
Mutation probability	0.3
Maximum iterations	1500

According to reference [19], the experimental case in this paper uses production data from a container terminal with a total shoreline length of 1500 meters. The hybrid berth consists of four sections of berths, each section has a length of 600 meters, 400 meters, 300 meters, and 200 meters respectively. The other variables are generated randomly and the distributions which the variables follow are shown in Table II.

TABLE II. THE SPECIFIC DATA OF VESSELS

Estimated arrival time/h	**Handling time/h**	**The length of vessel/m**	**The delayed time of vessels/h**
$U(1,168)$	$U(10,48)$	$U(150,350)$	$U(0,2)$

A. Validation of Model and Algorithm

To verify the correctness of the model and the effectiveness of the algorithm, several cases based on different numbers of vessels are randomly generated. We use CPLEX 12.8 and the GA to solve the model under these cases. Due to the random factors that existed in GA, we run the GA 20 times and analyze the mean value (Mean) and standard deviation (Stdev) of the results. TABLE III shows the computational results of CPLEX 12.8 and the GA.

Analyzing the results in Table III, it can be concluded that when the number of vessels is small, both CPLEX and GA can obtain the optimal solution in a limited time. As the number of vessels increases, the time that CPLEX spends to obtain the optimal solution increases rapidly, while the deviation between the optimal solution and the satisfied solution is no more than 4.1%. For instances with more than 21 vessels, CPLEX cannot find optimal solutions within 1 hour while GA can obtain solutions within a short time. Therefore, the GA is effective in solving this model, especially in large-scale instances.

TABLE III. THE COMPUTATIONAL RESULTS OF CPLEX AND GA.

The number of vessels	**CPLEX**		**GA**			**Gap(%)**
	Optimal	***CPU(s)***	***Mean***	***Stdev***	***CPU(s)***	
10	279.8	4.942	279.8	0	53.187	0
15	463.9	5.975	467.85	3.95	89.482	0.85
20	688.2	93.803	698.79	10.59	227.21	1.54
21	731.1	1496.05	761.32	30.22	236.49	4.1
25	/	/	988.66	/	242.68	/

Note: Stdev=Mean-Optimal; Gap=Stdev/Optimal*100%.

B. Validation of the HBRS

Berths are a significantly scarce resource within ports. The vessels' arrival delay may result in temporary unavailability of berths, consequently impinging upon the operational schedules of other vessels and the overall efficiency of the port. Therefore, it is imperative to use RSS and HBRS to promptly adjust the baseline schedule when vessels are delayed. This paper conducted experiments on 10, 15, 20, 25, and 30 vessels. The baseline schedule under different vessel numbers is obtained when the buffer time was 0. Then, the values of deviation from the baseline schedule are calculated using the right shift strategy and HBRS when the vessel is delayed. The experimental results are shown in Table IV.

Analyzing the experimental results in Table IV, it can be concluded that when the number of vessels is 10 and 15, due to the berth resources being sufficient, the results obtained by adjusting the baseline schedule using the right shift strategy and HBRS are the same. However, as the number of vessels increases, the difference between the results obtained using the two strategies becomes larger. When the number of vessels is 20, 25, and 30, better results can be obtained by using HBRS.

TABLE IV. EXPERIMENT RESULTS OF DIFFERENT NUMBERS OF VESSELS

The number of vessels	**Baseline schedule**	**RSS/h**	**HBRS/h**
10	(2,5,7,9),(3,8),(1,6,10),(4)	15	15
15	(1,5,7,10,11,15),(3,8,12),(2,6,9,13),(4,14)	23	23
20	(1,5,7,10,11,13,18,20),(3,8,12,16,17,19),(2,6,9,15),(4,14)	34.9	32.8
25	(5,2,10,12,8,24,17,13,15,22),(3,6,14,19,23,11,20),(1,9,16,18,25),(4,7,21)	40	38
30	(9,3,5,15,13,12,23,16,22,26,21),(2,6,8,11,20,28,24,30),(1,10,18,25,29,27),(7,4,17,19,14)	45	42

Note: Each "()" in the Baseline schedule represents a berth.

