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Optimization of Joint Scheduling of Trucks and Yard cranes in Automated Container Terminals under Half-shape

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Abstract: Aiming at the optimization problem of automated container terminal scheduling, this paper considers a new model of field Yard crane-Truck scheduling integer programming under the new layout of truck-accessible container area. In order to deal with a fixed number of tasks, the shortest on-site time of the truck and the interaction between the yard crane and the truck produce a multi-objective integer programming model with the smallest main cost. The constraint maintains the minimum safety distance between two adjacent yard crane and avoids the bridges crossing each other. At the same time, considering the limitation of the transportation network's bearing capacity in the yard, it avoids the traffic congestion caused by the scheduling scheme, thereby improving the operation of the container terminal effectiveness. In order to improve the global optimization ability of genetic algorithm, a new mutation operation is designed, the understanding space cutting method is introduced, and the gene repair technology is embedded in the algorithm framework, and an improved genetic algorithm is proposed to solve. Through the experimental analysis of different task scales, the effectiveness of the proposed scheduling method is verified.

Keywords: Half-shape yard; Trucks and yard cranes scheduling optimization; Truck-accessible yard

1. Introduction

With the advancement of technology and the rapid development of the container transportation industry, coupled with factors such as environmental and labor cost pressures, automated terminals are constantly emerging around the world. Compared with the traditional model, the automated terminal can free people from the heavy manual work environment through the process of automatic detection, information processing, analysis, judgment, manipulation and control to achieve the expected goals according to the requirements of people. How to study the scheduling of yard cranes and trucks in an automated wharf to increase the yard efficiency and increase customer satisfaction has become a major research issue. In terms of yard crane resource allocation and scheduling, some scholars have done a lot of research on the establishment of planning models and algorithm development. Ulrich and Schneider et al. [1] studied a field-bridge scheduling problem involving triple crossings. The main goal is to maximize the capacity of the yard crane at full load. At the same time, the delay of the loading and unloading process is considered in the model. The optimization of the heuristic algorithm makes the working efficiency of the system increase by 20%.Briskorn and Angeloudis et al. [2] assume that the task sequence of each yard crane has been determined and optimize it with the goal of minimizing the completion time. The image model is used to describe the operation path of the yard crane under the two systems. In order to reduce the average waiting time of the truck, Guo et al. [3, 4] established a multi-yard crane dynamic scheduling model and gave the corresponding solution. This study effectively solved the best sequence of the yard crane serving the truck problem.Hu et al. [5] established a loose constraint model for the field-bridge scheduling problem and used commercial software packages to solve it quickly, but failed to propose more effective and flexible algorithmic decision support. Ren [6] In order to overcome the problem of insufficient yard crane resources, a yard crane resource sharing mechanism was introduced, and a two-stage mathematical model with a time window and the minimum operating cost as the goal was constructed and solved by quantum genetic algorithm. Yan [7] in order to avoid the calculation time of large-scale field-bridge scheduling problem is too long, research and construct a field-bridge scheduling knowledge base system to guide the wharf scheduling of the field-bridge. In the field operations of container terminals, trucks are the main means of transportation to achieve the efficiency of terminal operations, and the level of dispatching directly affects the efficiency of terminal operations. In order to reduce the congestion of the container terminal and reduce the turnaround time of trucks, Xiao Zhang et al. [8] proposed an optimization model for truck appointments, optimized the appointment quota for each period and developed a BCMP queuing network to describe the queuing of trucks in the terminal process. Qiu et al. [9] made use of the feature that the vehicle routes would not conflict, and proposed two strategies to enable the truck to handle the continuous arrival tasks. Ye et al. [10] established a time-driven parallel system to study the route control and decision-making of Chika. Li Dong et al. [11] put forward the idea of taking road resources as the research object and gave the path control strategy of the truck based on the Euler method, so that the truck can predict the smoothness or blockage of the yard leading road from both time and space aspects Trend and thus choose a shorter route to travel. The scheduling of yard crane and truck has an important impact on the efficiency of terminal operations. If the truck arrives late, it will affect the operation of the yard crane and thus the operation efficiency of the yard. In order to reduce the difficulty of optimization, several studies have been conducted to optimize the two. However, in the actual production of the port, the operation processes of the bridge and the truck are closely linked, and the optimization of single equipment scheduling also lacks integrity, which is not conducive to the overall operation of the port equipment further increase in efficiency. With the advancement of optimization theory and methods, joint scheduling of yard crane and trucks has gradually attracted the attention of researchers. Lu Changliang [12] considering the influence of truck scheduling, studied the internal space allocation and yard crane scheduling problems of the yard, and integrated it into an integer linear programming model: under the constraints of the capacity of the transportation route, reasonable truck scheduling would reduce the field The bridge is transported between the yards, thereby reducing the overall operating costs of the yard. He Guizhu [13] considered the multi-objective model of continuous time in the study of the impact of the arrival time of the trucks on the yard crane scheduling. Its purpose is to reduce the time spent on the field and bridge ends through reasonable scheduling of the trucks and yard crane. He [14] proposed the integrated scheduling model of truck and yard crane, and designed the Benders decomposition algorithm. Lu Chen et al. [15] developed a three-stage algorithm. In the first stage, heuristic methods are used to generate the crane plan. In the second stage, based on the priority relationship of the transportation tasks obtained in the first stage, the problem of multi-collector routing was solved. In the final stage, a complete solution is constructed using the disjunction graph. To further reduce container ship berthing time. Cao Peng [16] comprehensively considered the practical constraints such as the safety distance of the bridge and the task optimization sequence, and constructed a joint scheduling optimization model of the yard crane and the truck with the shortest shipping time as the goal of the truck working surface mode, and used path optimization to determine the field The shortest driving path of the bridge [17].

