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Research Article

Optimization of Gantry Crane Scheduling in Container Sea-Rail Intermodal Transport Yard

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In the face of rising container throughput and the tasks associated with collecting and dispatching these containers, contributions to the development of sea-rail intermodal transport are required to improve the capacity of container transportation. According to the characteristics and the requirements of the operation of sea-rail intermodal transport, this paper puts forward a design for the transport yard which facilitates container loading and unloading. Through the establishment of a mixed integer programming model, a flexible schedule for gantry crane operation can be realized, so that, during the planned period, the amount of task overflow in loading and unloading operations and the distance covered by all gantry cranes in the yard is minimized. In addition, a genetic algorithm is designed to solve this model. Finally, a specific example of the loading and unloading of a container train at the sea-rail intermodal transport yard is selected to verify the model and the algorithm. The results show that the algorithm can reasonably schedule the gantry cranes to improve their loading and unloading efficiencies in the sea-rail intermodal transport yard.

1. Introduction

In 2017, China's total container throughput reached 237 million TEU, an increase of 8.3% compared to the same period the previous year [1]. Faced with such massive container traffic, sea-rail intermodal transport is becoming the trend. In short, sea-rail intermodal transport is the mode of transportation whereby the container is the transport object. On the export side, trains carry the containers to the terminal yard, which are then exported by ship and, on the import side, the ship arrives at the port and the containers are carried out of the yard by train. The whole transport process is simple and convenient, only needing "a declaration, a check, a release." Compared with the long-distance mode of transportation by container truck, the container sea-rail intermodal transport has the advantages of low cost, high efficiency, safety, reliability, significantly reduced carbon emission levels, energy savings, and environmental protection. As the main artery of China's transportation, China's railway technology has gained maturity and world-leader status. Therefore, we should take complete advantage of railway in the intermodal transport system, to carry out long-distance and large capacity of the container sea-rail intermodal transport business.

At present, few railways directly reach the port in China. In most cases, a railway container central station is located near the port and transport from the port to the railway container central station, and vice versa, is achieved using container trucks after the containers reach the port. This method will definitely increase the amount of container handling, extend the length of container stay in the port, and increase transportation costs. It does not utilize the advantages of railway transport. Under "The Belt and Road Initiatives" strategy background, the development of sea-rail intermodal transport has provided an unprecedented opportunity. A new Eurasian Land Bridge is established from Lianyungang in China, through Central and West Asia, to Europe. This started the international sea-rail intermodal transport business and opened the sea-rail intermodal transport cross-border logistics channel.

With reference to the loading and unloading equipment scheduling problem, research mainly focuses on scheduling of traditional container handling equipment in the port, but less research has been done on the scheduling of container handling equipment in the sea-rail intermodal transport yard. He J et al. [2] investigated scheduling for the traditional container terminal yard and established a mixed integer programming model and a two-stage heuristic algorithm is used to solve it. In Rodemann H et al. [3] according to gantry crane operational requirements and safety requirements in the actual yard, the associated constraints are listed. Kreutzberger E et al. [4] established the mixed integer programming model to carry out flexible scheduling of handling equipment. Then, a usage assignment genetic algorithm was designed to solve the model. Chang D et al. [5] proposed a novel dynamic rolling-horizon decision strategy to resolve yard crane scheduling problem. Boysen N et al. [6] propose a dynamic programming approach, which determines yard areas for gantry cranes, so that the workload is evenly spread among cranes and, thus, train processing is accelerated. Chen Lu et al. [7] study the interactions between crane handling and truck transportation in a maritime container terminal by addressing them simultaneously. Guo P et al. [8] formulated a mixed integer programming model which considers the effect of dwelling position dependent processing times. Cao Z et al. [9] focuse on double-rail-mounted gantry crane system and providing an efficient operation strategy for the double-rail-mounted gantry crane systems to load outbound containers. Bian Z et al. [10] discuss the load scheduling problem of multiple yard cranes. S.önke Behrends [11] examines the relationship between urban transport and road-rail intermodal transport with the goal of identifying possible actions on a local level to improve both the competitiveness and environmental benefits of rail freight. Sha M et al. [12] propose a novel integer programming model to solve optimal problem of yard crane scheduling with minimal energy consumption at container terminals from the low carbon perspective. Bierwirth C and Meisel F's [13] particular focus is put on integrated solution approaches; they developed a new classification schemes for berth allocation problems and quay crane scheduling problems. Yan We et al. [14] established a knowledge-based system with regard to yard crane scheduling, and then they illustrate the system through a case study. He J et al. [15] address the problem of integrated quay crane scheduling, internal truck scheduling, and yard crane scheduling. Tang L et al. [16] address the joint quay crane and truck scheduling problem at a container terminal, considering the coordination of the two types of equipment to reduce their idle time between performing two successive tasks. Li W et al. [17] develop an efficient continuous time MILP model for yard crane scheduling. Briskorn D et al. [18] treat the crane scheduling in a container port where two cooperative gantry cranes jointly store import containers arriving from the seaside in a storage yard.

