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Ningbo Container Terminal "Berth-Quayside Bridge-Container Truck" Optimization of Work Schedule

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Abstract

With the development of economy, container terminals are playing an increasingly important role. By rationally arranging various resources on the terminal, we seek to improve the efficiency of terminal loading and unloading and reduce various costs. This article mainly studies the improvement of the efficiency of the operation plan of the terminal. The main research contents include: (1) The completion of the operation process of the modern terminal includes the cooperation of berths, quay cranes, and trucks. Ships to ports and quay cranes unload goods. The cyclic operation of the three processes of trucks transporting goods to the yard greatly improves the efficiency of the terminal. In the scheduling process, we can use many methods to optimize the efficiency of terminal operations. (2) Berths, quay cranes, and trucks are all essential resources on the wharf. How to efficiently allocate them when their number cannot grow indefinitely has become the focus of our attention now. This paper establishes a cooperative model of the three, which is suitable for the actual berths, quay cranes, and trucks dispatching and distribution of the terminal, and uses algorithms to solve them.

Keywords

Container terminal; handling equipment; resource scheduling; process optimization.

1. Introduction

According to statistics, container ships spend more than 60% of their time in ports. A good container terminal is not only the geographical conditions of the terminal, the water depth conditions, and the economic advantage also depend on the working efficiency of the terminal. For this reason, each terminal is looking for the best solution to ensure the maximum efficiency of the terminal to obtain Absolute competitiveness in the market. In terms of the current situation of unit berths and unit berth quay cranes in China's terminals, the number of loading and unloading equipment in my country's container terminals is much higher than that of other countries. Therefore, how to make better use of the resources of the terminal under the limited resource conditions has become the focus. With the substantial increase in throughput, reasonable and effective operation arrangements can ensure the efficiency and stability of container terminal production activities. Jiang Meixian et al. (2017) conducted integrated scheduling research on berths, quay cranes and trucks, assigned berths through assignment problems, and combined the following quay crane and truck scheduling to achieve the overall optimization[1]. Tian Xing, Meng Qingzhu (2017) use the port day and night schedule to balance each ship and use integer programming to assign the arrival ships, establish a model with the overall logistics operation cost as the objective function, and use ILOGCPLEX to solve i[2]. Li Haoyuan, Sun Dongshi (2016) Facing the quay crane operation scheduling problem of container terminals, a simulation optimization method combining simulation model and intelligent optimization algorithm is used to analyze and solve, so as to analyze how to improve the work efficiency of quay crane[3] Le Meidong et al. (2015) studied the quay crane optimization problem based on single-ship task allocation and balanced, and used genetic algorithm to solve the model to obtain the most reasonable optimization plan[4] PyungHoiKoo (2004), studied the

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static transportation problem of the terminal, and used a two-stage heuristic tabu search algorithm to determine the optimal path of each trailer and meet the minimum number of trailers[5]; Rounald H. Ballou (1999) proposed the trailer Dynamic route scheduling method, and use genetic algorithm to solve[6]. Jiang Meixian (2015) optimizes berths, quay cranes and trucks with different service rules by developing a scheduling simulation plaorm for berths, quay cranes, and trucks, and divides them into single-ship and multi-ship research, and uses genetic algorithms[7]. To solve the model. Li Nan (2017) used Lingo to solve the optimization of container terminals based on flexible berths and "working surface" operations, based on the time cost minimization goal, through 0-1 programming and integer programming models[8]. According to the above research summary on the berths, quay cranes and trucks of container terminals, assuming that the berths are continuous, the waste of small boats occupying large berths is avoided. The coordinated dispatch of continuous berths and quay cranes can obtain a better solution than discrete berths. This article not only pursues the shortest berthing time in the scheduling model, but also increases the running time between the yard and the container ship in truck transportation after berthing. Under the premise of ensuring the shortest berthing time at the port, the shortest production and operation time of the terminal is achieved. Optimal overall configuration.

