

# *Optimization on Stockpiling and Yard crane Scheduling for Export Containers with Uncertain Delivery Time*

Xuehan Sui<sup>1</sup>, Wen Sheng<sup>1</sup>, Jiaying Hu<sup>1</sup> and Qianqian Shao<sup>1,a,\*</sup>

<sup>1</sup>*School of Transportation Engineering, Shenyang Jianzhu University, Shenyang, China  
a. 308977035@qq.com*

*\*corresponding author: Qianqian Shao*

**Keywords:** Container, yard crane scheduling, reshuffling, generalized delivery sequence, Markov Chain.

**Abstract:** There is no strict time limit for truck arrivals in the process of terminal consolidation. The uncertain truck arrival time directly affects the container stockpiling structure which is essential to the pick-up efficiency of yard crane in ship loading operations. Many unnecessary time-coasting actions such as reshuffling and frequent movement of yard crane caused by unreasonable stowage structure would lower terminal productivity. Generalized container delivery sequence with delivery time uncertainty is described by using Markov Chain (MC) and then an estimating delivery sequence would be achieved. Based on that, a two-stage mathematic model for stockpiling and yard crane scheduling optimization is formulated with the promise of minimizing pre-reshuffling and crane movement distance. As a methodology, heuristics solving the initial scheduling is developed to obtain a static pre-optimized plan. To conquer the deviation of predicted delivery sequence, a dynamic algorithm is proposed in optimizing the real-time scheduling. Several sets of experimental results demonstrated the effectiveness and robustness of the proposed model and algorithm.

## **1. Introduction**

Container yard is the distribution center of inbound/outbound containers in terminal and the indispensable resource supporting container transshipment. Yard crane, the main handling equipment in yard, has a direct impact on the productive efficiency of the yard or even the whole wharf. For export containers, the uncertainty of truck delivery sequence will directly increase the randomness of piling work, and thus leads to a certain number of relocations due to the pick-up operations handled by yard crane in ship loading process. Based on the survey data of Chinese high-modernized container terminal, the reshuffling rate is nearly 14% and has kept a long-term high. Reducing reshufflings has become the bottleneck factors affecting the operational efficiency of container terminal, how to optimize the export container stacking strategies to effectively improve work efficiency and reduce relocation operations for shipment has become an important subject faced by the terminal operators.

## 2. Literature Review

Many scholars have studied the optimization of yard crane stockpiling operations based on different optimization objectives. Among them, heuristic is often used to solve the problem. Hakan Akyüz and Lee[1]proposed a beam search heuristic, which can solve the dynamic container relocation problem (DCRP) efficiently, and the method performed better than the other two heuristic methods: index-based heuristics and heuristics using the binary IP formulation. Ting and Wu[2]also proposed a beam search heuristic to solve the problem, with a test on benchmark instances and a comparison with other leading heuristics. A tabu search based heuristic approach is proposed by Karpuzoğlu et al.[3]to solve the DCRP with the arrival and departure sequences of containers are assumed to be known in advance. Tanaka and Takiki[4]constructed a faster branch-and-bound algorithm that employs the proposed lower bound, and demonstrated its effectiveness by numerical experiments. Tricoire et al. [5] proposed a branch-and-bound algorithm embedded a new lower bound that generalizes existing ones, then assessed the influence of various factors on the efficiency of branch-and-bound algorithms for the block relocation problem (BRP). Borjian et al.[6] extended the A\* algorithm and combined it with sampling technique to solve the two-stage stochastic optimization problem, with the assumption of a probabilistic distribution on the retrieval order of unknown containers.

As the assumption of knowing the full retrieval order of containers is particularly unrealistic in real operations, Galle et al[7]studied the stochastic CRP, which relaxes the assumption. They introduced the batch model, the Pruning-Best-First-Search (PBFS) algorithm and a PBFS-Approximate algorithm with a bounded average error to solve the problem. With container reshuffling operations and inter-crane interference constraint considered and the dynamic processing times for retrieval containers taken into consideration, Zheng et al[8]investigated two-yard-crane scheduling with stockpiling and retrieval tasks in a container block. To solve the problem, a heuristic named dividing, sequencing, and comparing (DSC) and a genetic algorithm (GA) are proposed.

Most of the studies above set the container operation task to be given, and the actual operation of the port is undeterminable; moreover, in the process of port consolidation, it follows the rule that the properties of the containers from the same customer are basically the same, rather than the premise of “every two container operations have an order of priorities” in most of the current study. Taken the randomness and of the containers’ arrival sequence into consideration, this paper uses Markov Chain to deal with the random arrival sequence of the export container batches, and formulates the yard crane stockpiling model which considers both the relocation problem and the yard crane scheduling problem

## 3. Problem Description

The terminal consolidation process can be divided into three stages: truck appointment, stock plan preparation and terminal operation. Firstly, the truck company will provide booking information including container number and their type, size, unloading port and expected arrival time for appointment. According to the information, the yard operator prepare storage plan to determine the specific location of each container. Each truck company will have a number of containers needing service, this group of container will usually arrive at the terminal at the same time. According to the practical principle of centralizing the containers that belong to the same company, each container group can be stockpiled as several full stacks and some scattered containers, and these scattered containers caused the reshuffling operations in the subsequent ship loading operation.

