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A Proactive Approach for Yard Crane Scheduling Problem with Stochastic Arrival and Handling Time

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Abstract

For a container terminal system, efficient yard crane (YC) schedules have great impact on the improvement of both operation efficiency and customer satisfaction. In this paper we address yard crane problem with uncertainties of vessels or trucks arrival time and container handling time. Vessels and trucks arrive dynamically with different service priorities and total number of handling containers is allowed to be changeable on current recording, adding more flexibility to the terminal system. A mixed integer programming model is proposed, and a simulation based Genetic Algorithm (GA) search procedure is applied to generate robust YC schedule proactively. Computational experiments are conducted to show the satisfied performance of our development method under uncertainty.

***Keywords**: Container terminal, Yard crane scheduling, Genetic Algorithm, Stochastic simulation, Uncertainty*

1. Introduction

Container terminal is the transport hub station of water and land, which is the transportation of the buffer for the containers conversion mode. It's also the intersection of the goods. As a result, the container terminal occupies an important position in the whole process of container transportation (Stahlbock, *et al.*, 2008). Yard, as the largest size operation area in terminal, plays an important role during each process. No matter import or export, yard is always the transit point for containers' short storage. A typical yard layout consists of multiple rectangular blocks. Material handling equipment --- yard crane (YC), which is mainly used for outdoor goods yard handling operation --- serves one or multiple blocks. Therefore, a high-efficiency and reasonable yard crane scheduling is the decisive factor of the yard operation, even the whole terminal.

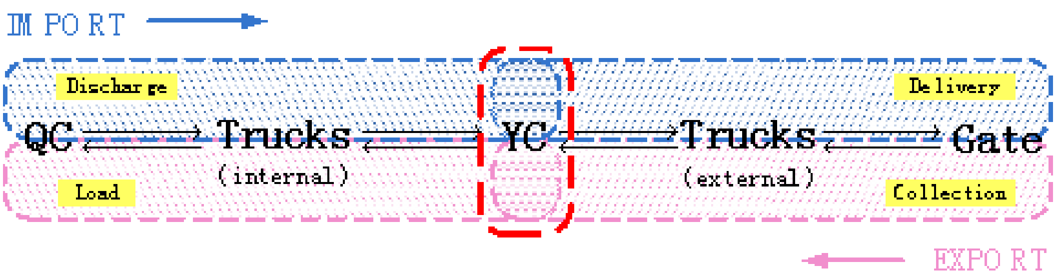

Figure 1. Construction Illustration of Yard Crane Operation

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The most important four processes concerned with yard crane operation are discharge, delivery, collection and load, as illustrated in Figure 1. The first two processes are part of import operation. After arriving at container terminals, vessels are ready to be discharged by one or more quay cranes (QC). Internal trucks then transport the container already unloaded to the storage yard, where they are temporarily stored (typically) by YCs. Depending on their different destinations, YCs deliver containers to specified external trucks as soon as consignors come to pick up. The others of the four process mentioned above belong to export operation, which is the reverse of the import process. YCs collect containers from external trucks when shippers send them to container terminals. After the unloading of the vessel completed, the loading process occurs and containers are relayed to internal trucks by YCs from storage yard. They are loaded by QCs on the quay side and ready to be transferred to the destination ports (Carlo, *et al.*, 2014).

The above process is a brief description of YC operation, and it follows yard plans, including storage space assignment, YC dispatching and routing, containers' reshuffling and so on. The arrangement of yard plans is influenced by any other terminal plans, hence it is required to be much more flexible. Especially YC scheduling, it is related to the operation from both seaside and landside. As the service interface between terminal and outside, high performance of YCs has direct or indirect impacts on the efficiency of the whole terminal. So how to make a well organized YC scheduling plan, which should meet both shipping companies' and customers' satisfaction, is the key to terminal managers.

Based on practical container terminal operation, we look into the yard cane scheduling problem to task groups optimizing the efficiency of container terminal operation, in which each task groups' start time and handling time are stochastic distributed. This paper is organized as follows. The next section provides a literature review. The mathematic formulation of our problem is given in Section 3. Section 4 proposes a solution procedure, and numerical experiment is presented in Section 5. Section 6 concludes this paper.

2. Literature Review

There are three crucial resources at container terminals; the yard, cranes and the vehicles. The main objective of the terminal is the efficient use of these resources while performing different operations (Güven, *et al.*, 2014). The current decade sees a considerable growth in worldwide container transportation and with it an indispensable need for optimization (Stahlbock, *et al.*, 2007). Many research works have been reported in the literature on container terminal operation, such as berth allocation, QC assignment, trailer routing problem, storage allocation, YC scheduling problem and so on. At the same time, a large number of operation researches have been proposed to optimize these important processes (Steenken, *et al.*, 2004). Bierwirth et al. also survey recent publications on the problems above in seaport container terminals (Bierwirth, *et al.*, 2014). About cranes, a dynamic allocation model using objective programming for berth allocation and quay crane assignments was preliminarily developed based on rolling-horizon approach (Chang et al., 2010). About vehicles, computational experiments are used to verify the effectiveness of the proposed SIMT strategy and simulation optimization method (He, *et al.*, 2013). Due to some of these problems are combinatorial, some analytical formulas are presented to estimate the behavior of the container terminal (Salido, *et al.*, 2012).

As one of the significant issues in such a complex system, YC scheduling problem catches tremendous focus. Container terminals are key nodes in the global transportation network and energy-saving is a main goal for them. Yard crane, as one type of handling equipment, plays an important role in the service efficiency and energy-saving of container terminals (He, *et al.*, 2014). A knowledge-based yard crane scheduling was proposed by conducting the knowledge acquisition and completing a knowledge sorting process (Yan, *et al.*, 2011). Some novel dynamic methods were proposed to make YC scheduling problem's solutions closer to the global optimum (He, *et al.*, 2010; Chang, *et al.*, 2011). Besides, a definition of task groups for YC scheduling was proposed to simplify the solving process.

Any operation in our actual life could be influenced a lot of uncertain factors, while the literature mentioned above are all under certain condition. In fact, many scholars have been considering uncertainty in their respective fields. For policymaker, the goal of communicating uncertainty is to provide enough background knowledge on the nature of uncertainty (Patt 2009). Projecting air pollution-related mortality requires a systematic consideration of assumptions and uncertainties, which will significantly aid policymakers in efforts to manage potential impacts of PM2.5 and O3 on mortality in the context of climate change (Madaniyazi, *et al.*, 2014). Due to the significance of uncertainty, it is important therefore that transportation researchers develop relevant approaches and models to analyze and predict decision-making under conditions of uncertainty (Rasouli, *et al.*, 2014). Two location-allocation models are proposed for handling uncertainty in the strategic planning of hospital networks (Mestre, *et al.*, 2015). Chen, *et al.*, did a research on uncertainty in measurement assisted alignment in aircraft assembly (Chen, *et al.*, 2013). Besides, Leung, *et al.*, examine uncertainty research in Impact Assessment (IA) (Leung, *et al.*, 2014). Xu, *et al.*, study a buyer's configuration of flexibility strategies under supply uncertainty (Xu, *et al.*, 2015).