2. Berth-quayside crane-truck dispatching model

The assumptions are as follows: (1) The amount of ships arriving at the port to be loaded and unloaded is known; (2) Each ship arriving at the port must be served only once; (3) The quay crane allocation is after the ship berths, and each The quay cranes do not affect each other; (4) Each ship has a specified maximum and minimum number of quay cranes that operate simultaneously (5) After the ship is parked, it will no longer move; (6) Each ship has the best The docking position, if not parked at this position, will have an impact on the time of the subsequent trucking operations; (7) Continuous berths with a length greater than any ship and no impact when the ship is parked. (8) After the ship is parked, the travel time of the trucks serving the ships to the designated box area is known; (9) The trucks only transport one TEU at a time.

2.1. Variable

Based on the above assumptions, how to berth the ship when it arrives at the port, and the allocation of quay cranes and trucks is of great significance to its time saving. This article studies the end of the ship's arrival to loading and unloading process. The effective time of terminal production operations is determined by the following two parts: the ship's port operation time and the truck transportation time.

L represents the length of the shoreline

Set S means, S=(1,2...s);s1,s2...ssship number

ls means captain

QC,QC={1,2,...nq}; indicates that the maximum and minimum number of quay cranes allowed to operate at the same time for each vessel in the port is represented by nsmaxand nsminrespectively;

P_SO represents the best docking position of ship s, based on the left end of the ship.

ps is the actual docking position of the ship s on the shoreline of the dock, and the left end of the ship is the actual docking position.

Xijs, Yijs represents the judgment symbol, if the ship s starts to berth from (I,j),Xijs=1 otherwise it is 0; if the ship s

Docked at (I,j), Yijs=1 otherwise 0

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α: Indicates the degree of amplification of the container's time in port by one unit of the ship s deviation from the best position (understood as the degree of influence of the unit offset distance on the time in port)

Δp_s: The deviation between the actual position and the best berthing position

d_s: actual departure time of ship s

a_s:: ship s arrival time

o_s: The truck transportation time of the container to be loaded and unloaded, the size is related to the docking position of the s ship and the truck path

E_S^U:Amount of TEU to be unloaded by calling ship S

$E_S^L L$: the amount of TEU to be installed on the calling ship S

γ: Single box loading and unloading efficiency of each quay crane

NusNls*s*, respectively, the planned number of import and export yards of ship S

Qjs: When ship s is docked at (I,j), Yijs=1, the number of quay cranes allocated to ship s at time j,

When Qjs>0, vjs=1. Otherwise, it is 0

H:Table any positive value of infinity Decision variables:

X_{ijs}: If the ship s berths from (I,j), Xijs=1, otherwise it is 0

Y_{ijs}: If the ship s is docked at (I,j), Yijs=1 otherwise 0

Q_{js}: When ship s is docked at (I,j), Yijs=1, the number of quay cranes allocated to ship s at time j,

When Q_{js}>0, vjs=1. Otherwise, it is 0

Z_{sp}: The number of trucks transported from the ship s to the import yard p but not back to the quay crane

Z_{pq}: It is the number of times and container volume of trucks transported from import yard p to export yard q.

Z_{qs}: It is the number of times the truck is transported from q to s without returning to q

Z_{spqs}: Refers to the number of transports of the truck from the ship's departure to unloading to the loading and finally back to the ship s.

$Z'_{qs\,qs}$: It is the number of transportation times of the empty truck returning to q after the truck has transported the box from q to s, that is, the number of transportation times when the truck is individually packed.

Z'_{sp}: It is the number of transportation times of the empty truck returning to q after the truck has transported the box from s to p, that is, the number of transportation of the truck alone in the box.

