Research on Coordinated Dispatching of Container Terminal Handling Equipment Considering Energy Consumption

Liangliang Ni[1, a], Xiaolong Han[1, b, *]

[1]Institute of logistics Science &Engineering, Shanghai Maritime University, Shanghai 201306, China

[a]18916167852@163.com, [b]xlhan@shmtu.edu.com

Abstract

Under the pressure of energy saving, emission reduction and resource shortage, reducing energy consumption and air pollution emissions, while optimizing operational efficiency, is an urgent problem for China's container terminals. The comprehensive coordination and dispatching of the main loading and unloading equipment QC (quay crane), IT (internal truck) and YC (yard crane) of the terminal plays an important role in the service level and energy saving of the container terminal. Therefore, the problem to be solved is expressed as mixed integer programming problem. A multi-objective mathematical model considering total operation time and total loading and unloading energy consumption is established. The genetic algorithm is used to optimize the model on MATLAB software. The results show that: considering loading and unloading The scheduling of equipment energy consumption is more economical than the scheduling of energy consumption of loading and unloading equipment. The solution based on genetic algorithm is better than the solution solved by particle swarm optimization algorithm, which verifies the effectiveness of the model and algorithm.

Keywords

Energy consumption; coordinated scheduling; mixed integer programming; genetic algorithm.

1. INTRODUCTION

With the rapid development of international trade, container terminals have become an important hub for transshipment goods, and their importance in transportation networks is increasing. Since the container transportation system is capital intensive, the turnaround time of the container terminal ship is an important factor for the liner company to reduce costs. Turnaround times include berthing, unloading, loading and departing. Therefore, proper scheduling of loading and unloading operations is critical to the efficiency of the container shipping system. In addition, the intensification of competition between ports has forced them to improve their service levels, making port operation efficiency an important factor in the success of fierce competition. At the same time, the acceleration of environmental pollution and energy consumption has become a global concern. In addition to the climate problem, we are facing the problem of depletion of resources, especially the energy consumption problem, and the terminal is one of the places with the most energy consumption. We should try our best not to improve the service level of the container terminal at the expense of environmental cost, so This paper will study another goal is how to achieve energy saving and emission reduction without reducing the level of terminal services.

In the literature, there are many researches on the main loading and unloading equipment dispatching of container terminals. Zhang Xiaoju et al(2019) used heuristic algorithm to solve the problem of coordinated scheduling of quay cranes, established a coordinated model of quay crane and internal truck coordination, and finally got the optimal operation sequence of the card and quay crane to save time and reduce costs. The goal. Zheng Jinlin(2018) built the card and quay crane collaborative operation model with the minimum total working time of the card, and solved the model with simulation software. Shell Ying Huang et al (2018) proposed a bounded two-level dynamic programming (DP) algorithm to optimize container terminal crane scheduling problems. Tian Xing et al (2018) considered the issue of co-scheduling of container berths, quay cranes and card collections, taking into account the sequence of ship arrivals, the constraints of quay cranes and card collection during actual operation, and the minimum total operating cost. , built a mathematical model and solved it with lingo. Huang Jiwei et al (2018) set the model of dual-track hoist cooperative scheduling with the shortest completion time of dual-track hoist, and solved the advantages and disadvantages of the two algorithms by using genetic algorithm and CPLEX algorithm. Chengji Liang (2018) mainly studied the configuration quantity and scheduling optimization of dock cranes. By analyzing the relationship between these two problems, a coupling model was established and solved by a three-stage genetic algorithm. Virgile Galle et al (2018) mainly studied the scheduling optimization problem of the yard crane, and proposed a heuristic local search scheme to actually simulate the dispatching configuration problem of the yard crane. Zheng Hongxing et al(2018) considered the fixed order of the work to be carried out, the safe distance between the bridges and the realistic constraints that cannot be crossed, and the waiting limit of the internal truck, focusing on the real-time pre-reverse box during the yard crane operation, constructed with penalty The total waiting time of the factor internal truck is at least the target mixed integer linear programming model, and a mixed simulated annealing algorithm is designed to solve the problem.

There is currently not much literature on the energy consumption of container terminal handling equipment. Jianbin Xin et al (2014) studied how to improve the processing capacity of container terminals under the consideration of energy-saving targets, and finally achieve the two goals of minimum operating time and minimum energy consumption. Mei Sha et al (2017) considered the energy consumption of the dock crane when lifting, translating and lowering the container, and established a mixed integer programming model to solve the direct relationship between the terminal crane and energy consumption from a low-carbon perspective, and provide benefits for the terminal to reduce energy consumption. reference. Junliang He et al.(2015)first transformed the YC scheduling problem into a vehicle routing problem with soft time window (VRPSTW), and established a mixed integer programming (MIP) model using genetic algorithm (GA) and particle swarm optimization (PSO). The two goals minimize the total completion delay for all task groups and the total energy consumption of all YCs. Sun Wenbo(2013) minimized the objective function of the ship in port time, established an optimal configuration model for the low-carbon container terminal quay crane, and solved it with genetic algorithm. Yan Nannan et al (2016) established a multi-objective mathematical model considering the energy consumption of the card and the time of the bank bridge collection, and solved the operation cost by using the genetic algorithm, which proves that the energy consumption is saved and the scheduling cost is saved. has practical significance. Guo Wei(2014) constructed a container terminal core resource integrated scheduling optimization model with the minimum total operating time and the minimum total energy consumption of dock loading and unloading machinery, and solved the hybrid optimization algorithm using genetic algorithm. Junliang He et al (20170 adopted genetic algorithm(GA) and particle swarm optimization(PSO), and the simulation-based optimization method achieved the goal of minimizing the total departure delay of all ships and the total transportation energy consumption of all tasks.