In summary, in these studies, some articles considered the scheduling problem of yard crane or trucks separately. From the gradual development of these studies, the joint scheduling of the two systems is the trend of future research. However, although some studies have considered the joint dispatch of yard crane and trucks, they are all in the context of traditional wharf layout.

2. Description

The automated container terminal process, which is characterized by loading and unloading at the end of the yard, has promoted the development of unmanned and intelligent terminals, but it also faces some problems. Two rail cranes in the same yard operate on common rail, and the operating space is restricted, which makes the production organization more difficult, especially when the operation is busy. It is difficult to take care of loading and unloading ships and gathering and transportation operations; horizontal transportation equipment inside and outside the yard can only reach the end of the yard, The container handling between the end and the shell position completely depends on the rail crane, which can only achieve point-to-point loading and unloading. In the traditional dock layout, the length of the car body and the long reversing time when the truck collects into the interactive zone easily affects the normal passage of other lanes, causing traffic jams in the field. Waiting for the truck to be collected on the bridge will incur a certain consumption cost.

The process design of the automated wharf must not only consider the full use of port resources to ensure the economic and social benefits of the enterprise, but also meet the need for rapid loading and unloading of ships and departures from the port. However, with regard to the problems mentioned above, the existing vertical layout can no longer meet the needs of automated terminals. Therefore, there is an urgent need to explore a new wharf design scheme based on the vertical layout—the half-turn runway scheme.