Each container group belonging to the same truck company is divided into two sets: One is presented as  $A_n$  in which containers would not be relocated, and another is presented as  $B_n$  in which containers could be relocated. Containers of  $A_n$  are able to construct a number of stacks composed of container belong to group  $n$ , and these stacks, called “pure stack” make up a set named  $A$ . Element number of  $B_n$  should be less than the nominal height a stack. Containers of  $A_n$  are able to construct a number of stacks composed of container belong to different groups, and these stacks, called “reshuffling stack” make up a set named  $B$ .

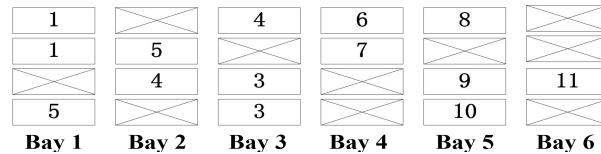


Figure 1: Illustration of the block.

Figure 1 illustrates the top view of a block. Each rectangle represents a stack. Stacks with number represent pure stacks, and the others represent reshuffling stacks. For instance, there are three pure stacks in bay 1, and containers in these three stacks belong to  $A_1$  and  $A_5$ . The purpose of the model is to optimize the global storage scheme of set  $A$  and set  $B$  based on the sub optimized stockpiling of containers of set  $B$ . All of these optimizations are carried out under the condition that the delivery sequence is uncertain

### 3.1. Assumptions

This model is based on the following assumptions:

- (1) The types of all the containers to be exported are same (e.g. 20 feet standard container);
- (2) The arrival time, unloading port, weight of containers are known, and these information of the containers belonging to the same company are same ;
- (3) The moving distance of the crane is calculated in the unit of bay length, and the initial position is bay 1.

### 3.2. First-Stage Model

$I$  : Rated height of a stack.

$N$  : Total number of truck company.

$M$  : A sufficiently large positive number.

$U_n$  : Container number of company  $n$ .

$F_n$  : Scattered container number of company  $n$ ,  $F_n = U_n \bmod I$ .

$O_n$  : Arrival order of company  $n$ .

$T$  : Total number of reshuffling stacks,  $T = [\sum_{n=1}^N F_n - (\sum_{n=1}^N F_n) \bmod I] / I + 1$ .

$d_n$  : Discharging port of containers belonging to company  $n$ .

$w_n$  : Weight class of containers belonging to company  $n$ , with the maximum level of  $W$ .

$c_n$  : Stockpiling priority of containers belonging to company  $n$ ,  $c_n = Wd_n + w_n$ .

$slot(t,i)$  : Slot at tier  $i$  of scattered stack  $t$ .

Decision variables:

$s_{nti}$ : Whether  $slot(t, i)$  is occupied by containers of company  $n$ ,

$$s_{nti} = \begin{cases} 1 & \text{if } slot(t, i) \text{ is occupied by containers of company } n \\ 0 & \text{others} \end{cases}$$

$n = 1, 2, \dots, N; t = 1, 2, \dots, T; i = 1, 2, \dots, I.$

$R_{t(i-z)}(s_{nti}, s_{nt(i-z)})$ : Whether the stockpiling priority of container at  $slot(t, i)$  is less than the one at  $slot(t, i-z)$ ,

$$R_{t(i-z)}(s_{nti}, s_{nt(i-z)}) = \begin{cases} 1 & \text{if } slot(t, i) \text{ is less than the one at } slot(t, i-z) \\ 0 & \text{others} \end{cases}$$

$t = 1, 2, \dots, T; i = 2, \dots, I; z = 1, 2, \dots, i-1.$

Objective function:

$$P_1 = \min \sum_{t=1}^T \sum_{i=2}^I \sum_{z=1}^{i-1} R_{t(i-z)}(s_{nti}, s_{nt(i-z)}) \quad (1)$$

