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AN INTEGRATING SCHEDULING MODEL FOR MIXED CROSS-OPERATION IN CONTAINER TERMINALS

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Abstract. This paper focuses on the optimization of operation scheduling in container terminals based on mix cross-operation. Mix cross-operation is a scheduling method which allows yard trailers to be shared by different yard cranes in different berths to decrease yard trailers' travel distance. An integrating scheduling model that optimizes the three key and interrelated issues, namely, berth assignment, equipment configuration and trailer routing are proposed. To solve the model, a bi-level genetic algorithm is designed. Numerical tests show that integrating scheduling method can reduce operation cost of container terminals significantly and mix cross-operation can decrease yard trailers' empty travel distance to a great extent.

Keywords: container terminal, integrated scheduling model, mixed cross-operation, bi-level genetic algorithm, optimization.

1. Introduction

With the rapid increase of the world container volumes, container terminals, as the important nodes in global transportation network, are faced with bigger challenges to improve port throughput capacity. Therefore, container terminals are speeding up the port construction on a large scale. Meanwhile, how to improve the production efficiency and reduce the operation cost has become one of the most important issues for container terminals. In this paper, an integrating scheduling method is studied based on mix cross-operation to optimize the operation scheduling of container terminals.

The operation process for an arrived vessel in container terminals involves several links, such as berth assignment, loading and unloading operations of quay cranes, receiving and delivery operations of yard trailers, pickup and storing operations of yard cranes. Different operation methods have different requirements on equipment configuration and trailer routing of those links. In traditional separate-operation method, loading operations are performed after all unloading operations are finished, and each yard trailer can only move in a closed circle between a fixed quay crane and yard crane. This method can guarantee the operation reliability of container terminals and make the schedule operations of different equipment easy. However, empty operation of quay cranes and empty travel of yard trailers lead to the decrease of the operation efficiency in container terminals. Moreover, due to the concentrated storage of outbound containers required in this method, shipping companies have to deliver containers to the yard within a limited time, consequently affecting the service quality of container terminals. Therefore, a new operation method, namely mix cross-operation, which realizes the loading and unloading operations performed simultaneously on the quay cranes and allows the yard trailers to move between any quay crane and yard crane, has become the major trend of operation method in container terminals.

In mix cross-operation, container terminals face the problem that several ships need to be served simultaneously and storage locations for containers are relatively scattered. Therefore, how to realize coordination among different links in the operation process, how to assign a berth for loading and unloading, how to determine the deployed size and operation plan of different equipment and how to arrange the routing of yard trailers are the important issues which directly affect the production efficiency and operation cost of container terminals. These issues can be summarized into three interrelated and restricted ones, i.e. berth assignment, equipment configuration and trailer routing.

In order to improve the production efficiency and reduce operation cost of container terminals, such issues as berth assignment, equipment configuration, and trailer routing are simultaneously considered and based on mix cross-operation.

This paper is organized as follows. In Section 2, a brief review of previous works is given. Descriptions of container terminal operations are presented in Section 3. The integrating scheduling model based on mix cross-operation is developed in Section 4. A bi-level genetic algorithm is designed in Section 5. Numerical examples are used to test the performance of the proposed model in Section 6. And the conclusions are given in Section 7.

2. Literature Review

All the links in operation process of container terminals are interrelated and interacted via different equipment; therefore, increasing studies are carried out on the cooperation among several links to improve the coordination and efficiency of operation in container terminals.

A lot of research efforts have been devoted to the operation plan in container terminals covering berth allocation and quay crane assignment. Zhou and Kang (2008) proposed a berth and quay-crane allocation model under stochastic environment to minimize the average waiting time of containership in terminal and develope a genetic algorithm with a reduced search set on its property. Meisel and Bierwirth (2009) integrated the decrease of marginal productivity of quay cranes into the combined problem of berth allocation and crane assignment. In order to solve the problem a construction heuristic, a local refinement and two meta-heuristics procedures are presented, and in 2010 they developed a new classification schemes for berth allocation problem and quay crane scheduling problem to provide a support in modeling and algorithm (Bierwirth, Meisel 2010). Zhang *et al.* (2009) conducted a mixed integer programming model considering the coverage ranges of quay cranes; a sub-gradient optimization algorithm was designed to solve the problem. Han *et al.* (2010) proposed a mixed integer programming model which allowed quay cranes to move to other berths before finishing processing on currently assigned vessels. Chang *et al.* (2010) constructed a dynamic allocation model based on rolling-horizon approach and employed a hybrid parallel genetic algorithm to resolve the model. Raa *et al.* (2011) developed a MILP model considering vessel priorities, preferred berthing locations and handling time.