The real-time execution of operation schedule at container terminal is affected by different kinds of uncertainties lying in truck arrival time, task handling time, equipment reliability, container information inaccuracy, weather variability, *etc.*, (Aytug, *et al.*, 2005). Although the research about uncertainty on container terminals is less than on other fields, there still exists some based scheduling with applications in terminal operation processes. In yard storage allocation process, a real-time decision support system (DSS) was proposed to replace the traditional recovery strategy, acting as an ultimate solution for coping with uncertainties (Lu, 2013). In berth allocation problem, researchers addressed a series of optimization models to get a robust schedule for berth allocation, considering the uncertainties of vessel arrival time and handling time (Lu, *et al.*, 2011; Lu, *et al.*, 2012; Golias, *et al.*, 2014). Furthermore, Han proposed to consider berth and quay crane scheduling problems simultaneously with stochastic events (Han, *et al.*, 2010). For automated container terminals, Cai, *et al.*, investigate replanning strategies for container-transportation task allocation of autonomous Straddle Carriers in the context of uncertainty (Cai, *et al.*, 2014).

Due to be in touch with real life, more and more uncertain factors are taken into account. However, uncertainties on YC scheduling are not considered in these studies, which is quite important for scheduling of complex and variable container terminal system. These uncertainties will cause extra cost and degrade the performance of the original YC schedule in production. This is our primary motivation for writing this paper. We generate a perturbation-insensitive robust schedule by considering some uncertainties while making plans. Through optimizing the dispatching and routing of YCs, minimize task groups' total penalty cost in a certain period, to improve the cost effectiveness and strengthen the whole competiveness to the container terminal.

3. Problem Description and Formulation

In this study, we refer to the concept of task group proposed by He Jun-liang. Several moves of the retrieval operation or the storage operation are comprised a task group based on some rules, *i.e.,* the task of one bay should be grouped together and the volume of a specific task group should not be more than the capacity of a YC in the planning horizon (He, *et al.*, 2013). For the traditional deterministic yard crane scheduling problem, port planners face two interrelated decisions: where and when the yard cranes should be deployed. The YC scheduling problem is usually represented in one-dimensional space to show the start time (shown in Figure 2) and handling sequence of each yard cranes to show which task groups they operate each time. The objective function is to minimize the waiting time and tardiness time cost in the time axis.

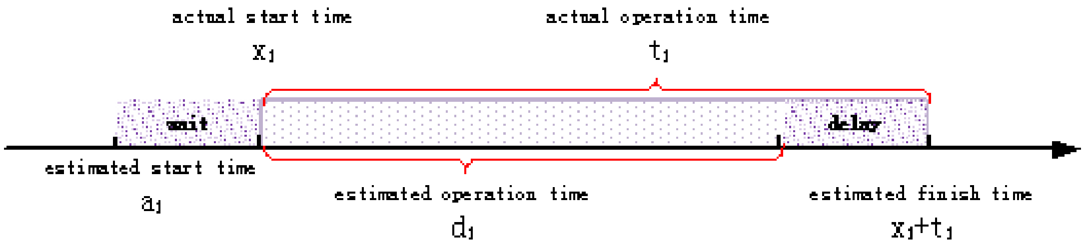


Figure 2. One-Dimensional Plane for YC Scheduling

In our problem the task group is of discrete type, i.e. the yard is divided into discrete segment which is called block, and all tasks of a specific group should be assigned to the same block, but one task group cannot be assigned across two blocks. Vessels or trucks have different priority levels, representing relative customer (or task group) importance, so they arrive dynamically, i.e. their arrival time can be after the planning moment. In our problem we make planning decisions on each task group's actual start time, service sequence and assigned YC. We assume the estimated start time and estimated end time of each task group are known. If the task group is related to ships handling, the estimated start or end time is defined by the time of ships handling; if the task group is related to external trucks handling, the estimated time is defined by the planned time of external trucks handling. All yard cranes are available at the beginning of scheduling time horizon. In addition, we assume that the productivity of each YC is the same.

There are plenty of uncertain factors in YC scheduling problem. In this study, we mainly consider two uncertainties: deviation of task group's start time and operation time. The first factor means that the vessels' or the external trucks' actual arrival time deviates from their estimated arrival time. Because of delay in previous ports or unforeseen events in voyage courses, vessels may arrive later. The external trucks may arrive later due to the traffic conditions along the way to the terminal. Both of them will cause task groups' later beginning. The second one means that the task group's actual operation time deviates from their estimated operation time. The operation time is usually estimated according to the number of loading and unloading containers. Sometimes, the actual number deviates from the one that is reported from the vessels to the port due to some unforeseen changes. And some external trucks may not arrive on time to get the containers, which will cause the deviation.

Parameter

J	the set of all task groups, $J = \{1,2,\dots,N_t\}$, N_t is the number of task groups
I	the set of all YCs, $I = \{1,2,\dots,N_y\}$, N_y is the number of YCs
K	the sequence of all handling task groups by one yard crane, N_k is the largest number of task groups handled by yard cranes
a_j	the estimated start time of the task group j
p_i	the handling time of YC i per task
d_j	the estimated operation time of the task group j, operated by yard crane i as the k^{th} task group
v_j	the actual volume of task group j
b^x_{i0}, b^y_{i0}	the block yard crane i stay in initially, represented by the coordinate of horizontal x and vertical y

b_j^x, b_j^y	the block task group j located in, represented by the coordinate of horizontal x and vertical y
t_x, t_y	the average time of a yard crane moving from one
M	a large positive number
c_j^1	the cost rate, resulting from delay in starting beyond the task group's estimated time
c_j^2	the cost rate, resulting from deviation from the task group's estimated operation time
c_j^{1+}, c_j^{1-}	the cost rate (or reward rate), resulting from more (or less) delay in starting in recovery process, $c_j^{1-} < 0$; here $c_j^{1+} \geq c_j^1 \geq -c_j^{1-}$ (it will be explained later)
c_j^{2+}, c_j^{2-}	the cost rate (or reward rate), resulting from more (or less) deviation from its estimated operation time in recovery process, $c_j^{2-} < 0$; here $c_j^{2+} \geq c_j^2 \geq -c_j^{2-}$
Ω	the set of discrete future scenarios, $\Omega = \{w_1, w_2, \ldots, w_s\}$, s is the number of scenarios
$p(w_s)$	the probability of scenarios w_s
$a_j(w_s)$	the actual start time of task group j in scenario w_s
$d_j(w_s)$	the actual operation time of task group j in scenario w_s
$v_j(w_s)$	the actual volume of task group j in scenario w_s

Decision variables

x_{ijk}	the start time of task group j in the baseline schedule, operated by yard crane i as the kth task group
y_{ijk}	the finish time of task group j in the baseline schedule, operated by yard crane i as the kth task group
$x_{ijk}^{+}(w_s)$ $x_{ijk}^{-}(w_s)$	the increment (or decrement) with respect to x_{ijk} in scenario w_s
$y_{ijk}^{\Delta+}(w_s)$ $y_{ijk}^{\Delta-}(w_s)$	the increment (or decrement) with respect to $y_{ijk} - x_{ijk}$ in scenario w_s
s_{ijk}	=1, if YC i is deployed to complete the task group j, as the kth task group; =0, otherwise
$s_{ijk}(w_s)$	=1, if YC i is deployed to complete the task group j as the kth task group in scenario w_s; =0, otherwise
mt_{ijk}	the move time of yard crane i transfer to the task group's block from the last one
$mt_{ijk}(w_s)$	the move time of yard crane i transfer to the task group's block from the last one in scenario w_s