2.2. Construction of berth-quayside crane-truck dispatching optimization model

According to the above parameter settings, an optimization model for berth, quay crane, and truck dispatching is obtained:

$$\mathrm{T} = \min \left\lfloor \sum_{s=1}^{n} \sum_{i=1}^{l} \sum_{j=1}^{k} x_{ijs} (1 + \partial \times \Delta p_s)(d_s - a_s) + \sum_{s=1}^{n} \sum_{\substack{i=1 \\ s=1}}^{l} \sum_{j=1}^{k} y_{ijs} O_s \right\rfloor \tag{1}$$

The objective function is divided into two parts. The operating time of the ship in the port is represented by the first part. Since the ship has a preferred berth position after arriving at the port, this position affects the transportation time of the subsequent trucks in each container section. The truck transports the boxes that need to be loaded and unloaded by the stopped ship to the designated box area, that is, the time it takes for the truck to unload the boxes from the ship to the designated storage yard. The second part thinks that the time of these two parts is affected. The last time the ship left port. Therefore, the objective function is more convincing and comprehensive by the two parts.

For this model, the problem to be solved in this paper is to solve the berthing position of the ship after arriving at the port, the distribution number of quay cranes and the route planning of the truck based on the principle of the shortest overall operation time of the terminal and the number of containers transported by the truck.

The constraints are as follows:

(1) Constraints on ship's time in port

$$\sum_{i=1}^{l}\sum_{j=1}^{k} x_{ijs} = 1, \forall s \in S \tag{2}$$

This formula shows that each ship only berths once in the port and only works once, and cannot move during the period.

$$\sum_{l}^{s} y_{ijs} \le 1, i = 1,2,\ldots,l;\ j = 1,2,\ldots,k \tag{3}$$

This formula shows that only one boat can be parked on a berth i at a time point j, and any two boats cannot park at the same position.

$$\mathrm{P}_s + l_s \le L, \forall s \in S \tag{4}$$

The formula guarantees the constraint of the length of the ship's berth.

$$\sum_{l}^{s} Q_{js} \le n_q \tag{5}$$

This formula shows that no matter when, the number of quay cranes allocated to each ship will not be greater than the total number of quay cranes in the terminal.

$$n_s^{\min} \le \sum_{j=1}^{k} Q_{js} \le n_s^{\max} \tag{6}$$

The formula states that the number of quay cranes operated by each ship must exceed the minimum specified number of quay cranes, but cannot exceed the specified maximum number to avoid waste of resources.

$$d_s - S_s = \frac{E_s^l + E_s^U}{\gamma \sum_j Q_{js}} \tag{7}$$

This formula shows that the service time of the quay crane is equal to the port time of the ship, and the ship can leave after the quay crane completes its operations.

$$\Delta \mathrm{P}_s = \left| P_s - P_s^o \right| \tag{8}$$

This formula indicates the difference between the ship's docking position and the best docking position. This difference will directly affect the transportation distance between the truck and the ship and the yard and thus affect the subsequent operation time.

$$l_s - \sum_{i=1}^{L} y_{ijs} \le H(1-\gamma_{js}) \tag{9}$$

This formula shows that when VJs is equal to 1, it means that the ship is stopping at i for operations.

Constraints on container transit time

$$\mathrm{Q}_s = \sum_{p=1}^{n_u^s} z'_{sp}(t_{sp}+t_{ps}) + \sum_{q=1}^{ns_l} z'_{qs}(t_{qs}+t_{sq}) + (\sum_{p=1}^{n_u^l} z_{sp}t_{sp} + \sum_{q=1}^{n_u^s} z_{pq}t_{pq} + \sum_{q=1}^{ns_l} z_{qs}t_{qs}) \tag{10}$$

Represents the total transportation time spent by the truck on the ship s. It is divided into three parts, unloading the boxes to the storage yard separately, and packing them to the ship separately, the total transportation time of loading and unloading.

$$\sum_{p=1}^{n_u^s} Z_{sp} = \sum_{p=1}^{n_u^s}\sum_{q=1}^{n_l^s} Z_{pq} = \sum_{q=1}^{n_l^s} Z_{qs} = \min\left\{E_s^u, E_S^l\right\} \tag{11}$$