The integration of yard trailer scheduling, yard crane scheduling and quay crane scheduling are also studied to optimize the terminal operations in the previous research. Bish (2003) proposed a method aiming to solve three problems, which (i) is to determine a storage location for each unloaded container, (ii) also to dispatch vehicles to containers, and (iii) to schedule the cranes operations. Lee *et al.* (2009) proposed a method that integrated yard trailer scheduling and storage allocation. Due to the intractability of the proposed problem, a hybrid insertion algorithm is designed for effective problem solutions. Cao *et al.* (2010) proposed a mixed-integer programming model for yard trailer and yard crane scheduling problems. Two efficient solution methods based on Benders' decomposition were developed for problem solution, and at the same year he proposed a new problem for the integrated quay crane and yard truck scheduling for inbound containers. A genetic algorithm (GA) and a modified Johnson's Rule-based heuristic algorithm (MJRHA) were used for the problem solution.

The operation method of container terminals can be divided into two kinds, i.e. loading/unloading separate-operation and mix cross-operation. Mix cross-operation, which can reduce empty travel distance and improve operation efficiency of yard trailers, has become the development trend of operation method. Thus issues related to mix cross-operation have gained much more attention in existing studies. For example, Nishimura *et al.* (2005) developed a more efficient trailer assignment model based on dynamic routing method to minimize the total travel distance of yard trailers and designed a heuristic algorithm to solve the model. Due to the characteristics of trailer routing in mix cross-operation, the yard routing problem can be treated as vehicle routing problem with backhauls (VRPB). In mix cross-operation, quay cranes allow the loading and unloading performance in the same cycle (Hall 1991). Goodchild and Daganzo (2006) studied the double-cycling problem to improve the efficiency of a quay crane and container port. Solution algorithms and simple formulations were developed to determine reductions in the number of operations and operating time using the method. In 2007 they further evaluated the performance of double cycling sequence over single cycling and developed a framework to show that double cycling can reduce the requirements for yard trailers and drivers (Goodchild, Daganzo 2007).

Most previous studies focus on the partial integrating scheduling problem in container terminal operations, which are limited in two links or two issues. Few of them considered the integrating scheduling of the whole system. Moreover, mix cross-operation method is mostly applied to yard trailer routing problem and quay crane scheduling problem. The combination of equipment configuration based on mix cross-operation needs further studies.

In this paper, a three-stage model based on mix cross-operation is developed to optimize the assignment of berths, the configuration of equipment, and the routing of yard trailers in container terminals. Meanwhile, a bi-level genetic algorithm is designed to solve the model. Numerical tests are given to illustrate the validity of the model and the algorithm.

3. Problem Descriptions

The operation process of container terminals involves the cooperation or coordination of different sub-processes via utilizing and scheduling different equipment in ports. Those sub-processes, such as the ship berthing, the loading and unloading, receiving and delivery containers and storage and pickup are included in the process. Each operation is realized by organizing and deploying some specific equipment, i.e. berth allocation, quay crane assignment, yard trailer routing and yard crane storage etc. The coordination among these equipments promotes the interrelationship of all the sub-processes.

Different operation method has different requirements for the operation scheduling of terminal equipment. For an arrived vessel, the loading operation is performed after the unloading operation in the traditional separate-operation method. Upon a ship's arrival, quay cranes unload containers from the ship to yard trailers, and yard trailers deliver inbound containers from quayside to storage yard, next yard cranes pick up containers from yard trailers to assigned slot, then yard trailers perform the next turn after an empty travel and vice versa (Fig. 1). It shows that yard trailers move just between some specific quay crane and yard crane of the same ship in a closed circle.

While in the mix cross-operation method, to avoid the empty running and improve the operation efficiency of terminal equipment, yard trailers move between different quay cranes and yard cranes of different ships based on the container storage plan. A certain yard crane receives containers unloaded from the ship by a certain quay crane and delivers them to a certain inbound block. After the yard crane picks up containers to their assigned location, the same yard trailer moves on to a certain outbound block to receive containers and delivers them to a certain quay crane for their loading operation. As shown in Fig. 2, the loading ship and loading quay crane may be different from the original ones. Thus it can be seen that those issues, i.e. berth allocation, equipment configuration, and trailer routing are directly influenced by ship berthing location, container storage plan, and the difference of quantity between inbound containers and outbound containers.

To ensure operation efficiency of container terminals, the equipment idle cost is also considered except for the possession cost and using cost. Because the equipment idle cost is in direct proportion to its investment, which means large equipment such as quay cranes and yard cranes has a higher idle cost than relatively small equipment such as yard trailers, it is reasonable that yard trailers are allowed to wait quay cranes and yard cranes in optimizing equipment configuration. Thus the opera-