Given the two parameters x_j and y_j taking stochastic values, our objective is to proactively plan a robust YC schedule which has statistically good performance under these uncertainties without rescheduling. Survey and analysis of actual terminal operation data show that under most ordinarily circumstances, these parameters are normal distributed. Under some extreme circumstances like bad weather condition or major failure of equipment, x_j or y_j fluctuates so much that rescheduling is usually required, which includes a different problem from ours. Our problem is formulated as the following model:

$$\begin{aligned} \text{Min} \sum_{j=1}^{N_t} \left\{ c_j^1 (x_{ijk} - a_j) + c_j^2 \left(x_j + \sum_{i=1}^{N_y} s_{ijk} v_j p_i - d_j \right) \right\} \\ + \sum_{s=1}^{s} \{p(w_s) \sum_{j=1}^{N_t} \{c_j^{1+} x_{ijk}^{+}(w_s) + c_j^{1-} x_{ijk}^{-}(w_s) + c_j^{2+} y_{ijk}^{\Delta+}(w_s) + c_j^{2-} y_{ijk}^{\Delta-}(w_s)\}\} \end{aligned} \tag{1}$$

s.t.

$$mt_{ijk} = \begin{cases} \left|b_j^x - \sum_{j=1}^{N_t} b_j^x * s_{ijk-1}\right| + \left|b_j^y - \sum_{j=1}^{N_t} b_j^y * s_{ijk-1}\right|, \forall i \in I, k \in K(k \geq 2) \\ \left|b_{i0}^x - \sum_{j=1}^{N_t} b_j^x * s_{ijk}\right| + \left|b_{i0}^y - \sum_{j=1}^{N_t} b_j^y * s_{ijk}\right|, \forall i \in I, k \in K(k = 1) \end{cases} \quad (2)$$

$$M * s_{ijk} \geq x_{ijk} \geq a_j + M * (s_{ijk} - 1) + mt_{ijk}, \forall j \in J \quad (3)$$

$$x_{ijk} + \sum_{i=1}^{N_y} s_{ijk} v_j p_i + mt_{ij'k+1} \leq x_{ij'k+1} - M\left(s_{ij'k+1} - 1\right), \forall j, j' \in J, \forall i \in I \quad (4)$$

$$\sum_{i=1}^{N_y} \sum_{k=1}^{N_k} s_{ijk} = 1, \forall j \in J \quad (5)$$

$$\sum_{j=1}^{N_t} s_{ijk} \leq 1, \forall i \in I, k \in K \quad (6)$$

$$\sum_{j=1}^{N_t} s_{ijk} \geq \sum_{j=1}^{N_t} s_{ijk+1}, \forall i \in I, k \in K \quad (7)$$

$$x_j + x_j^+(w_s) - x_j^-(w_s) \geq a_j(w_s), \forall j \in J, w_s \in \Omega \quad (8)$$

$$x_j + \sum_{i=1}^{N_y} s_{ijk} v_j p_i - d_j + y_{ijk}^{\Delta+}(w_s) - y_{ijk}^{\Delta-}(w_s) \geq d_j(w_s), \forall j \in J, w_s \in \Omega \quad (9)$$

$$mt_{ijk}(w_s) = \begin{cases} \left|b_j^x - \sum_{j=1}^{N_t} b_j^x * s_{ijk-1}(w_s)\right| + \left|b_j^y - \sum_{j=1}^{N_t} b_j^y * s_{ijk-1}(w_s)\right|, \forall i \in I, k \in K(k \geq 2) \\ \left|b_{i0}^x - \sum_{j=1}^{N_t} b_j^x * s_{ijk}(w_s)\right| + \left|b_{i0}^y - \sum_{j=1}^{N_t} b_j^y * s_{ijk}(w_s)\right|, \forall i \in I, k \in K(k = 1) \end{cases} \quad (10)$$

$$M * s_{ijk}(w_s) \geq x_{ijk}(w_s) \geq a_j(w_s) + M * (s_{ijk}(w_s) - 1) + mt_{ijk}(w_s), \forall j \in J \quad (11)$$

$$x_{ijk}(w_s) + \sum_{i=1}^{N_y} s_{ijk}(w_s) v_j(w_s) p_i + mt_{ij'k+1}(w_s) \leq x_{ij'k+1}(w_s) - M\left(s_{ij'k+1}(w_s) - 1\right), \forall j, j' \in J, \forall i \in I \quad (12)$$

$$\sum_{i=1}^{N_y} \sum_{k=1}^{N_k} s_{ijk}(w_s) = 1, \forall j \in J \quad (13)$$

$$\sum_{j=1}^{N_t} s_{ijk}(w_s) \leq 1, \forall i \in I, k \in K \quad (14)$$

$$\sum_{j=1}^{N_t} s_{ijk}(w_s) \geq \sum_{j=1}^{N_t} s_{ijk+1}(w_s), \forall i \in I, k \in K \quad (15)$$

The objective function (1) is to minimize the penalty cost of baseline schedule and the expected value of the recovery costs simultaneously. Considering the uncertainties about task groups' start time and volume, if realistic schedule deviates from the baseline schedule, this adjustment will incur extra cost that is named by 'recovery cost' in this study. Constraint (2) defines the move time of each yard cranes from current location to the next one, according to the blocks each task groups stays. Constraint (3) ensures that the actual start time of each task groups must be later than its estimated start time. Each task groups' estimated start time consists of the arriving time of vessels or external trucks and the move time from last task group handled. Constraint (4) ensures that the start time of each task groups must be later than the YC completing its last task group handled. In another words mean one YC can only handle one task group at the same time. Constraint (5) ensures that any task group only can be handled by one YC. Constraint (6) ensures that only one task group can be handled by one YC after completing a task group. Constraint (7) ensures all task groups are handled. Constraint (8) builds the relationship between the adjustment of start time $(x_{ijk}^{+}(w_s), x_{ijk}^{-}(w_s))$ and constraint (9) builds the change of operation time $(y_{ijk}^{\Delta+}(w_s), y_{ijk}^{\Delta-}(w_s))$. Constraints (10)-(15) ensure the corresponding conditions in each scenario.

4. Simulation based GA Search

Due to the computational scale of the NP-complete problem regarding YC scheduling, especially with a lot of scenarios, we adopt a simulation based Genetic algorithms (GAs) procedure to search for robust solutions. GA is a well-known meta-heuristic approach inspired by the natural evolution of the living organisms that works on a population of the solutions simultaneously. It combines the concept of survival of the fittest with structured, yet randomized, information exchange to form robust exploration and exploitation of the solution space. The flowchart for this procedure is shown in Figure 3.