In recent years, there have been more and more studies related to sea-rail transport. Reis V et al. [19] conduct analysis of the advantages and disadvantages of combining rail transport with the other transport modes, and they think the sea-rail intermodal transport is the trend of future development. Liu D et al. [20, 21] researched the scheduling optimization of handling equipment in railway container central station, with minimum handling completion times for container trains and handling equipment load as targets. The corresponding mixed integer programming model was established and the improved genetic algorithm was used to solve the problem. Woodburn A et al. [22] studied the optimization of handling equipment in the railway operating area. According to the requirements and characteristics of loading and unloading operations in the railway operating area, the concept of allowable job time was introduced. Jeong B J and Kim K H [23] address the problem of scheduling container transfer operations in rail terminals. Yang H [24] established a two-stage slot control optimization model for multi-Origin-Destination-Fare container sea-rail intermodal transport based on revenue management.

In this paper, the particularity of sea-rail intermodal transport yard is considered. With the railway directly entering the port yard, the gantry crane is researched. A multiobjective optimization model is established to simultaneously maximize loading and unloading efficiency and minimize transition distances.

2. Problem Description

Gantry cranes are the essential handling equipment of the terminal yard. They are more efficient and more flexible than rail-mounted gantry cranes and reach stackers; thus, all the loading and unloading tasks within the yard require gantry cranes. Gantry cranes are usually very large, so unreasonable scheduling can lead to gantry cranes occupying the yard space for a long time. Especially with the complex environment of the container sea-rail intermodal transport yard, blockage of the yard directly affects the loading and unloading efficiency of the entire yard. Therefore, it is necessary to research the scheduling of the gantry crane in the sea-rail intermodal transport yard.

In this paper, the container sea-rail intermodal yard is designed to have three railway lines entering directly into the port yard. There are four railway loading and unloading lines in the yard. Each railway loading and unloading line is divided into four loading and unloading areas, known as blocks. The gantry crane can be moved throughout the yard. Several baffles are provided on each railway loading and unloading line. When the gantry crane needs to work vertical across the loading and unloading line, the baffle is laid down to cover the railway tracks and the gantry crane passes through the baffle to complete the gantry crane scheduling task across the loading and unloading line. On the other hand, when the gantry crane needs to work along the same loading and unloading line, it has to move only in parallel to complete its scheduled task.

The layout of the railway yard and the movement of the gantry cranes among the blocks are shown in Figure 1.

The operation of the container sea-rail intermodal transport port is very different to that of the traditional container terminal and the railway container center in terms of the operational processes and the yard layout. With respect to these two aspects, it is currently difficult to apply the research results on loading and unloading equipment scheduling directly to the container sea-rail intermodal transport port. Therefore, this paper takes the gantry crane in the main yard

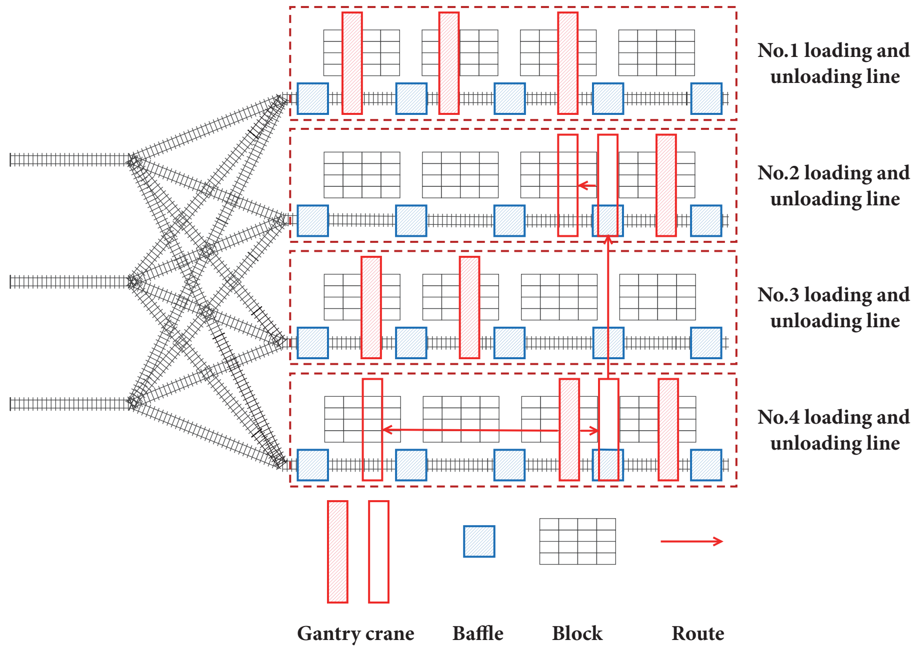

Figure 1: Layout of sea-rail intermodal transport yard.

of the container sea-rail intermodal transport port as the object of study and a special optimization model for gantry crane scheduling is established to maximize the loading and unloading efficiency of the yard and minimize transition distances between all gantry cranes in the yard.