In the half-turn layout, the storage yard is closely arranged on both sides of the channel, and the double cantilever rail crane is used to realize the automated operation of the AGV under the cantilever on one side and the operation of collecting cards under the other cantilever. The path of the outside collection card into and out of the box area is " half-turn "shaped, and there are two outside collection card driving channels for every other box area, and the two adjacent storage yards in turn share the collection and transportation half return channel. The trucks enter from the three lanes, and directly reach the target shell position of the yard along the truck track, carry out the pick-up operation, and then exit directly from the two lanes through the half-turn font. Although it will cause excess travel distance of the external collection card, it can effectively reduce the jam of the dock system and improve the efficiency of the dock. At the same time, the process can be combined with the collection card security corridor according to the specific conditions of the wharf, and can also be adapted to the sea-rail combined transportation and cross-car transportation technology. Based on this process, it is also possible to optimize the strategy of the business process, the adjacent yards share a set of road resources, and the final target position of the horizontal transportation equipment is flexibly adjusted. In addition, the semi-circular scheme yard management and scheduling system rules are simple, that is, the yard crane no longer needs relay operations, which makes the expansion and utilization of loading and unloading equipment significantly improved. These advantages of the half-turn font scheme are not available in the existing schemes introduced earlier, and these will also make the half-turn font scheme increasingly favored by major terminals. Provide a new idea for the continuous progress of the automated terminal, and provide a broad space for the continuous improvement of the terminal efficiency and the new thinking of customer satisfaction.

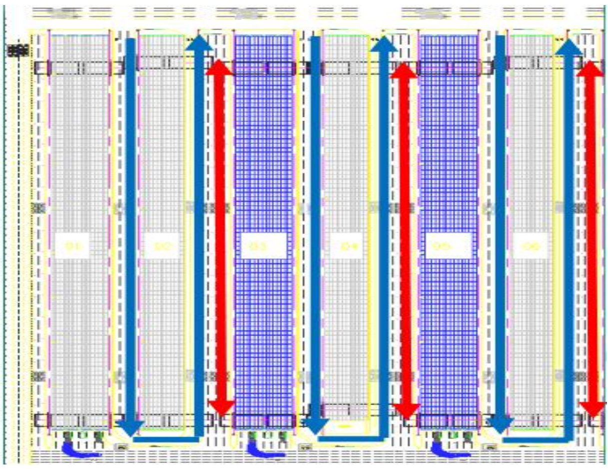

Figure 1. Half-turn layout

The problem studied in this paper is that when dealing with a fixed number of tasks, the shortest on-site time of the collection truck and the main cost when the yard crane collection truck works with each other is the smallest.

3. Model Building

3.1. Model assumptions

Only when the corresponding set card arrives at the operating position can it be loaded.
The yard crane must not cross each other and must have a safe distance.
The loading and unloading workload does not exceed the handling capacity of the yard crane.
This model is applicable to the two processes of picking up, loading and unloading inventory.
Information about the estimated arrival time of the truck is known.
When the cost of waiting time for the yard crane to collect cards exceeds the upper limit, the priority card is higher than the waiting limit. The waiting cost for the yard crane exceeds the upper limit and has the highest priority and must be served.

3.2. Symbol

M :Number of yard cranes
N :Number of trucks
Ω :Task set
L :Track length
a :Tail arc length
v_0 :Truck speed on the track
v_1 :Driving speed of yard crane in yard
d :The length of a shell
d_{safe} :Safe distance between two yard cranes
c_0 :The moving cost of the two yard cranes per shell
c_1 :The cost of time spent by the yard crane waiting for the card collection unit t
c_2 :Cost of time spent in the unit of waiting for the bridge unit
t_0 :Interaction time of truck and yard crane
t_n :Set card n actual time from entry to exit
P_m :How many times has the yard crane m been loaded and unloaded
X_{im} :Yard crane m ith loading and unloading mission
$S_{(X_{im})}$:Yard crane m reached the moment of loading and unloading at the i-th operation
$F_{(X_{im})}$:End time of yard crane m at the ith operation
$l_{(X_{im})}$:Yard crane m Time required to complete the i mission
$S_{(x^n_{im})}$:When the yard crane i reaches the i-th operation, the corresponding set card n reaches the operation position
$h_{(X_{im})}$:The location of yard crane m doing the ith operation
$t_{(x^n_{im})}$:The length of the time of waiting for the collection card n during the i-th operation of the yard crane m
$r_{(x^n_{im})}$:The length of the bridge n waiting time for the i-th job of the yard crane m

