

Berth Allocation Planning for Improving Container Terminal Performances

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Abstract

This paper proposed an integrated model of combining Berth Allocation Problems (BAP) and Quay Cranes Assignments (QCA). It aims to improve terminal performances by minimizing the total service time and vessel transfer rate, especially for those important customers (vessels). A Two-Level Genetic Algorithm (TLGA) approach was proposed for solving the problems. A number of experiments were conducted, and the results were compared with other 2 common approaches. The comparisons demonstrated the proposed TLGA can achieve the above mentioned objectives, providing better solutions for BAP and QCA in serving more important customers.

Keywords

Terminal, Genetic Algorithm, Berth Allocation Problem, Vessel Transfer

1. Introduction

In maritime transport, when a vessel arrives at a port, it enters in the harbor and waits for mooring at a berth. The location where mooring takes place is known as berth, equipped with quay cranes (QC) performing the loading and unloading operations (Cordeau et al. 2005). A berth plan indicates the berthing location and the berthing time of the incoming vessels. Similar to other scheduling problems, berth plans are usually sensitive to unexpected events, such as bad weather and extra arrival (Heyden et al. 2006). In general practice, a terminal should serve its customers (vessels) in its berth. However, subjected to facilities constraints, the terminal sometimes will transfer some of their customers to other terminals (hereafter called external terminals) to avoid long waiting time induced. Waiting time of a vessel is a crucial indicator as it reflects the efficiency of the terminal (Murty et al. 2005). Although the transfer operation is an advantage to vessels, it induces some drawbacks to the terminal. There are two main operations involved in a container terminal, uploading containers for exportation and unloading for importation. When a vessel is transferred to an external terminal, the containers stored in the original terminal will be required to send to the external terminal for uploading. Meanwhile, the containers after unloaded from the vessel at the external terminal will be required to send back to the original terminal. All these extra transshipments entail huge monetary. These activities may also induce poor terminal performance to the vessels and bad reputation to the customers (Imai et al. 2008).

In reality, some customers are more crucial and critical to terminals because they offer higher container business volumes or have a long-term partnership with the terminal. Since terminals may not be able to provide good service quality to every customer, there will be a bias to those customers whom they believed are important. In this connection, a stable and higher service priority should be provided to this group of customers. In literature, priority is always used to indicate the preference of the terminal to a particular vessel. Most of the studies only considered a single factor, either relationships between the customers and the terminal or volume of containers being served, to decide the vessel priority. However, both factors are important and should be considered simultaneously.

This paper is aiming to maximize the performance of the terminal in term of service quality. In more specific, it aims to minimize the total service time and vessel transfer rate by adequately coordinating the Berth Allocation Problem (BAP) and Quay Crane Assignment (QCA). A Two-Level Genetic Algorithm (TLGA) is proposed for solving the problem. The rest of the paper will be divided into the following sections. Section 2 gives a literature

review in this area. The corresponding problem formulation and the methodology will be described in Section 3. In Section 4, the results will be presented and discussed. Section 5 will conclude the paper.

2. Literature review

BAP is well recognized as the leading problem in terminal operations, involving two main issues (i) how to allocate scarce resources to different vessels, and (ii) when and where a vessel should moor (Steenken et al. 2004; Imai et al. 2007; Wang and Lim 2007). In general practice, it is widely known that many decisions in the operation planning are interrelated, especially the berth allocation planning and the quay crane assignment (Murty et al. 2005). However, in some studies, BAP and QCA have been considered separately. In fact, handling time of vessels required for BAP is based on the number of QC being assigned in the service (Imai 2003). Therefore, they should be considered simultaneously (Liang et al. 2009).

Terminals operate under multiple operation objectives. The most critical performance measure is recognized to be service quality (Monaco and Sammarra 2007). In the literature, there are some evaluation criteria used to measure the terminal performance, such as the total handling time, or the total service time that comprises of waiting time for berthing with handling time required (Imai et al. 2007; Imai et al. 2003; Imai et al. 2001; Nishimura et al. 2001; Mauri et al. 2008). Terminals always want to provide good service quality to all the vessels (Cordeau et al. 2005), meaning a shorter waiting time and a faster handling time (Imai et al. 2007). In some literatures (Imai et al. 2008; Wang and Lim 2007), vessels will be assigned with a maximum waiting time limitation. If the waiting time of the vessel exceeds the limitation, it will be transferred to other terminals for operation. Although this activity can effectively save the waiting time of a vessel, it may induce some extra transshipment between the terminals (Imai et al. 2008). It is a critical task for a terminal operator to achieve a satisfactory trade-off between these factors to provide high service quality.

In practice, many terminals are subject to some constraints, for examples, berth space and number of quay crane. It may be difficult for terminals to provide the same service quality to all the vessels. To determine the services assigned to vessels at a container terminal, Legato and Mazza (2001) pointed out that different service priorities should be given to vessels. Cordeau et al. (2005) and Dai et al. (2008) also mentioned that vessels should not have equal importance, a weighted sum of the vessel service time maybe a better method to reflect the management practice of some terminals. Therefore, priority should be considered to provide a good service quality for important customers.

