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Genetic mechanism-based coupling algorithm for solving coordinated scheduling problems of yard systems in container terminals

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ABSTRACT

This study develops models and methods utilized for solving the coordination scheduling problem in the yard of a container terminal. Based on the information shared by the yard storage subsystem and the YC scheduling subsystem, and the interaction between these subsystems, a coordination scheduling model, which is composed of a storage subsystem model, a YC scheduling subsystem and a coordinate controller model, is developed. A coupling algorithm, which is based on a genetic mechanism, is developed to solve the coordination scheduling problem. The algorithm adopts the genetic selection, crossover and mutation operations to adjust the yard storage plan and the YC scheduling plan. The performance of the coordination scheduling model and that of the proposed coupling algorithm are confirmed with reference to a numerical example.

1. Introduction

With the rapid increase in economic globalization and import–export trading, China has become the most important supplier of containers worldwide. To meet the increasing demand for containers, while enabling shipping companies to continue to provide the required high levels of service, a highly efficient container transportation system must be established and the efficiency of internal logistical operations at container terminals improved. The transportation bottleneck at a container terminal used to be sea side transfer. However, increases in efficiency due to quay crane (QC) innovation and the realization of simultaneous loading-and-unloading of yard trucks (YT) have eliminated this bottleneck. More recently, QCs have commonly waited for YTs, shifting the bottleneck to yard storage and yard crane (YC) operations. This study concerns the yard storage problem, the YC scheduling problem and the problem of the coordination for the two, which are all critical problems in a container yard that have been studied by several experts.

Many approaches to planning yard storage have been proposed. Zhang, Wan, Liu, and Linn (2003) were the first to formulate the storage space allocation problem (SSAP). Mohammad, Nima, and Nikbakhsh (2009) extended the SSAP such that the types of container affect decisions concerning the allocation of containers to blocks. Kim and Park (2003) formulated a mixed-integer linear programming model to allocate storage space for out-bound containers.

Numerous research papers have addressed the modeling of yard crane scheduling (YCS). Zhang, Wan, Liu, and Linn (2002) addressed the crane deployment problem, whose objective is to find the times and routes of crane movements among blocks that minimize the total delayed workload. Bish (2003) developed a heuristic algorithm that was based on formulating the yard scheduling problem as a transshipment problem. Huang, Liang, and Yang (2009) developed an optimum route method that is based on a genetic algorithm and satisfies such criteria as length, smoothness and clearance between YCs. Li and Han (2005) constructed a non-linear multi-objective programming model to solve the problem of dynamic crane deployment using a function that minimized the time of uncompleted workloads and the time wasted in operation.

Many efforts have been made to solving the SSAP and YCS independently of each other. However, an integrated approach to modeling these two systems is appropriate, given the relationship that exists between them. Kim and Kim (2002) developed a cost model that comprised of the space cost, the investment cost of transfer cranes, and the operating cost of transfer cranes and trucks. Lin, Gen, and Wang (2009) formulated an integrated

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multi-stage logistics network model that took into account the logistics of direct shipment and direct delivery and the associated inventory; they also presented an effective hybrid evolutionary algorithm (hEA) to solve this problem.

This paper studies the coordination scheduling problem for yard subsystems at a container terminal and develops a coordination scheduling model that is based on the interaction and sharing of information between the subsystems. The model is composed of a storage subsystem model, a YC scheduling subsystem model and a coordinated controller model. To apply the model, a coupling algorithm with global searching and probability searching is used. In the proposed coupling algorithm, a chromosome represents a quantity and initial positions of YCs, and after a series crossing operations and mutation operations, an optimal or best solution is obtained. Finally, computational experiments are performed to demonstrate the effectiveness of the proposed coupling algorithm.

2. Description of problem

2.1. Storage space allocation problem

In this paper, a vessel that is served by a quay crane is said to have a working line; a vessel that is served by two quay cranes is said to have two working lines, and so on. To minimize the cost and maximize the effectiveness of container operations, the number of working lines should be optimized. This optimization leads to the working line assignment problem and scheduling problem. In the daily operations of a container terminal, the number of working lines depend on the allocation of berths and the number of loaded/unloaded containers. Working line scheduling is the allocation of loading/unloading jobs to quay cranes to minimize time and cost. Working line scheduling systems are playing an increasingly important role at container terminals. The input of such a system is the number of loading/unloading containers and the availability of quay cranes, and its output is a scheduling schema that contains a series of job sets for each quay crane. The complex relationships between the working lines and the allocation of inbound/outbound yard space require a sophisticated dispatcher. With respect to the operating procedures at a container terminal, obeying a storage plan without considering the working line may lead to chaos when multi-working lines are used to perform loading/unloading containers simultaneously. First, outbound containers will been operated by a single working line may be dispersed to different blocks, making YC scheduling more difficult because of the reshuffle. Second, inbound containers from different working lines may be allocated in the same block, potentially leading to the blocking of YTs. As stated above, the relationship between the working lines and the allocation of container yard space resources in a container terminal is an important topic of research.