3.3. Model establishment

Objective function:

$$y = \min(y_1 + l * y_2)$$

$$y_1=\sum_{n=1}^{N} tn-(\frac{2L+a}{v_0}+t_0)*N$$

$$y_2=c_0*\sum_{m=1}^{M}\sum_{i=1}^{P_m}[h_{(x_{(i+1)m})}-h_{(x_{im})}]/d+$$
$$c_1*\sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{i=1}^{P_m} t(x^n{}_{im})/t+$$
$$c_2*\sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{i=1}^{P_m} r(x^n{}_{im})/t$$

y_1: The shortest difference between the actual time and the theoretical time of the truck from entry to departure

y_2: The cost of moving yard crane m from a task to the task immediately after it and the cost of waiting for each other with the yard crane collection card are minimized.

y : Represents the optimal value of the fixed number of tasks.

Constraint conditions:

$$\sum_{m=1}^{M} P_m=\Omega \qquad (1)$$

All tasks are operated

$$X_{im}\in\Omega \qquad (2)$$

The task of the i-th processing of yard crane m is in the task set

$$F_{(x_{im})}\geq S_{(x^n{}_{im})}+l_{(x_{im})} \qquad (3)$$

Ensure that the completion time of any task is not earlier than the sum of the time when the task set card arrives and the yard crane loading and unloading

$$S_{(x_{(i+1)m})}\geq S_{(x_{im})}+\left[h_{(x_{(i+1)m})}-h_{(x_{im})}\right]/v_1+l_{(x_{im})}] \qquad (4)$$

The start time of the next task is not earlier than the sum of the start time of the previous task and the movement time of the yard crane immediately after the task, and the length of time the bridge is loaded

$$F_{(x_{(i+1)m})}=l_{(x_{im})}+\max\left\{F_{(x_{im})}+h_{(x_{(i+1)m})}-h_{(x_{im})}]/v_1, S_{(x^n{}_{im})}\right\} \qquad (5)$$

Constraints for the equality between the completion time of a task, the arrival time of the collection card, the length of loading and unloading, etc.

$$t_n\geq F_{(x_{im})}-S_{(x^n{}_{im})}+\frac{2L+a}{v_0} \qquad (6)$$

Inequality constraints for the time of trucks entering the field, the time to reach the yard crane task, the time to complete the task, and the time to leave the field

$$h_{(x_{(i+1)m})}-h_{(x_{im})}\geq d_{safe} \qquad (7)$$

Ensure that the yard cranes will not cross and leave a safe working distance

$$t_{(x^n{}_{im})}\geq 0 \qquad (8)$$

$$r_{(x^n{}_{im})}\geq 0 \qquad (9)$$

The waiting time of the yard crane collection card is positive

$$F_{(x_{im})}-S_{(x_{im})}\geq t_{(x^n{}_{im})}\geq S_{(x^n{}_{im})}-S_{(x_{im})} \qquad (10)$$

$$F_{(x_{im})}-S_{(x_{im})}\geq r_{(x^n{}_{im})}\geq S_{(x_{im})}-S_{(x^n{}_{im})} \qquad (11)$$

Calculate the early and late time constraints of the yard crane

$$X_{im}\neq X_{jm}\quad (i\neq j\quad i,j\in\Omega) \qquad (12)$$

Ensure that each mission can only be loaded and unloaded by one yard crane and can only be loaded and unloaded once

4. Model Solution

The mathematical model established in this paper obviously has feasible solutions that satisfy various constraints (for example, some solutions obtained by using the first-come-first-served rule are feasible solutions), and because Xim all take positive integers, the feasible solution set is a finite set, and there must be The solution with the smallest objective, that is, the model must have the optimal solution. Although the model has an optimal solution, the model belongs to the integer programming model and is also an NP-hard problem. Exact solution algorithms (such as enumeration, branch and bound, and cut plane, etc.) can only solve problems with a small task size. Larger, it is necessary to design a heuristic algorithm to quickly search for the approximate optimal solution. Therefore, this paper designs an improved genetic algorithm (IGA) to solve the model. The specific algorithm is as follows.