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It means that the number of times from the unloaded box from the truck transport ship until p is empty to q and then back to ship s is equal.

$$\sum_{p=1}^{n_u^s} Z'_{sp} = \max\{E_s^u - E_s^l, 0\} \tag{12}$$

$$\sum_{q=1}^{n_u^s} Z'_{qs} = \max\{E_s^l - E_s^u, 0\} \tag{13}$$

Indicates the container volume of the truck when the ship is only unloaded or only loaded

$$\sum_{p=1}^{n_u^s} Z'_{sp} + \sum_{p=1}^{n_u^s} Z_{sp} = E_S^U \tag{14}$$

$$\sum_{p=1}^{n_l^s} Z'_{qs} + \sum_{q=1}^{n_l^s} Z_{qs} = E_S^L \tag{15}$$

It represents the total number of times and the volume of containers unloaded by trucks from the ship to the import yard.

$$\sum_{p=1}^{n_u^s} Z_{pq} = Z_{ps}, q = 1,2,\ldots n_l^s \tag{16}$$

$$\sum_{q=1}^{n_l^s} Z_{pq} = Z_{sp}, p = 1,2,\ldots n_u^s \tag{17}$$

It is a constraint on the balance of the transport container quantity between the ship and each import and export yard. Z_{sp}, Z'_{sp}, Z_{pq}, Z_{qs} Z'_{qs}, Z_{spqs}, Is a non-negative integer.

2.3. Algorithm flow

The objective function consists of two parts, the first part is 0-1 integer programming problem, and the second part is integer linear programming problem. The model has two parts of constraint conditions. First, the initial solution of the ship's call position, the number of quay cranes, the departure time and the call sequence is determined through the constraint condition 1, and the second part of the model is solved based on the obtained initial solution data. The optimal driving path of the truck is determined with the goal of the shortest truck transportation operation time. We can use lingo to solve the objective function.

2.4. Case analysis

Take the Meishan Wharf of Ningbo Zhoushan Port as a case study. The shoreline of the terminal is continuous, with a total length of 2150 meters.There are 10 container berths, 10 ships in one cycle and 8 bridge cranes are used for research. No. 1 to 8, the operating efficiency of each quay crane is 2 boxes min. The coefficient of deviation α=0.1. The information of ships arriving at the port in a period is shown in Table 1.

Table 1 Information of Arriving Ships

Ship number	L_s	a_s	p_o	n_s^{min}	n_s^{max}	$E_s^u(TEU)$	$E_s^l(TEU)$	n_u^s	n_l^s
1	200	1	50	2	3	2400	2600	3	4
2	250	3	350	2	4	3600	3120	4	3
3	220	5	600	2	3	1800	3600	3	5
4	260	8	1	2	4	4800	5400	5	5
5	270	10	1000	2	5	1200	2160	3	3
6	180	15	1500	2	3	2880	3120	4	4
7	210	17	1300	2	3	5040	4200	5	4

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8	240	18	1700	2	4	4200	4800	5	5
9	250	20	800	2	4	4320	4440	4	4
10	280	22	600	2	5	7200	5400	5	4

We can get the number of quay cranes required and the actual time the ship leaves the port through the data in the above table and the set constraints. The data of truck and storage yard are shown in Table 2. There are 9 import and export container areas in Meishan Wharf. The transportation time of the trucks between each container area is shown in Table 2. After the ship arrives at the port, the corresponding containers are stacked in accordance with the specified requirements. The total number of containers stacked in the corresponding import and export container areas of ships is shown in Table 3 and Table 4.