Compared with the existing literature, the innovation of this paper is to consider the energy consumption factor for the problem of coordinated dispatching of container terminal handling equipment. In the existing research on container terminal equipment scheduling, most of them only consider the scheduling optimization of a single loading and unloading equipment, and most of the considerations for the energy consumption of the terminal are in a single equipment or considering the macroscopic energy consumption of the terminal. In order to meet the requirements of energy saving and emission reduction, this paper takes into account the energy consumption of the main loading and unloading equipment of the container terminal, and establishes a mixed integer programming model with the minimum total operating time and minimum energy consumption of the loading and unloading equipment, and solves it on the MATLAB software by genetic algorithm.

2. MODEL CONSTRUCTION

2.1. Description of the problem

The traditional container terminals mainly include loading and unloading equipment: quay crane (Qc), internal truck (IT) and yard crane (Yc). The three types of equipment cooperate with each other to complete the loading and unloading operations. After the ship arrives at the port, the unloading process is as follows: the quay crane first unloads the imported container onto the internal truck, and then the card is transported to the yard import box area according to the specified route, and finally the container is placed by the yard crane to the designated area. The box is released and the card is released. Boxing is a series of completely opposite operational procedures. Due to the efficiency difference and randomness of the equipment operation, there may be four possible situations in the process of waiting for the quay crane, waiting for the bridge, and waiting for the bridge. Therefore, how to reasonably allocate the task to achieve the minimum total time of the comprehensive scheduling of the quay crane, the card, the yard crane and the minimum energy consumption of the three loading and unloading equipment is the main content of this paper.

This paper considers that there are many factors involved in container terminal loading and unloading scheduling. In order to facilitate calculation, some assumptions are made, including the following aspects:

(1) The same type of quay crane, internal truck and yard crane loading and unloading efficiency is the same.

(2) Only consider the transportation of the internal truck between the quay crane and the yard crane, and do not consider the path optimization problem of the card.

(3) Does not consider the impact of the yard and the rummaging on the ship on the operational efficiency.

(4) Assuming that the loading and unloading operations of the quay crane are fixed, there may be four cases of loading and unloading (LU), loading and unloading (LL), unloading and loading (UL), and unloading and unloading (UU). This article assumes that the order of tasks that need to be handled is fixed.

2.2. symbol definition

J : All collections that require loading and unloading tasks, $i \in J(|J| = n)$.

J^U : All tasks that need to be uninstalled.

J^L : All tasks that need to be loaded, $J^U \cup J^L = J$.

Q : Represents a collection of all quay cranes, $q \in Q$

R : Collection of all internal trucks, $r \in R$

Y : Collection of all yard cranes $y \in Y$

e_u :Energy consumption per unit time of a internal trucks at no load (unit/s)

e_l :Energy consumption per unit time of a internal trucks during loading (unit/s)

e_w :Energy consumption per unit time while a internal trucks is waiting (unit/s)

α :Average unit energy consumption of a quay crane (unit/s)

β :Average unit energy consumption of a yard crane (unit/s)

s_i^q : Quay crane q job task i start time

t_i^q : Quay crane q job task i time

t_p : The time taken by the quay crane container q

t_i^l : The time taken by the quay crane q to extract the rise phase after i

t_i^o : Quay crane q extraction task i middle part translation time

t_i^d : The time taken by the quay crane q to extract the task i after the falling phase

s_i^r : Internal truck r to start the start time of task i

t_i^r : The end time of the internal truck r execution task i

$t_r^{ii'}$: Set the time internal truck r from the end of the previous task i to the start of the current task i'

t_r^{wq} : Time when the internal truck loading task i waits for the quay crane extraction

t_r^{wy} : The time it takes for the bridge to be fetched when the card is loaded with task i

s_i^y : Yard crane y start time of job task i

t_i^y : End of yard crane y job task i

$\mu_i \in \{0,1\}$ $\mu_i = 1$ Representing imported containers, $\mu_i = 0$ Express export container

H : A positive integer large enough

Decision variables:

$hs_{ii'}^r \in \{0,1\}$: The internal truck r travels from the end of the task i to the task i' starting point is 1, otherwise 0;