4.1. Chromosome coding

Using real number coding, the length of the chromosome is (number of tasks + number of yard crane s -1), the basic structure of the chromosome is shown in the figure, which is represented by the chromosome of a program of 10 containers loaded and unloaded by two yard cranes. Each locus value represents the task number; chromosomes from left to right represent the loading and unloading sequence of the yard crane; a locus of 0 represents the interval symbol between different yard cranes.

4.2. Generation of initial population

The problem studied in this paper requires that each task can only be loaded and unloaded by a yard crane once, so an initial population generation method is proposed. The specific steps are as follows:

Step 1: Determine the natural value of the gene in the range of 1~n (number of tasks), and record it as set G;

Step 2: Randomly select n non-repeating numbers from G, and arrange the selected numbers into a row vector in the order of selection;

Step 3: Randomly insert "0" between any two adjacent elements in the row vector generated in step 2, and record the new row vector after inserting "0" (obtain a chromosome);

Step 4: Return to step 2 until the number of cycles reaches the initial population capacity (NIND).

4.3. Solution space cutting

The scheduling model requires that two adjacent yard cranes cannot interfere or cross each other. Some individuals (solutions) in the initial population may not meet the above conditions, so such non-feasible solutions need to be eliminated. This paper proposes a solution space cutting method, specifically: using the constraints that do not need to cross or interfere between adjacent yard cranes, cutting the current population (solution space) once, that is, directly deleting individuals (solutions) that do not meet the conditions; then using restore the population to its original size by randomly copying the remaining individuals.

4.4. Fitness function and selection mechanism

The problem in this paper guarantees that the completion time of any task is not earlier than the sum of the arrival of the task set card and the loading and unloading time of the yard crane, and when the task size is large, there will be more individuals (solutions) in the optimization process of the algorithm that do not meet the above constraint. If the solution space cutting method is still used, the remaining feasible solutions will be few or even zero. Therefore, an appropriate function with a penalty rule is introduced to ensure that the task completion time in the solution corresponding to the solution of the scheduling problem is higher than respective upper limit.

4.5. Cross operation

According to the characteristics of chromosome coding, the sequence cross method is used to recombine chromosomes. The specific steps are as follows:
Step 1: Randomly select the two intersections X and Y, determine the gene fragments of the two parents (P1, P2) that will be copied to the progeny, and initially obtain the two incomplete progeny a, b;
Step 2: List the original gene code sequence from the second cross point Y for P1 and P2 to obtain the gene code arrangement of P1 and P2;
Step 3: Delete the gene codes of the copied progeny of P1 and P2 from the gene code arrangement of P1 and P2, respectively, to obtain the arrangement a' and b';
Step 4:For a, from the second intersection point, fill in the gene code of b's from left to right in the corresponding gene position and replace "╳". Do the same for b, and get two new offspring individuals O_1 and O_2. As shown in the figure is a cross instance of two individuals.
In the random crossover process, some "wrong individuals" (individuals with "0" in the first and last position of the gene chain) may appear. For example, any P1 and P2 crossover sequence may have the "0" gene in the first or tail of the entire chromosome. Therefore, after each crossover operation of each generation of the algorithm is completed, the gene repair program is immediately called to repair the erroneous individuals in the generated new population as viable individuals.

4.6. Improve mutation operation and termination rules

The improved mutation operation is proposed as follows: the first mutation, in order to achieve the change of the task distribution between the bridges, the "inverted mutation" is adopted, that is, two gene switching positions are selected on both sides of "0"; the second mutation is followed To change the order of loading and unloading tasks of a certain bridge using "sequencing mutation", that is, select two gene transpositions on the same side of "0".

