Integrated Optimizing of Berth Allocation and Storage Space Assignment in Container Transhipment Terminals

Zigen Chen¹, Qingcheng Zen¹

¹ School of Transportation Management, Dalian Maritime University, Dalian, China, 116026

Abstract

This paper studies the feature of transhipment operation in container terminals. The interrelationship of berth allocation problem and yard space assignment in container terminals is discussed. An integrated optimization model is proposed minimizing operational cost including transportation cost in the yard and penalty cost at the quay. As both berth allocation problem and yard assignment problem are NP-hard, a heuristic algorithm based on genetic simulated annealing algorithm is developed for solving the integrated optimization problem. A Numerical experiment is conducted to validate the proposed model and the heuristic algorithm helpful in reducing operational cost in the terminal management.

Key Words: Berth Allocation; Yard Space Assignment; Genetic Algorithm; Simulated Annealing

1 Introduction

Maritime transportation is an important method of global transportation. With the introduction of containerization and mega-container-ships such as Post-Panamax class and Super-Post-Panamax class, throughput of containers in ports all over the world had been growing rapidly till the subprime lending crisis which caused global economic recession. To reduce cost, mega lane companies began to implement the “hub-and-spoke” system, concentrating on the main lines while leaving the feeder lines to business partners. Thus, more container transhipment occurs in the hub terminals, making them key nodes in the whole logistic system and bringing more challenges to container terminal management.

Terminal operation planning can be divided into two levels: tactical and operational, according to their time frame. The tactical planning gives mid-term or short-term solutions of allocating resource or assigning equipment. Decisions of tactical planning usually come out with the help of highly experienced specialist or more scientific methods of operational research. The operational planning solves real-time detailed problems equipment scheduling, deployment and incident management. This study focuses on the tactical planning as the quality of the decisions in this level affects the efficiency of the terminal greatly. According to the feature of transhipment, this study focuses on the integrated optimization of two operations related to container transhipment: berth allocation and yard assignment.

Berth Allocation Problem (BAP) refers to the problem of when and where to berth a vessel to the quay. With the know conditions of ship length, arrival time, handling speed, etc. and the constraints of the berth position can be occupied by only one vessel at the same time, the solution of BAP has to meet requirement of the practical situation, such as: minimizing make span, minimizing total service time, minimizing total wait time and minimizing deviation from its best berth position, etc. And Yard Assignment Problem (YAP) refers to the problem of which space to store how many containers for a vessel, concerning on minimizing operating cost such as: yard trailers’ route length. It’s worth mentioning that the other end of the route is the vessel’s berth position which is essential in calculating the length of the route. However, in the BAP, the best berth position of a vessel is decided directly by the corresponding yard position for the containers to be loaded or discharged. Furthermore, BAP determines the start time of loading and discharging operation which is the time the corresponding space in the yard to be released or occupied. These two problems are directly interrelated.

In practice, small terminals which have less containers to handle, solve BAP first without considering the best berth position, then assign the yard to their nearest vessels, thus their yards are usually stacked in perfect order. In the mega terminals, where yards are usually fulfilled with containers, yard space sometimes has to be assigned without considering berth position, and the BAP will be adjusted later. However, things come
different in the transhipment hubs. Transhipment containers come along with the vessel at the same time and cause the terminal in a difficult position deciding which one of the two cycle-impacting items should be scheduled first. In this study, we seek an integrated solution for BAP and YAP.

The paper is organized as follow: the next section introduces the literature review. Section 3 introduces the mixed integer program model. Section 4 demonstrates the developed heuristic which is based on genetic simulated annealing algorithm. Section 5 organizes a numeric experiment to illustrate the validity of the proposed model and algorithms and the conclusions of this paper are presented in Section 6.

2 Literature Review


Among the above researches, there are several opinions about vessel handling time: (1) They are known in advance and unchangeable; (2) They depend on the deviation from their berth position to the best berth position; (3) They depend on the number of quay cranes assigned to the vessels;(4) they obey to combinations of (2)(3).

Many studies were conducted on yard storage management in general container terminals, etc.: Kim and Kim (1999, 2002), Kim and Park (2003), Kim et al. (2000), Kozan and Preston (2006), Preston and Koyan (2001), Zhang et al. (2003), and Bazzazi et al. (2009). Few papers concentrate on the transhipment hub terminals, etc.: Lee et al. (2006) focuses on reducing traffic congestion in the yards of transhipment hubs, Nishimura et al. (2009) aims at the minimization of handling time for transhipment containers flow and the waiting time for feeders.