$x_{ii'}^r \in \{0,1\}$: Task i, i', when working from the same internal truck r, task i completes 1 before task i', otherwise 0;

$y_{ii'}^q \in \{0,1\}$: Task i, i', when working from the same quay crane q, task i completes 1 before task i', otherwise 0;

$z_{ii'}^y \in \{0,1\}$: Task i, i', when tasked by the same bridge y, task i completes 1 before task i', otherwise 0;

$x_i^r \in \{0,1\}$: Task i is transported to 1 by the internal truck r, otherwise 0;

$y_i^q \in \{0,1\}$: Task i is transported to 1 by the internal truck q, otherwise 0;

$z_i^y \in \{0,1\}$: Task i is transported to 1 by the internal truck y, otherwise 0;

rq_i : When uninstalling task i, the time when the internal truck r reaches the quay crane where the task i is located;

$\tilde{o}_i^q$: Quay crane q time spent performing task i;

$\bar{o}_i^y$: Yard crane y time spent performing task i;

o_r^i : Set the time internal truck r from the start of task i to the end of task i;

ry_i : When task i is loaded, the time when the internal truck r reaches the side of the yard where task i is located;

2.3. Multi-objective model construction

Energy model construction:

$$\mathrm{E}^{sq} = \sum_{q \in Q} \alpha \cdot (\max \sum_{i=1}^{n} \tilde{o}_i^q) \tag{1}$$

$$\mathrm{E}^{sy} = \sum_{y \in Y} \beta \cdot (\max \sum_{i=1}^{n} \bar{o}_i^y) \tag{2}$$

$$E_i^{wq} = \sum_{i \in I} \left[e_w \cdot u_i \cdot (\tilde{o}_i^q - s_i^q - rq_i) + \mathrm{e}_w \cdot (1-u_i) \cdot (\tilde{o}_i^q - rq_i) \right] \tag{3}$$

$$E_i^{wy} = \sum_{i \in I} \left[e_w \cdot (1-u_i) \cdot (\bar{o}_i^y - s_i^y - ry_i) + \mathrm{e}_w \cdot u_i \cdot (\bar{o}_i^y - ry_i) \right] \tag{4}$$

$$E_{rii'} = \sum_{r \in R} \sum_{q \in Q} x_{ii'}^r \cdot e_u \cdot t_r^{ii'} \tag{5}$$

$$E_{ri} = \sum_{r \in R} e_l \cdot (\mathrm{o}_i^r - s_i^r) \tag{6}$$

Equations (1) to (6) are the energy consumption that occurs when the card is collected throughout the work process. Equation (1) is the energy consumption of the quay crane during the entire working time. Equation (2) is the energy consumption of the yard crane during the entire working time. Equation (3) is the energy consumption generated by the card arriving at the quay crane and waiting for the quay crane to complete the mission. Equation (4) the energy consumption that occurs when the card reaches the yard and waits for the bridge to complete the task. Equation (5) is the energy consumption generated by the card from the end of the previous task to the starting point of the current task. Equation (6) is the energy consumption generated by the card to transport the task from the starting point to the end point.

Mathematical model construction:

$$f_1 = \min \left(\sum_{q \in Q} \max_i \tilde{o}_i^q + \sum_{r \in R} \max_i o_i^r + \sum_{y \in Y} \max_i \bar{o}_i^y \right) \tag{7}$$

$$f_2 = \min \sum_{i \in I} \left[\left(E_i^{wq} + E_i^{wy} + E_{rii'} + E_{ri} \right) + \mathrm{E}^{sq} + \mathrm{E}^{sy} \right] \tag{8}$$

Equation (7) is one of the objectives to be achieved in this paper. The total time for the comprehensive scheduling of the three loading and unloading equipments of quay crane, internal truck and yard crane is the smallest. Equation (8) is another goal, and the total energy consumption of each device is the lowest during the loading and unloading process.

Restrictions:

$$\sum_{r\in R} x_{ir} = 1, \forall i \in J \tag{9}$$

$$\sum_{r\in R} x_{i^{'}r} = 1, \forall i^{'} \in J \tag{10}$$

$$\sum_{q\in Q} y_{iq} = 1, \forall i \in J \tag{11}$$

$$\sum_{q\in Q} y_{i^{'}q} = 1, \forall i^{'} \in J \tag{12}$$

$$\sum_{y\in Y} z_{iy} = 1, \forall i \in J \tag{13}$$

$$\sum_{y\in Y} z_{i^{'}y} = 1, \forall i^{'} \in J \tag{14}$$

$$\sum_{i,i^{'}\in J^{U}, i\neq i^{'}} x_{ii^{'}}^{r} \leq 1, \forall i, i^{'} \in J^{U},\ \ r \in R \tag{15}$$

$$\sum_{i,i^{'}\in J^{L}, i\neq i^{'}} x_{ii^{'}}^{r} \leq 1, \forall i^{'}, i \in J^{L},\ \ r \in R \tag{16}$$