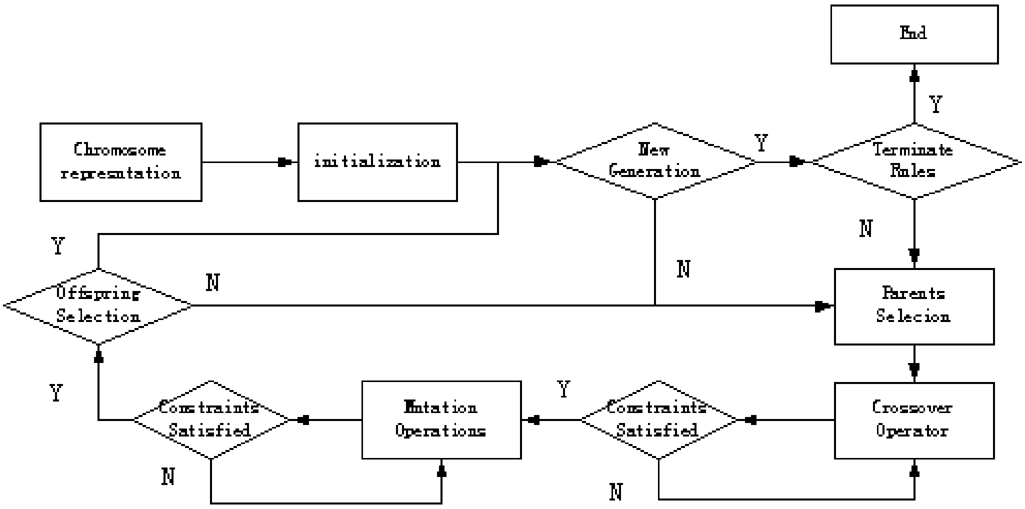
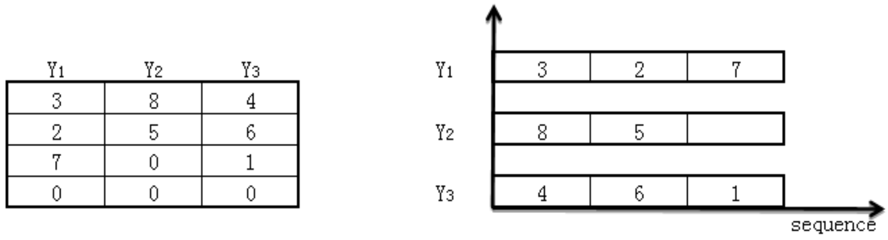


Figure 3. Procedure of Simulation based GA

4.1. Chromosome Representation

A fitness value derived from the objective value of the schedule is assigned to each single individual, called a chromosome. So the solution representation or chromosome design is not only the initial step of GA implementation, but also the most important step. In this paper, a chromosome, used to represent the solution of the problem, is a rectangular matrix with Y columns and T rows, where Y and T mean the number of YCs and the greatest number of task groups assigned to one YC, respectively. One chromosome consists of $Y \times T$ genes, in which the sum of these digits must be less than or equal to the total number of task groups and each of them cannot be duplicated. Noted that columns represented YCs are one-to-one corresponded and the entire set of task groups assigned to each YC are encoded by a vertical single string listed in corresponding column. After being assigned all task groups randomly, the rest of empty genes are set zero, called virtual task groups. Figure 4 (a) is a chromosome example with 3 yard cranes and 8 task groups, and its related Gantt chart is in Figure 4 (b).



(a)

(b)

Figure 4. An Example of the Chromosome Procedure

4.2. Initialization

It is a well-known fact that the structure of the initial population plays an essential role in determining the efficiency of GAs. In initialization, chromosomes are randomly generated to construct the population for initiation. First the number of task groups assigned to each YC is generated as a random integer between 0 to the max task groups' amount. The sum of them is equal to the total number of task groups. We derive its genes by generating a random sequence of task groups and then assigning them to each column in sequence with the assigned number. The empty genes are set amount zero, called virtual jobs. The chromosome will be added into the initial population unless it does not satisfy the constraints above. The generating process is repeated until the population size reaches a given number.

4.3. Crossover Operators Design

Crossover operation is performed on pairs of chromosomes chosen out of the population by crossover probability and randomly matched. In this paper, the crossover operator we use refers to the one proposed in Chen and Gen (1997), called uniform order-based crossover. The crossover procedure for each pair of chromosomes (ch1, ch2) is:

Step 1. Randomly generate a template binary matrix consisting of "1"s and "0"s, where the number of "1"s is equal to [(Y×T)/2].

Step 2. Randomly choose two parents (ch1, ch2) from the population.

Step 3. According to the template, interchange the genes corresponding to the "1"s' location between ch1 and ch2.

Step 4. The repetition of a gene in the child is avoided. Cross out the genes interchanged and list the repetition from redundant genes.

Step 5. Randomly exchange the repetition between ch1 and ch2. If the generated chromosome satisfies the constraints above, terminate procedure; else go to step 1.

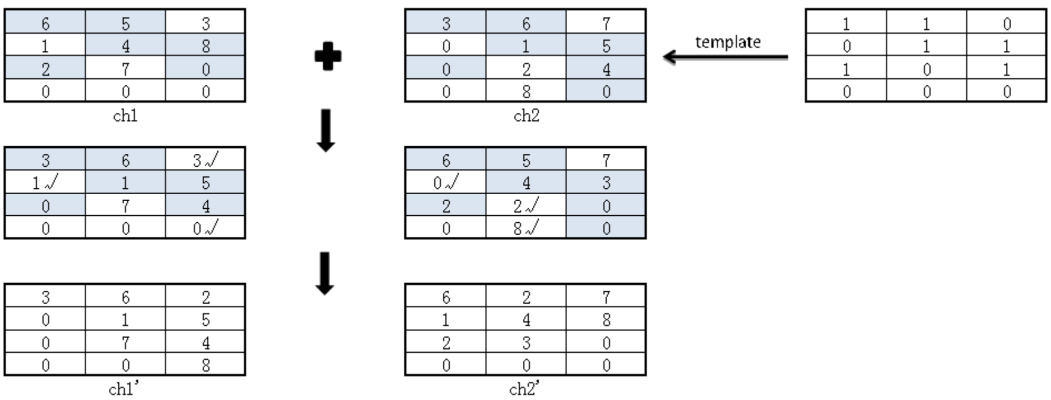


Figure 5. An Example of Crossover Operation

4.4. Mutation Operators Design

The main task of the mutation operator is to maintain the diversity of the population in then successive generations and to exploit the solution space. Mutation operation is performed on chromosomes bit by bit chosen out of the population by mutation probability. The mutation procedure for each chromosome is:

Step 1. Randomly generate a template binary matrix consisting of "1"s and "0"s, where the number of "1"s is equal to [(Y×T)/2].

Step 2. Randomly choose a chromosome from the population.

Step 3. According to the template, transport the genes corresponding to the "1"s' to the same positions in the child directly.

Step 4. List the genes, the numbers of task groups, which have not been mentioned in the new offspring.

Step 5. Fulfill the child chromosome with redundant genes and zero randomly by preserving their gene sequence.