The YAP is a typical operational research problem comparing with the many problems occurred in the yard. When proposing alone, its simplicity draws no attention. However, a recent research trend of integrating quay-side operations and the yard-side ones brings the YAP into our notice. Moorthy and Teo (2006) introduce the concepts of berth template and yard template. Their study focuses on the maximization of service levels indicated by vessels waiting time to meet realistic requirements in the port of Singapore. A robust berth allocation plan is developed integrating BAP and YAP to eliminate the impact from vessels’ late arrival. Cordeau et al. (2007) discuss the Service Allocation Problem (SAP) which is a tactical problem arising in the yard management of a container transhipment terminal and has been proven NP-Hard. The study focuses on minimizing container rehandling operations inside the yard. The SAP is formulated as a Generalized Quadratic Assignment Problem and then is linearized. An evolutionary heuristic is developed to solve large size instances. Zhen et al. (2011) propose an integrated model for the BAP and YAP in transshipment hubs. Their study introduces the factor of quay crane assignment, and sets the handling times related to the number of quay cranes assigned to the vessels. The objective is minimization of the service cost that is incurred by the deviation from vessels’ expected turnaround time intervals, and the operation cost that is related to the route length of transshipment container flows in yard. The model can be solved within a reasonable time by their heuristic which is an iteration of the two interrelated models for BAP and YAP respectively.

This paper follows the trend on integrated optimization of quay-side operations and the yard-side ones. The objective is to minimize the sum of penalty cost from vessels’ delayed departure and yard operational cost related to trailers’ route length. This study seeks a united solution by introducing genetic simulated annealing algorithm.
3 Model

In this section, we first describe the background of the problem. Then independent models of BAP and YAP will be introduced before the final integrated model is proposed.

3.1 Problem background

In container terminals, the handling procedure of transshipment containers is different from those the general import or export containers. The import containers refer to the containers transfer from seaside to landside. After discharged from the vessels, import containers will be trailed to stacking space in the back-side yard far away from the quay where they can wait for the consignees to pick them up. And the export containers refer to the containers transfer from landside to seaside. Export containers are first delivered into the terminals by trailers from the shipping companies, and usually stacked in the front-side yard to accelerate the loading speed of the vessels. The procedure of transshipment ones are like the combination of import and export. After discharged from vessels, transshipment containers will be stacked in the yard before they got loaded onto the other vessel. The point is that both transportation of from and to the yards is carried by trailers of the terminal. And the cost of the transportation is directly decided by the route length. For just one transshipment container, the decision variables would be the berth positions of the two vessels and the stacking position of the container. For the entire terminal, the decision variables would be the berth positions of every vessel and stacking position of every container.

To decide the berth position, concept of the Berth Allocation Problem (BAP) must be involved. Given information of ship lengths and handling times, the BAP decides the berth time and position for each vessel arrival in the future with a specific objective. It is quite similar to rectangular cutting stock problem which widely exists in the industrial application field.

As shown in Figure 1, where rectangles and entire background (or an everlasting rectangles) stands for the berthing ships and the berth resource in the terminal respectively, horizontal lengths represents the physical length while vertical lengths represents the time. With $P_a$, $P_b$ and $P_c$ represent berth positions of vessel A, B and C while $T_a$, $T_b$ and $T_c$ represent berth times of vessels. Solving the BAP will just be like cutting these rectangles out of the background.

In this study, the objective in the bigger picture is the minimization of the operational cost. In spite of the transportation cost related to the trailers’ route length, there may be other costs related to the vessels’ departure time. In practice, according to the common contract signed between shipping companies and the terminals, the vessels don’t have to be berthed as soon as possible after their arrival. The terminals just have to
make sure that handling work of the vessels must be accomplished within an agreed time period recorded in the contracts. In case that the terminals failed finishing handling work before the deadline, penalties related to the length of the delay time have to be paid to the shipping company. Thus, the minimization of that penalty comes into our concern.

The first assumption is about the handling time. As mentioned in the literature review, studies of BAP take different opinions on the handling time of vessels. The handling time is considered unchangeable in this study. For the reason that building costs of quay and quay cranes are much higher than the price of container trailers, when containers’ stacking position is far away from the berth position, terminal managers would rather deploy more trailers into the yards than to keep the quay cranes and the vessels waiting. Thus, the distance between berth position and stacking position should not be related to the handling time. Furthermore, mega-terminals usually equip quay cranes according to its quay length, assuring every 30~50metres having a crane. The shortage of quay cranes usually happens in smaller terminals. As this study focuses on mega transshipment hub terminals, the number of quay crane is considered irrelevant; the quay crane assignment problem is also out of the concern.

