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Yard template planning in transshipment hubs under uncertainty

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Abstract: This paper is concerned with yard management in transshipment hubs, where a consignment strategy is often used to reduce reshuffling and vessel turnaround time. This strategy groups unloaded containers according to their destination vessels. In this strategy, yard template determines the assignment of the spaces (subblocks) in the yard to the vessels. This paper studies how to make a robust yard template under uncertain environment, e.g., uncertain arrival time and berthing positions of the arriving vessels. To reduce the potential traffic congestion of prime movers, the workload distribution of subblocks within the yard is considered. A mixed integer programming model is formulated to minimize the expected value of the route length of container transshipping flows in the yard. Moreover, a heuristic algorithm is developed for solving the problem in large-scale realistic environments. Numerical experiments are conducted to prove the necessity of the proposed model and also validate the efficiency of the proposed algorithm.

Keywords: Transportation; Port operation; Yard template; Transshipment hubs; Container terminals; Yard management.

1. Introduction

Container terminals can be categorized into two types: gateway ports, which are mainly for import and export activities; and transshipment hubs, where transshipment of containers is the major activity. Some of the mega container terminals around the world are transshipment hubs, e.g., Singapore, Hong Kong. This paper focuses on a port operation problem in transshipment

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hubs, as the transshipment has become more and more important in terminals around the world. This trend is expected to continue especially when ocean liners are using larger vessels and visiting only fewer ports. Hence, the study on managing transshipment activities will become even more important in the future.

The yard template is a concept applied in transshipment hubs that utilize the consignment strategy. This strategy stores export and transshipment containers, which will be loaded onto the same departing vessel, at the same assigned storage locations. The yard template planning is concerned with the assignment of storage locations (subblocks) in yard to vessels. Some dedicated subblocks are reserved for each vessel. The yard template planning aims to minimize the route length of container flows from their incoming berths to the storage subblocks in the yard and then to their outgoing berths.

The most of studies on yard template planning are based on a deterministic environment with respect to berthing positions and berthing time for vessels. However, there are a lot of uncertain factors, e.g., the deviation of vessels' arrival time from their expected time. These uncertainties will result in: (1) the changes of berthing positions for vessels, which may incur the increase of total length of transportation routes if the previously determined yard template is used; (2) the changes of berthing time for vessels, which may incur the uneven workload distribution within the subblocks in yard. Yard template planning belongs to a tactical level decision in ports. Once determined, it is hard to change in the planning horizon. This paper investigates how to obtain a robust yard template under uncertain berthing time and berthing positions of vessels. A mixed integer programming model is developed. Moreover, a meta-heuristic approach is proposed for solving the above problem in large-scale realistic environments. Numerical experiments are conducted to validate the effectiveness and efficiency of the proposed method.

2. Literature review

For an introduction to the general terminal operations, we refer readers to the review work given by Vis and de Koster (2003), Steenken et al. (2004), Stahlbock and Voß (2008). This paper is related to the strategies of allocating storage space in yard to arriving containers. Chen (1999) investigated the major factors that influence operational efficiency and cause unproductive container movements in the yard. Kim and Kim (1999) proposed a segregation strategy to allocate storage space for import containers. Kim et al. (2000) designed a methodology to determine the storage location of arriving export containers by considering its weight. Zhang et al. (2003) studied a storage allocation problem by a rolling horizon approach. Murty et al. (2005) developed an online dispatching procedure for assigning containers to storage blocks. Kozan and Preston (2006) proposed an iterative search algorithm for the integrated container transfer and allocation model to determine the optimal storage strategy. Different from the above studies, the yard management in this paper is based on a consignment strategy, which was studied by Chen et al. (1995), Davies and Bischoff (1999), Scheithauer (1999), and Dekker et al. (2006). This strategy attempts to store containers with the same destination vessel together in some dedicated storage area. The yard template is related to the assignment of storage area to arriving vessels. The concept of yard template was first mentioned in a paper by Moorthy and Teo (2006), but their study mainly focused on the berth allocation planning. Our research team extended the above work, and developed an integrated model for berth allocation planning and yard template planning (Zhen et al., 2011b). A heuristic algorithm was developed for solving the problem in large-scale realistic environments.

For the yard management problem, various studies were conducted, e.g., Kim and Kim (2002), Kim and Park (2003), Preston and Kozan (2001), Zhang et al. (2003). These papers do not sufficiently address the particular needs of transshipment hubs, but more on general terminals which emphasize on import and export activities. Nishimura et al. (2009) investigated the storage arrangement of transshipment hubs. An optimization model is proposed to minimize the sum of the handling time for transshipment containers flow and the waiting time for feeders. Lee et al. (2006) studied the yard storage management problem

particularly for transshipment hubs. A high-low workload balancing protocol was used to reduce the potential traffic congestion of prime movers. They also extended their work in Han et al. (2008) to optimize the yard template and the yard storage allocation simultaneously. This study builds on the research by Han et al., but takes the uncertainties into account.