4.7. Gene repair technology

In the iterative process of the algorithm, the crossover operation may cause the wrong individuals to appear in the group. In order to eliminate the influence of these erroneous individuals on the entire program (interruption or endless loop), traditional genetic algorithms adopt methods such as directly skipping individuals, replacing individuals, or deleting individuals directly. But this kind of method will make most of the correct genetic information in the wrong individuals be ignored, and when the constraints of the problem are more strict, the population will be occupied by some individuals.
Therefore, this article proposes gene repair technology. For example: the gene chain length of a chromosome is n, and the location of the "0" gene in the chromosome is zero_index,. Compared with the traditional genetic algorithm for the treatment of erroneous individuals, gene repair technology can not only use the useful information of erroneous individuals, maintain population diversity, but also eliminate the effects of erroneous individuals on the overall program.

5. Numerical Experiment

5.1. Algorithm performance experiment

To verify the superiority of IGA, the genetic algorithm (GA) before the improvement will be compared. Using the parameter settings of the Chinese and German algorithm in the experiment of Section 4.1, Python 3.7 is programmed and solved on the Intel(R) Core TM i5-2450M 2.50GHz processor, 4GB memory PC.
The population size is 300, the crossover probability is 0.4, the probability of two consecutive mutations is 0.1 and 0.08, and the maximum number of iterations of the algorithm is 1000. The average value of the IGA experiment results is compared with the experimental results before the improvement. The specific comparison indicators are the total waiting time of the truck and the solution time. The comparison of the experimental results of the two is shown in Table 1.

Table 1. Comparison of experimental results

EX	IGA	GA

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	Solution time /s	Total waiting time /min	Solution time /s	Total waiting time /min
EX	117.253	106.3943	676.7	105.8903

5.2. Truck-Yard crane scheduling experiment

This paper uses real data from a wharf in a city to carry out the yard crane-truck scheduling experiment. The experiment is mainly aimed at the yard crane loading and unloading task on a box area of the wharf when processing 50 tasks, that is, the experiment is carried out under the condition of the number of yard cranes $Y = 2$. Among them: loading and unloading tasks, each task position, the time of arrival of the corresponding collection card, the length of loading and unloading, the corresponding bridge-collector waiting situation, as shown in the table, RT in the table is the time when the corresponding collection card reaches the operation position of the task, the initial time of the system is 0; OT is the loading and unloading time required for the task; GT is the time of the collection card in the port; Type is the type of collection card corresponding to the task, "1" represents the bridge waiting for the collection card, "0" represents the collection card waiting for the collection yard crane or not waiting for each other.

Table 2. Details of examples

Task	Bay	RT/min	OT/min	GT/min	Type	Task	Bay	RT/min	OT/min	GT/min	Type
1	4	3.0	5.7	11.4	1	26	9	63.5	4.0	12.2	0
2	6	3.2	3.0	10.5	1	27	5	65.0	5.0	11.3	0
3	11	4.0	3.7	12.1	0	28	7	66.2	2.5	10.9	0
4	10	4.9	2.8	13.2	0	29	8	68.9	4.0	10.0	0
5	13	5.3	5.4	12.6	0	30	7	71.3	5.1	11.8	0
6	4	7.2	4.6	10.9	1	31	11	72.4	4.1	10.7	1
7	5	9.4	2.5	11.2	1	32	3	73.5	3.4	10.6	1
8	1	13.0	4.0	11.9	0	33	19	73.7	2.1	11.2	1
9	4	14.8	4.1	12.1	0	34	12	75.0	3.7	11.7	1
10	9	16.0	4.5	11.8	0	35	11	76.2	5.6	12.2	0
11	12	18.2	3.4	10.3	1	36	13	76.9	3.2	12.9	0
12	19	20.0	2.9	10.7	1	37	14	78.4	4.6	12.5	0
13	21	21.4	6.2	11.1	1	38	15	80.2	6.0	11.5	0
14	15	23.7	5.0	12.3	0	39	17	80.7	4.3	11.8	0
15	17	26.0	3.7	11.5	0	40	12	81.5	3.9	10.9	0
16	12	29.5	2.4	12.0	0	41	10	82.6	4.7	10.5	1
17	14	36.3	6.7	11.8	0	42	3	83.5	3.8	11.9	0
18	17	40.5	6.1	10.9	1	43	1	84.1	4.0	11.6	0
19	20	43.0	5.4	10.0	1	44	6	85.2	3.7	10.9	1
20	14	46.7	2.3	12.1	0	45	4	87.9	4.2	11.7	0
21	2	49.2	4.4	12.7	0	46	6	89.0	5.1	12.1	0
22	1	54.6	3.0	11.7	0	47	8	90.3	4.9	11.8	0
23	5	57.1	2.9	10.6	1	48	1	92.4	5.1	10.7	1
24	7	57.9	4.1	11.9	0	49	9	92.8	4.7	11.8	0
25	4	59.0	5.4	12.6	0	50	4	95.1	4.3	12.4	0