2.2. YC scheduling problem

In this study, a yard crane (YC) can move from one yard zone to another, supporting the handling efficiency in yard. Since YCs are bulky and slow, effective scheduling is essential to reducing the waiting time of trucks in the yard, by coordinating the yard cranes with the working lines. To fully utilize the YCs and to overcome the workload imbalance among blocks, a YC may have to move from one block to another or from one yard zone to another. The allocation and the movement of YCs among blocks or yard zones is called YC scheduling herein. Since moving a YC from one yard zone to another takes a long time, the need for such movement should be eliminated. Since one YC cannot move through another, the possibility of YC–YC collisions must be taken into consideration.

2.3. Coordinated relationship between storage subsystem and YC scheduling subsystem

The storage subsystem and the YC scheduling subsystem perform important functions at a container terminal. A poor storage plan may result in the wastage of loading/unloading resources, and unreasonable allocation of loading/unloading resources may also cause a delay of vessels. Under such circumstances, every independent subsystem has difficultly in following the coordination plan. Accordingly, coordinating the two subsystems and sharing information between them is very important. Based on the above analysis, an optimization model of a yard system at a container terminal is developed based on the multidisciplinary variable coupling design optimization method. In this method, two mathematic model are established to represent storage subsystem and YC scheduling subsystem respectively and a coordinating controller is responsible for optimizing the whole yard system by the sharing of information between the storage subsystem and the YC scheduling subsystem.

3. Coordinated model of yard system

In solving the coordinated planning problem of a container yard, the effective use of yard resources and integrating the storage plan with the YC scheduling plan can globally optimize the yard system through the sharing of information. The sharing of information causes each subsystem to understand the goals of all subsystems, and enables each subsystem to be optimized in a manner that does not detrimentally affect another subsystem. The sharing of information among subsystems is dynamic, and so may cause non-linearities, time-variability and imbalance in multi-system coordination.

Owing to the complexity of the coordinated planning problem of a container yard, finding the global optimum using a traditional optimization method is difficult. This work develops a coordination planning method that is based on a genetic algorithm, employing the number of YCs and the initial position of each to code the genes. Although genetic algorithms have been used to solve particular systems used in container terminals in some studies, these studies have focused on the separate subsystems but not the overall system. In the problem of coordinated planning, the optimal solution for any subsystem is not the global optimum of the whole system. However, the coordinated model that is proposed in this paper can solve the global problem effectively.

3.1. Assumptions and framework of coordinated model of yard system

Assumptions of the model are presented as follows:

(1) The unloading and loading jobs of each working line of each vessel are known.
(2) The number of YCs and their initial positions are decision variables.
(3) The objective of the storage subsystem is to minimize the sum of distance moved by the YTs, and that of the YC scheduling subsystem is to minimize the maximum operating time.
(4) Different types of containers can be stored in a single block.
(5) To reduce the complexity of the problem, re-handling is neglected.

The framework of coordinated model of yard system are presented as follows:

The framework of the coordinated model of a container yard, presented in Fig. 1, is composed a storage subsystem and a YC

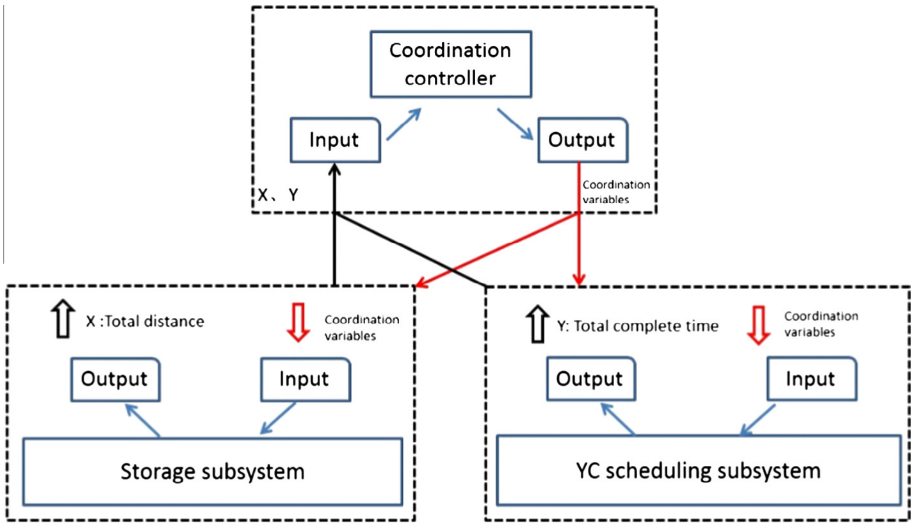

Fig. 1. Framework of coordinated model of yard.

scheduling subsystem. The determination of the coordination variables is important in solving the problem of the coordinated system that is considered herein. Since the scheduling and assignation of YCs depend on very many factors, and are crucial to the operations in a container yard, the scheduling and assignation of YCs will affect the handing efficiency and quality of service of the container yard as a whole, which are generally carried out by staff based on their experience. In this work, the number of YCs and their initial positions in a planning period are coordination variables, which are shared by the storage subsystem and the YC scheduling subsystem.