$$\sum_{i^{'},i\in J^{U}, i\neq i^{'}} y_{ii^{'}}^{q} \leq 1, \forall i, i^{'} \in J^{U}, q \in Q \tag{17}$$

$$\sum_{i,i^{'}\in J^{L}, i\neq i^{'}} y_{ii^{'}}^{q} \leq 1, \forall i, i^{'} \in J^{L}, q \in Q \tag{18}$$

$$\sum_{i,i^{'}\in J^{U}, i\neq i^{'}} z_{ii^{'}}^{y} \leq 1, \forall i, i^{'} \in J^{U}, y \in Y \tag{19}$$

$$\sum_{i,i^{'}\in J^{L}, i\neq i^{'}} z_{ii^{'}}^{y} \leq 1, \forall i, i^{'} \in J^{L}, y \in Y \tag{20}$$

$$t_i^q \geq s_i^q + t_p + t_i^l + t_i^o + t_i^d, \forall i \in J, q \in Q \tag{21}$$

$$s_{i+1}^{q} \geq \begin{cases} t_i^q + \Delta T_q \\ t_i^q + t_i^l + t_i^t + t_i^d + \Delta T_q \end{cases} \left| \begin{array}{l} \forall i, i+1 \in J \\ q \in Q \end{array} \right. \tag{22}$$

$$t_i^r \geq s_i^r + o_r^i, \forall i \in J, r \in R \tag{23}$$

$$ry_{i'} + H\cdot(1-hs_{ii'}^{r}) \ge (o_i^r + t_{ii'}^r \cdot hs_{ii'}^r)\cdot u_i, \forall i,i' \in J, i \ne i', r \in R \quad (24)$$

$$rq_{i'} + H\cdot(1-hs_{ii'}^{r}) \ge (o_i^r + t_{ii'}^r \cdot hs_{ii'}^r)\cdot (1-u_i), \forall i,i' \in J, i \ne i', r \in R \quad (25)$$

$$t_i^y \ge s_i^y + \overline{o}_i^y, \forall i \in J, y \in Y \quad (26)$$

$$rq_i, ry_i, \tilde{o}_i^q, \overline{o}_i^y, o_r^i \ge 0, \forall i \in J, q \in Q, r \in R, y \in Y \quad (27)$$

$$u_i, hs_{ii'}^r, x_{ii'}^r, y_{ii'}^q, z_{ii'}^y, x_{ir}, y_{iq}, z_{iy} \in \{0,1\} \quad (28)$$

Equations (9) to (14) indicate that each container is operated by only one quay crane, internal truck or yard crane. Equations (15)~(20) indicate that when the quay crane, the card, and the yard crane are loaded and unloaded for the container, there is at most one pre- or post-order operation for each container. Equation (21) defines the relationship between the start time and the end time of the quay crane execution task i. Equation (22) defines the loading and unloading order UU, LL, LU, UL, respectively, ΔT_q is the loading and unloading time interval, and the relationship between the starting time of task $i+1$ and the end time of task i. Equation (23) is defined as the relationship between the start time and the end time of the internal truck r execution task i. Equation (24) defines the relationship between $ry_{i'}$, t_i^r, $hs_{ii'}^r$, when the task i' is the exit box and the card r completes the task i and continues the job task i'. Equation (25) defines the relationship between $rq_{i'}$, t_i^r, $hs_{ii'}^r$, when the task i' is the import box and the card r completes the task i and then continues the job task i'. Equation (26) is the relationship between the start time and the end time of the yard crane y. Equations (27) and (28) are constraints on decision variables.

3. GENETIC ALGORITHM

Since the research problem belongs to the multi-objective optimization problem and belongs to the NP-hard problem, it is effective to use the genetic algorithm to solve the problem. Genetic algorithm (GA) is a random search algorithm that simulates the natural evolution of biological processes. Because the genetic algorithm has the characteristics of global search, the solution obtained by the genetic algorithm is usually better than the solution obtained by other methods, and the search speed of the genetic algorithm is faster, so the algorithm is a very effective solution method. The basic steps of applying the genetic algorithm in this paper are shown in Figure 1.

Considering the characteristics of the model established above, the weight coefficient method in the evaluation function method is used for conversion. That is, the objective function normalizes $f = w_1 f_1 + w_2 f_2$ to establish a generalized objective function. The weight coefficient is given according to the actual situation of the terminal operation. When the terminal is in a congested state, the container loading and unloading efficiency operation is a key target. At this time, the weight coefficient corresponding to the total working time target should take a larger value, and the weight of the total working energy target coefficient should be a smaller value. The opposite is true when the container terminal is idle. The terminal operator should set the weighting factor according to the actual situation of the terminal, the development strategy and the government's energy conservation and emission reduction requirements.