The values of constant parameters such as the moving speed of the bridge truck in the model, the traveling speed of the truck and the cost rate are shown in the table. During the experiment, as the number of genetic algorithms increases, the convergence between the optimal value and the mean of each generation is shown in the figure. The target value converges to 3786 when the algorithm evolves to 574 generations, and the corresponding satisfactory solution (individual) is: [1 5 4 7 9 13 15 16 18 20 23 22 26 27 28 31 30 34 37 39 42 43 46 48 49 0 2 3 6 8 10 11 12 14 17 19 21 24 25 29 32 33 35 36 40 41 38 44 45 47 50]. Therefore, the order of loading and unloading the task boxes on the two bridges is:

YC1:1→5→4→7→9→13→15→16→18→20→23→22→26→27→28→31→30→34→37→39→42→43→46→48→49;

YC2:2→3→6→8→10→11→12→14→17→19→21→24→25→29→32→33→35→36→40→41→38→44→45→47→50.

Table 3. Parameter values

Parameter	L/m	a/m	v_0/(m•min^{-1})	v_1(m•min^{-1})	d/m	d_{safe}	c_0/(RMB•b^{-1})	c_1/(RMB•min^{-1})	c_2/(RMB•min^{-1})
Value	570	75.36	90	81	8	1	80	30	5

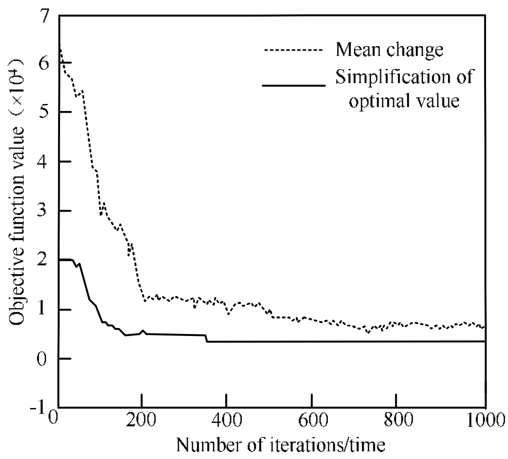

Figure 2. IGA convergence process

The detailed operation results of the experiment are shown in Table 4. The real-time walking path of the two yard cranes between the shells in the box area is shown in the figure. It can be seen from the figure that the path curves of the two yard cranes have no intersections, indicating that the obtained scheduling scheme does not have interference or crossing between the yard cranes.