3.2. Model of storage subsystem

The storage planning model determines the storage strategy. The input of the storage planning model is the coordination variable and its output is the storage plan. Fig. 2 presents the model of the storage subsystem.

Sets

V set of vessels waiting for processing
W_j set of working lines of handling vessel, $j \in V$
B set of blocks in the yard

Parameters

N^U_{jp} number of unloading containers from vessel j handled by working line p
N^L_{jp} number of loading containers from vessel j handled by working line p
C_i maximum stacking capacity of block i
E_{jp} maximum number of blocks allocated to all handled containers of vessel j handled by working line p
F_{jp} minimum number of blocks allocated to all handled containers of vessel j handled by working line p
d_{ij} distance between block i and vessel j
M an arbitrarily large number

Decision variables

x^U_{ijp} the number of unloading containers of vessel j handled by working line p and stored in block i
x^L_{ijp} the number of loading containers of vessel j handled by working line p and stored in block i
s^U_{ijp} =1 if more than one unloading container of vessel j handled by working line p and stored in block i; otherwise 0
s^L_{ijp} =1 if more than one loading container of vessel j handled by working line p and stored in block i; otherwise 0

Objective function

$$\min \sum_{i\in B}\sum_{j\in V} d_{ij}\sum_{q\in Q_j}\sum_{t\in T}\left(x^U_{ijp}+x^L_{ijp}\right) \tag{1}$$

subject to :

$$\sum_{i\in B} x^U_{jp} = N^U_{jp},\ \forall j\in V,\ p\in W_j \tag{2}$$

$$\sum_{i\in B} x^L_{jp} = N^L_{jp},\ \forall j\in V,\ p\in W_j \tag{3}$$

$$\sum_{j\in V}\sum_{P\in W_j}\left(x^U_{ijp}+x^L_{ijp}\right) \leqslant C_i,\ \forall i\in B \tag{4}$$

$$0 \leqslant x^U_{ijp} \leqslant M\cdot s^U_{ijp},\ \forall i\in B,\ j\in V,\ p\in W_j \tag{5}$$

$$0 \leqslant x^L_{ijp} \leqslant M\cdot s^L_{ijp},\ \forall i\in B,\ j\in V,\ p\in W_j \tag{6}$$

$$\sum_{i\in V}\left(s^U_{ijp}+s^L_{ijp}\right) \geqslant F_{jp},\ \forall j\in V,\ p\in W_j \tag{7}$$

$$\sum_{i\in V}\left(s^U_{ijp}+s^L_{ijp}\right) \leqslant E_{jp},\ \forall j\in V,\ p\in W_j \tag{8}$$

$$x^U_{ijp} \geqslant 0,\ \forall i\in B,\ j\in V,\ p\in W_j \tag{9}$$

$$x^L_{ijp} \geqslant 0,\ \forall i\in B,\ j\in V,\ p\in W_j \tag{10}$$

$$s^U_{ijp} = 0,\ 1,\ \forall i\in B,\ j\in V,\ p\in W_j \tag{11}$$

$$s^L_{ijp} = 0,\ 1,\ \forall i\in B,\ j\in V,\ p\in W_j \tag{12}$$

The objective function minimizes the total distance traveled by the containers from vessel j to its destination blocks. Constraints (2) and (3) ensure that all of the unloaded and loaded containers of each vessel are handled. Constraint (4) ensures that the storage capacity of each yard block is satisfied. Constraints (5) and (6) present the relationship between x_{ijp} and s_{ijp} and also non-negativity constraints for x_{ijp}. Constraints (7) and (8) limit the number of blocks that is allocated to each working line of each vessel. Finally, constraints (9)–(12) respectively define the integrity and non-negativity requirements.

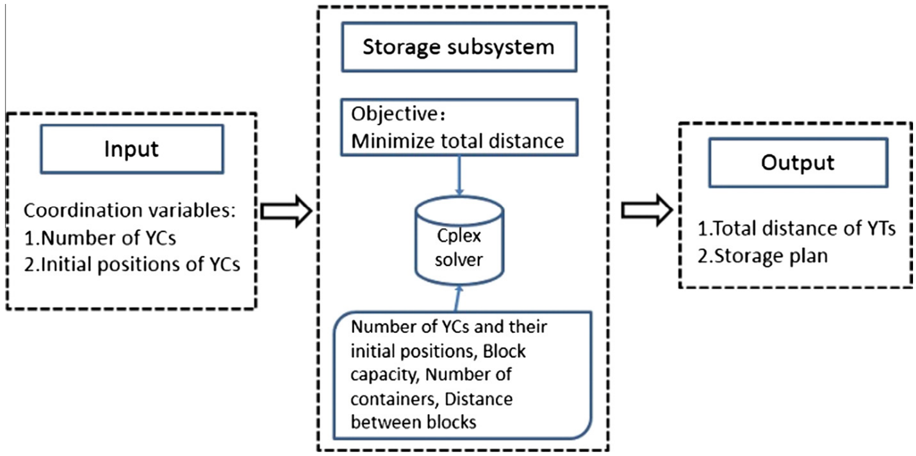

Fig. 2. Model of storage subsystem.