Gantry crane scheduling operations generally have a fixed range scheduling mode and a flexible range scheduling mode. Today, many ports use a fixed range scheduling mode. Based on the number of gantry cranes, this model divides the yard into several areas with one or more gantry cranes responsible for a fixed area. Although the operation of this model is less complex, it is likely to cause low utilization of gantry cranes, resulting in an inefficient operation of the entire yard. In the flexible range scheduling mode, the gantry crane does not have a fixed operating area. In other words, gantry cranes can be moved throughout the yard according to the needs and safety of the entire yard. This model greatly improves the utilization of the gantry crane, but the operation is very complex. In order to improve the utilization of gantry cranes, this paper adopts a flexible range scheduling mode.

Container ports usually operate for 24 hours in a row and the arrival time of the container train is uncertain. Divide a day into four periods; that is, there are six hours for a planned period. Define the action to deposit or remove a container as a task and a set of tasks that are continuously completed in the same block as a task group. First, implement the scheduling plan for the first period. Then, according to the operational situation of the previous period, the plan of the next period of the plan can be adjusted and so on, and the gantry crane scheduling operations in the yard are continually optimized and updated in real time.

This paper aims to study the optimization of multiple gantry crane scheduling among the blocks in the entire railway loading and unloading area, while coordinating between multiple goals. On the one hand, in order to improve the quality of port services, the first goal is to improve the efficiency of port loading and unloading operations. This requires that the time to complete the task groups is minimal and the total number of scheduled tasks completed by all task groups in each period is as close as possible to the total number of scheduled tasks for all task groups in that period. In other words, the number of tasks left for the next period should be minimum. On the other hand, because the gantry crane is large and its speed is limited, when it crosses a block, it occupies the road space for a long time, causes traffic jams, and affects the efficiency of other gantry crane operations. So the second goal is to minimize the distance travelled among the blocks in the yard.

3. Model Building

3.1. Model Assumptions. (1) The efficiency of each gantry crane is the same.

(2) Gantry crane job start and end times are in the same period.

(3) Due to the limited size of the block area, in order to avoid collisions between gantry cranes, the number of gantry cranes in any block at any period cannot exceed one.

(4) The gantry crane is very large and its operation is slow, especially when turning. Frequent transitions are likely to cause traffic jams in the yard, so it is assumed that each gantry crane is only allowed to turn in or out of a block once, when a new task group arrives.

(5) The amount of work in each period is equal to the sum of the number of task groups left over from the previous

period and the number of task groups predicted for the current period.

(6) The task group that was not completed in the previous period will be prioritized in the current period; the uncompleted task group from the previous period will be dealt with first, followed by the predicted task group for the current period.

(7) The gantry crane can be moved across the blocks throughout the yard. This includes horizontal movement along the same loading and unloading line and vertical movement across the different loading and unloading lines.

3.2. Symbols and Variable Definitions. For the sake of clarity, Table 1 presents the description of symbols in the article.

3.3. Objective Function

$$\min Z_1 = \sum_{i \in I} C_{i+} \tag{1}$$

Formula (1) shows that the sum of task overflows is minimal during the planned period, with the amount of overflow equal to the number of tasks planned to be completed during the planned period minus the number of tasks actually completed.

$$\min Z_2 = \sum_{j \in J} \sum_{m \in N} \sum_{n \in N} Y_{mn}^{j} \cdot d_{mn} \tag{2}$$

Formula (2) shows that the sum of the transition distances of all the gantry cranes in the yard is minimal during the planned period.

In the optimization of the gantry crane scheduling, we need to consider these two goals. So the target normalization method can be used to combine the above two objective functions into one objective function. The dimension of the first objective function is the number of tasks and its unit is TEU. The dimension of the second objective function is the distance and its unit is meters. Obviously, the dimensions of the two objective functions are different. Therefore, it is necessary to nondimensionalize the above two objective functions first.

3.3.1. The Normalization of Objective Function 1. Assuming that the maximum amount of overflow for task group i is $C_{i+}^{\max}$ and the minimum amount of overflow for task group i is $C_{i+}^{\min}$, then normalization of objective function 1 is given in

$$f(Z_1) = \frac{Z_1 - \sum_{i \in I} C_{i+}^{\min}}{\sum_{i \in I} C_{i+}^{\max} - \sum_{i \in I} C_{i+}^{\min}} \tag{3}$$

with $C_{i+}^{\min} = 0$, $C_{i+}^{\max} = Q_i$.

3.3.2. The Normalization of Objective Function 2. Assuming that the maximum transition distance of gantry crane j is $d_j^{\max}$ and the minimum transition distance of gantry crane j is $d_j^{\min}$, then normalization of objective function 2 is given in

$$f(Z_2) = \frac{Z_2 - \sum_{j \in J} d_j^{\min}}{\sum_{j \in J} d_j^{\max} - \sum_{j \in J} d_j^{\min}} \tag{4}$$

with $d_j^{\min} = 0$, and $d_j^{\max}$ is the maximum transition distance for gantry crane j in the yard.

Assume that ω_1 is the weight attributed to the sum of the work overflows in each task group and ω_2 is the weight attributed to the sum of the transition distances of each gantry crane. Then, after normalization, the objective function can be expressed in

$$\min Z = \omega_1 \cdot f(Z_1) + \omega_2 \cdot f(Z_2) \tag{5}$$

From the point of view of the efficiency of yard operation, minimizing the task overflow is more important than minimizing the transition distances of all the gantry cranes, so the two weights need to satisfy the condition $\omega_1 > \omega_2$. In this paper, we assume that $\omega_1 = 0.7$ and $\omega_2 = 0.3$.