For the studies on the port operations under uncertainties, the existing literature mainly focuses on berth allocation problems. For example, our research team developed a two-stage decision model for berth allocation under uncertain arrival time and operation time (Zhen et al., 2011a); Han et al. proposed a simulation based genetic algorithm search procedure for berth allocation and quay crane assignment problem with stochastic arrival and handling time (Han et al., 2010). To the best of our knowledge, few scholars have studied the problem on yard template planning under uncertainties. This paper makes an exploratory study in this field.

3. Problem background

Before formulating the mathematical model, we elaborate on the background for the yard template planning problem. The concept of ‘yard template’ is applied in transshipment hubs which utilize the consignment strategy. This strategy stores export and transshipment containers, which will be loaded onto the same departing vessel, at the same assigned sub-blocks. The yard template planning is concerned with the assignment of sub-blocks to vessels. Some dedicated sub-blocks in the yard are reserved for each vessel. The incoming containers that will be loaded onto the vessel V_i in the future are discharged from incoming vessels and placed in the sub-blocks reserved for V_i . When V_i arrives at the terminal, all the containers stored in these dedicated sub-blocks are loaded onto it. This strategy can evidently reduce the number of reshuffles and vessels’ turnaround time.

In Figure.1, under the consignment strategy in the terminal, sub-blocks in the yard are reserved for some vessels. Vessel B arrives at the port, and the dashed lines denote the unloading

process: containers that will be loaded onto other vessels (i.e., Vessel *D* and Vessel *E*) in future are unloaded to the sub-blocks which are reserved for these vessels, i.e., *K21,23,42,45* for Vessel *D*, and *K16,36,38* for Vessel *E*. Meanwhile, the loading process is denoted by the solid lines in Figure.1. All the containers in sub-blocks reserved for Vessel *B* (i.e., *K9,29,48,50*) are loaded onto Vessel *B*.

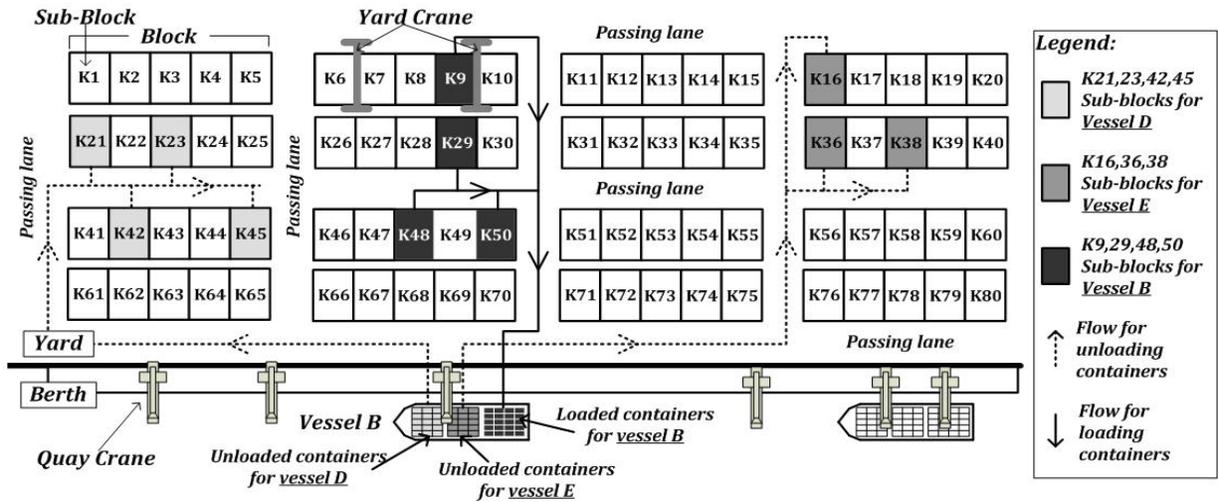


Figure.1 A typical configuration of transshipment terminal

Traffic congestion is a crucial issue in planning the yard template. The traffic congestion may happen when too much workload needs to be handled within a small area at the same time. For example, if there are a lot of container movements in subblocks *K27* and *K47*, then there will be many prime movers (trucks) waiting or moving nearby, which will cause traffic congestion. The pair of *K27* and *K47* could be regarded as neighbor subblocks. Actually, the pairs of (*K27*, *K26*) and (*K27*, *K28*) are also neighbor subblocks. Subblocks are neighbors if they are adjacent, which implies prime movers must use the same passing lane. It should be mentioned that subblocks *K27* and *K7* are not neighbors even though they are back to back. We can define a vicinity matrix to represent the neighborhood relationships between different subblocks.