The second assumption is related to the way stacking position be dealt with. It is assumed that the transportation cost between the same vessel and the same yard block should be fixed. The precise location inside the block (i.e.: bay, column and tier) is out of the concern, because the trailers route won’t change if a container’s position is switched to another bay or column. Thus, for one container, the decision variable is just which block it should be stacked; for the entire terminal, the decision variable should be the numbers of containers from every vessel to every block.

The third assumptions is that the corresponding stacking space is occupied or released the moment the moment a vessel is berthed. The space stacking containers to be loaded onto a vessel don’t have to remain occupied till the vessel departed. In fact, if the space is occupied shortly after it’s released, working efficiency of the yard crane got boosted as the loading and discharging can be handled simultaneously.

### 3.2 Model of BAP

As shown in Fig. 1, the BAP problem can be formulated as a Rectangular cutting stock problem. Aiming the minimization of penalty cost related to vessels delayed departure, the mixed-integer program model can be formulated with the following notations:

**Parameters:**

- \(i, j, n (=1,2,3, \ldots ) \in V\): set of vessels;
- \(P_i\): berth position;
- \(Q\): quay length;
- \(M\): an enormous number;
- \(L_i\): length of vessel \(i\);
- \(H_i\): handling time of vessel \(i\);
- \(A_i\): arrival time of vessel \(i\);
- \(D_i\): deadline of vessel \(i\);
- \(C_i\): penalty rate of vessel \(i\);

**Intermediate variables**

- \(O_{ij}^b\): \(\begin{cases} 1, & \text{vessel } i \text{ is berthed left of the tail position of vessel } j \\ 0, & \text{else} \end{cases}\)
- \(O_{ij}^o\): \(\begin{cases} 1, & \text{vessel } i \text{ is berthed earlier than the departure time of vessel } j \\ 0, & \text{else} \end{cases}\)
- \(B_i\): \(\begin{cases} 1, & \text{vessel } i \text{ fails to depart before its deadline} \\ 0, & \text{else} \end{cases}\)

**Decision variables**

- \(T_i\): berth time of vessel \(i\);
- \(P_i\): berth position of vessel \(i\)(here refers the head position);
The model is formulated as follow:

\[
\min \sum_{i \in V} C_i \times B_i \times \left( T_i + H_i - D_i \right) \tag{1}
\]

s.t.:

\[
T_i \geq A_i \quad (\forall i \in V) \tag{2}
\]

\[
P_i + L_i \leq P_j + M \times (1 - O^x_{ji}) \quad (\forall i, j \in V, i \neq j) \tag{3}
\]

\[
T_i + H_i \leq T_j + M \times (1 - O^x_{ij}) \quad (\forall i, j \in V, i \neq j) \tag{4}
\]

\[
O^x_{ij} + O^y_{ij} + O^y_{ji} \geq 1 \quad (\forall i, j \in V, i \neq j) \tag{5}
\]

\[
T_i + H_i \leq D_i \times M \times (1 - B_i) \quad (\forall i \in V) \tag{6}
\]

\[
P_i + L_i \leq Q \quad (\forall i \in V) \tag{7}
\]

\[
P_i \geq 0 \quad (\forall i \in V) \tag{8}
\]

\[
O^x_{ij}, O^y_{ij}, B_i \in \{0, 1\} \tag{9}
\]

The objective function to minimize is the penalty cost related to the length of the delayed departure time. Constraint (2) ensures vessels can only berth after they arrived. Constraints (3-5) are the non-overlapping restriction. If the berth positions of vessel i and j are too close, \(O^x_{ij} + O^y_{ij} = 0\) and if vessel i and j are berthed at the same time, \(O^x_{ij} + O^y_{ji} = 0\). Thus constraint (5) guarantees vessels are either berthed far apart or not berthed in the same time. Constraint (6) calculates whether vessels depart later than the deadline. Constraints (7, 8) make sure vessels berth within the quay.

### 3.3 Model of YAP

For the YAP part, assuming the berth allocation problem already settled and berth sequence known, model is proposed with objective of minimizing container transportation cost between quay and yard. There are two constraints need to be subjected to: (1) the number containers stacking in any yard block should not exceed its capacity; (2) all containers discharged from vessels should be stacked in the yards.