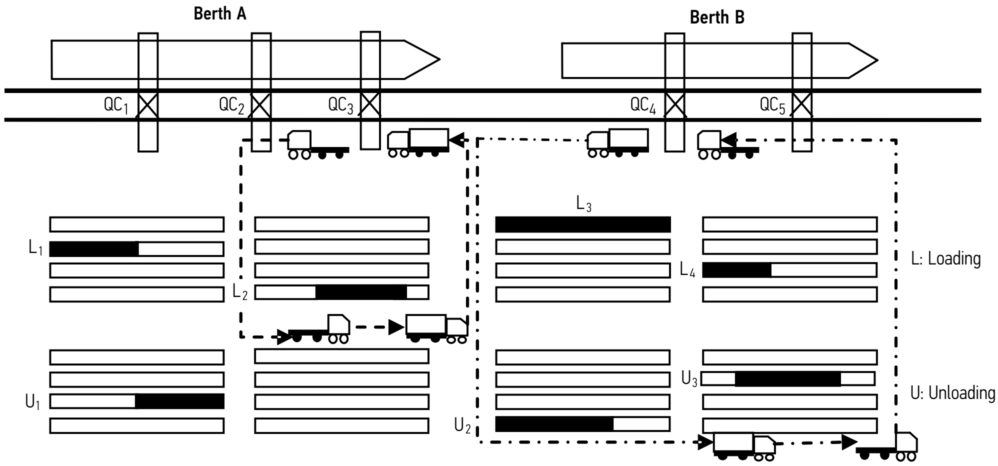

Fig. 1. Process of traditional separate-operation

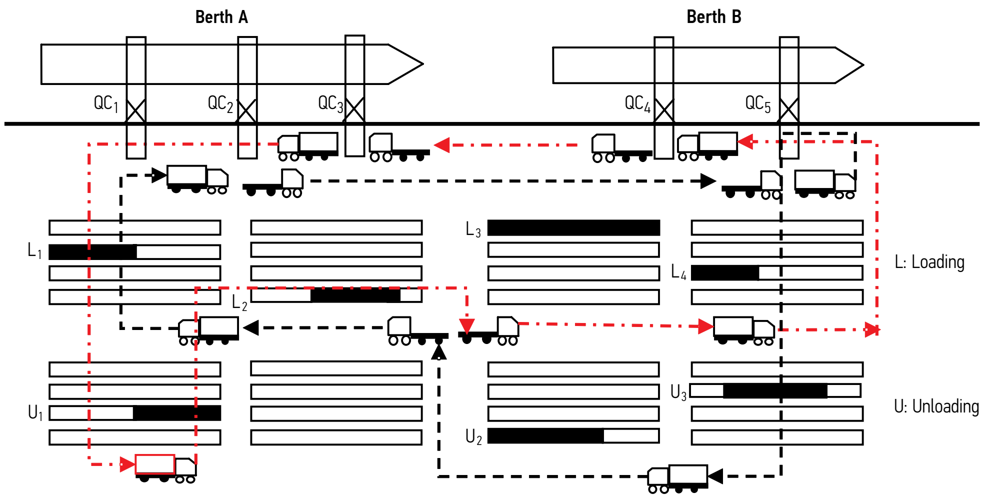

Fig. 2. Process of mix cross-operation

tion cost of container terminals can be presented more close to reality by taking the idle cost and the using cost of terminal equipment into consideration.

By analyzing the operation process of container terminals in mix cross-operation method, it is shown that the main factors which affect the production efficiency and operation cost of container terminals are berth allocation, equipment configuration, trailer routing, idle cost and using cost of equipment. Among them berth allocation is a typical assignment problem (AP), and equipment configuration can be reduced to a multiple knapsack problem (MKP), while trailer routing is modeled on a traveling salesman problem (TSP) basis. Since those issues are interrelated and interacted with each other, the integrating scheduling problem for container terminal operations can be formulated as a mixed integer non-linear programming problem (MINP) with three stages, based respectively on the berth allocation, equipment configuration and trailer routing.

4. Model Formulations

As described above, the integrating scheduling problem for container terminals consists of three sub-problems. The first one is assigning the optimal berths for those ships to be loaded or unloaded in a certain period. The second is determining the optimal number of quay cranes, yard trailers and yard cranes deployed for the set of ships. The last problem is optimizing the routing of yard trailers in the mix cross-operation method. Since there are interrelations and interactions among these sub-problems, the integrating scheduling problem can be modeled at three stages. The optimal model can be developed as follows:

Stage 1:

The berth allocation problem in container terminals is a typical 0–1 assignment problem. Let B denote a set of berths and N denotes a set of ships to be berthed in a certain period. D denotes a set of candidate schemes of berth allocation, $s \in D$ denotes the sth assignment scheme. If the berth allocation plan s is chosen $\rho_s = 1$, and 0, otherwise. Z^s denotes the operation cost of container terminals in allocation plan s. The model can be formulated as follows:

$$\left[AP\right] \min \sum_{s \in D} Z^s \rho_s \; ; \tag{1}$$

$$\text{Subject to } \hat{\sigma}, \hat{S}, \hat{\gamma}^{(p)} \; ; \tag{2}$$

$$\rho_s \in \{0,1\} \; ; \; \forall s \in D \, . \tag{3}$$

Objective function (1) is to minimize the operation cost of container terminals; constraints (2) ensure that only one berth allocation plan is chosen; constraints (3) are simple binary constraints.