To ensure smooth flow of traffic, we have some restrictions during the yard template planning: (1) two neighbor subblocks should not have high-workload loading/unloading activities simultaneously; (2) the total workload of the five subblocks within a block should not exceed the maximum capacity of two yard cranes (YCs), as at most two YCs are deployed in each block. Here the workload is measured by the number of loading and unloading containers (in TEUs) handled in a time shift. In this study, four-hour is a time shift. The formulae for calculating the workload of each subblock in each time shift will be elaborated in the next section. In addition, the definition of high-workload, i.e., ranges of high- and low-workload, will also be defined in the next section.

4. Model formulation

Parameters:

V	set of all vessels
K	set of all subblocks
g	group of five subblocks that belong to the same block
G	set of all blocks, i.e., the groups of subblocks g , $g \in G$
n	pair of two subblocks that are neighbors
N	set of all pairs of the neighbor subblocks, i.e., $n \in N$
T	set of all time shifts
Ω	set of all scenarios
B_k	set of subblocks that belong to the same block as Subblock k
$c_{i,j}$	number of containers transshipped from Vessel i to Vessel j
$D_{b,k}^L$	length of the loading route from Subblock k to Berth b

- $D_{b,k}^U$ length of the unloading route from Berth b to Subblock k
- $b_i(\omega)$ berthing position of Vessel i in Scenario ω
- r_i number of subblocks reserved for Vessel i
- h_i length (number of time shifts) of handling time for Vessel i
- $p(\omega)$ probability of Scenario ω
- $\sigma_{i,t}(\omega)$ set to 1 if Vessel i is handled (loading or unloading) in the time shift t in Scenario ω , 0 otherwise
- HL lower bound that a high workload can take, we set $HL = 50$ in this study
- HH higher bound that a high workload can take, we set $HH = 100$ in this study
- LL lower bound that a low workload can take, we set $LL = 0$ in this study
- LH higher bound that a low workload can take, we set $LH = 50$ in this study
- C maximum handling capacity of a YC in a time shift, we set $C = 80$ in this study

Decision variables:

- $x_{i,k}$ set to 1 if Subblock k is reserved for Vessel i , and 0 otherwise
- $\lambda_{i,j}^U(\omega)$ average length of the unloading routes from the berth position for Vessel i to the subblocks reserved for Vessel j in Scenario ω
- $\lambda_i^L(\omega)$ average length of the loading routes from the subblocks reserved for Vessel i to the berth position for Vessel i in Scenario ω
- $W_{k,t}^U(\omega)$ average workload for the unloading activity in Subblock k , in time shift t , in Scenario ω
- $W_{k,t}^L(\omega)$ average workload for the loading activity in Subblock k , in time shift t , in Scenario ω
- $\delta_{k,t}$ set to 1 if the average workload of Subblock k is high in time shift t , and 0 otherwise

Mathematical model:

$$(M_0) \text{ Minimize } Z = \sum_{\omega \in \Omega} p(\omega) \cdot \sum_{i,j \in V} c_{i,j} \cdot (\lambda_{i,j}^U(\omega) + \lambda_j^L(\omega)) \quad (4.1)$$

$$s.t. \quad \lambda_{i,j}^U(\omega) = (\sum_{k \in K} x_{j,k} \cdot D_{b_i(\omega),k}^U) / r_j \quad \forall i, j \in V, \forall \omega \in \Omega \quad (4.2)$$

$$\lambda_j^L(\omega) = (\sum_{k \in K} x_{j,k} \cdot D_{b_j(\omega),k}^L) / r_j \quad \forall j \in V, \forall \omega \in \Omega \quad (4.3)$$

$$\sum_{i \in V} x_{i,k} \leq 1 \quad \forall k \in K \quad (4.4)$$

$$\sum_{k \in K} x_{i,k} = r_i \quad \forall i \in V \quad (4.5)$$

$$\sum_{k \in n} x_{i,k} \leq 1 \quad \forall i \in V, \forall n \in N \quad (4.6)$$

$$W_{k,t}^L(\omega) = \sum_{i \in V} \sigma_{i,t}(\omega) \cdot x_{i,k} \cdot \left(\frac{\sum_{l \in V} c_{l,i}}{r_l \cdot h_i} \right) \quad \forall k \in K, \forall t \in T, \forall \omega \in \Omega \quad (4.7)$$

$$W_{k,t}^U(\omega) = \sum_{i \in V} \sigma_{i,t}(\omega) \cdot \left(\sum_{j \in V} x_{j,k} \cdot \left(\frac{c_{i,j}}{r_j \cdot h_i} \right) \right) \quad \forall k \in K, \forall t \in T, \forall \omega \in \Omega \quad (4.8)$$

$$LL + (HL - LL) \cdot \delta_{k,t} \leq \sum_{\omega \in \Omega} p(\omega) \cdot (W_{k,t}^L(\omega) + W_{k,t}^U(\omega)) \leq LU + (HU - LU) \cdot \delta_{k,t} \quad \forall k \in K, \forall t \in T \quad (4.9)$$