Additional notations for YAP:

**Parameters**

\[ n = \{1, 2, 3, \ldots\} \in V \quad \text{set of vessels;} \]

\[ k = \{1, 2, 3, \ldots\} \in B \quad \text{set of blocks;} \]

\[ X^k_i \quad \text{number of export containers to vessel i and already stacked in block k;} \]

\[ C(p, k) \quad \text{transportation cost rate between berth position p and yard block k;} \]

\[ Q_i \quad \text{berth order of vessel i in the queue;} \]

\[ F_k \quad \text{full stacking capacity of block k;} \]

\[ TS_i \quad \text{total import containers from vessel i;} \]

\[ TW_{ij} \quad \text{total transshipment containers from vessel i to vessel j;} \]

**Decision variables**

\[ S^k_i \quad \text{number of import containers from vessel i and will be stacked in block k;} \]

\[ W^k_{ij} \quad \text{number of transhipment containers from vessel i to vessel j and will be stacked in block k;} \]

A typical integer model is formulated as follow:
\[
\text{Min: } \sum_{i \in V, k \in B} \left\{ C(P_i, k) \times \left[ S_i^k + X_i^k + \sum_{j \in V} (W_{ij}^k + W_{ji}^k) \right] \right\} \\
\text{s.t.}
\]
\[
\sum_{i \in V, Q_i > n} X_i^k + \sum_{i \in V, Q_i < n} S_i^k + \sum_{j \in V} W_{ij}^k \leq F_k \quad (\forall k \in B) \\
\sum_{k \in B} S_i^k = TS_i \quad (\forall i \in V) \\
\sum_{k \in B} W_{ij}^k = TW_{ij} \quad (\forall i, j \in V)
\]

The objective function to minimize is the transportation cost of containers in the yards, taking all the import, export and transshipment containers into consideration. Constraint (11) ensures the capacity of yard blocks not exceeded. Notice that the time points the yard status changes are the berth time points of the vessels as the third assumption mentioned in Section 3.1. At anytime, the total number of import, export and transshipment containers in each block should not exceed the block’s capacity. Constraints (12, 13) make sure all the discharged containers (both direct import and transshipment ones) will be stocked in the yard. Notice that there might be conflicts in physical meanings in transshipment and berth sequence. For example, in case that vessel A has transshipment containers to vessel B while actually vessel B got berthed first and already departed as we assume the handling time is fixed, the transshipment containers can never be loaded to vessel B before discharged from vessel A. Thus, berthing sequence has to be dealt with elaborately in the integrated model.

### 3.4 Integrated Model

To integrate the models of BAP and YAP, several issues have to be taken care of: (1) Vessels must be berthed in proper order to guarantee that transshipment containers are discharged into the yard before loaded onto another vessel. (2) Berth sequence has to be calculated according to the vessels’ berth time. The integrated model of can be formulated as follow:

\[
\text{min: } \sum_{i \in V} \left\{ C_i \times B_i \times (T_i + H_i - D_i) + \sum_{k \in B} \left\{ C(P_i, k) \times \left[ S_i^k + X_i^k + \sum_{j \in V} (W_{ij}^k + W_{ji}^k) \right] \right\} \right\} \\
\text{s.t.}
\]
\[
\text{constraints (2-9) of the BAP model} \\
\text{constraints (11-13) of the YAP model}
\]
\[
T_i > T_j \quad (\forall (i, j) \in \{(a, b) | TW_{ab} > 0\}) \\
T_i > T_j + \lambda_{ij} \times M \quad (\forall i, j \in V) \\
Q_i = \sum_{j \in V} \lambda_{ij} \quad (\forall i \in V) \\
\lambda_{ij} \in (0,1)
\]

Constraint (14) guarantees the berth order do not violate the transshipment relation. Constraint (15) calculates a matrix a binary intermediate variables: \( \lambda_{ij} \) s. If vessel i is berthed before vessel j, \( \lambda_{ij} = 1 \); otherwise, \( \lambda_{ij} = 0 \). Constraint (16) accumulates the matrix of binaries into a set of integer which is the berth order of each vessel.