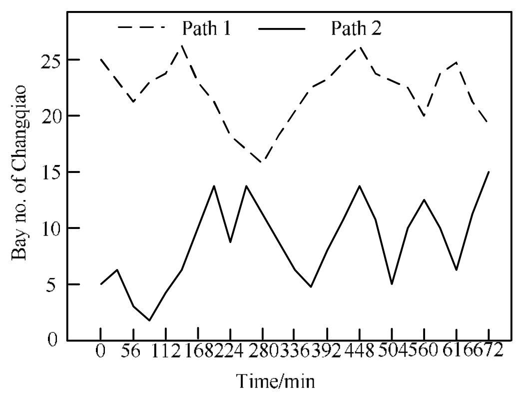

Figure 3. Real-time walking path of two yard crane

Table 4. Experimental results

YC Job serial number	YC_1			YC_2		
	Task	**ST/min**	**FT/min**	**Task**	**ST/min**	**FT/min**
1	1	2.36	8.47	2	3.00	5.47
2	5	13.40	15.80	3	11.50	14.50
3	4	16.47	21.00	6	16.00	24.87
4	7	26.50	29.56	8	28.75	29.00
5	9	31.00	33.55	10	32.45	33.95
6	13	36.26	40.47	11	34.00	35.71
7	15	40.72	46.93	12	37.25	39.82
8	16	47.53	51.00	14	44.00	47.45
9	18	53.36	57.30	17	48.21	52.48
10	20	59.00	61.28	19	55.43	57.89
11	23	81.36	84.50	21	67.45	75.60
12	22	84.63	87.74	24	86.50	87.00
13	26	89.00	91.50	25	88.90	90.45
14	27	91.84	96.95	29	110.80	115.67

15	28	109.36	113.00	32	120.70	125.89
16	31	117.40	124.12	33	127.00	132.05
17	30	128.00	133.41	35	139.65	144.56
18	34	138.22	142.39	36	146.50	149.20
19	37	147.91	152.30	40	159.60	163.02
20	39	156.21	161.00	41	164.65	168.34
21	42	165.71	170.89	38	170.40	173.45
22	43	174.60	177.20	44	176.04	178.35
23	46	181.60	183.64	45	180.98	182.30
24	48	187.40	191.30	47	185.67	188.70
25	49	194.25	197.56	50	196.70	201.80

Note: ST represents the moment when the yard crane starts loading and unloading a certain task; FT represents the moment when the yard crane loading and unloading completes a certain task.

5.3. Multi-yard crane scheduling experiment under different task scales

Through experiments under different task scales, the effectiveness of the proposed scheduling method is further verified. During the experiment, the algorithm's population size, crossover rate, mutation rate, termination algebra and related parameter values are not changed, but only the task size and distribution of the example are changed. The comparison and analysis of the experimental results are shown in Table 5, the CPU in the table -time is used to count the running time of the algorithm, that is, the algorithm efficiency index.

Table 5. Comparison and analysis of experimental results of different task scales

Experiment serial number	Algorithm scale (Number of tasks)	CPU-time/min	FCFS Objective function	Optimize scheduling Objective function	Cost reduction(%)
1	20	1.4059	696.49	621.07	12.14
2	22	1.5904	939.12	706.51	32.92
3	24	1.6013	1196.50	862.46	38.73
4	30	1.7951	1823.21	1510.73	20.68
5	80	4.2091	6409.80	6040.10	6.12
6	100	5.6101	12880.30	11896.02	8.27

It can be seen from Table 5: With the increase of task size, CPU-time increases linearly and relatively flat, so when the scale of the problem increases, the calculation time of the algorithm in this paper will not increase geometrically. The above analysis further demonstrates the effectiveness of the truck-yard crane scheduling method proposed in this paper, and can obtain a better scheduling scheme in a short time.

6. Conclusion

This paper analyzes the new layout model of automated container terminals-truck-accessible container area and yard crane scheduling problem, establishes the truck-yard crane scheduling model in the container area and designs an improved genetic algorithm to solve the model. Numerical experiment results show that the algorithm proposed in this paper can solve similar problems well; at the same time, compared with the traditional field-bridge scheduling method (FCFS), the scheme obtained by using the scheduling model in this paper can reduce the waiting time of the truck-yard crane waiting for each other. The additional cost and the total cost of moving the bridge and truck are reduced by 6.12%~38.73%. Therefore, this study can provide a more scientific basis for the bridge-truck dispatching of automated container terminals, and then improve the efficiency and overall service level of the terminal.

In this study, the loading and unloading time required for each task is considered to be known, but due to the effect of box reversal in actual operations, the loading and unloading time of some tasks will be deviated. Therefore, on the basis of this research, we can add the inverted box problem to the research, and we can further study the yard crane-collector joint real-time scheduling problem of multiple box areas.

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