Stage 2:

The equipment configuration problem of container terminals is a typical multiple knapsack problem. Given a container terminal, V denotes the set of configuration combination of terminal equipment, $k \in V$ denotes the k-th candidate combination scheme. If the k-th scheme is chosen $\rho_k = 1$, and 0, otherwise. Z^k denotes the operation cost of container terminals in configuration combination plan k. The model can be formulated as follows:

$$\left[MKP\right] \min \sum_{k \in V} Z^k \rho_k \; ; \tag{4}$$

$$\text{Subject to } \sum_{k \in V} \rho_k = 1 \; ; \tag{5}$$

$$\rho_k \in \{0,1\} \; ; \; \forall k \in V \, . \tag{6}$$

Objective function (4) is to minimize the operation cost of container terminals; constraints (5) ensure that only one equipment configuration combination plan is chosen; constraints (3) are simple binary constraints.

Suppose $Z^s = Z^k$, abbreviated to Z, denotes the operation cost of container terminals in a certain berth allocation plan and a certain equipment assignment plan. The operation cost consists of berth using cost, equipment using cost and idle cost. x_i the number of quay cranes assigned for ship i; m_L^i, m_U^i the number of yard cranes assigned for ship i for loading and unloading respectively; $D(\cdot)$ the total travel distance of yard trailers determined by next stage model; T_i the required time of terminal operation for ship i; T_i' the total time for ship i in port; T_i'' the loading and unloading time for ship i; t_p the berthing unproductive time; X_i the maximum number of quay cranes assigned for ship i; M_U, M_L the maximum number of storage blocks for inbound and outbound containers respectively; v_q the operation speed of quay cranes per hour; v_t the running speed of yard trailers per hour; v_g the operation speed of yard cranes per hour; c_b the berth using cost per hour; c_t the operation cost of yard trailers per hour; c_g the operation cost of yard cranes per hour; c_t' the idle cost of yard trailers per hour; $n_b{}^i$ the bay number for ship i; Q_L^i, Q_U^i the number of loading and unloading containers for ship i respectively. The operation cost of container terminals can be formulated as follows:

$$Z = \sum_{i=1}^{N} T_i' c_b + \sum_{i=1}^{N} T_i'' x_i c_q + \frac{D(n)}{v_t} c_t + \sum_{i=1}^{N} T_i'' \left(m_U^i + m_L^i\right) c_g + \sum_{i=1}^{N} T_i'' x_i c_t' / 4 \; ; \tag{7}$$

$$\text{Subject to } x_i \le \frac{n_b^i + 1}{2} \; ; \tag{8}$$

$$x_i \le X_i \; ; \tag{9}$$

$$m_U^i + m_L^i \ge \frac{x_i v_q}{v_g} \; ; \tag{10}$$

$$\max\left(m_U^i\right) \le M_U \; ; \tag{11}$$

$$\max\left(m_L^i\right) \le M_L \; ; \tag{12}$$

$$T_i' \prec T_i \; ; \tag{13}$$

$$T_i' = T_i'' + t_p = \frac{Q_U^i + Q_L^i}{v_q x_i} + t_p \; ; \tag{14}$$

$$x_i , \; m_U^i , \; m_L^i \; \text{ nonnegative integer.} \tag{15}$$

Objective function (7) is to minimize the operation cost of container terminals; constraints (8) ensure that there is at least one bay' space between two quay cranes; constraints (9) guarantee that the number of quay cranes assigned to a specific ship should not exceed its maximum; constraints (10) define the speed relation between quay cranes and yard cranes to prevent quay cranes from waiting for yard trailers; constraints (11) and (12) ensure that the number of storage blocks is equal to or less than its maximum; constraints (13) is the time requirement for ships in port; constraints (14) give the calculation of port time for ships; constraints (15) are simple value constraints.

Stage 3:

The trailer routing problem of container terminals is a typical traveling salesman problem. Yard trailers can be divided into two groups based on their routing in the mix cross-operation. One consists of yard trailers performing cross operation whose moving path is as follows: a certain unloading quay crane for ship i → a certain storage block for inbound containers of ship i → a certain storage block for outbound containers of ship j → a certain loading quay crane for ship j. The other is for yard trailers performing mix operation whose moving path is as follows: a certain unloading quay crane for ship i → a certain storage block for inbound containers of ship i → a certain storage block for outbound containers of ship i → a certain unloading quay crane for ship i. n_{ij}, n_i the number of yard trailers performing cross operation and mix operation respectively; c_{ij}, c_i the average number of round trips for yard trailers performing cross operation and mix operation respectively; D_{uvst} the travel distance of yard trailers performing cross operation; D_{hklm} the travel distance of yard trailers performing mix operation; d_{ij} the distance between two berths; M the maximum of yard trailers assigned to ships in container terminals. The model can be formulated as follows:

$$\left[TSP\right]\min D(n) = \sum_{u=1}^{x_i}\sum_{v=1}^{m_U^i}\sum_{s=1}^{m_L^j}\sum_{t=1}^{x_j}\left(D_{uvst}+d_{ij}\right)n_{ij}c_{ij} + \sum_{h=1}^{x_i}\sum_{k=1}^{m_U^i}\sum_{l=1}^{m_L^i}\sum_{m=1}^{x_i} D_{hklm}n_i c_i\,; \quad (16)$$

$$\text{Subject to } 2n_i c_i + 2n_{ji}c_{ji} \geq Q_L^i\,; \quad (17)$$

$$2n_i c_i + 2n_{ij}c_{ij} \geq Q_U^i\,; \quad (18)$$

$$\frac{D_{uvst}+d_{ij}}{n_{ij}v_t} \leq \min\left(\frac{4}{v_q},\frac{2}{v_g}\right); \quad (19)$$

$$\frac{D_{hklm}}{n_i v_t} \leq \min\left(\frac{4}{v_q},\frac{2}{v_g}\right); \quad (20)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} n_{ij}/2 + \sum_{i=1}^{N} n_i \leq M\,; \quad (21)$$

$$n_{ij}, n_i, c_{ij}, c_i \text{ nonnegative integer.} \quad (22)$$

Objective function (16) is to minimize the total travel distance of yard trailers; constraints (17) and (18) guarantee that all the loading and unloading containers for ship i can be delivered by yard trailers; constraints (19) and (20) ensure that quay cranes and yard cranes will not wait yard trailers for operation; constraints (21) restrict the number of yard trailers assigned to a specific ship to its maximum; constraints (22) are simple value constraints.

5. Solution Algorithms

To reflect the interrelation among the three stage models, a bi-level genetic algorithm (GA) is designed. The upper level genetic algorithm is used for searching the combination of equipment configuration in container terminals and a lower level genetic algorithm is applied for searching a minimum travel distance of yard trailers. Based on the specific combination of equipment configuration by the upper level, the lower level algorithm optimizes the trailer routing. Then the outcome of the lower level is feedback to the upper level to calculate the objective function of the lower level algorithm. The process is shown in Fig. 3.

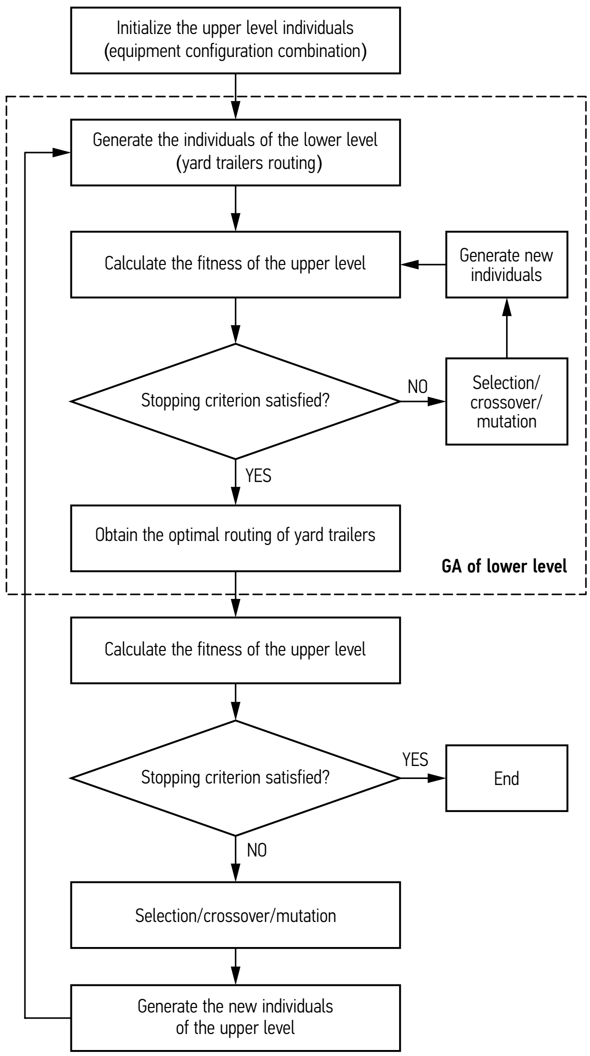

Fig. 3. Bi-level genetic algorithm

Representation of chromosomes

The chromosomes of the upper level algorithm are represented as decimal bit string in double structure. The length of a chromosome equals to the number of terminal equipment assigned to the berthing ships. Suppose there are ships A and B to be berthed at a certain time, from the beginning till the end, the figures of a chromosome represent the berth number of ship A and ship B, the number of quay cranes for ships A and B, the number of storage blocks for inbound containers and outbound containers to ships A and B, the number of yard trailers for ship A's unloading and ship B's loading operation, the number of yard trailers for ships A and B in the mix operation, the number of yard trailers for ship B's unloading and ship A's loading operation. The representation of chromosomes is formed by variable code and calibration code. $s(i)$ in the upper line is the calibration code of variable x_j, $s(i) = j$ and the figure in the lower line is the value of x_j. The value of calibration code is the maximum of different terminal equipment. The chromosome is verified infeasible if $x_j > s(i)$ and a new chromosome is generated. Fig. 4 shows a feasible chromosome in which the value of each variable code is less then its corresponding calibration code.