3.3. Model of YC scheduling subsystem

The input to the YC scheduling subsystem are a coordination variable and the containers number of each set of storage jobs, and its output is the YC scheduling schema. The value of the objective function is sent to the coordination controller as feedback. Fig. 3 shows the model of the YC scheduling subsystem.

Sets

G	set of yard cranes
M	set of jobs
B	set of yard blocks

Parameters

t_m	the operation time of job m
A_m	the arrive order of job m
p_m	the block of job m
T_{ij}	the moving time of yard crane to move between block i and block j

Decision variables

x_{gmo}	=1 if job m is assigned as the o-th job of yard crane g; otherwise 0

Objective function:

$$\min\max\left\{\sum_{m\in M}\sum_{k\in M}\sum_{o\in M}T_{p_m p_k}x_{gmo}x_{gk(o+1)}+\sum_{o\in M}\sum_{m\in M}t_m x_{gmo}\right\} \quad (13)$$

$$\text{subject to}: \sum_{g\in G}\sum_{o\in M}x_{gmo}=1,\ \forall m\in M \quad (14)$$

$$\sum_{m\in M}x_{gmo}\leqslant 1,\ \forall g\in G,\ o\in M \quad (15)$$

$$\sum_{m\in M}x_{gmo}\leqslant \sum_{m\in M}x_{gmo+1},\ \forall g\in G,\ o\in M \quad (16)$$

$$\sum_{m\in M}A_m x_{gmo}\leqslant \sum_{k\in M}A_k x_{gk(o+1)},\ \forall g\in G,\ o\in M \quad (17)$$

$$x_{gmo}=0,\ 1,\ \forall g\in G,\ m\in M,\ o\in M \quad (18)$$

The objective of the problem (13) is to minmax the total time taken by each yard crane to complete all jobs. Constraints (14) ensure that each job should be assigned to one yard query. Constraints (15) ensure that a yard crane should perform no more than one job at a time. Constraints (16) ensure that a yard crane handles its jobs in order, so if no job is assigned to the o-th task of a yard crane, then no job should be assigned to $(o + 1)$-th task. Constraints (17) ensure that the yard crane obeys the first-come-first-served rule. Constraint (18) define the integrity requirement.

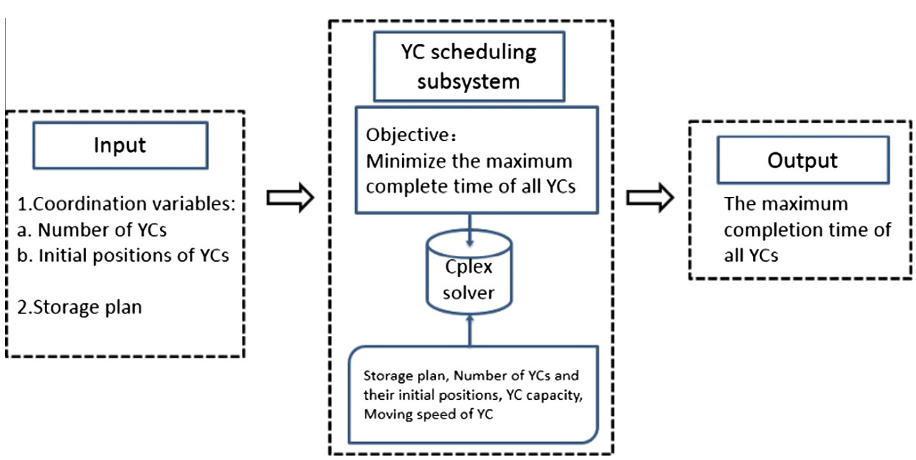

Fig. 3. Model of YC scheduling subsystem.