$$\sum_{k \in n} \delta_{k,t} \leq 1 \quad \forall n \in N, \forall t \in T \quad (4.10)$$

$$\sum_{k \in g} \sum_{\omega \in \Omega} p(\omega) \cdot (W_{k,t}^L(\omega) + W_{k,t}^U(\omega)) \leq 2 \cdot C \quad \forall g \in G, \forall t \in T \quad (4.11)$$

$$x_{i,k}, \delta_{k,t} \in \{0,1\}; \lambda_{i,j}^U(\omega), \lambda_j^L(\omega), W_{k,t}^U(\omega), W_{k,t}^L(\omega) \geq 0 \quad (4.12)$$

The objective (4.1) is to minimize the number of transshipped containers multiplied by their transportation route length in the yard. For a group of containers $c_{i,j}$, they are unloaded from the berthing position of vessel i to the sub-blocks reserved for vessel j , and then are loaded from these sub-blocks to the berthing position of vessel j . The average of route length for unloading is $\lambda_{i,j}^U(\omega)$, and the route length for loading is $\lambda_j^L(\omega)$. The calculation of the two λ -variables is given in (4.2-4.3). Constraint (4.4) states that each subblock can be reserved for at most one vessel. Constraint (4.5) is concerned with the number of subblocks that should be reserved for each

vessel. Constraint (4.6) guarantees that neighbor subblocks cannot be reserved for a vessel. The reason is related to the traffic congestion in the yard. According to the consignment strategy, all the subblocks assigned to a vessel will be in loading activities when the vessel arrives at the port. This process may cause very busy traffic flows near the areas, as all the containers stored in these subblocks need to be loaded onto the vessel in a limited period of time. Thus we enforce that subblocks assigned to a vessel cannot be neighbors. Constraints (4.7) and (4.8) state the calculation on the workload of loading and unloading activities respectively, i.e., the average number of loading and unloading containers handled in each subblock in each time shift. Constraint (4.9) ensures that the expected workload of loading and unloading activities in each subblock in each time shift is either high-workload (i.e., $\delta_{k,t} = 1$) or low-workload (i.e., $\delta_{k,t} = 0$). Constraint (4.10) guarantees that two neighbor subblocks should not have high-workload loading/unloading activities simultaneously. Constraint (4.11) limits that the total workload of the five subblocks within a block should not exceed the maximum capacity of two yard cranes (YCs), as at most two YCs are deployed in each block. Decision variables are defined in (4.12).

5. Meta-heuristic for large-scale problems

For the model M_0 , large-scale problem cases are hard to be solved by some commercial software (e.g., CPLEX, LINDO). Thus a meta-heuristic algorithm is suggested to solve the model in the large-scale applications.

The main idea of the meta-heuristic is to obtain an initial solution by relaxing some constraints in the model M_0 . The initial solution may be infeasible for some certain subblocks with respect to the previously relaxed constraints. We set $\{x_{i,k}\}$, which are related to the ‘infeasible’ subblocks, as decision variables, and the remainder $\{x_{i,k}\}$ are fixed with the values as the initial

solution. By solving the model with much less decision variables, we can obtain a feasible solution on the basis of the initial solution. Then we improve the solution by enlarging the scope (number) of decision variables until no improvement is achieved. The detailed flow of the meta-heuristic is addressed as follows:

Step 1: Obtain an initial solution $\{x_{i,k}\}$ by solving a relaxed model with objective (4.1) and constraints (4.2-4.6).

Step 2: Analyze the feasibility of the obtained solution according to constraints (4.7-4.11), if feasible, the obtained solution $\{x_{i,k}\}$ is the optimal solution, otherwise perform the following steps:

Step 2.1: Based on $\{x_{i,k}\}$ and formulae (4.7-4.9), find the set of $\{(n, t)\}$ that violate the constraint (4.10), which means a pair (n) of neighbor subblocks are in high-workload status simultaneously in a time shift (t) ; then record all the subblocks (denoted by a set K^a), which are involved in the obtained subblock pairs.

Step 2.2: Based on $\{x_{i,k}\}$ and formulae (4.7-4.8), find the set of $\{(g, t)\}$ that violate the constraint (4.11), which means a block (g) 's workload in a time shift (t) exceeds the limit of YC capacity; then record all the subblocks (denoted by a set K^b), which are involved in the above obtained blocks.

Step 3: For the subblocks that are not in the set $\{K^a \cup K^b\}$, their assignments (for vessels) are fixed according to the solution $\{x_{i,k}\}$; while, for the subblocks in the set $\{K^a \cup K^b\}$, their assignments are still decision variables. We define a set K^D to denote the set $\{K^a \cup K^b\}$, i.e., $K^D \leftarrow K^a \cup K^b$. Then we solve the original model M_0 with $\{x_{i,k} | k \in K^D\}$ as decision variables, and $\{x_{i,k} | k \in \overline{K^D}\}$ as known data. The model contains much less decision variables than M_0 , so it can be solved easily.