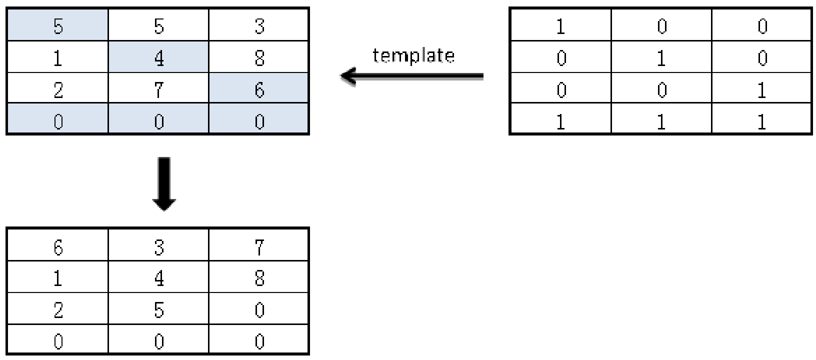


Figure 6. An Example of Mutation Operation

4.5. Reproduction

Parent selection is the first step in the reproduction process. It is important in regulating the bias and its strategy is to choose the chromosomes in the current population. In this study, we choose roulette wheel, the most common method, to generate the next generation. Each chromosome is assigned a slice of a circular wheel according to its fitness. Different proportion ensures the better solutions have more chance to be selected as parents for creating offspring.

Offspring selection is another significant step in this process. This time we use a semi-greedy strategy to accept the child chromosomes generated by the operators mentioned in 4.3 and 4.4. We accept the new one for next generation if its fitness is less than the average of its parents. It is useful to reduce the computational time and lead to a monotonous convergence toward the optimum solution neighborhood.

4.6. Termination Criteria

We use a common criterion, the maximum number of elapsed generation, as the stoppage rule to terminate. This parameter implies the degree of diversity in the current population, to guarantee the final generation is different from and is better than elapsed ones.

Table 1. List of Initial Data

Task Group	Estimated starting time	Estimated completion time	Estimated volume (move)	Block
T1	0:00:00	2:12:00	55	(3,1)
T2	0:00:00	2:28:00	67	(2,2)
T3	0:00:00	1:46:00	42	(4,2)
T4	0:32:00	3:38:00	63	(2,1)
T5	1:42:00	3:00:00	66	(6,1)
T6	0:50:00	4:06:00	84	(5,3)
T7	1:20:00	5:28:00	112	(3,3)
T8	0:54:00	4:22:00	93	(4,3)
T9	1:38:00	3:48:00	51	(1,4)
T10	1:08:00	3:28:00	57	(1,2)

Table 2. List of Available Yard Cranes

Yard crane	Block
01	(3,1)
02	(4,2)
03	(2,1)
04	(2,5)
05	(6,1)

5. Computational Experiment

To verify the effectiveness and reliability of the proposed model and approach, the performance test and analysis of our algorithm for the YC scheduling problem are conducted in this Section. In Section 5.1, a case is first applied where the actual data is from a specific container terminal. In the other two sections, both small and large scales are conducted to provide a more comprehensive evaluation.

5.1. Case Study

To illustrate the proposed approach for YC scheduling, a case is first applied using the actual data from a specific container terminal. The container terminal contained 68 blocks and 26 yard cranes. In addition, the average operation time of yard cranes for one move was 2 min. The moving speed and turn times of each YC are set as 120 m/min and 2 min for each turn, respectively. In this case, there were 20 task groups and 15 available yard cranes, where five task groups were in current planning period and 15 task groups were newly available. As well, the estimated starting time, estimated completion time, volume and block of each task group were listed in Table 1. In addition, the initial positions of all available yard cranes were shown in Table 2, where the block was denoted as (x, y), denoting the horizontal and vertical serial number of the block, respectively.

Table 3. List of Cost Rate

Task Group	Wait Cost$	Delay Cost$	Wait_up Penalty$	Wait_down Reward$	Delay_up Penalty$	Delay_down Reward$
T1	6.3	10.8	7.3	4.1	12.4	8.2
T2	2.1	9.3	3.4	1.6	11.3	7.9
T3	7.3	10.4	8.2	4.9	11.7	8.3
T4	0.8	4.6	3.4	0.5	6.2	3.4
T5	3.1	8.1	5.2	1.8	9.3	6.8
T6	1.7	5.9	2.3	0.9	6.8	4.2
T7	2.3	6.3	4.1	1.1	7.4	5.6
T8	3.1	7.1	4.6	1.7	8.9	5.1
T9	4.3	9.6	6.3	2.8	10.5	7.3
T10	2.8	5.5	3.9	1.4	6.7	3.2

In spite of the berth and mechanical parameters mentioned above, there is a large amount of data about cost rate. We evaluate the strength of each scheduling by considering the cost rate of deviation from estimated plan. As containers belong to different ship companies and consignees, the cost rate of each task groups depends on their respective importance, seen in Table 3. Being closer to actual operation in terminal yard, we research YC scheduling problem under uncertain condition specially. There is still a part of data in Table 3 to describe the penalty and reward cost when comparing the deviation under baseline schedule with uncertain scenarios. Due to the uncertain factors we considering, the details of uncertain scenarios are randomly generated as shown in Table 4. Shaded cells emphasize the variation on starting time and operation volume.

Table 4. List of Possible Scenarios

Task Group	Scenario 1 0.23		Scenario 2 0.28		Scenario 3 0.17		Scenario 4 0.09		Scenario 5 0.23	
	Actual start	Actual volume	Actual start	Actual volume	Actual start	Actual volume	Actual start	Actual volume	Actual start	Actual volume
T1	0:00:00	55	0:00:00	55	0:00:00	47	0:00:00	55	0:00:00	55
T2	0:00:00	67	0:00:00	67	0:00:00	67	0:00:00	82	0:15:00	67
T3	0:28:00	42	0:00:00	42	0:28:00	42	0:00:00	42	0:00:00	50
T4	0:32:00	63	0:24:00	63	0:32:00	63	0:24:00	63	0:32:00	63
T5	1:33:00	79	1:42:00	74	1:42:00	66	1:33:00	66	1:42:00	66
T6	0:50:00	84	0:50:00	84	0:50:00	84	0:50:00	84	0:43:00	84
T7	1:03:00	112	1:20:00	130	1:04:00	130	1:20:00	130	1:20:00	112
T8	0:54:00	93	0:54:00	93	0:54:00	93	0:54:00	93	1:08:00	93
T9	1:38:00	42	1:24:00	51	1:38:00	51	1:24:00	51	1:38:00	51
T10	1:08:00	57	1:08:00	42	1:08:00	50	1:08:00	42	0:53:00	57

The results of a certain size YC dispatching and total cost, considering uncertainty, from the proposed approach were listed in Table 5 and Table 6, respectively.