### 4 Genetic Simulated Annealing Approach

As mentioned in Section 3.1, the BAP in the study is quite similar to the rectangle cutting stock problem which has been known as an NP-Complete optimization problem essentially reducible to the knapsack problem. Since the YAP is also similar to an NP-Hard problem which is Service allocation problem, the integration of YAP and BAP is definitely NP-Hard. Therefore, to solve the integrated optimization problem in this study, a heuristic based on genetic simulated annealing algorithm is developed.
4.1 Outline of the solution procedure

We apply the genetic algorithm (GA) as the solution framework, as it is widely applied in solving rectangle cutting stock problem. As presented in Fig.1, GA creates new identities by crossover and mutation in each generation and picks up the best one ever found through the entire iteration as the final solution. Although the genetic algorithm can solve the problem in this study as well as solving the typical rectangle cutting stock problem, its efficiency is not satisfactory as matching complicated constraints (such as the ones from YAP) slows its speed in dealing crossover and mutation calculations. Actually, typical GA can do nothing but to create a new identity every time the constraints were not met. The Simulated Annealing (SA) algorithm is introduced to help new identity creating procedures. The participation of SA in processing population initialization is presented in Fig.3 as an example. After genes of the identity were randomly created, SA is applied to help carving the identity feasible to the problem. The detailed procedure of SA is presented in Fig.4. When an identity fails the constraint, SA slightly changes its gene to make a new identity. By comparing deviations of the two identities from the constraints, SA decides whether the new identity will be kept. In case the new identity is closer to meet the constraints, it will be kept with no hesitation. If the new identity is farther, it may still be kept according to a possibility related to the “temperature”. The possibility to accept a worse solution is bigger with a higher temperature, and when the temperature is fixed as 0, SA is reduced to the greedy algorithm.

![Fig.2. Overview Flow Chart](image-url)

![Fig.3. Init Population Flow Chart](image-url)

![Fig.4. S.A. Flow Chart](image-url)

4.2 Genetic Algorithm (GA)

As GA is widely applied in solving NP-Hard problems, we do not discuss its mechanism in detail. Here we introduce the major characteristics:

The chromosome is shown in Fig.5. Same as the decision variables in the model, the chromosome we use need to include information of berth position and time and the stacking assignment in the yard. The sample in Fig.5 shows a schedule plan for three vessels to berth in a terminal with four stacking blocks in the yard. The first three loci represent the berth positions, the next three represent the berth time, the following 12 loci
represent the assignment of direct import container in the yard and the last 8 loci represent the assignment of transhipment containers.

<table>
<thead>
<tr>
<th>Berth Info</th>
<th>Import</th>
<th>Transhipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>Time</td>
<td>Vessel 1</td>
</tr>
<tr>
<td>180</td>
<td>500</td>
<td>260</td>
</tr>
<tr>
<td>50</td>
<td>92</td>
<td>60</td>
</tr>
<tr>
<td>68</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>19</td>
<td>77</td>
<td>25</td>
</tr>
</tbody>
</table>

**Fig. 5 presentation of typical chromosome**

The adaption value is calculated as the objective function proposed in the integrated model. The crossover and mutation operations are organized in two parts: berth part and the yard part with no consideration of the constraints.

### 4.3 Simulated Annealing (SA)

Noticing that the SA processes are all the same in the three procedure of GA (population initialization, crossover and mutation), the purpose of introducing SA is to find feasible solutions to the problem. As shown in Fig. 4, the deviation value from the constraints can easily be calculated according the model. Same as the crossover and mutation operations, the SA is also organized in two parts, because the constraints with physical meanings are independent from each other.

For the berth part, overlapping and boundary-out are the concerns. Using the concept of rectangle cutting stock problem, the deviation value is the area overlapped or outside the boundary. Using the notations in Section 3, the deviation value function for berth part is as follow:

$$\sum_{i,j \in V} (1 - O_{ij}^x - O_{ij}^y) \left[ \min(P_i + L_i, P_j + L_j) - \max(P_i, P_j) \right] \left( 1 - O_{ij}^x - O_{ij}^y \right) \left[ \min(T_i + H_i, T_j + H_j) - \max(T_i, T_j) \right]
+ \sum_{i \in V} |A_i| - T_i
$$

The first line of the formulation is the overlapping area between rectangles and the second line is the outbound area. Notice that $|a|_a = a$ when $a > 0$, otherwise $|a|_a = 0$. And For the yard part, the concerns are the exceeded number in each stack and the difference between total number in yard and on vessels. The deviation value is formulated as follow:

$$\sum_{i \in V} \sum_{k \in B} \left[ \sum_{j \in V, Q_j > n} X_{ij}^k + \sum_{j \in V, Q_{j} < n} S_{ij}^k + \sum_{j \in V, Q_{j} \leq n} W_{ij}^k - F_i \right]
+ \sum_{i \in V} \left[ TS_i - \sum_{k \in B} S_{ik}^k + \sum_{j \in V} TW_{ij} - \sum_{k \in B} TW_{ij}^k \right]$$

The first line of the formulation is the total number of containers over-stacked in each block. The second line is the sum of differences between the number of containers assigned to the yard and the number of containers discharged from vessels. Temperature of each loop is the 95% of the temperature on the last loop. The acceptance possibility obeys to the metropolitan policy. Other detailed features of SA is illustrated in detail.