Re-modeling of objective function 13

$$\min\ y \tag{19}$$

$$z_{gmko} \leqslant x_{gmo},\ \forall g \in G,\ k \in M,\ m \in M,\ o \in M \tag{20}$$

$$z_{gmko} \leqslant x_{gk(o+1)},\ \forall g \in G,\ k \in M,\ m \in M,\ o \in M \tag{21}$$

$$z_{gmko} \geqslant x_{gmo} + x_{gk(o+1)} - 1,\ \forall g \in G,\ k \in M,\ m \in M,\ o \in M \tag{22}$$

$$\sum_{m\in M}\sum_{k\in M}\sum_{o\in M} T_{p_m p_k} z_{gmko} + \sum_{o\in M}\sum_{m\in M} t_m x_{gmo} \leqslant y,\ \forall g \in G \tag{23}$$

It is shown that the objective function is non-linear. In order to linearize the formulation, a decision variable y is introduced to represent the maximum value of the object, which is ensured by Constraints (20)–(23). Formula (19) is the transformed objective function.

3.4. Model of coordination controller

In the process of coordination, the coordination controller balances the objective of storage subsystem with the objective of YC scheduling subsystem by executing a coordinating algorithm. The global objective of the yard system is the sum of the objective value of the storage subsystem and the objective value of the yard crane scheduling subsystem. Fig. 4 presents the model of the coordination controller.

4. Algorithm to apply coordinated model

A coupling algorithm that is based on the genetic mechanism is proposed to solve the coordination scheduling problem in the yard of a container terminal.

4.1. Framework of algorithm

A genetic mechanism is used to find the global optimum value of yard system. Under the premise of obtaining the objective of subsystems, the global optimal value will be got through iteratively searching. Fig. 5 presents the framework of the algorithm.

4.2. Process of solving

First, the encoding and fitness function of the chromosomes should be established. Then, the initial population is generated. Finally, after iterative crossover and mutation operations, the global optimal solution is obtained.

Main parameters are presented as follows:

In the algorithm that is proposed in this paper, the number of YCs and their initial positions are coordination variables. The algorithm uses the genetic selection, crossover and mutation

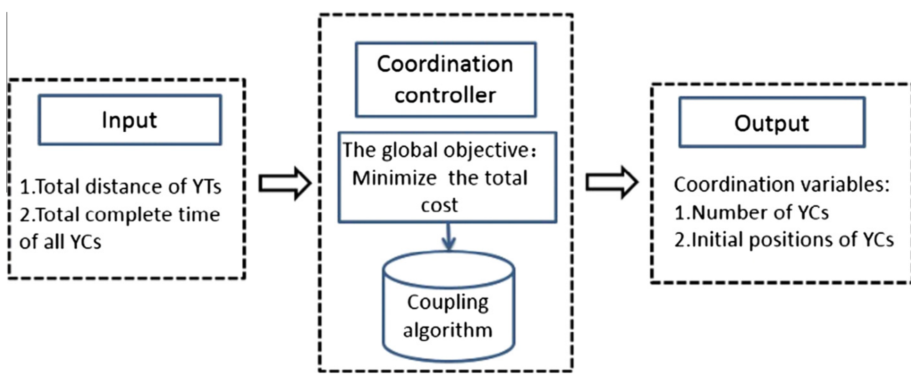

Fig. 4. Model of coordination controller.

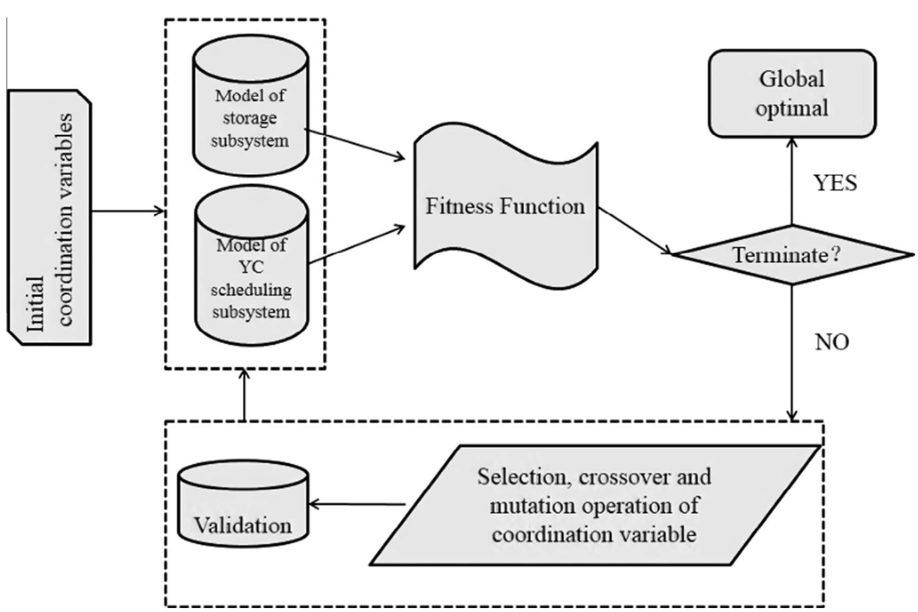

Fig. 5. Framework of algorithm.

	number of YCs	YC No.x											
		1	2	3	4	5	6	7	8	9	10	11	12
chromosome	9	5	12	6	14	3	8	14	12	1	0	0	0

Fig. 6. Sample chromosome.

mechanism for adjusting the plan. With respect to encoding, the YC is the crucial facility at a container terminal and it influences the handling efficiency and service quality of the whole terminal. In the chromosome, the first bit represents the number of YCs and the other bits represent the initial block of each YC. Fig. 6 presents a sample chromosome.