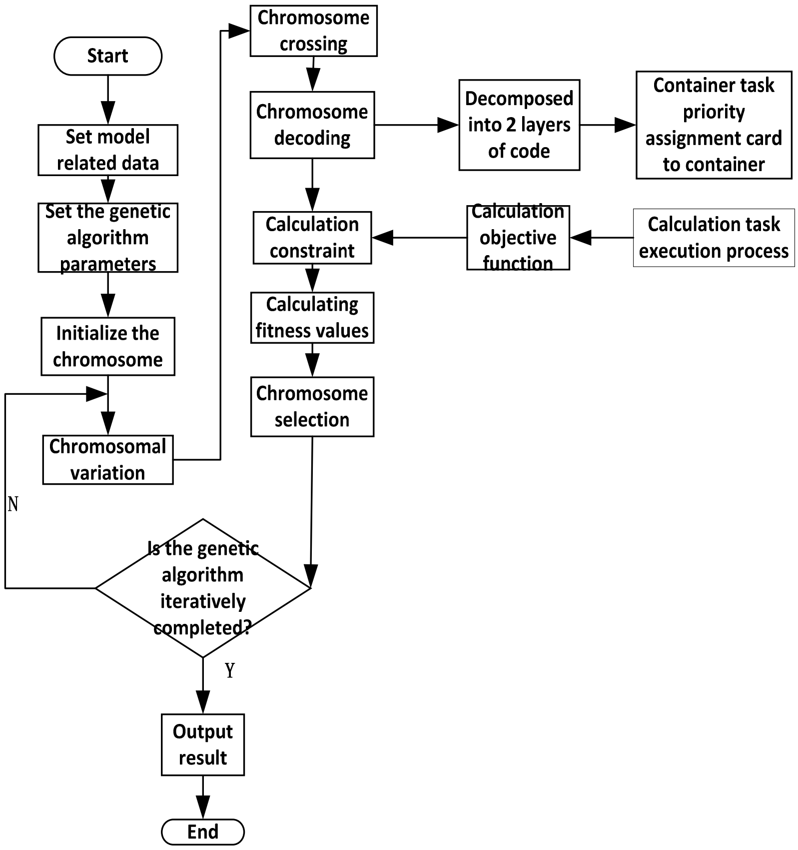

Figure 1. Basic steps of the genetic algorithm

3.1. Chromosome coding

This article assumes that the container order of QC and YC job tasks is fixed, so it is only necessary to optimize their job sequence. Using matrix coding, as shown in Figure 2, each chromosome gene has two layers of code, the first line refers to the container number, the second line refers to the card service container operation sequence and the operation sequence, the author assumes that there are 10 containers, 2 Taiwan quay crane, 4 sets of cards, 3 sets of bridges; according to the operation plan, containers 1, 2, 3, 4, 5, 9 are completed by QC1 operation, and containers 6, 7, 8, 10, 11, 12 are operated by QC2 Completed; containers 3, 4, 5, 9 in the yard area 1, completed by YC1, containers 1, 2, 10, 11 in the yard area 2, completed by YC2. Containers 6, 7, 8, 12. In the yard box area 3, it is completed by YC3. Each chromosome value is a real number between 1 and 1, which respectively indicates the order in which the card is processed, that is, the size value of the chromosome value is determined, and the minimum value is preferentially processed. As can be seen from Fig. 2, the QC1 operation sequence is 3→2→4→1→5→9, the QC2 operation sequence is 6→10→8→7→11→12, and the IT 1 operation sequence is 3→1→10, IT 2 operation sequence 4→2→8, IT 3 job sequence 9→6→5, IT 4 job sequence 7→12→11, YC 1 job sequence 3→4→5→9, YC 2 job sequence 11→2→1→10, YC 3 operation sequence 8 → 6 → 7 → 12.

Container number	1	2	3	4	5	6	7	8	9	10	11	12
chromosome	1. 3	2. 4	1. 2	2. 2	3. 7	3. 5	4. 3	2. 6	3. 3	1. 7	4. 8	4. 5
IT job sequence	1	2	1	2	3	3	4	2	3	1	4	4

Figure 2. Chromosome coding

3.2. Population initialization

This paper uses a random method to generate initial populations in order to ensure the diversity of the population. The initial solution randomly generated in this paper does not require a feasible solution repair. Randomly generated chromosome individuals are shown in Figure 3.

Container number	6	4	3	10	5	7	11	8	1	2	12	9
chromosome	3.5	2.7	4.2	2.5	3.6	1.5	4.1	2.8	3.4	1.9	4.7	1.3
IT job sequence	3	2	4	2	3	1	4	2	3	1	4	1

Figure 3. randomly generated chromosome individuals

3.3. fitness function

In this paper, the minimum value of the objective function is solved, so the reciprocal of the objective function is taken as the fitness function, that is, the fitness function is $F(x)=1/\left(w_1 f_1+w_2 f_2\right)$. It is intuitive and clear to judge the superiority and inferiority of the individual. The greater the fitness value, it is left. The probability is also greater.

3.4. Genetic manipulation

3.4.1 Selection

This paper uses the roulette selection operation, that is, the ratio of the chromosome self-adaptation to the population fitness is the probability that each chromosome is left behind. If the population is P_n and the fitness of the j th chromosome is f_j, the probability that the j th chromosome is preserved is $p_{jl}=\dfrac{f_j}{\sum_{j=1}^{p_N} f_j}$.