### 5 Numerical Experiment

For verification and testing, a numeric experiment is organized. The experiment scene is that 6 vessels with 4 pairs having transhipment relations are going to call at a port with 600 meter quay line and 9 blocks available in the yard within the next 40 hours. The transhipment relations among the vessels are $\{(1, 3), (2, 5), (3, 6), (4, 6)\}$. Other detailed information is shown in Table 1.
Table 1: parameters of vessels in the experiment scene

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Vessel Length (m)</th>
<th>Handling Time (h)</th>
<th>Arrival Time (h)</th>
<th>Deadline (h)</th>
<th>Penalty Rate (Yuan/h)</th>
<th>Total import containers (TEU)</th>
<th>Total export containers (TEU)</th>
<th>Total transhipment containers (TEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>170</td>
<td>11</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>460</td>
<td>1250</td>
<td>820</td>
</tr>
<tr>
<td>2</td>
<td>190</td>
<td>12</td>
<td>6</td>
<td>20</td>
<td>420</td>
<td>480</td>
<td>1410</td>
<td>960</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>9</td>
<td>12</td>
<td>23</td>
<td>600</td>
<td>800</td>
<td>590</td>
<td>740</td>
</tr>
<tr>
<td>4</td>
<td>170</td>
<td>11</td>
<td>10</td>
<td>23</td>
<td>350</td>
<td>720</td>
<td>1280</td>
<td>600</td>
</tr>
<tr>
<td>5</td>
<td>290</td>
<td>8</td>
<td>20</td>
<td>36</td>
<td>600</td>
<td>1580</td>
<td>630</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>180</td>
<td>8</td>
<td>23</td>
<td>37</td>
<td>500</td>
<td>1250</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The layout of the yard is shown as Fig. 6. Capacity of each block is 600 TEUs. The cost of transportation is defined as each more block further the trailers have to run, cost increases by 1 Yuan, no matter which direction. For example, the transportation cost from vessel A to block 2 will be set 0 Yuan, meanwhile cost between vessel 1 and block 1 or block 5 will be 1 Yuan per container.

The calculation result is shown in Table 2. Total operation cost is reduced to 27480 Yuan, with vessel 4 departed terminal 6 hours later than its deadline causing penalty 2100 Yuan. Further data digging shows that vessel 4 was berthed far away from all the corresponding stacking space, its transportation cost of 5560 Yuan is the highest among all the vessels.

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Berth position</th>
<th>Berth time</th>
<th>Depart time</th>
<th>penalty</th>
<th>Transportation Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>import</td>
<td>export</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>1160</td>
<td>1680</td>
</tr>
<tr>
<td>2</td>
<td>410</td>
<td>6</td>
<td>18</td>
<td>0</td>
<td>1220</td>
<td>1240</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>12</td>
<td>21</td>
<td>0</td>
<td>1820</td>
<td>1300</td>
</tr>
<tr>
<td>4</td>
<td>530</td>
<td>18</td>
<td>29</td>
<td>2100</td>
<td>2130</td>
<td>2840</td>
</tr>
<tr>
<td>5</td>
<td>140</td>
<td>21</td>
<td>29</td>
<td>0</td>
<td>1640</td>
<td>1210</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>29</td>
<td>37</td>
<td>0</td>
<td>1620</td>
<td>1620</td>
</tr>
</tbody>
</table>

6 Conclusions

This paper proposes an integrated optimization model for berth allocation and yard space assignment in container transhipment terminals. As both berth allocation problem and yard assignment problem are NP-hard, a heuristic algorithm based on genetic simulated annealing algorithm is developed for solving the integrated optimization problem. A Numerical experiment is conducted to validate the proposed model and the heuristic algorithm helpful in reducing operational cost in the terminal management. However, the minimized cost...
doesn’t equal to the maximized efficiency which is the main limitation of this study and also a future study direction.

References


Kozan, E., P. Preston. (2006), Mathematical modelling of container transfers and storage locations at seaport terminals. OR Spectrum 28(4) 519–537.