3.4. Constraint Condition

$$\sum_{n \in N} B_{in} = 1 \quad \forall i \in I \tag{6}$$

Formula (6) ensures that any task group can only be assigned to the only block.

$$\sum_{j \in J} \sum_{m \in N} \left(Y_{mn}^{j} + A_{jn} \right) \leq 1 \quad \forall n \in N \tag{7}$$

Formula (7) ensures that the number of gantry cranes in any block during the planned period should not exceed one.

$$\sum_{j \in J} \sum_{g \in G} X_{ji} \leq |I| \tag{8}$$

Formula (8) ensures that the sum of task groups handled by all gantry cranes during the planned period can not exceed the total number of task groups for that period.

$$\sum_{j \in J} X_{ji} \leq 1 \quad \forall i \in I \tag{9}$$

Formula (9) ensures that a task group is handled by up to one crane during the planned period.

$$\sum_{n \in N} \sum_{m \in N} Y_{mn}^{j} \leq 4 \quad \forall j \in J \tag{10}$$

Formula (10) ensures that any one gantry crane can be moved up to 4 times during the planned period.

$$\frac{\sum_{n \in N} Q_{jn}}{E} \leq \frac{Q_{\max}}{E} - \sum_{n \in N} \sum_{m \in N} t_{mn} \cdot Y_{mn}^{j} \quad \forall j \in J \tag{11}$$

Table 1: The definitions of symbols.

Symbol	Definition
I	The set of task groups
Q_i	The number of tasks that are included in task group i
J	The set of gantry cranes that can be scheduled in the yard
N	The set of blocks
Q_{jn}	The number of tasks completed by gantry crane j in block n during the planned period
C_{i+}	Task overflow of task group i during the planned period
C_{n-}	Task overflow in the block n during the previous period
$Q_{\max}$	The maximum working capacity of each gantry crane during the planned period
d_{mn}	The distance from block m to block n
t_{mn}	The time when gantry crane moves from block m to block n
t_r	The time when gantry crane tires are rotated through 90 degrees once
v	The moving speed of gantry cranes
E	Average operating efficiency of gantry cranes
L	The set of railway loading and unloading lines
t_{al}^{j}	The moment when the gantry crane j reaches loading and unloading line l
t_{dl}^{j}	The moment when gantry crane j departs loading and unloading line l
t_{al}^{p}	The moment when the pth container train reaches loading and unloading line l
t_{dl}^{p}	The moment when the pth container train departs loading and unloading line l
B_{in}	A binary parameter satisfying $B_{in}=1$, if block n has task group i; and $B_{in}=0$, otherwise
A_{jn}	A binary parameter satisfying $A_{jn}=1$, if gantry crane j is placed in block n in the initial state; and $A_{jn}=0$, otherwise
X_{ji}	A binary variable satisfying $X_{ji}=1$, if gantry crane j handles task group i during the planned period; and $X_{ji}=0$, otherwise
Y_{mn}^{j}	A binary variable satisfying $Y_{mn}^{j}=1$, if gantry crane j moves from block m to block n; and $Y_{mn}^{j}=0$, otherwise

Formula (11) ensures that the actual working capacity of each gantry crane cannot exceed the maximum working capacity of the gantry crane.

$$\sum_{i\in I} B_{in}\cdot Q_i + C_{n-} - \sum_{j\in J} Q_{jn} = \sum_{i\in I} B_{in}\cdot C_{i+} \quad \forall n\in N \tag{12}$$

Formula (12) ensures that the relationship between the number of tasks actually completed and the number of task overflows in any block during the planned period.

$$t_{mn} = \begin{cases} \dfrac{d_{mn}}{v}, & m,n \text{ block in the same loading and unloading line} \\ \dfrac{d_{mn}}{v} + 2\cdot t_r, & \text{otherwise} \end{cases} \tag{13}$$

Formula (13) ensures that the time required for the gantry crane to move between different blocks is not equal.

$$\sum_{i\in I} B_{in}\cdot X_{ji} \le A_{jn} + \sum_{m\in N} Y_{mn}^{j} \quad \forall n\in N\ \forall j\in J \tag{14}$$

Formula (14) ensures that if the gantry crane j handles the task group i in block n, only two situations may occur: gantry crane j is placed in block n in the initial state; the other is that the gantry crane j moves from block m to block n.

$$t_{dl}^{j} - t_{dl}^{p} > 0 \quad \forall j\in J\ \forall l\in L \tag{15}$$

$$t_{al}^{j} - t_{al}^{p} < 0 \quad \forall j\in J\ \forall l\in L \tag{16}$$

Formulas (15) and (16) ensure that when the container train stops on a loading and unloading line in the sea-rail intermodal transport yard, none of the gantry cranes can move to any block in this loading and unloading line.