3.4.2 Cross

This paper uses a crossover operator to find a broader search space and optimal solution. Using a two-point crossover method, two parents are randomly selected, and two chromosomal bits are randomly selected from the two parents, and then the two chromosomal bits are exchanged.

On the corresponding value, there are repetitions and deletions in the offspring (as shown in Figure 4). Therefore, the progeny chromosomes should be repaired, and the repeated culling is added as the missing container number (as shown in Figure 5).

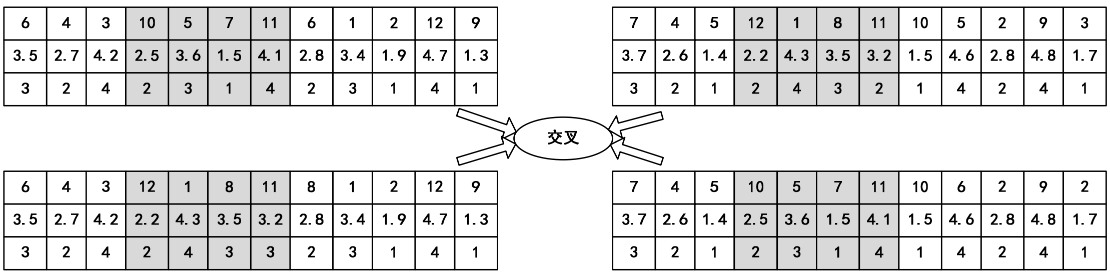

Figure 4. Chromosome crossover

6	4	5	12	1	8	3	5	7	2	10	9
3.5	2.7	4.2	2.2	4.3	3.5	1.5	2.6	3.4	1.9	4.7	1.3
3	2	4	2	4	3	1	2	3	1	4	1

1	4	8	10	5	7	11	12	6	2	9	3
3.7	2.6	1.4	2.5	3.6	1.5	4.1	1.5	4.6	2.8	4.3	3.9
3	2	1	2	3	1	4	1	4	2	4	3

Figure 5. Cross-repaired chromosome individuals

3.4.3 Variation

In this paper, exchange mutation operators are used for the sequence of operations on all chromosomes. The ancestors randomly select two chromosomal locations and exchange the values on these two chromosomal locations, as shown in Figure 6.

6	4	3	10	5	7	11	8	1	2	12	9
3.5	2.7	4.2	2.5	3.6	1.5	4.1	2.8	3.4	1.9	4.7	1.3
3	2	4	2	3	1	4	2	3	1	4	1

7	4	5	12	1	8	3	10	6	2	9	3
3.7	2.6	1.4	2.2	4.3	3.5	3.2	1.5	4.6	2.8	4.3	1.7
3	2	1	2	4	3	3	1	4	2	4	1

Figure 6. Chromosomal variation operation

4. CASE ANALYSIS

In order to verify the validity of the model and algorithm, the following arithmetic columns are solved by Matlab. In this paper, the maximum number of iterations in the genetic algorithm is 500, the probability of crossover is 0.7, the probability of variation is 0.1, and the population size is 100.

4.1. study parameter design

This article has 2 quay cranes, 4 sets of cards, 2 sets of bridges, 50 containers, numbered 1-50, 1-25 for imported containers, number ≥25 for export containers. The following initial parameters are randomly generated according to the relevant literature: Table 1:

Table 1. parameter settings

parameter name	Parameter value
Time of loading and unloading containers on the quay crane	130 s
Time when the bridge is loading and unloading containers	120 s
Energy consumption per unit time of quay crane	3 unit
yard crane energy consumption per unit time	2 unit
Driving energy consumption per unit time when the card is empty	2.6unit
Driving energy consumption per unit time when collecting load	4 unit
Driving energy consumption per unit time when the card is waiting	2 unit
The cost of using each quay crane unit [yuan/h]	882
Cost per unit of card collection [yuan/h]	52
Cost per unit of bridge unit [yuan/h]	650

4.2. Study results and analysis

The genetic algorithm designed in this paper combined with the example is solved by MATLA software. The total operation time is 2.36h, which is 8496s, the total energy consumption is 653unit/h, and the total dispatch cost is 1693 yuan. Figure 7 shows the genetic algorithm convergence graph of the objective function considering the energy consumption; Figure 8 is the optimization diagram of the four card routing paths obtained by the genetic algorithm in this paper, the blue line is the path of the card 1, and the red line is the card 2 The path, the green line is the path of the internal truck 3, and the purple line is the path of the internal truck 4.