Table 5. Result of YC Dispatching from the Proposed Approach

Yard crane	Original block	First task group	First block	First moves	Second task group	Second block	Second moves
01	(3,1)	T1	(3,1)	0	T5	(6,1)	3
02	(4,2)	T3	(4,2)	0	T7	(3,3)	2
03	(2,1)	T2	(2,2)	1	T4	(2,1)	1
04	(2,5)	T8	(4,3)	3			
05	(6,1)	T6	(5,3)	3			

Table 6. Result of Total Cost from the Proposed Approach

Task group	YC dispatched	Waiting time	Delay time	Best YC dispatched under different scenarios				
				Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
T1	01	0	0	01	01	01	01	01
T2	03	3	0	02	03	02	03	03
T3	02	0	0	05	02	04	02	02
T4	03	108	48	02	03	02	03	03
T5	01	11	65	01	01	01	01	01
T6	05	0	0	04	05	04	05	05
T7	02	8	0	05	02	03	02	02
T8	04	0	0	03	04	05	04	04
Total penalty for deviation		837.4	2716.3	986.7	207.6	859.2	683.7	781.7
Objective value								4226.157

5.2. Numerical Investigation on Different-Scale Problem

In this Section, eight sets of experiments with different sizes are conducted to compare the results obtained from the optimal objective values solved by proposed approach. All sets of experiments with different sizes are tested based on the data mentioned in previous section. The same size problem is put both into baseline condition and uncertain scenarios, not only to obtain objective value but also to prove the necessity of integrating uncertainty when solving practical problems. A series of tables and figures showed below are used to record and analyze the component of total penalty, as well the solution gap between baseline and uncertainty.

Table 7. Comparison the Optimal Decision Results between Baseline and Uncertainty with Eight Sets of Experiments

No.	Problem size		Baseline schedule		Total cost for uncertain scenarios					Min Gap %	Max Gap %	Average Gap
	YC	TG	Delay cost	Wait cost	P1	P2	P3	P4	P5			
1	3	5	524.8	69.5	1048.7	730.3	687.0	704.5	630.9	6.16	76.46	
2	3	6	806.3	191.4	1503.9	1133.7	1142.2	1370.7	1199	13.63	50.74	
3	3	7	1540.8	418.9	2633.4	2374.1	2296.4	2496.5	2136	9.00	34.38	
4	3	8	2716.3	837.4	4688.6	4117.7	4115.3	4249.5	4177.2	15.80	31.94	33.35%
5	5	7	526.5	58.8	989.3	805.9	687.0	780.1	625.1	6.80	69.02	
6	5	8	747.3	145.2	1365	1154.5	1142.2	1391.5	997.1	11.72	55.91	
7	5	9	1341.1	401.6	2132.5	2622.5	4258.5	2279.8	1996.7	14.58	144.36	

8		5	10	2058.3	789.4	4339.6	4547.1	3540.5	4638.9	4103.3	24.33	62.90

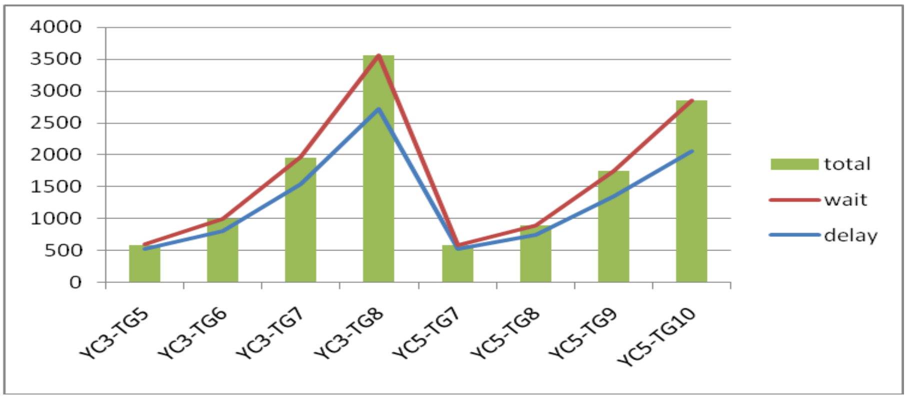


Figure 7. Development of Different Type Cost under Baseline Schedule with Eight Sets of Experiments

Table 7 shows the optimal decision results of eight sets of experiments under baseline and uncertainty respectively, in which different number of YCs and task groups are taken into account. Exact Figures of delay and wait cost under baseline schedule are listed in the third portion. The variation trends of each cost are obviously displayed in Figure 7. In one certain environment, no matter which type of cost, there is always a growth development when the number of task group is increased one by one with the same yard crane operation. Cost, resulting from deviation from the task group's estimated operation time, makes up the larger part of total penalty from which we can see that improving YC handling efficiency is imperative. Two different growth rates means that the more yard cranes are dispatched the less penalty is pay under the same difference between the quantity of yard cranes and task groups.

Total penalty costs for each uncertain scenario under the best solution are also listed in Table 7. Last three columns are filled with total cost gap between certain and uncertain scenarios. The minimum gap among them is 6.80 % and the maximum reaches up to 144.36 %. As observed in Figure 8, the difference between two conditions is more apparent by viewing the excess part of dark blue bubbles. The area out of baseline scope increase rapidly with the growth of task groups.

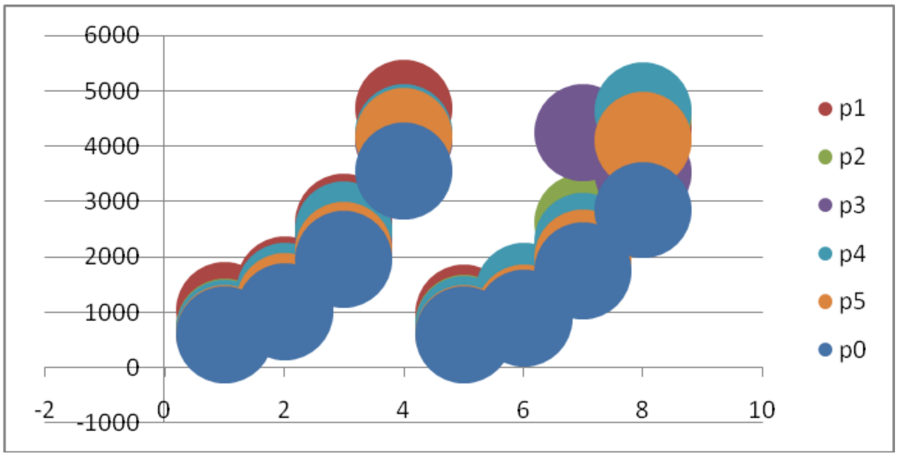


Figure 8. Difference about Total Penalty Coat between Baseline p0 and other Five Uncertain Conditions

Table 9. Specific Cost Values in baseline Schedule and Uncertain Scenarios with Eight Sets of Experiments

No.	Problem size		Objective value	Baseline cost	Uncertain cost	Cost for deviation in each scenario				
	YC	TG				P1	P2	P3	P4	P5
1	3	5	998.8	594.3	404.5	885.7	74.4	485.3	92.1	387.9
2	3	6	1417.9	997.7	420.2	913.8	74.4	535.3	262.5	324.4
3	3	7	2722.3	1959.7	762.6	1322.7	410.8	657.6	692.5	736.2
4	3	8	4936.0	3553.7	1382.3	2207.5	607.1	1159.4	758.7	1909.8
5	5	7	2829.6	585.3	2244.3	1324.6	706	1078.5	826.9	477.5
6	5	8	4226.1	892.5	3333.6	986.7	207.6	859.2	683.7	781.7
7	5	9	5077.6	1742.7	3334.9	1225.5	1582.8	2818.7	527.8	1183.7
8	5	10	6345.4	2847.7	3497.7	2763.9	2725.6	1554.1	2744.1	3833.4

We use a series of graph above to explain the significance of adding uncertain factors into solving process. The final objective values and specific values in baseline or uncertainty are both shown in Table 9, where cost resulting from deviation for each scenario is also recorded. "Baseline cost" just means the penalty cost under optimal decision for certain environment, while "uncertain cost" means the additional cost on account of operation deviation when considering uncertainty. The share of these two costs for each experiment is displayed in Figure 9. It is easily to find out that these two costs have predominance separately when the number of YCs is changed. The leader of objective value transfers from "baseline cost" to "uncertain cost" with increasing of YCs.