4. Genetic Algorithm

The gantry crane scheduling problem has proved to be an NP-hard problem [25]. So we propose a genetic algorithm to solve it. According to the principle of survival of the fittest, the genetic algorithm screens out the better solution in each

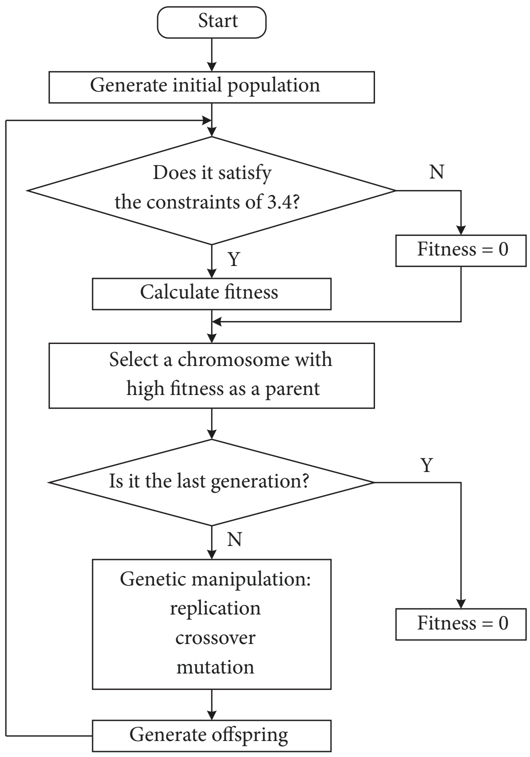

Figure 2: Flow chart of genetic algorithm.

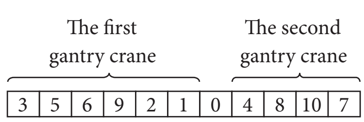

Figure 3: Schematic diagram of chromosome.

generation to finally obtain the approximate optimal solution. The flow design of the genetic algorithm is shown in Figure 2.

4.1. Chromosome Coding. In this paper, the chromosome is denoted via real coding; that is, the task group serial number represents the gene on the chromosome. The sequence of the genes represents the operation sequence of gantry cranes. The chromosome of each gantry crane is concatenated to form a complete scheduling chromosome, which is a complete gantry crane scheduling program. Figure 3 is a schematic diagram of chromosome. It represents that there are two gantry cranes and ten task groups, the first gantry crane handling task group $\{3, 5, 6, 9, 2, 1\}$ and the second gantry crane handling task group $\{4, 8, 10, 7\}$. The works of two gantry cranes are separated by 0.

4.2. Individual Feasibility. The steps to screen chromosomes are as follows.

Step 1. The task groups to be processed will be arranged according to the arrival time.

Step 2. The individual feasibility is judged using the constraints described in Section 3.4. If the individual is feasible, the fitness is directly calculated and the parent chromosome is selected. Otherwise, the fitness of the chromosome is recorded as 0.

Step 3. Repeat Step 2 until there are no chromosomes that do not satisfy the constraints described in Section 3.4.

4.3. Fitness Calculation. The fitness function of an individual can be constructed according to the objective function given in this paper. This paper aims to minimize the objective function. Therefore, when the value of the objective function gets smaller, the fitness of the individual becomes greater. Thus, the fitness function is the reciprocal of the objective function,

$$fitness = \frac{1}{Z} \tag{17}$$

4.4. Parent Selection. The probability of any individual being selected is given by the proportion of individual fitness to population fitness. With the roulette method, the higher the proportion, the greater the probability of being selected. Thus, the most adaptive individuals are selected as a parent to the next generation.

4.5. Chromosome Crossover. Chromosome crossover is an important operation in genetic algorithm. The schematic diagram is shown in Figure 4. The crossover steps used in this paper are as follows.

Step 1. Randomly select a string of genes in parent 1.

Step 2. Copy these genes to the vacancies in the same position of the offspring.

Step 3. Find the same genes as parent 1 in parent 2 (except for genes in substrings) and copy these genes to the vacancies at the same position in the offspring.

Step 4. Put the remaining genes in parent 2 into the remaining vacancies of the offspring from left to right.

4.6. Chromosome Mutation. This article uses real number coding, so we need to randomly select two genes in the mutation operation and exchange their positions. The schematic diagram is shown in Figure 5.

5. Example Analysis

This paper divides the day into four periods, that is, six hours for a planned period, to achieve the optimization of gantry crane scheduling with rolling plan idea. In this example, the railway yard at the container terminal has four railway lines and each loading and unloading line accesses four blocks. That is, there are 16 blocks in the whole yard, numbered from 1 to 16. The total number of gantry cranes that can be called for the whole yard is 8 and they are labelled from J_1 to J_8.

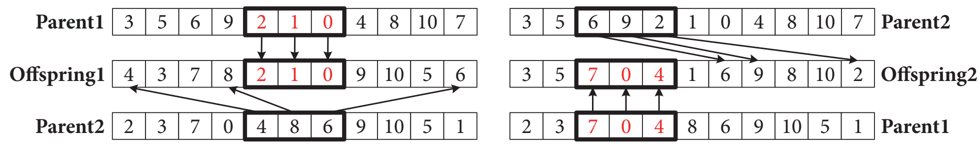

Figure 4: Schematic diagram of chromosome crossover.