The chromosomes of the lower level are represented as character strings. Each chromosome denotes a trailer routing and each integer in the chromosome denotes the location number on the route. The length of a chromosome equals to 16 where loci 1 to 4 represent the route of yard trailers for ship A's unloading and ship B's loading operation, loci 5 to 8 represent the route of yard trailers for ship A in the mix operation, loci 9 to 12 represent the route of yard trailers for ship B in the mix operation, loci 13 to 16 represent the route of yard trailers for ship B's unloading and ship A's loading operation. Fig. 5 shows a feasible chromosome.

4	4	5	5	9	8	9	8	9	9	9	9
2	3	2	3	6	4	7	4	4	4	6	8

Fig. 4. Representation of upper-level chromosome

2	4	3	1	2	3	1	2	1	3	4	3	1	2	3	3

Fig. 5. Representation of lower-level chromosome

Initialization

The initialization method of the upper level algorithm is based on selecting the combination of equipment configuration in container terminals. The initialization method of the lower level algorithm is randomly selected routing of yard trailers. $M1$ and $M2$ individuals are generated for the upper and lower levels.

Calculation of the fitness value

Minimization is the problem of the paper, thus the smaller is the objective function value the higher the fitness value must be. Therefore, the fitness function of the upper and lower levels can be defined as equations (23) and (24):

$$F_1(x) = \begin{cases} \dfrac{1}{Z - Z_{\min}}, & Z \geq Z_{\min}; \\ M, & Z \prec Z_{\min}, \end{cases} \tag{23}$$

where: M is a sufficiently large number and Z_{min} is the current optimal objective function value.

$$F_2(x) = \begin{cases} \dfrac{1}{D - D_{\min}}, & D \geq D_{\min}; \\ M, & D \prec D_{\min}, \end{cases} \tag{24}$$

where: M is a sufficiently large number and D_{min} is the current optimal objective function value.

The selection method for M: M is close to the reciprocal of the difference between the minimum and the second minimum objective function value to avoid precociousness in the initial iteration and the gap is gradually expanded in the later iteration.

Reproduction

Reproduction is a process in which individual chromosomes are copied according to their scaled fitness function values. Chromosomes with a higher fitness value would be selected with higher probabilities. Selection probability can be expressed in the following way:

$$p(x_i) = \frac{F(x_i)}{\sum_{i=1}^{M} F(x_i)}, \ i = 1, 2, ..., M, \tag{25}$$

where: $p(x_i)$ is defined as the selection rate and the roulette-wheel selection method is adopted to choose two parents to apply the crossover operation.

Crossover operation

Based on the characteristics of chromosome representation, the process of crossover for upper and lower GA is as follows: generating a 0–1 vector randomly of the same length with chromosomes and swapping the genes of two parents in the locus where 1 is represented (Fig. 6).

Vector:	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**1**	**0**
Parent A:	2	4	3	1	2	3	5	3	1	3	2	4
Parent B:	3	2	4	2	3	1	2	4	5	2	4	1
Offsping A:	2	2	4	1	2	1	2	3	5	3	2	1
Offsping B:	3	4	3	2	3	3	5	4	1	2	4	4

Fig. 6. Crossover operator of upper-level genetic algorithm

Mutation

Mutation introduces random changes in the chromosomes by altering the value to a gene with user-specified probability P_m called the mutation rate. The mutation method of the upper and lower levels generates two random numbers between 1 and the length of chromosomes first and exchanges the values of the gene at these two positions second.

Stopping criterion

Having reached the pre-determined stopping generations, the algorithm stops.

6. Numerical Tests

Suppose there are four berths in a certain container terminal and ships *A*, *B*, *C* and *D* to be berthed in a certain time. The quantity of loading and unloading containers for ship *A* is 700 TEU and 640 TEU respectively, 500 TEU and 430 TEU for ship *B* respectively, 400 TEU and 320 TEU for ship *C* respectively, 360 TEU and 400 TEU for ship *D* respectively. The layout structure of the container terminal is shown in Fig. 7. Table 1 shows the parameters related to berths and ships. Based on these data, the decision variables of the optimization models can be solved via MATLAB software.