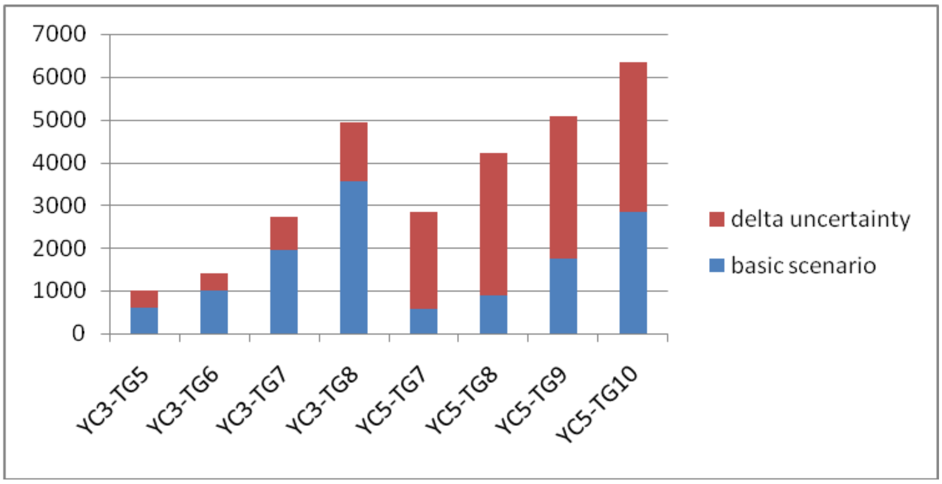


Figure 9. Share of "Baseline Cost" and "Uncertain Cost" with Eight Sets of Experiment

A set of graphs in Figure 10 show the component of "uncertain cost" inside. They are divided into additional penalty for deviation in starting time and handling volumes. The specific data under each scenario could be found in corresponding figure. Combined with parameters set in previous sub-section, the value of "uncertain cost" has something to do with the variation in each scenario. Get rid of the last two bars in each figure because of their possibly abnormal value, the value in scenario one (Fig.10_a) is always higher than the same set experiment in other scenarios. That is because the variation in scenario one is relatively close to the front task groups. When the number of YCs deployed is not enough and the time interval is small, the variation in early task groups leads to a greater influence to the whole scheduling. So we should put much more focus on early start task groups under such condition in practical.

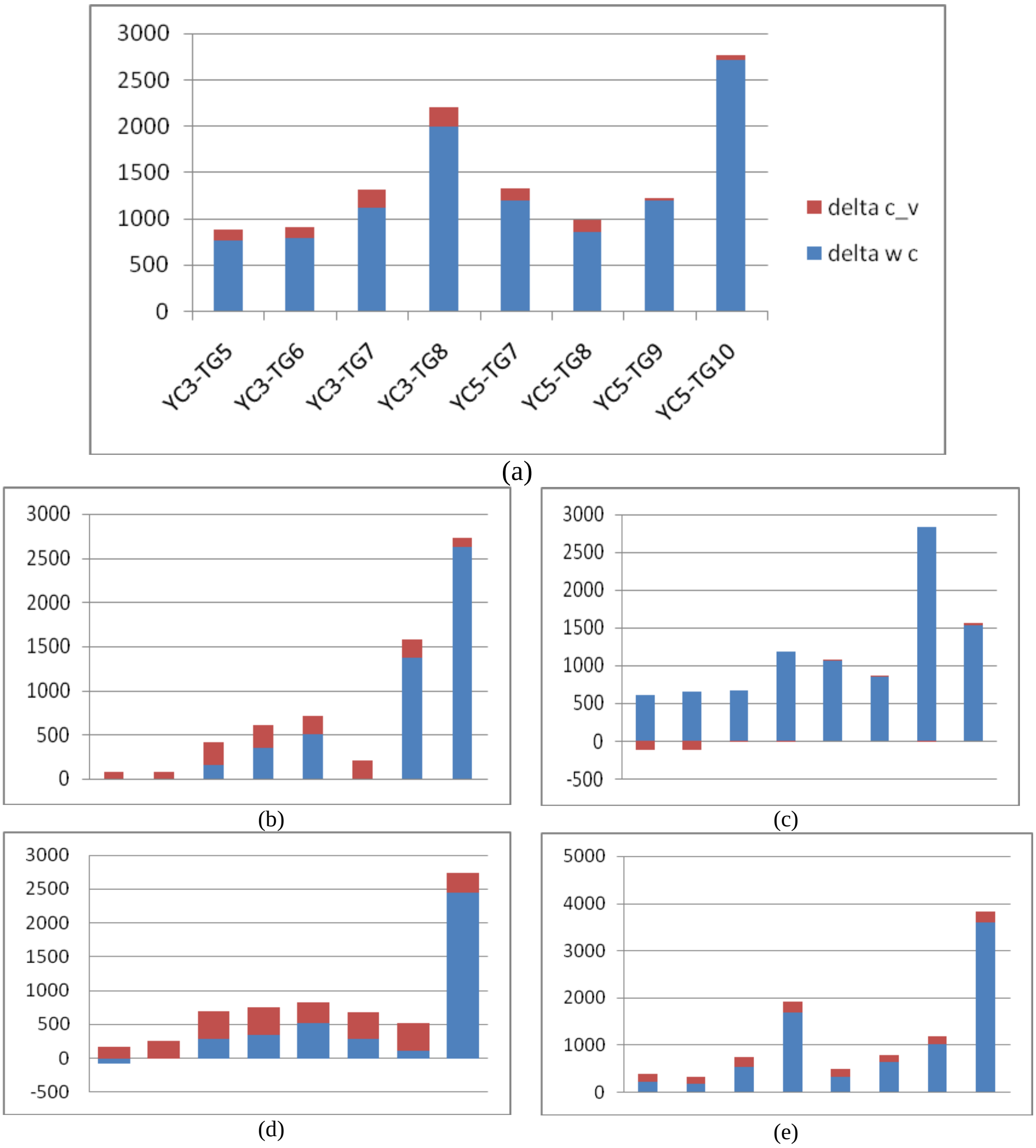


Figure 10. Additional Penalty for Different Type Deviation in "Uncertain Cost" for Five Scenarios

6. Conclusion

This paper proposes an efficient mathematical model to solve a yard crane scheduling problem under uncertainty, which is quiet important for container terminal operation for two reasons. The first one is the inherent relationship between YC scheduling and other container terminal operation. No matter the export, import or transshipment, yard must be the link between each other. Yard crane, as the most usual equipments deployed in it, should load and unload containers each time. So it is essential to address this problem separately. The other one is the inevitability of the uncertainty, whose influence cannot be denied in actual operation. The entire container terminal system is capital intensive and complicated so that terminal operators look forward to finding robust solutions to maintain the stable running of the whole system.