This chromosome means that the terminal manger should provide nine yard cranes to perform the jobs and the initial position of YC No. 1 is block 5 and that of YC No. 2 is block 12, and so on.

A fitness function is used to evaluate the performance of every chromosome, as follows.

$$fitness = \alpha \cdot C_{\text{storage}} + \beta \cdot C_{\text{YC}}$$

$$C_{\text{storage}} = \frac{D_{\text{storage}}}{N_{\text{truck}} V_{\text{truck}}}$$

where $C_{storage}$ denotes the transformed objective of the yard storage model; $D_{storage}$ is the minimum distance moved by the yard trucks; N_{truck} represents the number of yard trucks; V_{truck} is the velocity of

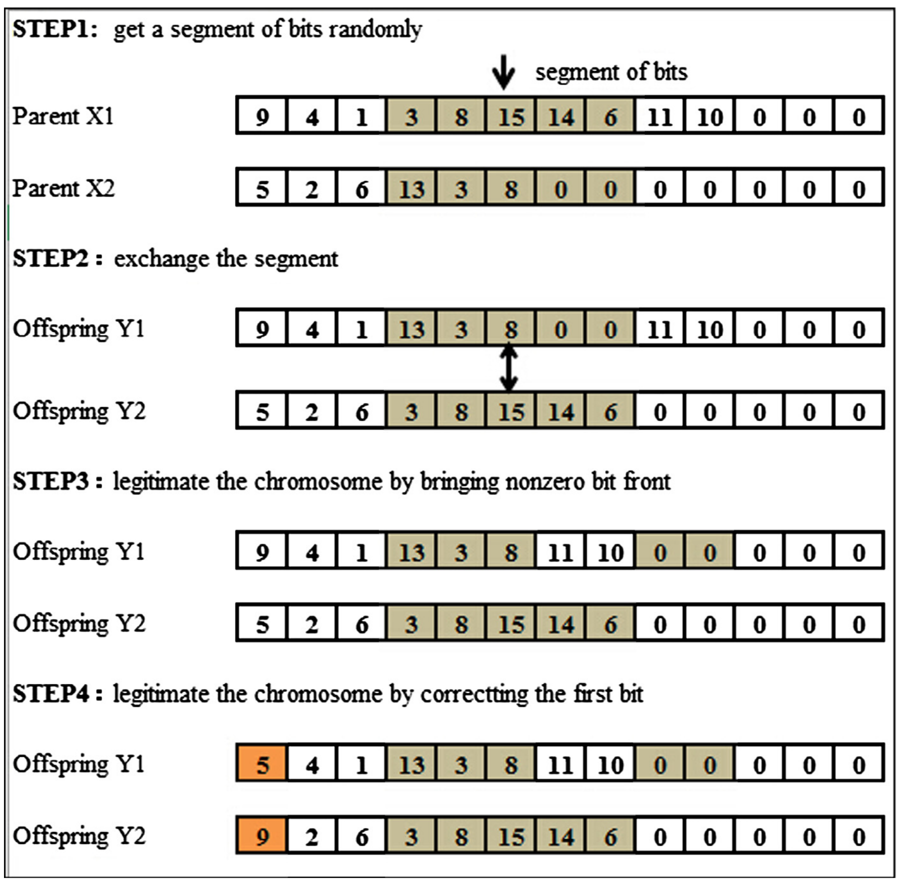

Fig. 7. Example of crossing operation.

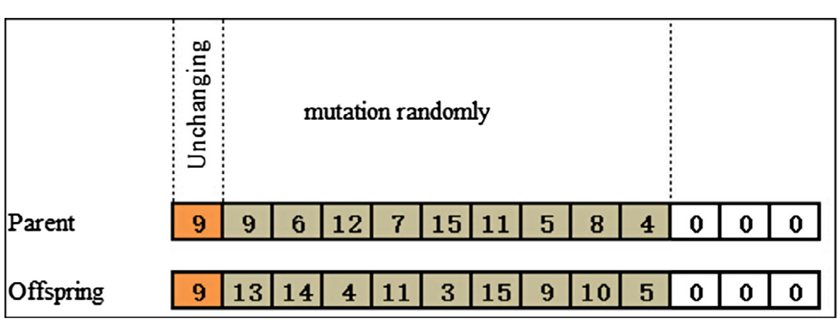

Fig. 8. Example of mutation.

the yard trucks, and C_{YC} is the objective of the YC scheduling model. Parameter α and β are adjusting coefficients and their values lie between 0 and 1.