Constraints:

$$\sum_{t=1}^T \sum_{i=1}^I s_{nti} = F_n \quad (n = 1, 2, \dots, N) \quad (2)$$

$$\sum_{n=1}^N s_{nti} \leq 1 \quad (t = 1, 2, \dots, T; i = 1, 2, \dots, I) \quad (3)$$

$$\sum_{n=1}^N s_{nti} \leq \sum_{n=1}^N s_{nt(i-1)} \quad (t = 1, 2, \dots, T; i = 2, \dots, I) \quad (4)$$

$$\sum_{n=1}^N O_n s_{nti} + (1 - \sum_{n=1}^N s_{nti})M > \sum_{n=1}^N O_n s_{nt(i-1)} \quad (t = 1, 2, \dots, T; i = 2, \dots, I) \quad (5)$$

$$R_{t(i-z)}(s_{nti}, s_{nt(i-z)}) = \left\lceil \frac{V}{\exp(V)} \right\rceil, \text{ when } V = \sum_{n=1}^N s_{nti} \left[ \exp \left( \sum_{n=1}^N c_n s_{nt(i-z)} - \sum_{n=1}^N c_n s_{nti} \right) - 1 \right] \quad (6)$$

$(t = 1, 2, \dots, T; i = 2, \dots, I; z = 1, 2, \dots, i-1)$

The objective function affiliation: is to minimize the total pre-reshuffling number. Constraint (2) ensures that the total number of slots occupied by each company in reshuffling stacks is equal to its scattered container number. Constraint (3) enforces that each slot is occupied exactly once. Constraint (4) ensures that each container will not be suspended. Constraint (5) ensures that the arrival order of container at each slot is behind the container under it. Constraint (6) ensures that a pre-reshuffling is recorded when the stockpiling priority

of container at  $slot(t, i)$  is less than the container at  $slot(t, i - z)$ .

### 3.3. Second-Stage Model

As the output of the first-stage model, the stockpiling plan of  $T$  reshuffling stacks will participate in the second-stage model. We define  $H$  as the set of the  $T$  reshuffling stacks, and  $H_t$  denotes the  $t$ th reshuffling stack in  $H$ . Furthermore, We define  $Z$  as the set of the all pure stacks, and its subset  $Z_n$  denotes the pure stacks composed of  $A_n$ . The element number of  $Z_n$  can be hence calculated as  $ZE_n = (U_n - F_n) / I$ .

$K$ : The total number of bays in the assigned block.

$J$ : Stack number of each bay.

Decision variables:

$h_{ijk}$ : Whether stack  $j$  of bay  $k$  is occupied by  $H_t$ ,

$$h_{ijk} = \begin{cases} 1 & \text{if stack } j \text{ of bay } k \text{ is occupied by } H_t \\ 0 & \text{others} \end{cases}, \quad t = 1, 2, \dots, T; j = 1, 2, \dots, J; k = 1, 2, \dots, K.$$

$g_{ijk}$ : Whether stack  $j$  of bay  $k$  is occupied by  $Z_n$ ,

$$g_{ijk} = \begin{cases} 1 & \text{if stack } j \text{ of bay } k \text{ is occupied by a element of } Z_n \\ 0 & \text{others} \end{cases}$$

$n = 1, 2, \dots, N; j = 1, 2, \dots, J; k = 1, 2, \dots, K$ .

$e_{nk}$ : Whether bay  $k$  contains containers belonging to company  $n$ ,

$$e_{nk} = \begin{cases} 1 & \text{if bay } k \text{ contains containers belonging to} \\ & \text{company } n \text{ (namely } \sum_{j=1}^J g_{ijk} + \sum_{t=1}^T \sum_{j=1}^J (h_{ijk} \sum_{i=1}^I s_{nti}) \geq 0) \\ 0 & \text{others} \end{cases}, \quad n = 1, 2, \dots, N; k = 1, 2, \dots, K.$$

After consolidation of each truck company, yard crane will stay at the bay where it handles the last operation. Before the next consolidation of a certain truck company, it needs to move to the initial bay to prepare the subsequent work. The moving distance is called as switching distance. The different distribution of containers belonging to the same company caused 3 kinds of switching operation as shown in Figure 2.

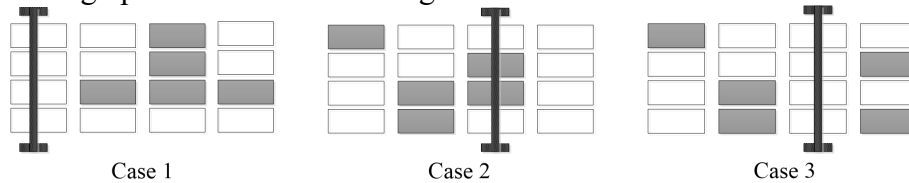


Figure 2: Three kinds of switching operation.

We assume that yard crane obeys sequential operation between different bays containing the containers belonging to the same company. Consequently, a rule is proposed to determine the initial bay for the stockpiling of containers of  $A_n \cup B_n$ . The operated crane will:

(1) Move to the nearest bay that contains the containers of  $A_n \cup B_n$  when all bays contains the containers of  $A_n \cup B_n$  are all on the same side. (For case 1 and case 2)

(2) Move to the nearest terminal bay that contains the containers of  $A_n \cup B_n$  when the staying bay is among the bays contains the containers of  $A_n \cup B_n$ . (For case 3)

$E_{nkp}$ : Whether sequential operation exists between bay  $k$  and bay  $p$ ,

$$E_{nkp} = \begin{cases} 1 & \text{if sequential operation exists between bay } k \text{ and bay } p \\ & \text{(namely } e_{nk}e_{np}(1 + \sum_{q=k+1}^{p-1} e_{nq}) = 1) \\ 0 & \text{others} \end{cases}$$

$k = 1, 2, \dots, K-1; p = k+1, k+2, \dots, K$ .