The extended YC scheduling problem develops a decision model considering uncertainties, which is the outstanding advantage in this paper. The model is a mixed-integer programming one designed to balance the initial cost of baseline schedule and the expected cost deviated from the initial one. A GA method is proposed to solve the exploratory study for better exploring and exploiting of the feasible space. Some computational investigations are conducted to analyze the performance of YC scheduling process under uncertainties. And a number of numerical experiments are conducted to verify and validate the effectiveness of the proposed method.

However, there are some limitations for the current method. The vessels or trucks arrival time and the containers handling time is regarded as normal distribute, while there may be other kind of irregular distributes in practice. Besides, we only consider two major uncertainties in model and use the re-schedule strategy to handle the conflicts between the initial plan and realistic environments. It is not only incomplete due to unconsidered accidental events, but also a bit complex because the compression strategy may be easier to handle. To incorporate much more uncertainties into the problem and use much more different approaches are our future research direction.

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References

[1] R. Stahlbock and S. Voß, “Operations research at container terminals: a literature update”, OR Spectrum, vol. 30, **(2008)**, pp. 1-52.
[2] H. J. Carlo, I. F. A. Vis and K. J. Roodbergen, “Storage yard operations in container terminals: Literature overview, trends, and research directions”, European Journal of Operational Research, vol. 235, **(2014)**, pp. 412-430.
[3] C. Güvena and D. T. Eliiyi, “Trip allocation and stacking policies at a container terminal”, Transportation Research Procedia, vol. 3, **(2014)**, pp. 565-573.
[4] D. Steenken, S. Voß and R. Stahlbock, “Container terminal operations and operations research—a classification and literature review”, OR Spectrum, vol. 26, **(2014)**, pp. 3–49
[5] C. Bierwirth and F. Meisel, “A follow-up survey of berth allocation and quay crane scheduling problems in container terminals”, European Journal of Operational Research, **(2014)**.
[6] D. F. Chang, Z. H. Jiang, W. Yan and J. L. He, “Integrating berth allocation and quay crane assignments”, Transportation Research Part E, vol. 46, **(2010)**, pp. 975-990.
[7] J. L. He, W. M. Zhang, Y. F. Huang and W. Yan, “A simulation optimization method for internal trucks sharing assignment among multiple container terminals”, Advanced Engineering Informatics, vol. 27, **(2013)**, pp. 598-614.
[8] M. A. Salido, M. R. Molins and F. Barber, “A decision support system for managing combinatorial problems in container terminals”, Knowledge-Based Systems, vol. 29, **(2012)**, pp. 63-74.
[9] J. L. He, Y. F. Huang and W. Yan, “Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption”, Advanced Engineering Informatics, **(2014)**.
[10] W. Yan, Y. F. Huang, D. F. Chang and J. L. He, “An investigation into knowledge-based yard crane scheduling for container terminals”, Advanced Engineering Informatics, vol. 25, **(2011)**, pp. 462-471.
[11] J. L. He, D. F. Chang, W. J. Mi and W. Yan, “A hybrid parallel genetic algorithm for yard crane scheduling”, Transportation Research Part E, vol. 46, **(2010)**, pp. 136-155.
[12] D. F. Chang, Z. H. Jiang, W. Yan and J. L. He, “Developing a dynamic rolling –horizon decision strategy for yard crane scheduling”, Advanced Engineering Informatics, vol. 25, **(2011)**, pp. 485-494.
[13] A. Patt, “Uncertainties in environmental modeling and consequences for policy making”, In: Philippe Baveye, editor. NATO science for peace and security series C: environmental security. Springer Science and Business Media B.V. (NL), **(2009)**, pp. 231–51.
[14] L. Madaniyazi, Y. M. Guo, W. W. Yub and S. L. Tong, “Projecting future air pollution-related mortality under a changing climate: progress, uncertainties and research needs”, Environmental International, vol. 75, **(2015)**, pp. 21-32
[15] S. Rasouli and H. Timmermans, “Applications of theories and models of choice and decision-making under conditions of uncertainty in travel behavior research”, Travel Behaviour and Society, vol. 1,

(2014), pp. 79-90.
[16] A. M. Mestre, M. D. Oliveira and A. P. B. Póvoa, "Location–allocation approaches for hospital network planning under uncertainty", European Journal of Operation Research, vol. 240, **(2015)**, pp. 791-806.
[17] Z. H. Chen, F. Z. Du and X. Q. Tang, "Research on uncertainty in measurement assisted alignment in aircraft assembly", Chinese Journal of Aeronautics, vol. 26, no. 6, **(2006)**, pp. 1568-1576.
[18] W. Leung, B. Noble, J. Gunn and J. A. J. Jaeger, "A review of uncertainty research in impact assessment", Environmental Impact Assessment Review, vol. 50, **(2015)**, pp. 116-123.
[19] H. Xu, X. L. Zuo and Z. X. Liu, "Configuration of flexibility strategies under supply uncertainty", Omega, vol. 51, **(2015)**, pp. 71-82.
[20] H. Aytug, M. A. Lawley, K. McKay, S. Mohan and R. Uzsoy, "Executing production schedules in the face of uncertainties: A review and some future directions", European Journal of Operational Research, vol. 161, no. 1, **(2005)**, pp. 86–110.
[21] Z. Lu, "Storage allocation in transshipment hubs under certainties", International Journal of Production Research, **(2013)**.
[22] Z. Lu, L. H. Lee and E. P. Chew, "A decision model for berth allocation under uncertainty", European Journal of Operation Research, vol. 212, **(2011)**, pp. 54-68.
[23] Z. Lu and D. F. Chang, "A bi-objective model for robust berth allocation scheduling", Computers & Industrial Engineering, vol. 63, **(2012)**, pp. 262-273.
[24] M. Golias, I. Portal, D. Konur, E. Kaisar and G. Kolomvos, "Robust berth scheduling at marine container terminals via hierarchical optimization", Computers & Operations Research, vol. 41, **(2014)**, pp. 412-422.
[25] X. L. Han, Z. Q. Lu and L. F. Xi, "A proactive approach for simultaneous berth and quay crane scheduling problem with stochastic and handling time", European Journal of Operational Research, vol. 207, **(2010)**, pp. 1327-1340.
[26] B. H. Cai, S. D. Huang, D. K. Liu and G. Dissanayake, "Rescheduling policies for large-scale task allocation of autonomous straddle carriers under uncertainty at automated container terminals", Robotics and Autonomous Systems, vol. 62, **(2014)**, pp. 506-514.
[27] J. L. He, W. M. Zhang, Y. F. Huang and W. Yan, "An efficient approach for solving yard crane scheduling in a container terminal", Shanghai Jiaotong University, vol. 18, no. 5, **(2013)**, pp. 606-619.

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