Besides the reactive strategy, we also use a proactive strategy to improve the robustness of the baseline schedule. In this paper, the buffer strategy is added to the mixed-integer programming model to obtain a robust baseline schedule. Several experiments are conducted on different kinds of buffer time when the number of vessels is set as 20. The experimental results are shown in Table V.

Analyzing the experimental results in Table V, it can be concluded that the HBRS can significantly reduce the time deviation from the baseline schedule after adding buffer time compared with the RSS. Meanwhile, as the buffer time increases, the total time that vessels stay in port also increases.

As shown in Table V, when the buffer time is less than 0.7 hours, the allocation plan obtained by using HBRS has a smaller deviation from the baseline schedule than the plan obtained by using the RSS. When the buffer time is greater than 0.7 hours, the deviation values between the scheduling plan obtained by the two strategies and the baseline allocation are the same because the baseline schedule can absorb the uncertainty caused by ship delays. Meanwhile, it can be seen from Table V that the HBRS can obtain allocation plans with the same robustness under a shorter buffer time compared with the RSS. Additionally, compared with RSS, HBRS can reduce the total time vessels spend in ports and improve berth utilization efficiency.

TABLE V. EXPERIMENT RESULTS OF DIFFERENT BUFFER TIME

Buffer time/h	**Baseline schedule**	**Make-span/h**	**RSS/h**	**HBRS/h**
0	(1,5,7,10,11,13,18,20),(3,8,12,16,17,19),(2,6,9,15),(4,14)	688.2	34.9	32.8
0.1	(1,5,7,9,11,13,15,20),(3,8,12,16,17,19),(2,6,10,18),(4,14)	691.4	23.2	19.7
0.2	(1,5,7,9,11,13,15,20),(3,8,12,16,17,19),(2,6,10,18),(4,14)	694.6	20.4	16.6
0.3	(2,5,7,10,11,13,18,20),(3,8,12,16,17,19),(1,6,9,15),(4,14)	697.8	17.5	16.6
0.4	(1,5,7,10,11,13,18,20),(3,8,12,16,17,19),(2,6,9,15),(4,14)	701	16.4	15.0
0.5	(2,5,7,10,11,13,18,20),(3,8,12,16,17,19),(1,6,9,15),(4,14)	704.2	14.5	13.5
0.6	(1,5,7,10,11,13,18,20),(3,8,12,16,17,19),(2,6,9,15),(4,14)	707.4	18.2	15.2
0.7	(1,5,7,10,11,13,18,20),(3,8,12,16,17,19),(2,6,9,15),(4,14)	710.6	9.5	9.5
0.8	(1,5,7,10,11,13,18,20),(3,8,12,16,17,19),(2,6,9,15),(4,14)	713.8	5.4	5.4

V. SUMMARY AND EXPECTATION

This paper mainly studies the allocation problem of hybrid berths under vessels arrival delay and designs a proactive-reactive approach which is suitable for hybrid berths. By analyzing, it is found that using a buffer strategy is one of the effective methods to improve the robustness of berth allocation plans, but as the buffer added increases, the total time that vessels stay in port becomes longer. To solve this problem, this paper designs a reactive strategy that can obtain scheduling plans with the same robustness under smaller buffer conditions. The results show that a proactive-reactive approach can obtain a better berth allocation plan for container terminals.

However, this study also has some room for improvement. For example, the handling time of vessels is affected by meteorological conditions and presents fuzzy uncertainty characteristics, but it has not been considered in this paper. The optimization objective of this paper is minimizing the total service time of vessels, which mainly benefits ports, but might affect the interests of vessels. Therefore, how to balance the interests of them is also a direction for future research.

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