$O'_n$ : The number of the  $n$ th truck company entering the yard,  $O'_n = n, n = 1, 2, \dots, N$ .

$Max_n$ : The maximum order number of bays containing the containers belonging to the  $n$ th truck company entering the yard, is equal to  $\max\{kt_{o'_n, k}\}, n = 1, 2, \dots, N$ .

$Min_n$ : The minimum order number of bays containing the containers belonging to the  $n$ th truck company entering the yard, is equal to  $\min\{kt_{o'_n, k}\}, n = 1, 2, \dots, N$ .

$SW_n$ : The order number of the last operating bay containing the containers belonging to the  $n$ th truck company entering the yard. We have the formula:

$$SW_1 = Max_1, \\ SW_n = \begin{cases} Min_n & \text{当 } SW_{n-1} \geq Max_n \\ Max_n & \text{当 } SW_{n-1} \leq Min_n \\ Max_n & \text{当 } SW_{n-1} - Min_n > Max_n - SW_{n-1} \\ Min_n & \text{当 } SW_{n-1} - Min_n \leq Max_n - SW_{n-1} \end{cases} \quad n = 2, 3, \dots, N.$$

$DS_n$ : Crane switching distance between the  $n$ th truck company entering the yard and the  $(n-1)$ th truck company entering the yard. We have the formula:

$$DS_1 = Min_1 - 1, \\ DS_n = \begin{cases} SW_{n-1} - Max_n & \text{当 } SW_{n-1} \geq Max_n \\ Min_n - SW_{n-1} & \text{当 } SW_{n-1} \leq Min_n \\ \min\{SW_{n-1} - Min_n, Max_n - SW_{n-1}\} & \text{当 } Min_n < SW_{n-1} < Max_n, \end{cases} \quad n = 2, 3, \dots, N.$$

Objective function:

$$P_2 = \min\left(\sum_{n=1}^N DS_n + \sum_{n=1}^N \sum_{k=1}^{K-1} \sum_{p=k+1}^K (p-k)E_{nkp}\right) \quad (7)$$

Constraints:

$$\sum_{j=1}^J \sum_{n=1}^N g_{nj} + \sum_{j=1}^J \sum_{t=1}^T h_{tj} = J \quad (k = 1, 2, \dots, K) \quad (8)$$

$$\sum_{k=1}^K \sum_{j=1}^J g_{nj k} = ZE_n \quad (n = 1, 2, \dots, N) \quad (9)$$

$$\sum_{k=1}^K \sum_{j=1}^J h_{tjk} = 1 \quad (t = 1, 2, \dots, T) \quad (10)$$

$$\sum_{n=1}^N g_{nj k} + \sum_{t=1}^T h_{tjk} = 1 \quad (j = 1, 2, \dots, J; k = 1, 2, \dots, K) \quad (11)$$

The objective function is to minimize the total moving distance of yard crane. Constraint (8) ensures that the total number of stacks is less than the rated quantity. Constraint (9) enforces that the total number of pure stacks occupied by each company is equal to its initial quantity. Constraint (10) ensures that each reshuffling stack only and must occupies one stack. Constraint (11) enforces that each stack is occupied by a pure stack or reshuffling stack exactly once.

#### 4. Solution Algorithm

The algorithm consists of two parts corresponding to the two stages of the formulated model. The flowchart of the developed algorithm is shown in Figure 3.