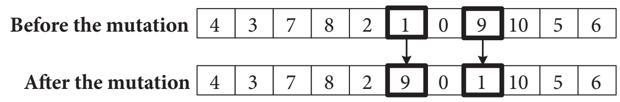

Figure 5: Schematic diagram of chromosome mutation.

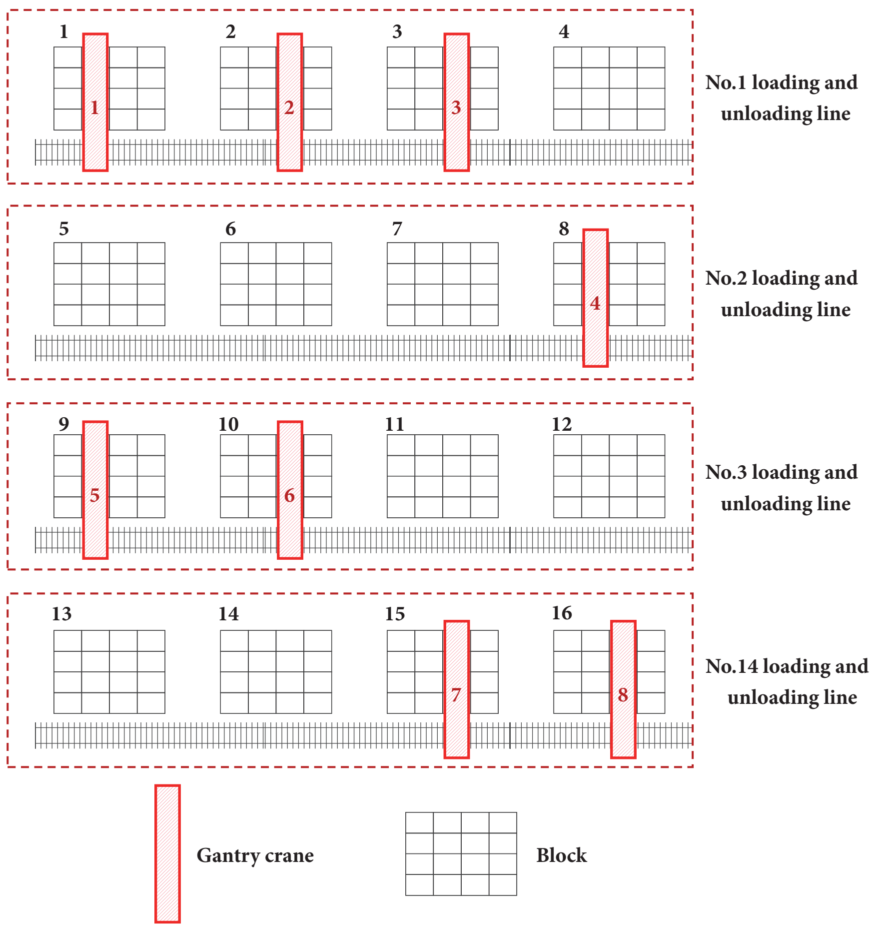

Figure 6: Distribution of blocks in the yard.

The average moving speed of the gantry crane is 35 m/min, the average completion time for a task for each gantry crane is 120 seconds, and the average time for the tires to rotate through 90 degrees is 150 seconds. The layout of the loading and unloading lines and the blocks in the yard is shown in Figure 6.

This example only considers the scheduling of the gantry cranes for a single period of time from 0 to 6 o'clock. There are 26 task groups in this example, with I_1 to I_{26} used to represent them as they gradually evolve over time. When a train arrives, it is equivalent to a set of task groups that arrives. Each task group is assigned to a unique block. For example, when the first train arrives, it stops at line 1, and the number of tasks will increase by 95 TEU. It will be allocated to 1, 2, 3, and 4 blocks of 30, 20, 15, and 30 TEU, respectively. The task arrival time, the number of tasks, and the assigned loading and unloading line and block of each task group are shown in Table 2. The number of task overflows in each block during the previous period is shown in Table 3. In addition, the initial positions of all gantry cranes that can be called are shown in Table 4.

Table 2: Task group list.

Task group	Task arrival time	The number of tasks/TEU	Loading and unloading line	Block
I_1	00:10:00	30	Line 1	1
I_2	00:10:00	20	Line 1	2
I_3	00:10:00	15	Line 1	3
I_4	00:10:00	30	Line 1	4
I_5	00:10:00	45	Line 4	15
I_6	00:10:00	60	Line 4	16
I_7	01:20:00	40	Line 1	1
I_8	01:20:00	40	Line 1	2
I_9	01:20:00	40	Line 1	3
I_{10}	01:20:00	40	Line 2	6
I_{11}	01:20:00	20	Line 2	8
I_{12}	02:15:00	50	Line 3	9
I_{13}	02:15:00	60	Line 4	15
I_{14}	02:15:00	60	Line 4	16
I_{15}	02:50:00	40	Line 1	1
I_{16}	02:50:00	40	Line 1	2
I_{17}	02:50:00	40	Line 1	3
I_{18}	02:50:00	40	Line 1	4
I_{19}	04:30:00	45	Line 1	1
I_{20}	04:30:00	45	Line 1	2
I_{21}	04:30:00	45	Line 2	5
I_{22}	04:30:00	45	Line 2	6
I_{23}	04:30:00	45	Line 2	7
I_{24}	04:30:00	45	Line 2	8
I_{25}	04:30:00	30	Line 3	11
I_{26}	04:30:00	30	Line 3	12
I_{27}	04:30:00	60	Line 4	16

Table 3: The number of task overflows in each block during the previous period.