Table 2 Transportation time between trucks in each container area (min)

Container area	L1	L2	L3	L4	L5	L6	L7	L8	L9
U1	2	2.5	2	4	3.5	5	4.5	6	5.5
U2	3	4	4.5	5	3.5	4	4.5	5	5.5
U3	1.5	3	2	2.5	3.5	4	4	4.5	5
U4	4	4.5	5	3.5	4	5	4	4.5	5
U5	3	3.5	5	4	3.5	4.5	5	5.5	6
U6	3	3.5	3	3.5	4.5	4	5.5	5	6.5
U7	5	4.5	6	5.5	5	4.5	5	5.5	5
U8	5.5	5	6.5	4	5.5	5	4	4.5	4.5
U9	4.5	5	4.5	5	4.5	4	5	5.5	5.5

Table 3 The total amount of containers stacked in the corresponding import container area of the ship

Container quantity	u_1^1	u_2^1	u_3^1	u_4^1	u_5^1	u_6^1	u_7^1	u_8^1	u_9^1
S1	1080	600	720	_	_	_	_	_	_
S2	_	840	960	1200	600	_	_	_	_
S3	_	_	_	_	480	480	840	_	_
S4	_	1080	840	1200	360	1320	_	_	_
S5	_	_	_	_	_	360	600	240	_
S6	_	_	_	1000	380	500	1000	_	_
S7	_	_	_	_	1650	800	500	1090	1000
S8	1800	500	900	700	300	_	_	_	_

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S9	1500	1000	1150	670	_	_	_	_	_
S10	2500	_	_	_	_	1200	800	1200	1500

Table 4 The total amount of containers stacked in the corresponding export container area of the ship

Container quantity	l_1^s	l_2^s	l_3^s	l_4^s	l_5^s	l_6^s	l_7^s	l_8^s	l_9^s
S1	720	960	360	600	_	600	_	_	_
S2	_	_	960	1080	1080	_	_	_	_
S3	_	720	960	840	480	_	_	_	_
S4	_	_	_	_	1200	_	1080	1560	960
S5	_	_	_	_	_	_	840	600	720
S6	600	_	500	500	_	_	1520	_	_
S7	_	_	_	_	_	1000	1550	1100	600
S8	_	_	_	1500	_	1500	500	_	1000
S9	_	_	_	_	_	1300	1200	1000	900
S10	1400	900	1200	_	_	_	_	_	1900

The above respectively represent the number of containers stored in the p-th import container area and the q-th export container area of the ship. Corresponding to ship s1.The storage volume of the storage bin area is shown in Table 5 below. In the same way, s2-s10 can be obtained. The model solving process is solved with lingo9.0 software.

Table 5 The storage volume (TEU) of the storage bin area corresponding to the ship S1

S1-Container area	U1	U2	U3	L1	L2	L3	L4
Container quantity	1080	600	720	720	960	360	600

2.5. Solution results

First, set the initial call position (i, j) of the ship at a certain time j at i, and determine the number of quay bridges to be allocated to ship s according to the setting of the above-mentioned constraint conditions, according to the ship to each box area Time can solve the corresponding shortest terminal production operation time. Secondly, change the docking position of the ship, find the corresponding T, and compare with it to get the smallest and newest optimal solution, and keep doing it until all (i, j) are done, and the solution process is complete. And for all ships

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in a cycle to do the same thing to get the minimum production time, thus completing the optimization of the terminal operation process in a cycle.

Based on the above solution ideas and lingo calculations, coupled with the shortest port time and truck operation time and the lack of quay crane resources, in order to achieve the shortest terminal operation time, the ship stops at the preferred position. Q1=3, Q2=4, Q3=3, Q4=4, Q5=5, Q6=4, Q7=5, Q8=5, Q9=4, Q10=5.

As a case solution, the following analysis only selects five ships for optimization analysis.Due to the different locations where the ships arrive at the port, the time required for the truck to travel from the ship to the planned container area is also different. This time is obtained when the ship's docking location and the number of quay cranes are known. And because the reload and no-load times of the truck are also different, see Table 6 below for details

Table 6: One-time transportation schedule of trucks from ship to container (min)