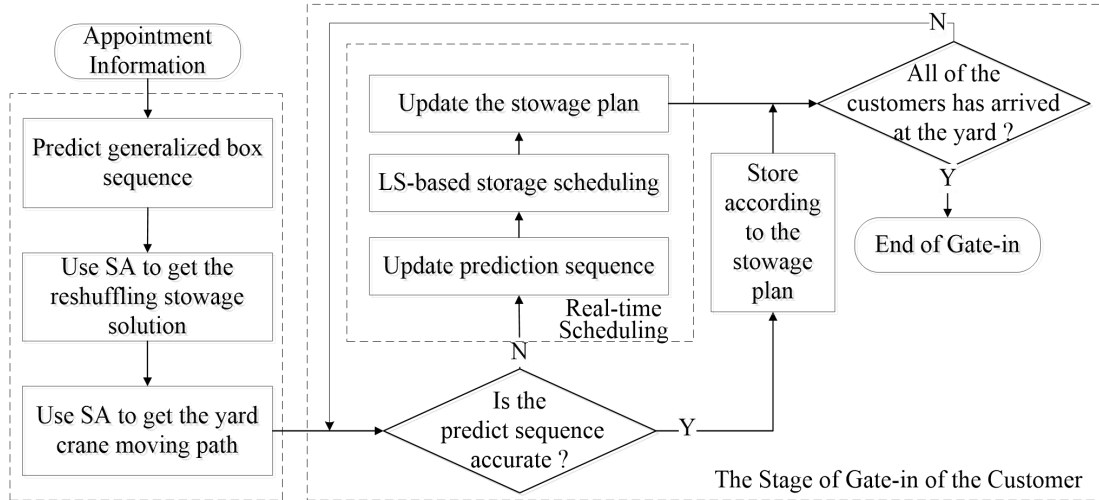


Figure 3: Flowchart of the proposed algorithm.

(1)The first part is designed to achieve an initial stockpiling plan. Based on the historical data, MC is used to predict the generalized delivery sequence and a SA is developed to solve the two optimization problem.

(2)The second part is designed as a dynamic heuristic to optimize the two objections in real-time. MC is used to renew the predicted delivery sequence when the actual delivery sequence does not match the predicted delivery sequence.

#### 4.1. Algorithm For Initial Planning

In practice, the arrival times of partial trucks can't match their appointment time because of the uncertain traffic conditions, which leads to the dynamically changing of delivery sequence. A typical discrete stochastic process, Markov Chain, is used to describe the uncertain sequence.

Based on the selected discrete state, times number of each other's transformation of each sequence in the historical data is counted, and the transition probability is calculated, thus the state transition probability matrix of the Markov chain can be obtained. Further, referring to the previous consolidation sequence as the initial state, the generalized delivery sequence of the customers at the current consolidation can be predicted based on the maximum likelihood value ( $\max P_{ij} = (X_{t+1} = S_j | X_t = S_i)$ ) of the state transition probability.

According to the structural characteristics of the solution of the first-stage model, a MSA is developed to lower the pre-reshuffling number. Code for each feasible solution is set to a bi-dimensional matrix of  $I$  rows and  $T$  columns, which consists of truck company number and '0'. Each reshuffling stack is denoted by a column of the matrix. The tabu search for a solution is shown in Figure 4. Neighborhood is constructed by exchanging two numbers from two different stacks randomly. Infeasible solution may generate in case that the number in new solution do not conform the delivery sequence. Reordering the number within stack is carried out to ensure the new solution feasible. As shown in Figure 4 (a), if the current delivery sequence is 3-1-2-4, the 1column and column 3 of new solution do not obey the sequence, and the result of renewing the code is shown in Figure 4 (b).



(a) Illustration of neighborhood construction

(b) Illustration of the new solution

Figure 4: Neighborhood construction of the first-stage model.

The stockpiling scheme of reshuffling stacks can be obtained through the algorithm above, which constructs the scheduling base of the second-stage model. In view of the structural characteristics of the second stage solution is similar to the first stage, the MSA is used again to solve the problem. For the second-stage model, stack is treated as the scheduling unit and the encoding is designed from the top view of a block. A solution is represented by a matrix to describe the block distribution. Each element denotes a stack and each column denotes a bay. If the stack is a pure stack, the corresponding element value is the truck company number, or the value is  $N + t, t = 1, 2, \dots, T$ . Exchanging two different stack number from different bay is used as the tabu search of the algorithm. No infeasible solution is able to be generated because of the block physical construction. The algorithm parameters are set as follows:

- (1) Initial temperature is set on the basis of  $\Delta f$  under different scales of cases.
- (2) End temperature is set as 1.
- (3) Temperature drop coefficient is set as 0.8.
- (4) Internal circulation times is set as an adaptive function of where  $t$  is the current temperature.



## 4.2. Algorithm For Real-Time Optimization

The real time scheduling is based on the modified MC readjusting the deviation of predicted sequence. Considering a consolidation with  $N$  truck companies, each delivery time is regarded as a real-time scheduling point, hence  $N$  rescheduling is carried out during the horizon. The delivery sequence predicted using MC is set to  $Q$ , and the  $n$ th arrival truck company of  $Q$  is set to  $Q_n$ ; The actual delivery sequence is set to  $C$ , and the  $n$ th arrival truck company of  $C$  is set to  $C_n$ ; When  $C_n$  does not match  $Q_n$ , the current predicted delivery sequence will be replaced by a new one extracting from  $S$  with the conditions as follows:

- (1) Its partial sequence from the first digit to the  $n-1$  digit should match  $Q$ ;
- (2) Its  $n-1$  digit should match  $C_n$ .

The all sequence of  $S$  satisfying the above conditions construct the temporary alternate set denoted by  $S'$ . Based on the initial state  $X_t$ , we can obtain the maximum likelihood of state transition probability,  $\max P_{ij} = (X_{t+1} = S_j | X_t = S_i)$ , and the corresponding state  $S'$  replaces the current one as an updated predicted delivery sequence.