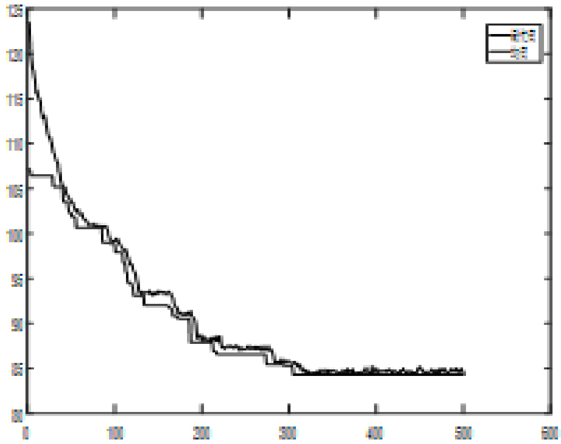

Figure 7. Genetic algorithm convergence graph

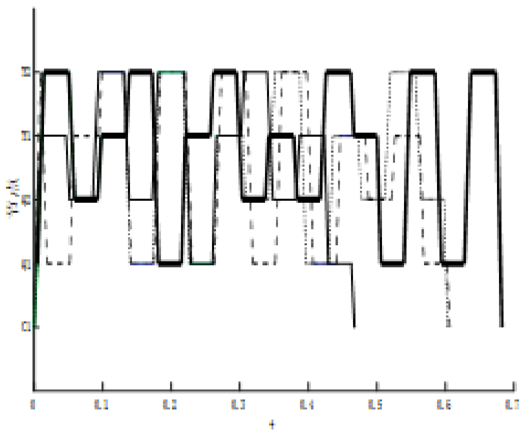

Figure 8. Internal truck path optimization map

4.3. Loading and unloading equipment energy consumption results

As can be seen from Table 2, if the energy consumption is not considered, the total operation time of the loading and unloading equipment is 2.24h, which is 8064s, and the total dispatching cost is 1845 yuan. The energy consumption of this fashion unloading equipment is 706 units. At this target, the total working time of the loading and unloading equipment is 2.36h, which is 8496s, which is 432s more than the energy consumption without considering the energy consumption, but the energy consumption of 153 units is reduced and the scheduling cost of 151 yuan is saved. In terms of time saved, the energy consumption and cost saved are more economical, so the goal of considering energy consumption has practical significance and can optimize the overall objective function.

Table 2. Comparison of energy consumption and energy consumption

Energy constraint	Equipment operation time/h	Equipment operation energy unit/h	Total scheduling cost / yuan
Do not consider energy consumption	2.24	706	1845
Consider energy consumption	2.36	653	1694

4.4. Comparison of different algorithm solutions under different sizes of containers

In order to fully study the effectiveness of the genetic algorithm-based model solution proposed in this paper, the genetic algorithm-based model solving method and particle swarm optimization algorithm designed in different container scales are designed to compare the results obtained by the two algorithms. , compare the advantages and disadvantages of the algorithm.

Table 3. Comparison of different algorithm solutions under different container sizes

Number of containers	Genetic algorithm (GA)				Particle swarm optimization (PSO)			
	Equipment operation time / h	Equipment operation energy unit/h	Total scheduling cost / yuan	Run time / s	Equipment operation time /h	Equipment operation energy unit/h	Total scheduling cost / yuan	Run time / s
20	0.89	269	696	49	1.01	294	766	18
50	2.36	653	1694	96	2.58	712	1875	44
100	5.00	1338	3491	150	6.33	1679	4437	77

According to Table 3, compare the working time, equipment energy consumption and total scheduling cost calculated by the two algorithms under different container sizes. Compared with the particle swarm algorithm, the genetic algorithm is used in different container sizes despite the slow running time. Equipment operating time, equipment energy consumption and total scheduling cost are lower, so genetic algorithms can achieve better results than particle swarm optimization.

4.5. Sensitivity analysis

To further validate the results of the model, the weights of the two goals of time and energy consumption are analyzed.

4.5.1 Impact of time and energy weight changes

Table 4. Find the objective function value under the weight change

coefficient	Equipment operation time / h	Equipment operation energy unit/h	Total scheduling cost / yuan
W_1=0.89,W_2=0.1	2.36	653	1694
W_1=0.69,W_2=0.3	2.50	683	1777
W_1=0.59,W_2=0.4	2.51	688	1798
W_1=0.39,W_2=0.6	2.44	669	1741

It can be seen from Table 4 that the change time and the energy consumption target weight coefficient respectively give different target values. When w_1 is getting smaller and smaller, the total operation time value and total energy consumption value are getting larger and larger, and the corresponding total scheduling cost is also It becomes larger, but when the coefficient is $w_1 = 0.39, w_2 = 0.6$, although the time function value becomes larger, the value of energy consumption and total dispatch cost is smaller, because the loading and unloading equipment may be in different operating states, resulting in energy. The consumption value and total scheduling cost become smaller. Therefore, the operator of the terminal can set the weight coefficient value according to the needs of his actual interest preference. The pursuit of the best time cost should be as large as possible, ignoring the time cost and pursuing the optimal energy consumption and total scheduling cost. The equalization of the weight coefficients to achieve the overall goal optimization.