The parameters of bi-level genetic algorithm are set as follows: $p_c = 0.9$, $p_m = 0.08$, $maxgen = 200$. Via MATLAB software, it is solved that berth number for ship *A*, *B*, *C*, *D* is 3, 2, 1, 4 respectively, while other variables are as follows: $x_A = 4$, $x_B = 4$, $x_C = 3$, $x_D = 3$, $m_U^A = 4(U_3, U_4, U_6, U_8)$, $m_L^A = 4(L_2, L_3, L_6, L_7)$, $m_U^B = 4(U_2, U_4, U_5, U_7)$, $m_L^B = 4(L_1, L_3, L_4, L_5)$, $m_U^C = 2(U_1, U_2)$, $m_L^C = 2(L_1, L_4)$, $m_U^D = 2(U_5, U_7)$, $m_L^D = 2(L_6, L_8)$, $n_A = 6$, $n_B = 4$, $n_C = 4$, $n_D = 5$, $n_{AB} = 7$, $n_{BA} = 5$, $n_{BC} = 5$, $n_{DA} = 4$, $D(n)_{min} = 14374.8$km, $Z_{min} = 196052.6$ ¥. The optimal routing of yard trailers is shown in Table 2.

Table 3 shows the assignment plan and travel distance of yard trailers in the traditional separate operation. The number of yard trailers for ship *A*'s loading and unloading operation is 15 and 16 respectively, 13 and 19 for ship *B*, 8 and 7 for ship *C*, 7 and 8 for ship *D*. Compared to the mix cross-operation, the traditional separate operation increases the assignment number of yard trailers by 27.5% and the total travel distance by 21.1%.

Table 4 shows the comparison between the integrating scheduling method and the separate scheduling method for container terminals. In the separate scheduling method, different terminal equipment is assigned separately. The berth allocation is determined according to the ship's location and the idle berths, while equipment configuration is optimized according to their corresponding operation efficiency and the requirement for ship berthing time on port.

It is shown in Table 4 that the integrating scheduling method in container terminal operation can decrease the travel distance of yard trailers by 17.4% and reduce the operation cost of container terminals by 4.6%. Based on the results of the numerical tests, it can be concluded that the integrating scheduling method can reduce the operation cost significantly and the mix cross-operation method can decrease the empty travel distance of yard trailers to a great degree.

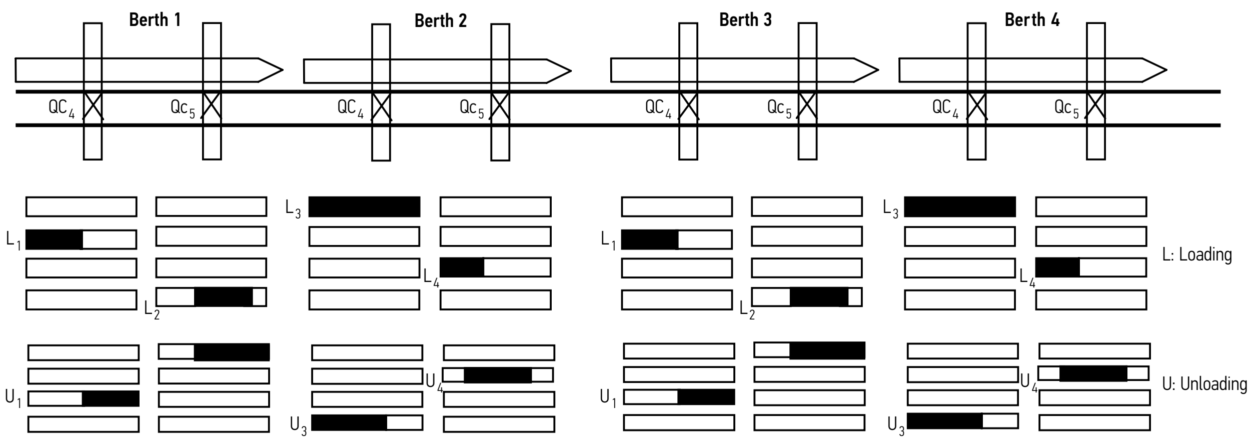

Fig. 7. Layout structure of container terminals

Table 1. Related parameter data

Parameters	Units	Values	Parameters	Units	Values
v_t	km/h	18	X_A	set	4
v_q	TEU/h	40	X_B	set	4
v_g	TEU/h	20	X_C	set	3
c_b	¥/h	1600	X_D	set	3
c_t	¥/set·h	52	M_U	set	8
c_t'	¥/set·h	30	M_L	set	8
c_g	¥/set·h	169	N	set	40
$n_b{}^A$	bay	10	T_A	h	12
$n_b{}^B$	bay	8	T_B	h	12
$n_b{}^C$	bay	6	t_p	h	2
$n_b{}^D$	bay	6	c_q	¥/set·h	882