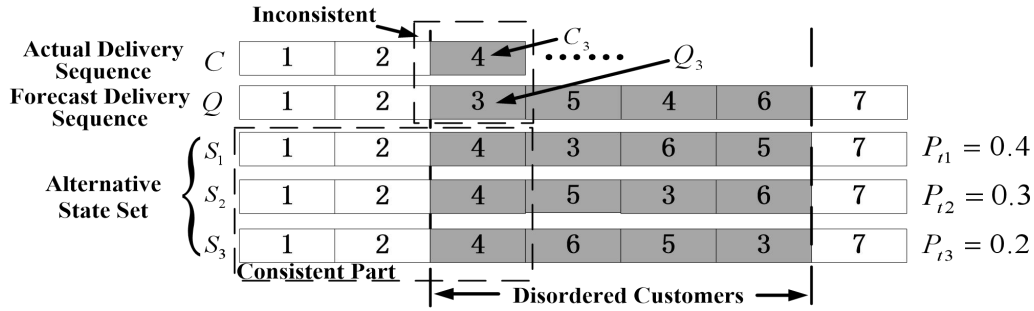


Figure 5: Updating of the forecast delivery sequence.

A renewing process of the predicted delivery sequence is shown in Figure 5. The actual delivery sequence is not consistent with the predicted one in the illustration.  $S_1$ ,  $S_2$  and  $S_3$  constructing the alternate state set own the same partial sequence of 1-2-4 in front.  $S_1$  is chosen as the updated predicted delivery sequence  $Q'$  due to its maximum state transition probability  $P_{11}$ .

Considering the dynamic scheduling should be acute, real-time algorithm needs to have the characteristics of fast convergence. Hence a Local Search (LS) is designed to solve the real-time scheduling problem.  $Pl$  is set to denote the set of stockpiling planning, and  $Pl_n$  denotes the stockpiling planning before the arrival of truck company  $n$ ;  $ST_n$  denotes the stockpiling state in  $n$ th decision point, and hence  $ST_1$  denotes the Empty block. The essence of the proposed real-time algorithm is to optimize the un-stockpiled slots of  $Pl_n$  based on  $Q'$  and afterwards to stockpile the containers of  $C_N$  converting  $ST_n$  to  $ST_{n+1}$ .

Set  $f(x)$  as the function calculating the pre-reshuffling number of a stack, and hence  $f(H_T)$  denotes the pre-reshuffling number of stack  $H_t$ . For the stockpiling planning of  $B_{C_n}$ , iterative steps of the LS are as follows:

Step1: Optimize the stockpiling of each stack in  $Pl_n$  based on  $Q'$ , set positive integer  $\beta$ ,  $a=0$ ;

Step2: If  $a = \beta$ , steps end, or select two containers belonging to different truck company from two different reshuffling stacks  $H_{i1}$  and  $H_{i2}$ , exchange them to form  $H'_{i1}$  and  $H'_{i2}$ , adjust the stockpiling order inside the stack based on  $Q'$ .

Step3: Calculate the gap of pre-reshuffling number between the two schemes before and after the change,  $\Delta f = f(H'_{i1}) + f(H'_{i2}) - f(H_{i1}) - f(H_{i2})$ . If  $\Delta f \leq 0$ , the new solution will be accepted and make  $a = 0$ , or preserve the original solution and make  $a = a + 1$ . Go back to Step2.

Constant  $\beta$  is the threshold of the not-improved iteration number for controlling the convergence of the algorithm.

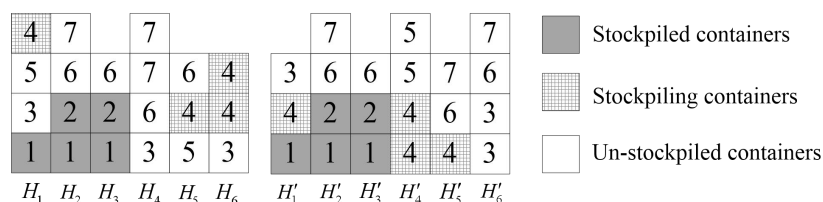


Figure 6: Comparison of stockpiling situation.

tuses of reshuffling stacks before and after real-time scheduling. The stockpiling statuses in the left picture of Figure 6 is the optimized result before the consolidation of  $C_3$  (truck company 4), and in the right picture is after the consolidation. According to the renewed  $Q'$ , stockpiled order is adjusted to avoid the suspending.