Block	The number of task overflows/TEU	Block	The number of task overflows/TEU
1	0	9	10
2	10	10	0
3	15	11	0
4	0	12	0
5	0	13	0
6	0	14	0
7	0	15	15
8	20	16	0

The moving times of the gantry cranes between each pair of blocks are shown in Table 5.

Based on the results of the numerical test, the genetic algorithm parameters are as follows:

(1) The population number is set to 100.

(2) The crossover probability is set to 0.8.

Table 4: Gantry crane initial position list.

Gantry crane number	Initial position
J_1	Line 1 (Block 1)
J_2	Line 1 (Block 2)
J_3	Line 1 (Block 3)
J_4	Line 2 (Block 8)
J_5	Line 3 (Block 9)
J_6	Line 3 (Block 10)
J_7	Line 4 (Block 15)
J_8	Line 4 (Block 16)

(3) The probability of variation is set to 0.05.

(4) The maximum number of iterations is set to 100.

The final scheduling scheme of the gantry cranes for the 6-hour period, obtained by the dynamic scrolling strategy proposed in this paper, is shown in Table 6.

The specific scheduling scheme of gantry crane between 0 and 6 o'clock is shown in Table 7. Gantry crane 1 operation block order is 1-1-1-1-1, gantry crane 2 operation block order is 2-2-2-2-2, gantry crane 3 operation block order is 3-3-3-3-7, gantry crane 4 operation block order is 8-4-8-4-8,

Table 5: Moving times of gantry crane between each pair of blocks.

Move time		Block															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Block	1	0	1	2	3	8	9	10	11	11	12	13	14	14	15	16	17
	2	1	0	1	2	9	8	9	10	12	11	12	13	15	14	15	16
	3	2	1	0	1	10	9	8	9	13	12	11	12	16	15	14	15
	4	3	2	1	0	11	10	9	8	14	13	12	11	17	16	15	14
	5	8	9	10	11	0	1	2	3	8	9	10	11	11	12	13	14
	6	9	8	9	10	1	0	1	2	9	8	9	10	12	11	12	13
	7	10	9	8	9	2	1	0	1	10	9	8	9	13	12	11	12
	8	11	10	9	8	3	2	1	0	11	10	9	8	14	13	12	11
	9	11	12	13	14	8	9	10	11	0	1	2	3	8	9	10	11
	10	12	11	12	13	9	8	9	10	1	0	1	2	9	8	9	10
	11	13	12	11	12	10	9	8	9	2	1	0	1	10	9	8	9
	12	14	13	12	11	11	10	9	8	3	2	1	0	11	10	9	8
	13	14	15	16	17	11	12	13	14	8	9	10	11	0	1	2	3
	14	15	14	15	16	12	11	12	13	9	8	9	10	1	0	1	2
	15	16	15	14	15	13	12	11	12	10	9	8	9	2	1	0	1
	16	17	16	15	14	14	13	12	11	11	10	9	8	3	2	1	0

Unit: minutes.

Table 6: Final scheduling scheme.

Gantry crane	Initial block	1st block	1st task	2nd block	2nd task	3rd block	3rd task	4th block	4th task
J_1	1	1	$30(I_1)$	1	$40(I_7)$	1	$40(I_{15})$	1	$45(I_{19})$
J_2	2	2	$30(C_{2-}+I_2)$	2	$40(I_8)$	2	$40(I_{16})$	2	$45(I_{20})$
J_3	3	3	$30(C_{3-}+I_3)$	3	$40(I_9)$	3	$40(I_{17})$	7	$45(I_{23})$
J_4	8	4	$30(I_4)$	8	$40(C_{8-}+I_{11})$	4	$40(I_{18})$	8	$45(I_{24})$
J_5	9	9	$60(C_{9-}+I_{12})$	5	$45(I_{21})$	—	—	—	—
J_6	10	6	$40(I_{10})$	6	$45(I_{22})$	—	—	—	—
J_7	15	15	$60(C_{15-}+I_5)$	15	$60(I_{13})$	11	$45(I_{25})$	—	—
J_8	16	16	$60(I_6)$	16	$60(I_{14})$	16	$60(I_{26})$	—	—

gantry crane 5 operation block order is 9-9-5, gantry crane 6 operation block order is 10-6-6, gantry crane 7 operation block order is 15-15-15-11-12, and gantry crane 8 operation block order is 16-16-16-16. Take gantry crane 7 as an example. When there are no tasks initially, it is positioned in block 15 (on the loading and unloading line 4). There is 15 TEU task overflows in block 15 during the previous period. When I_5 arrives, block 15 has its tasks increased by 45 TEU, and the total number of tasks is 60 TEU, which are completed by gantry crane 7. When I_{13} arrives, block 15 has its tasks increased by 60 TEU and these are also completed by gantry crane 7. When I_{25} and I_{26} arrive, the tasks are assigned to block 11 and block 12, respectively. At this time, gantry crane 7 moves from block 15 to block 11 and it completes the tasks of I_{25}. Finally, when gantry crane 7 completed I_{25}, gantry crane 7 moves from block 11 to block 12 and it completes the tasks of I_{26}. At the end of this period, the minimum task overflow from 0 to 6 o'clock is 31 TEU and the total transition distance of the eight gantry cranes is 875 meters in this yard.