Step 4: Improve the solution by enlarging the set K^D : $K^D \leftarrow EL(K^D, Pct)$; here EL is a function, whose output is the union of K^D and a Pct -percentage of their neighbor subblocks. The Pct -percentage subblocks are randomly selected from all the neighbors of the subblocks in K^D . The parameter Pct is initially set according to the complexity of the model and the capacity of the computer.

Step 4.1: The decision variable set K^D is enlarged by the function $EL(\cdot)$. Then we solve M_0 with $\{x_{i,k} | k \in K^D\}$ as decision variables.

Step 4.2: (1) If the model can be solved, we repeat the above process by randomly selecting another Pct -percentage subblocks. The process is repeated for several times, among the results of which, the set of subblocks that leads to the best result is assigned to K^D . (2) If the model cannot be solved, we could reduce the value of Pct gradually so that the model can be solved.

Step 5: we go on with the enlarging process, i.e., $K^D \leftarrow EL(K^D, Pct)$, until no improvement is achieved, or the model cannot be solved in a limited period of time.

6. Computational experiments

We conduct some experiments to validate the efficiency of the proposed meta-heuristic and the effectiveness of the proposed model. The mathematic models, embedded in the meta-heuristic, are implemented by CPLEX12.1 with concert technology of C# (VS2008) on a PC (Intel Core i5, 1.6G Hz; Memory, 4G).

The planning horizon is one week. Each day is divided into six time shifts of four hours. Hence each week has 42 time shifts. For the yard configuration, an illustrative example is shown in Figure.2. The yard has a length of 1200 m quay, and 32 blocks (160 subblocks). The depth of

each block is six containers (TEU), and the length is 40 containers. Every block is further divided into five sub-blocks, where the length of each sub-block is eight containers. The length of a sub-block is around 50 m. The stacking height is five containers (which we call tier). Thus the capacity of a sub-block is about 240 ($= 6 \times 8 \times 5$) TEUs. The basic unit for yard storage allocation process and yard template planning is at the subblock level. For the width of the passing lanes in the yard, we set it at 30 m. According to the configuration in Figure.2, the loading/unloading route length (i.e., $D_{b,k}^L$ and $D_{b,k}^U$) can be calculated in advance.

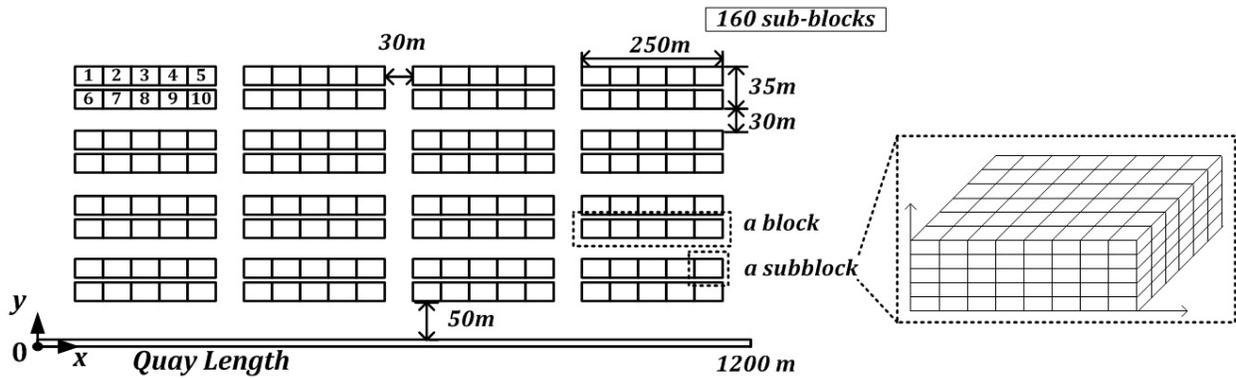


Figure.2 The yard configuration for the test instances

The computational experiments in this study include two parts: the performance analysis on the proposed meta-heuristic, and the numerical investigation on the proposed model M_0 .

6.1 Performance analysis on the proposed meta-heuristics

We conduct some experiments to compare the results obtained by the proposed meta-heuristic and the optimal objective value solved by CPLEX directly. Table.1 shows the results on 31 small-scale instances, in which 20-30 vessels are considered. In Table.1, N and S are the number of vessels and scenarios.