Genetic operation are presented as follows:

(1) Rule for selection.
To retain the optimal individual in selection and to ensure that the performance of the offspring is not inferior to that of the parents, offspring are divided into optimal offspring, crossed offspring and mutated offspring, whose numbers are φ, γ and δ, respectively. Dim popSize as p; then $p = \varphi + \gamma/2 + \delta$. Apply the stochastic uniform rule in the crossing and mutation operations.

(2) Rule for crossing.
Randomly select two parents X_1 and X_2, and then apply the extended version of PMX (partially matched crossover method). Fig. 7 presents an example of the crossing operation.

(3) Rule for mutation.
Randomly select a parent. Retain the first gene, but change the other nonzero genes randomly. Fig. 8 presents an example of the mutation operation.

4.3. Process of coupling algorithm

The process of the coupling algorithm is as follows:

Step 1: Determine the group of initial coordination variables, which are the number of YCs and their positions.
Step 2: Determine the yard storage plan cost $D_{storage}$ and the YC scheduling plan cost C_{YC}; transform the storage plan cost to $C_{storage}$; this process is equivalent to converting distance to time.
Step 3: Determine the fitness value, as the sum of the storage plan cost and the YC scheduling plan cost.
Step 4: If the stopping conditions are satisfied, then terminate the genetic process; else continue.
Step 5: Perform crossing operations or mutation operations to obtain a new group of coordination variables.
Step 6: Check the new group of coordination variables; if it is valid, go to Step 2; else go to Step 5.

Table 1
Number of containers from each working line.

Working line	Import	Export	Total
1	20	22	42
2	31	64	95
3	62	43	105

Table 2
Storage capacity of each block (TEU).

Block no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Capacity	40	50	45	35	30	78	100	150	110	90	118	140	172	136	120	129

Table 3
Distances from blocks to berths.

Berth	Blocks															
	Line1				Line2				Line3				Line4			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	400	550	700	850	600	750	900	1050	1200	800	950	1100	1000	1150	1300	1450
2	550	400	550	700	750	600	750	900	950	800	950	1100	1150	1000	1150	1300
3	700	550	400	550	900	750	600	750	1100	950	800	950	1300	1150	1000	1150
4	850	700	550	400	1050	900	750	600	1250	1100	950	800	1450	1300	1150	1000

Table 4
Matrix of YC moving times.

Block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	10	20	30	20	30	40	50	40	50	60	70	60	70	80	90
2	10	0	10	20	30	20	30	40	50	40	50	60	70	60	70	80
3	20	10	0	10	40	30	20	30	60	50	40	50	80	70	60	70
4	30	20	10	0	50	40	30	20	70	60	50	40	90	80	70	60
5	20	30	40	50	0	10	20	30	20	30	40	50	40	50	60	70
6	30	20	30	40	10	0	10	20	30	20	30	40	70	60	50	40
7	40	30	20	30	20	10	0	10	40	30	20	30	60	50	40	50
8	50	40	30	20	30	20	10	0	50	40	30	20	70	60	50	40
9	40	50	60	70	20	30	40	50	0	10	20	30	20	30	40	50
10	50	40	50	60	30	20	30	40	10	0	10	20	30	20	30	40
11	60	50	40	50	40	30	20	30	20	10	0	10	40	30	20	30
12	70	60	50	40	50	40	30	20	30	20	10	0	50	40	30	20
13	60	70	80	90	40	50	60	70	20	30	40	50	0	10	20	30
14	70	60	70	80	50	40	50	60	30	20	30	40	10	0	10	20
15	80	70	60	70	60	50	40	50	40	30	20	30	20	10	0	10
16	90	80	70	60	70	60	50	40	50	40	30	20	30	20	10	0

5. Numerical experiment on coordination model

To confirm the effectiveness of the method that is proposed in this paper, a numerical experiment is performed. Given the complexity of the coordination scheduling problem in the yard of a container terminal, which demand several mathematical models and numerous constraint, a small yard at Shanghai Port with 16 blocks is the subject of the experiment. All numerical experiments are performed on a personal computer with an Intel Core i5 2.5 GHz CPU and 4 GB RAM.

Table 1 presents the jobs on each of the three working lines. Table 2 presents the capacity of each block. Table 3 presents the distance from each block to each berth. Five YCs are available in the yard, and the average capacity of a YC is 50TEU per period. Approximately 10 min and 0.2 min are required for a YC to move between two parallel bocks and from one bay to an adjacent one, respectively. Table 4 presents the time taken by a YC to move between blocks.

The storage model and YC scheduling model are formulated in C# and solved by an ILOG CPLEX 12.2, respectively. The adopted parameters in the genetic mechanism-based coupling algorithm are as follows. popSize = 30; maximum number of generations = 300; crossover probability = 0.8; mutation probability = 0.2. Table 5 presents the computational results.

Table 5
Computational results.