The stockpiling planning of reshuffling stacks is replaced in  $Pl_n$  and a new  $Pl'_n$  is obtained. Set  $g(x)$  as the function to calculate the crane moving distance, and the real-time scheduling algorithm for crane moving path is as follows:

Step1: set positive integer  $\lambda$ ,  $a = 0$ ;

Step2: If  $a = \lambda$ , steps end, or select two un-stockpiled stacks from two different bays  $K_1$  and  $K_2$ , exchange them to form a new stockpiling planning  $Pl''_n$ ;

Step3: Calculate the gap of moving distance between  $Pl_n$  and  $Pl''_n$ ,  $\Delta g = f(Pl''_n) - f(Pl'_n)$ . If  $\Delta g \leq 0$ , the new solution will be accepted and make  $a = 0$ , or preserve the original solution and make  $a = a + 1$ . Go to Step2.

Constant  $\lambda$  is the threshold of the not-improved iteration number for controlling the convergence of the algorithm.

## 5. Numerical Experiments

The numerical experiments are divided into two parts. The first part is to verify the practicability of the algorithm through the cases of different scales, and the actual scheduling rules of yard are used as comparison. In the second part, two different real-time storage strategy are proposed to verify the dynamic efficiency of the second stage algorithm.

## 5.1.Comparison With The Practical Scheduling Rules

### 5.1.1. Practical Scheduling Rules.

Based on investigation, the practical rule for yard stockpiling operation can be divided into two stages: For stock planning, the containers belonging to the same company are stocked in the same stack or the neighbor stacks in the same bay furthest, and the containers having the same or similar discharging port are pushed for the largest possible to be stocked in the same bay or the neighbor bays. For real-time scheduling, the yard operator proposes to adjust the stockpiling according to the actual arrival sequence, as containers owning the same weight class or the same discharging port are stocked in adjacent position as much as possible.

### 5.1.2. Comparison and Analysis of Results.

We design 3 groups of experiments with different truck company number and block size, as shown in Table 1. The actual arrival orders in last 5 weeks were selected as the simulated delivery sequence.

Table 1: Parameters of numerical experiments.

Group	Bay number	Truck company number	Rated stacking height	Stack number for each bay
1	15	$20 \pm 5$	5	8
2	15	$30 \pm 5$	5	8
3	20	$40 \pm 5$	5	8

The comparison of average values of pre-reshuffling number and crane moving distance for 2 kinds of stockpiling strategy are shown in Table 2. Comparing with the practical rules, the effectiveness of proposed optimizing algorithm in reducing the reshuffling number is remarkable. The crane moving distance of the proposed algorithm is inferior to the compared rules because that the practical rules follow the "nearest storage" principle. Effects of crane moving distance and reshuffling number on yard efficiency is mainly reflected in the operational time. According to the practical operation experience, the average time for the crane to move a bay distance is 2 seconds, and one reshuffling operation costs 2 minutes. After converting each solution into time value, the solution of optimization algorithm proposed in this paper is reduced by 30% to 50% compared to practical stockpiling rules, the optimization effect is obvious.

Table 2: Results and time comparison with the practical rules.

Group	Solutions of proposed algorithm		Solutions of practical rules		Gap (%)		TVOS (s)	TVPS (s)	Gap (time) (%)
	PRN <sup>1</sup>	CMD <sup>1</sup>	PRN <sup>2</sup>	CMD <sup>2</sup>	PRN	CMD			
1	31	102	70	86	55.7	-18.6	3924	8572	54.2
	39	99	72	77	45.8	-28.57	4878	8794	44.5
	36	81	71	62	49.3	-30.65	4482	8644	48.1
	34	83	62	69	45.2	-20.29	4246	7578	44
	12	106	41	84	70.7	-26.19	1652	5088	67.5
2	50	142	95	112	47.4	-26.79	6284	11624	45.9
	42	141	89	107	52.8	-31.78	5322	10894	51.1
	66	133	97	105	32.0	-26.67	8186	11850	30.9
	59	147	72	104	18.1	-41.35	7374	8848	16.7
	38	135	88	99	56.8	-36.36	4830	10758	55.1
3	61	165	106	134	42.5	-23.13	7650	12988	41.1
	65	172	101	129	35.6	-33.33	8144	12378	34.2
	79	155	89	106	11.2	-46.23	9790	10892	10.1
	48	159	112	123	57.1	-29.27	6078	13686	55.6
	55	161	107	117	48.6	-37.61	6922	13074	47.1

PRN: pre-reshuffling number; CMD: crane moving distance; Gap for PRN =  $(PRN^2 - PRN^1) / PRN^2 \times 100\%$ ; Gap for CMD =  $(CMD^2 - CMD^1) / CMD^2 \times 100\%$ ; TVOS: Time value of optimized solutions; TVPS: Time value of practical solutions; Gap(time) =  $(TVPS - TVOS) / TVPS \times 100\%$ .

## 5.2. Comparison of the Real-time Scheduling Rules

### 5.2.1. Real-time Scheduling Rules as Contrast

Rule 1: Invariant strategy

The same initial storage scheme is used. In real-time scheduling, no re-scheduling will be carried out even if there is a deviation in the predicted sequence.