Table.1 Performance comparison between CPLEX and the proposed meta-heuristic

Problems			CPLEX		Meta-heuristic		GAP
<i>Case_ID</i>	<i>N</i>	<i>S</i>	<i>OBJ_C</i>	<i>CPU Time</i> (<i>second</i>)	<i>OBJ_H</i>	<i>CPU Time</i> (<i>second</i>)	$\frac{OBJ_H - OBJ_C}{OBJ_C}$
c20_1	20	30	22165832	490	22167783	123	0.009%
c20_2	20	30	22298904	235	22298904	89	0.000%
c20_3	20	30	22106547	732	22111348	144	0.022%
c20_4	20	30	22357435	598	22360782	137	0.015%
c20_5	20	40	22376888	282	22376888	95	0
c20_6	20	40	22450671	623	22452511	198	0.008%
c20_7	20	40	22723864	452	22726867	156	0.013%
c20_8	20	40	22685870	378	22687248	177	0.006%
c20_9	20	50	out of memory		22591428	316	N.A.
c25_1	25	20	29012516	474	29016545	251	0.014%
c25_2	25	20	29825576	772	29827442	290	0.006%
c25_3	25	20	29536538	483	29540182	159	0.012%
c25_4	25	20	29293257	551	29296576	204	0.011%
c25_5	25	30	29654771	385	29659012	187	0.014%
c25_6	25	30	29716362	354	29717510	261	0.004%
c25_7	25	30	29842755	827	29847274	310	0.015%
c25_8	25	30	29498372	479	29501336	223	0.010%
c25_9	25	40	out of memory		29234926	254	N.A.
c30_1	30	5	35281150	1177	35286247	287	0.014%
c30_2	30	5	34461638	324	34470593	223	0.026%
c30_3	30	5	33966652	313	33969962	211	0.010%
c30_4	30	5	34028872	641	34036592	340	0.023%
c30_5	30	10	35436790	517	35438820	452	0.006%
c30_6	30	10	35426931	662	35430197	386	0.009%
c30_7	30	10	35144732	206	35146429	127	0.005%
c30_8	30	10	35208905	479	35213143	889	0.012%
c30_9	30	15	36123056	397	36124041	270	0.003%
c30_10	30	15	36701284	566	36702313	383	0.003%
c30_11	30	15	35697409	386	35701651	211	0.012%
c30_12	30	15	35923776	454	35929138	302	0.015%
c30_13	30	20	out of memory		36143000	369	N.A.
Average Gap (%)							0.011%

From Table.1, it is noted that the proposed meta-heuristic approach could obtain optimal or near-optimal solutions with comparing the results calculated by CPLEX. The gap between the two results is not evident, and the average gap value is only 0.011%. It implies that the proposed

meta-heuristic approach is an effective method for solving the proposed model M_0 . As to the computing time of two methods, the meta-heuristic method is shorter than the CPLEX method. From Table.1, we observe that CPLEX cannot solve some instances when the number of scenarios exceeds some limits, but the meta-heuristic approach could solve them in the reasonable computing time.

6.2 Numerical investigation on the proposed model

To validate the effectiveness of the proposed model, we compare the model with an intuitive method that makes a yard template according to some rules. The intuitive method makes a yard template in a way as follows: (1) First, we sequence all the vessels according to their priorities. In this study, we use the number of containers that are transshipped to a vessel to reflect the vessel's priority. (2) Then, based on the sequence of vessels, we allocate available subblocks in the yard to the vessels one by one. When allocating subblocks to a vessel, we select the subblock that has the shortest *distance* from the berthing position of the vessel. It should be noted that as the berthing positions of a vessel are different in scenarios, the aforementioned *distance* is the average distance between the subblock and the berthing positions of the vessel in different scenarios. We repeat the selection process until the required number of subblocks (i.e., r_i) has been assigned to the vessel. The subblocks assigned to a vessel should not be neighbors according to Constraint (4.6).

The comparison experiments are performed under different *magnitude of variation* for berthing time and berthing position of vessels. When generate the instances for the experiments, we set a certain berthing time and a certain berthing position for each vessel, denoted by t_i^0 and p_i^0 respectively. Then, the actual berthing time and berthing position for the vessel in different scenarios are randomly generated by following the uniform distributions $U(t_i^0 - Var_T, t_i^0 + Var_T)$,

$t_i^0 + Var_T$) and $U(p_i^0 - Var_P, p_i^0 + Var_P)$ respectively. The aforementioned ‘*magnitude of variation*’ is reflected by Var_T and Var_P . The experiments investigate whether the uncertainty degree (i.e., magnitude of variation) of the berthing time and position influences the final result in the yard template planning.