Table 2. Optimized routes of yard trailers

Delivery routes	Routes length	Container quantity
Berth *A* QC 1 → Inbound block 8 → Outbound block 3 → Berth *B* QC 3	11.5	100
Berth *A* QC 2 → Inbound block 3 → Outbound block 4 → Berth *A* QC 2	9.8	156
Berth *A* QC 3 → Inbound block 6 → Outbound block 3 → Berth *A* QC 3	7.7	204
Berth *A* QC 4 → Inbound block 4 → Outbound block 1 → Berth *B* QC 4	11.9	96
Berth *B* QC 1 → Inbound block 2 → Outbound block 4 → Berth *B* QC 1	5.6	170
Berth *B* QC 2 → Inbound block 4 → Outbound block 5 → Berth *B* QC 2	6.3	150
Berth *B* QC 3 → Inbound block 5 → Outbound block 6 → Berth *A* QC 4	8.1	192
Berth *B* QC 4 → Inbound block 7 → Outbound block 7 → Berth *A* QC 1	9.2	168
Berth *B* QC 4 → Inbound block 4 → Outbound block 1 → Berth *C* QC 2	8.2	80
Berth *C* QC 1 → Inbound block 1 → Outbound block 1 → Berth *C* QC 1	3.5	220
Berth *C* QC 3 → Inbound block 2 → Outbound block 4 → Berth C QC 3	7.1	100
Berth *D* QC 1 → Inbound block 7 → Outbound block 6 → Berth *A* QC 4	6.3	40
Berth *D* QC 2 → Inbound block 5 → Outbound block 8 → Berth *D* QC 2	8.5	160
Berth *D* QC 3 → Inbound block 7 → Outbound block 6 → Berth *D* QC 3	5.9	200

Table 3. Configuration and routing of YTs for loading and unloading separate-operations

Delivery routes	YT number	Routes length	Container quantity
Berth *A* QC 1 → Inbound block 3	9	7.9	109
Berth *A* QC 2 → Inbound block 4	5	4.2	204
Berth *A* QC 3 → Inbound block 6	5	3.9	220
Berth *A* QC 4 → Inbound block 8	9	8.1	107
Outbound block 2 → Berth *A* QC 1	11	9.3	105
Outbound block 3 → Berth *A* QC 2	8	7.2	135
Outbound block 6 → Berth *A* QC 3	4	3.5	279
Outbound block 7 → Berth *A* QC 4	6	5.4	181
Berth *B* QC 1 → Inbound block 2	10	8.3	88
Berth *B* QC 2 → Inbound block 4	5	4.1	179
Berth *B* QC 3 → Inbound block 5	9	7.9	93
Berth *B* QC 4 → Inbound block 7	12	10.5	70
Outbound block 1 → Berth *B* QC 1	8	7.2	80
Outbound block 3 → Berth *B* QC 2	4	3.3	175
Outbound block 4 → Berth *B* QC 3	4	3.4	169
Outbound block 5 → Berth *B* QC 4	9	7.6	76
Berth *C* QC 1 → Inbound block 1	2	2.1	120
Berth *C* QC 2 → Inbound block 2	2	3.5	110
Berth *C* QC 3→ Inbound block 2	3	4.7	90
Outbound block 1 → Berth *C* QC 1	2	2.2	150
Outbound block 1 → Berth *C* QC 2	2	2.3	150
Outbound block 4 → Berth *C* QC 3	4	6.9	100
Berth *D* QC 1 → Inbound block 7	2	3.4	160
Berth *D* QC 2 → Inbound block 7	2	3.6	150
Berth *D* QC 3 → Inbound block 5	4	7.2	90
Outbound block 8 → Berth *D* QC 1	2	2.4	130
Outbound block 8 → Berth *D* QC 2	2	2.3	140
Outbound block 6 → Berth *D* QC 3	3	4.3	90

Table 4. Comparison of scheduling modes for container terminals

Items	Separate scheduling	Integrating scheduling
Berth number for ship *A*	1	3
Quay crane number for ship *A*	4	4
Inbound block number for ship *A*	4	4
Outbound block number for ship *A*	4	4
Berth number for ship *B*	2	2
Quay crane number for ship *B*	3	4
Inbound block number for ship *B*	4	4
Outbound block number for ship *B*	4	4
Berth number for ship *C*	3	1
Quay crane number for ship *C*	3	3
Inbound block number for ship *C*	2	2
Outbound block number for ship *C*	2	2
Berth number for ship *D*	4	4
Quay crane number for ship *D*	3	3
Inbound block number for ship *D*	2	2
Outbound block number for ship *D*	2	2
Yard trailers number	51	40
Total travel distance of yard trailers	17392.7	14374.8
Operation cost of container terminals	20507.1	196052.6

7. Conclusions

1. This paper applied the mix cross-operation method to optimize the container terminal operation problem based on the integrating scheduling approach. An integrated optimization model is developed to determine the three key interrelated and interacted issues, i.e. berth allocation, equipment configuration, and trailer routing in the mix cross-operation method. A

bi-level genetic algorithm is designed for the model and numerical tests are used to test the proposed model and algorithm.

2. Numerical experiments indicates that the integrating scheduling method in the mix cross-operation can reduce the operation cost of container terminals and decrease the empty travel distance of yard trailers.
3. Ships to be berthed at the same time are supposed in this paper, while in practice, different ship arrives in the terminal at different time. Thus a mitigation of this restriction is an interesting topic for future research.

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