Rule 2: Greedy strategy

### 5.2.2. Comparison and Analysis of Results.

In order to further detect the dynamic optimizing effect of the proposed algorithm, the disordered degree of the generalized delivery sequence is classified according to two dimensions: One is to be classified according to the disordered companies number in the sequence. For instance, group 1 of study cases can be classified into 6 levels corresponding to disordered number of 6,8,10,12,14,16. The second is to be classified according to the dispersion degree of disordered truck companies.

Figure 7 shows the results of 3 different real-time scheduling strategies to group 1 with sequence disordered levels from 1 to 6 and dispersion degree of 2. Cases in each disordered level are repeated 100 times. Two real-time scheduling strategies are superior to the static strategies. Strategy 2 is inferior to the proposed algorithm, because the greedy algorithm only considers the optimal scheduling of current containers, not fully combined with the updated

information and delivery sequence arrangements for all truck companies.

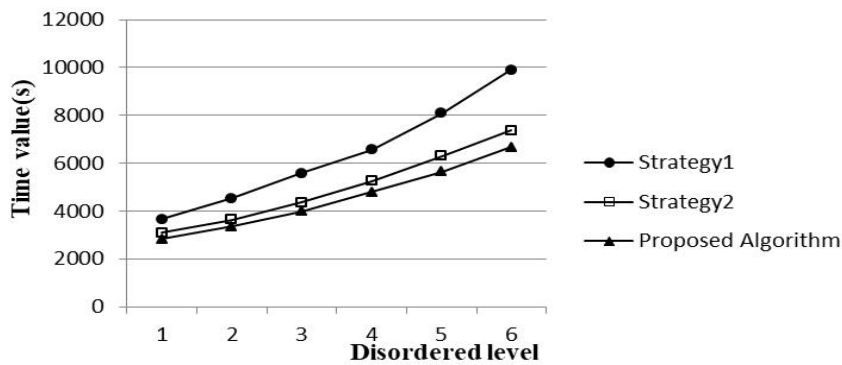


Figure 7: Computational results of different disordered levels.

Figure 8 shows the increase of the pre-shuffling number of each strategy in scheduling horizon. Since the initial stockpiling planning are based on the same predicted delivery sequence, the performance of the optimization results are basically the same in early-term in which relatively less truck companies arrive. With the increase of consolidated containers, strategy 1 shows a significant disadvantage in the medium-term while the optimization effect of strategy 2 is better than the proposed algorithm. This is because the proposed algorithm is combined with the all un-arrived containers based on the updated predicted sequence. The schedule is not the best in current but the best in global. At the late-term, with the arrival of all containers, results of the proposed algorithm are prior to strategy 2.

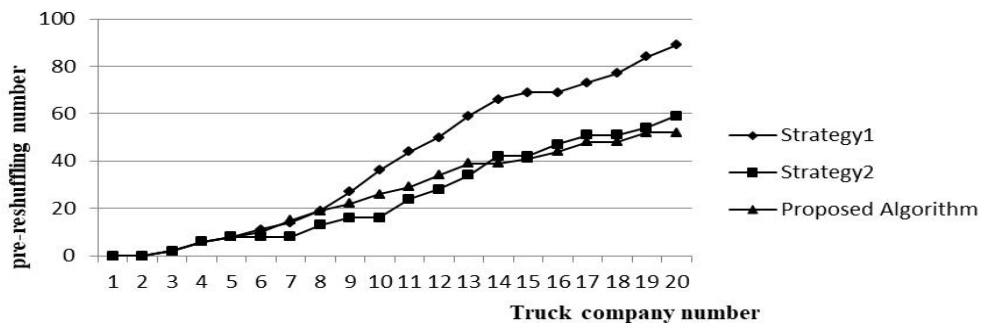


Figure 8: Comparison of reshuffling number under 3 scheduling strategies.

## 6. Conclusions and Further Study

This paper constructs the generalized delivery sequence and then constructs optimized mathematical models of export container stockpiling operation with the goal of minimizing the number of pre-reshuffling and moving distance of crane respectively. Also, a simulated annealing two-stage algorithm was developed to solve. Aiming at the prediction deviations of MC, a real-time scheduling algorithm based on renewing predicted sequence was designed with the idea of Local Search. A series of numerical experiments validate the practicability and effectiveness of the proposed stockpiling models and algorithms.

Further research will focus on building the inner link between crane moving distance and the number of pre-reshuffling.

## Acknowledgments

This work was financially supported by the Students' Innovation and Entrepreneurship Training Plan Project of Shenyang Jianzhu University (201910153069), the Scientific Research Project of the Educational Department of Liaoning Province (lnqn201916) and the Scientific Research Innovation Project of Shenyang Jianzhu University Fund (CXPY2017006).

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