Table.2 and Table.3 show the results of the comparison experiments under different magnitudes of variation for berthing time (i.e., Var_T) and berthing position (i.e., Var_P), respectively. For each row of the tables, ten test instances are randomly generated according to a certain pair of Var_T and Var_P . The average values of the ten instances results are recorded in each row of the tables. It should be mentioned that the intuitive method cannot guarantee two restrictions are satisfied: two neighbor subblocks should not have high-workload loading or unloading activities simultaneously; and the total workload of the five subblocks within a block should not exceed the maximum capacity of two yard cranes. Therefore we record how many times two neighbor subblocks are in high-workload status simultaneously, and how many times a block’s workload exceed the maximum value in a time shift. The two measures are denoted by ‘ $\#_subblk$ ’ and ‘ $\#_block$ ’ respectively in Table.2 and Table.3.

In Table.2 and Table.3, OBJ_H is lower than OBJ_C , which validates that the proposed model can generate a better yard template than an intuitive way. The average gap of the objective value between them is about 8~9%, which means the proposed model can save the length of container transportation routes by 8~9% than the traditional method. Moreover, the proposed model can balance the workload among blocks and avoid the traffic congestions in some yard areas, which are caused by the high-workload in neighbor subblocks. From the numerical experiments, it is noted that the intuitive method will cause a lot of such situations that some blocks’ workload exceeds limits, and some neighbor subblocks are in high-workload status simultaneously. The frequencies for these two types of situations are about 8~11 and 74~97 times, respectively.

Table.2 Comparison between the proposed model and the intuitive method under different magnitude of variation for berthing time of vessels

Case Scale	Degree of Uncertainty		Proposed Model OBJ_H	Intuitive Method OBJ_U	GAP $\frac{OBJ_U - OBJ_H}{OBJ_H}$	Violations of constraints	
	Var_T	Var_P				#_subblk	#_block
20 Vessels	0	360	20490275	21613976	5.5%	151	12
	1	360	20460765	21558716	5.4%	152	8
	2	360	20366884	21545520	5.8%	124	7
	3	360	20232023	21341815	5.5%	80	5
	4	360	20543706	21463278	4.5%	83	5
	5	360	20636421	21541646	4.4%	82	5
	6	360	20914319	21701257	3.8%	94	6
	7	360	21038086	21746852	3.4%	89	5
	8	360	21098335	21698401	2.8%	103	6
	9	360	21184028	21752358	2.7%	98	9
	10	360	21202962	21591273	1.8%	111	12
25 Vessels	0	360	26733212	29447372	10.2%	153	16
	1	360	26452869	29099251	10.0%	150	17
	2	360	26721287	29355039	9.9%	147	14
	3	360	26931530	29301672	8.8%	102	7
	4	360	27094109	29369912	8.4%	71	8
	5	360	27321653	29283075	7.2%	71	7
	6	360	27801242	29601028	6.5%	73	6
	7	360	28321219	29737867	5.0%	63	7
	8	360	28393846	29834592	5.1%	70	7
	9	360	28443295	29852475	5.0%	59	6
	10	360	28512393	29793454	4.5%	63	8
30 Vessels	0	360	32704762	36847004	12.7%	144	29
	1	360	32785467	37558058	14.6%	145	26
	2	360	32975057	37396099	13.4%	141	24
	3	360	32521666	38116275	17.2%	130	19
	4	360	32940079	37600321	14.1%	89	13
	5	360	33706168	37354290	10.8%	72	11
	6	360	34026383	37982760	11.6%	74	12
	7	360	34303329	38028633	10.9%	58	10
	8	360	34585351	37639827	8.8%	53	10
	9	360	34749274	37832762	8.9%	49	9
	10	360	34835054	37749766	8.4%	47	9
Average					7.8%	97	11

Table.3 Comparison between the proposed model and the intuitive method under different magnitude of variation for berthing position of vessels

Case Scale	Degree of Uncertainty		Proposed Model OBJ_H	Intuitive Method OBJ_U	GAP $\frac{OBJ_U - OBJ_H}{OBJ_H}$	Violations of constraints	
	Var_T	Var_P				#_subblk	#_block
20 Vessels	5	0	18020400	19434208	7.8%	84	4
	5	60	18338297	19791337	7.9%	85	5
	5	120	18828961	20106875	6.8%	84	6
	5	180	19379232	20481362	5.7%	83	6
	5	240	19842120	20813788	4.9%	83	5
	5	300	20138489	21206439	5.3%	82	6
	5	360	20636421	21541646	4.4%	82	5
	5	420	21340056	22191085	4.0%	83	7
	5	480	21871455	22553074	3.1%	77	6
	5	540	22187104	23194206	4.5%	76	5
	5	600	22448115	23533985	4.8%	79	5
25 Vessels	5	0	23605021	26127590	10.7%	47	4
	5	60	24273431	27094633	11.6%	53	6
	5	120	24672066	27245759	10.4%	60	7
	5	180	25402748	28047338	10.4%	67	6
	5	240	26151665	28383205	8.5%	68	7
	5	300	26583522	28798960	8.3%	70	8
	5	360	27321653	29283075	7.2%	71	7
	5	420	28292566	29842302	5.5%	69	5
	5	480	29187685	31262691	7.1%	62	8
	5	540	29739483	31693257	6.6%	53	7
	5	600	30185142	31868973	5.6%	50	6
30 Vessels	5	0	29215680	34857024	19.3%	89	12
	5	60	29490382	35247339	19.5%	93	12
	5	120	29621933	36310330	22.6%	85	11
	5	180	30682574	36798365	19.9%	79	13
	5	240	31795167	37065687	16.6%	72	10
	5	300	32843921	37202351	13.3%	74	9
	5	360	33706168	37354290	10.8%	72	11
	5	420	35232479	38116452	8.2%	70	10
	5	480	36397818	38522973	5.8%	72	12
	5	540	37094722	39587589	6.7%	83	11
	5	600	37496021	39965216	6.6%	80	12
Average					9.1%	74	8