Ship	u_1^1	u_2^1	u_3^1	l_1^1	l_2^1	l_3^1	l_4^1
S1	7-5.2	9-8	10-7.6	2-1	5-3	5-3	4-2
S2	u_2^2	u_3^2	u_4^2	u_5^2	l_3^2	l_4^2	l_5^2
	6-4	9-7	7-4	10-7	5-3	6-3.6	4-2.6
S3	u_5^3	u_6^3	u_7^3	–	–	–	–
	6-4.1	5-3.6	8-6	_	_	_	_
	l_2^3	l_3^3	l_4^3	l_5^3	l_6^3	–	–
	3-2	2-1.2	5-4	4-3	3-2.4	_	_
S4	u_2^4	u_3^4	u_4^4	u_5^4	u_6^4	–	–
	6-4	7-5	5-4	7-5.2	8-6	_	_
	l_5^4	l_6^4	l_7^4	l_8^4	l_9^4	–	–
	2-1	4-2	2.4-1.6	4-2	6-4	_	_
S5	u_6^5	u_7^5	u_8^5	l_7^5	l_8^5	l_9^5	–
	6-4	8-6	7-5	5-4	4-2	2-1	_

The big number in the table means heavy-duty driving, and the small one means no-load driving.Therefore, after the ship s1 is berthed, the optimal path of the truck is determined based on the shortest overall operation time, and all the paths of the truck to the ship are obtained. The transport container volume and travel time are shown in Table 7, Table 8, Table 9, and Table 10.

Table 7 The optimal path of the truck based on the shortest time (1)

Route	Discharge quantity	Loading quantity	transportation
L1-s1-L1	0	240	648
S1-u1-L1-s1	480	480	4752

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S1-u1-L4-s1	600	600	8100
S1-u2-L2-s1	600	600	9720
S1-u3-L2-s1	360	360	5832
S1-u3-L3-s1	360	360	5508

Table 8 The optimal path of the truck based on the shortest time (2)

Route	Discharge quantity	Loading quantity	transportation
S2-u2-L5-s2	360	360	4374
S2-u4-L5-s2	720	720	9720
S2-u4-L4-s2	480	480	7218
S2-u3-L3-s2	960	960	13824
S2-u5-L4-s2	600	600	10800
S2-u2-s2	480	0	4320

Table 9 The optimal path of the truck based on the shortest time (3)

Route	Discharge quantity	Loading quantity	transportation
S3-u6-L6-s3	480	480	5184
S3-u5-L2-s3	480	480	5400
S3-u7-L4-s3	840	840	13986
L6-s3-L6	0	120	583.2
L6-s3-L2	0	240	1080
L3-s3-L3	0	960	2073.6
L5-s3-L5	0	480	3024

Table 10 The optimal path of the truck based on the shortest time (4)

Route	Discharge quantity	Loading quantity	transportation
S4-u4-L4-s4	1080	1080	12636
L5-s4-L5	0	600	1620
S4-u6-L9-s4	960	960	17712
S4-u2-L8-s4	1080	1080	14580
S4-u2-L8-s4	120	120	1458
S4-u6-L8-s4	360	360	5508
S4-u3-L5-s4	600	600	6750
S4-u3-L6-s4	240	240	3240
S4-u5-L6-s4	360	360	5022

All the above transportation times are multiplied by 0.9 to offset the deviation coefficient α.

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3. Conclusion

This paper considers the influence of the ship's preferred position, and effectively combines the berth,quay crane, and truck together. It not only considers the ship'sIn port time, the time of the truck transportation operation process is increased to minimize the total time, which makes the terminal operation more complete and smooth.According to calculations, the total time of the trucks serving the five ships is 184582.8 minutes. If the trucks are packed or unloaded separately, the total truck transportation time is 215038.9 minutes. Therefore, the optimization saves 16.5% of the time and improves the trucks. Transportation efficiency to improve the overall operating efficiency of the terminal rate. The solution results of the optimized model show that the trucks should reduce the time of occupancy. Ships should be docked reasonably and a certain number of quay cranes should be allocated to maximize the use of the terminal facilities to improve the efficiency of the terminal. The research results illustrate the effectiveness and practicability of the model to a certain extent.

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