4.5.2 Impact of changes in quay crane loading and unloading time

Table 5. Find the objective function value under the change of the loading and unloading time of the quay crane

Loading and unloading time / s	Equipment operation time / h	Equipment operation energy unit/h	Total scheduling cost / yuan
70	1.89	508	1247
130	2.36	653	1694
160	2.67	756	2013

It can be seen from Table 5 above that when the loading and unloading time of the quay crane increases, the total loading and unloading time, total energy consumption and total dispatching cost increase, indicating that there is economies of scale between the terminal loading and unloading time, equipment energy consumption and total dispatching cost. Therefore, the terminal operator can improve the performance of the quay crane as much as possible or adopt better loading and unloading equipment, which can reduce the loading and unloading time, save energy consumption, reduce the scheduling cost, and achieve the overall optimal goal.

5. CONCLUSION

This paper proposes a multi-objective coordinated scheduling problem considering the operation time and energy consumption of container terminal handling equipment. The mathematical model of multi-objective optimization is given and solved by genetic algorithm combined with MATLAB software. From the results of the calculation, considering the energy consumption of the loading and unloading equipment can reduce the energy consumption and save the cost, the overall goal can be optimized. The results obtained by the genetic algorithm are better than those obtained by the particle swarm algorithm. Therefore, the scheduling of container terminal handling equipment considering energy consumption can minimize the operation cost of the terminal than the container terminal loading and unloading equipment that does not consider energy consumption, which is in line with the green terminal management concept and is also an inevitable trend of the future development of the terminal.

REFERENCES

[1] ZHANG Xiaoju, ZENG Qingcheng, CHEN Zigen, LI Taoying. Optimization Model of Coastal Bridge and Internal truck Joint Scheduling Based on Simultaneous Loading and Unloading[J].Journal of Shanghai Jiaotong University,Vol. 53(2019)NO.3, p.188-196.

[2] Zheng Jinlin. The choice of container terminal card routing under the cooperation of card and quay crane[J].Tianjin Science and Technology, Vol.45(2018) NO.12,p.43-46.

[3] Shell Ying Huang, Ya Li, A Bounded Two-Level Dynamic Programming Algorithm for Quay Crane Scheduling in Container Terminals. Computers & Industrial Engineering, In press, accepted manuscript, Available online 22 June 2018.

[4] Tian Xing, Meng Qingzhu. Cooperative Scheduling Optimization of Container Code Berth, Quay crane and Internal truck[J].Logistics,Vol.37(2018)NO.3,p.32-36+130

[5] Huang Jiwei, Han Xiaolong. Research on Cooperative Scheduling Optimization of Automated Container Terminal Double Track Crane Based on Genetic Algorithm[J]. Computer Applications and Software, Vol.35(2018)NO.9,p.92-98+143.

[6] Chengji Liang, Lubin Fan, Dehong Xu, Yi Ding, Mitsuo Gen. Research on coupling scheduling of quay crane dispatch and configuration in the container terminal. Computers & Industrial Engineering, Volume 125, November 2018, p. 649-657.

[7] Virgile Galle, Cynthia Barnhart, Patrick Jaillet. Yard Crane Scheduling for container storage, retrieval, and relocation. European Journal of Operational Research, Volume 271, Issue 1, 16 November 2018, Pages 288-316.

[8] Zheng Hongxing, Liu Baoli, Yan Haibo, Yan Xu. Optimization of multi-station scheduling for export box yard considering real-time pre-reverse boxing[J]. Chinese Management Science,Vol.26(2018)NO.9,p.85-96.

[9] Jianbin Xin, Rudy R. Negenborn, Gabriël Lodewijks. Energy-aware control for automated container terminals using integrated flow shop scheduling and optimal control. Transportation Research Part C: Emerging Technologies, Volume 44, July 2014, Pages 214-230.

[10] Mei Sha, Tao Zhang, Ying Lan, Xin Zhou, Tianbao Qin, Dayong Yu, Kai Chen. Scheduling optimization of yard cranes with minimal energy consumption at container terminals. Computers & Industrial Engineering 113 (2017) p.704–713.

[11] Junliang He, Youfang Huang, Wei Yan. Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption. Advanced Engineering Informatics 29 (2015) p.59–75.

[12] Sun Wenbo. Research on optimal allocation of container terminal quay crane under carbon emission constraints [D]. Dalian University of Technology, 2013.

[13] YAN Nannan, YANG Ying.Coordinated Scheduling of Bank Bridge Collection Card Considering Energy Consumption of Collecting Cards[J].Journal of Guangxi University(Natural Science Edition),Vol.41(2016)NO.6,p.1949-1959.

[14] Guo Wei. Research on core resource scheduling of container terminals considering energy consumption [D]. (MS. Dalian Maritime University, 2014.)

[15] Junliang He, Youfang Huang, Wei Yan, Shuaian Wang. Integrated internal truck, yard crane and quay crane scheduling in a container terminal considering energy consumption. Expert Systems with Applications 42 (2017) p.2464–2487.