Generation	YC number	Objective value			
		$D_{storage}$ (m)	$C_{storage}$ (min)	C_{YC} (min)	Global object (min)
1	2	151,450	378.625	195	573.625
30	4	157,600	394.000	100	494.000
60	5	157,600	394.000	80	474.000
93	5	151,450	378.625	80	458.625
116	2	150,750	376.875	75	451.875
242	5	151,450	378.625	72	450.625
243	5	151,450	378.625	70	448.625

Table 6
Initial positions of YCs.

Number of YC	Initial block of each YC				
	YC1	YC2	YC3	YC4	YC5
5	3	1	2	6	8

Table 7
Optimal storage planning schema.

Working lines	Storage planning
Working line1	4(7), 6(35)
Working line 2	3(30), 5(30), 6(35)
Working line 3	1(40), 2(50), 3(15)
A(B) means B TEU containers are assigned to block A	

Table 8
Optimal YC scheduling schema.

YC	Job sequence
1	4(1)
2	7(3)
3	6(5)
4	1(4)–3(7)–8(8)
5	2(2)–5(6)
A(B) means job A with arrive order B	

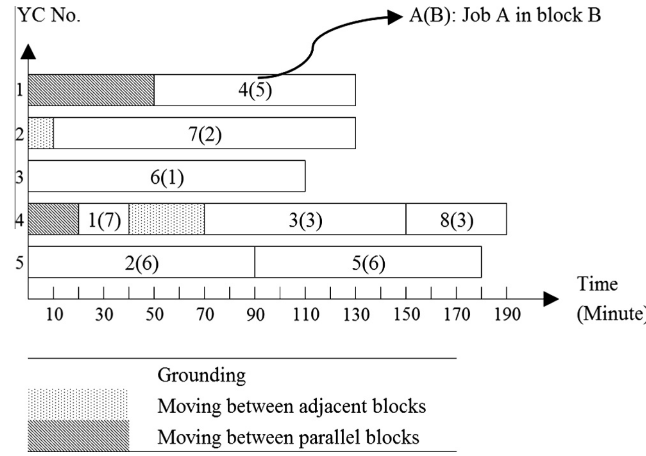

Fig. 9. Gantt chart of YC scheduling.

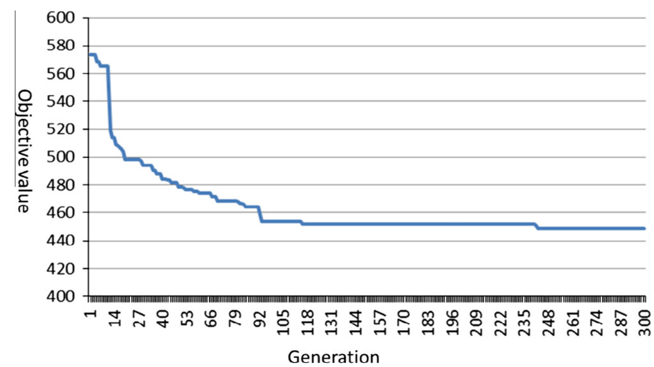

Fig. 10. Process of convergence.

Table 5 reveals that the optimal number of YCs is five, whose initial positions are given in Table 6. Table 7 presents the optimal storage plan. Table 8 presents the optimal YC scheduling planning schema, and Fig. 9 shows the corresponding Gantt chart. The result demonstrates the feasibility of the coupling algorithm that is proposed in this paper.

This work proposes a coupling algorithm for global searching, multi-point searching, and probability optimization; it adopts genetic selection, crossover and mutation mechanisms and utilizes a genetic iterative process for coordination. The computational results reveal that the algorithm has good convergence, as shown in Fig. 10.

6. Conclusions

This paper concerned a container yard system coordination model and a method for applying. First, based on the sharing of information between subsystems, a coordinated model of a yard system is established, comprising a storage subsystem model, a YC scheduling subsystem model and a coordination controller model. Then, a coupling algorithm that performs global searching, multi-point searching, and probability optimization, based on a genetic mechanism, is proposed. A computational experiment is performed, and reveals the feasibility of the proposed coordination model and the coupling algorithm.

The most important characteristic for the proposed model is the coordination of the storage plan and YC scheduling plan, which consider the inner effects between these two subsystems. The model is obviously closer to the real work environment than independent ones. For the coupling algorithm it is very effective in solving coordinated yard planning and YC scheduling of container terminal for shortest total yard operation time.

The main conclusion of this paper is that the genetic mechanism based coupling algorithm constitutes a successful approach for the coordinated yard planning and YC scheduling problem, generating near-optimal solution for small and medium-sized problem. To further advance the matter, additional circumstances should be considered in storage plan subsystem, such as the effects of query crane work plan as well as stowage plan, to decrease the amount of re-handling containers for YCs. Also, it is highly recommended that future work pursues the implementation of distributed computing for large-sizes and dynamic rolling coordinated model.

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