Besides the above implication, some phenomena are observed from Table.2 and Table.3:

(1) The berthing position related uncertainty has more evident influence on the length of container transportation routes than the berthing time related uncertainty. According to the data column of ' OBJ_H ' in the tables, it is observed that when the uncertainty degree (i.e., Var_T or Var_P) increases, the OBJ_H values in Table.3 vary in a more evident way than the values in Table.2. This phenomenon is easily understood because the length of container transportation routes (i.e., the objective of the model) is more dependent on the berthing positions of vessels. When the berthing positions of vessels have a high degree of uncertainty, the obtained yard template may be worsened in the aspect of the length of container transportation routes. If more vessels can arrive at the port on schedule, fewer changes on vessels' berthing positions are incurred during execution of the berth allocation schedule. In this case, the port operators can make a yard template that leads to shorter transportation routes in the yard.

(2) The berthing time related uncertainty has more evident influence on in-yard traffic congestions and block workload balance than the berthing position related uncertainty. The average values of the data columns ' $\#_subblk$ ' and ' $\#_block$ ' in Table.2 are higher than the values in Table.3. This phenomenon is also easily understood as the high-degree uncertainty of vessels' berthing time would cause highly probable occurrences of the workload imbalance, which can incur that some blocks' workload exceeds limits, and some neighbor subblocks are in high-workload simultaneously. Similar as the previous analysis, if more vessels can arrive at the port on schedule, fewer changes on vessels' berthing time is incurred during execution of the berth allocation schedule. In this case, the port operators can make a yard template that leads to less traffic congestions and block workload imbalance in the yard.

(3) With the uncertainty degree increasing, the outperformance of the proposed model fades gradually. According to the data column of ' GAP ' in Table.2 and Table.3, it is observed that

when the uncertainty degree (i.e., Var_T or Var_P) increases, the GAP values decrease evidently. This phenomenon is unexpected and may be hard to explain in a rigorous and theoretical way. This result could tell port practitioners that when the berthing time and positions are extremely stochastic, an elaborately designed model may not have more advantage than some intuitive and random featured methods. However, in the realistic port environments, the uncertainties of vessel arrivals are not very common because the ship voyage routes and port scheduling activities are highly on the basis of some previously determined baseline schedules. Thus the proposed model still has its usefulness in realistic port environments.

(4) With the number of vessels increasing, the outperformance of the proposed model becomes evident. This phenomenon is also validated from the GAP values in Table.2 and Table.3. It implies that the proposed model could illustrate more advantages when facing some larger container terminals, especially transshipment hubs.

7. Conclusions

This paper develops a model for yard template planning problem under uncertainties, which are considered from two aspects, i.e., berthing time (time-dimension) and berthing position (space-dimension). A heuristic algorithm is developed for solving the problem in large-scale realistic environments. Numerical experiments are conducted to validate the proposed model and the heuristic algorithm. By comparing with other scholars' work in this area, the major contribution mainly includes two aspects:

(1) Most of researches on yard template planning concern how to obtain an optimal yard template in a static and deterministic environment. This paper makes an exploratory study on yard template planning under uncertainties. A mixed integer programming model is developed.

Some computational investigations are conducted to analyze the performance of yard template planning process under uncertainties.

(2) The proposed model is hard to solve by some software directly. We propose a meta-heuristic approach for solving the above problem in large-scale realistic environments. Numerical experiments are conducted to validate the effectiveness of the proposed method.

In terms of future research, one possibility is a combination of the yard template planning problem with the berth allocation problem under uncertainties, as these two decision problems are intertwined for port operators. For the integrated problem under deterministic environments, we have conducted an exploratory study (Zhen et al., 2011b). This integrated problem under uncertainties is still an interesting topic. Another possible extension is to link the current model with the yard storage allocation problem. The yard template problem is only to decide which subblocks should be reserved for which vessels, but is not concerned with the decisions about which unloaded containers should be allocated to which subblocks. In addition, the amount of the unloaded containers and the timing of their unloading activities are also the decision variables in the problem. All of the above will be our research directions in the future.

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