In order to assess the effectiveness of the proposed model and the efficiency of genetic algorithm, some experiments are conducted to compare the results obtained by genetic algorithm and the optimal objective value solved by CPLEX directly. We use CPLEX 12.8 software to solve the small-sized instances. For the large-sized instances, the solutions given by CPLEX with a time limit of 30 minutes are compared with the results from genetic algorithm. Let obj_C denote the objective value of the results obtained by CPLEX and obj_{GA} denote the objective value of the results obtained by genetic algorithm. Then the effectiveness of the corresponding solution approach can be measured by the following formula:

$$GAP = 100\% \cdot \frac{(obj_{GA} - obj_C)}{obj_C} \tag{18}$$

The GAP value represents the gap between the result obtained by genetic algorithm and that obtained by CPLEX, so lower values of GAP are preferable.

Table 7 shows the results on 15 instances. J represents the number of task groups, and I represents the number of gantry

Table 7: Performance comparison between CPLEX and Genetic Algorithm.

Instance			CPLEX		Genetic algorithm		GAP(%)
No.	J	I	obj_C	CPU(s)	obj_{GA}	CPU(s)	$(obj_{GA} - obj_C)/obj_C$
1	2	4	6	0.06	6	0.08	0.00
2	2	6	25	0.48	26	0.26	4.00
3	2	8	32	2.66	34	0.34	6.25
4	4	8	14	7.79	14	0.39	0.00
5	4	10	26	50.85	28	1.65	7.69
6	4	12	28	1800.00	30	2.24	7.14
7	6	12	34	381.52	35	4.81	2.94
8	6	14	26	565.75	27	1.68	3.85
9	6	16	N/A	1800.00	35	3.72	N/A
10	8	16	70	1508.85	72	5.88	2.85
11	8	18	N/A	1800.00	46	9.18	N/A
12	8	20	N/A	1800.00	62	12.76	N/A
13	10	20	87	1800.00	88	29.86	1.15
14	10	30	N/A	1800.00	42	43.26	N/A
15	10	40	N/A	1800.00	79	52.01	N/A
Average			17.89	1007.86	31.27	11.21	3.59

cranes in the yard. From Table 7, CPLEX can directly obtain results when the size of instances is small. This shows that the model proposed in the paper is effective. The gap between the two results obtained by the two methods is not evident, and the average gap value is only 3.59%. It implies that the proposed genetic algorithm is an effective method for solving the gantry crane scheduling problem in the container sea-rail intermodal transport yard. As to the computing time of two methods, genetic algorithm is shorter than CPLEX. However, as the size of the instance increases, the computational times of CPLEX will increase rapidly, and it will hardly terminate within the runtime limit. In other words, CPLEX usually cannot give an optimal solution in a reasonable time or can only find the local optimal solution within the runtime limit. However, the proposed genetic algorithm can solve them in the reasonable computing time. In summary, according to the computational experiments with small and large sizes, the model is effective in solving the gantry crane scheduling problem after the container train arrives, and the proposed genetic algorithm has been well tested to be a competitive algorithm for solving the gantry crane scheduling problem in container sea-rail intermodal transport yard.

6. Conclusions

This paper aimed to optimize the gantry crane scheduling in the container sea-rail intermodal transport yard. Design of the railway entering directly into the sea-rail intermodal transport yard avoids the secondary transportation. Based on the characteristics and specific requirements of the loading and unloading process in the container sea-rail intermodal transport yard and a flexible scheduling mode, a mixed integer programming model is constructed to minimize the sum of task overflows during the planned period and the sum of the transition distances of the gantry cranes. A genetic algorithm is then designed to solve this model. Finally, an example is used to demonstrate how this algorithm gets a scheduling solution after a container train reaches the sea-rail intermodal transport yard. The example results show that the proposed genetic algorithm obtains near-optimal solutions within reasonable runtime. CPLEX is competitive if the instances are of small size, whereas the genetic algorithm is capable of delivering fairly good solutions even for the large-sized instances. In other words, the model and the algorithm can be used to realize reasonable scheduling of the gantry cranes in the sea-rail intermodal yard after the container train arrives, while minimizing task overflow and transition distance. This final schedule improves the efficiency of the gantry cranes and reduces loading and unloading times in order to meet the actual requirements of yard operation.

Data Availability

(1) The ["Container throughput"] data that support the findings of this study are available from resource name ["Chinaports"], [hyperlink to data source "http://www.chinaports.com/"]. (2) The [the other] data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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