To define an important customer, in literatures, different researchers have different views on this issue. For instance, some terminals in China may consider small feeder vessels as important customers while some terminals in Singapore give large vessels high priority because they may provide more profit (Imai et al. 2003). Dai et al. (2008) also stated that some particularly important customers may have guaranteed berth-on-arrival service (i.e. within two hours of arrival) in their contract with the terminal. Another stream of research papers defines the important customers by using their relationship with the terminals, for example, long-term partnership (Imai et al. 2008; Wang and Lim 2007; Oliver 2005; Notteboom and Winkelmann 2001; Soppe et al. 2009).

BAP and QCA are widely known to be NP-hard (Park and Kim 2003; Kozan and Preston 1999). It is difficult and complex to solve especially in large-scale dimensions. Many researchers solved NP-hard problem by using different meta-heuristics approach, such as Tabu Search (Cordeau et al. 2005), Simulated Annealing (SA) (Dai et al. 2008; Kim and Moon 2003), and Genetic Algorithm (GA) (Imai et al. 2008; Liang et al. 2009; Nishimura et al. 2001; Kozan and Preston 1999). GA is well known as a practical, robust, effective and widely applied heuristic for solving NP-hard problem with short computation time (Imai et al. 2003). Therefore, GA is employed in this paper for developing the optimization model.

3. Methodology

3.1 Problem formulation

In this section, a mathematical model is presented. The BAP and QCA problems studied in this paper are in the discrete berth layout stream. For each incoming vessel, a fixed arrival time is given. The handling time will be varied based on the number of QCs assigned to the vessel and the QC rate is keep at a constant. In addition, the customers will further be classified into three level types according to their relationship with the terminal. The third

level customers are defined as the most important one, with long-term partnership. The second level customer defines those often used customers, while others are defined as the first level one. In this paper, the importance of a vessel is determined by both their customer level (w_j) with their handling volume (h_j). The objective is to maximize the overall service quality of the terminal as shown in Equation 1.

Notations used for the parameters in the mathematical model are shown in the following:

Input Data:

$(i = 1, \dots, Q) \in B$ set of berth in terminal, where Q is the number of berths in the terminal

$(j = 1, \dots, T) \in V$ set of vessels, where T is the number of incoming vessels

$(k = 1, \dots, T) \in U$ set of service orders

a_j Expected arrival time of the vessel j

h_j Handling volume for vessel j

α_1 Weighting of total service time

α_2 Weighting of total vessel transfer

w_j Weighting of customer level for vessel j

L Wait time limit for all vessels

C Handling volume per each QC hour

M A large number

TQ Total number of QC in terminal

Variables:

b_j Berthing Time of vessel j

s_j Service Time of vessel j

Decision Variables:

x_{ijk} = 1 if vessel j served as service order k at berth i in home terminal, and = 0 otherwise;

t_j = 1 if vessel j is transferred to other terminal for serving, and = 0 otherwise;

y_i Number of QC assigned to berth i

$$\text{Minimize } Z = \sum_{j=1}^T (w_j h_j (\alpha_1 s_j + \alpha_2 t_j)) \quad (1)$$

$$\text{, where } s_j = b_j - a_j + \frac{h_j}{c y_i}$$

Subject to

$$t_j + \sum_{i=1}^Q \sum_{k=1}^T x_{ijk} = 1, \forall j \in V \quad (2)$$

$$\sum_{j=1}^T x_{ijk} \leq 1, \forall i \in B, \forall k \in U \quad (3)$$

$$\sum_{i=1}^Q \sum_{k=1}^T (b_j - a_j + (x_{ijk} - 1)M) \leq L, \forall j \in V \quad (4)$$

$$\sum_{i=1}^Q \sum_{k=1}^T x_{ijk} (a_j + s_j - \sum_{j=1}^T (x_{ijk+1} b_j)) \leq 0, \forall j \in V \quad (5)$$

$$b_j - a_j \geq 0, \forall j \in V \quad (6)$$

$$\sum_{i=1}^Q y_i \leq \text{TQ} \quad (7)$$

$$x_{ijk} \in \{0,1\}, \forall i \in B, \forall j \in V, \forall k \in U \quad (8)$$

$$t_j \in \{0,1\}, \forall j \in V \quad (9)$$

For the BAP, a binary decision variable x_{ijk} is used to define the j^{th} vessel with the service order k at berth i , while a binary decision variable t_j is used to define the j^{th} vessel being transferred. For the QCA, a decision variable y_i is

used to define the number of quay crane being assigned to berth i . Objective (1) minimizes the total service time for vessel berth at home terminal and total number of vessel transfer of the important customers, where the service time is comprised of vessel waiting time and handling time. Constraint (2) ensures every vessel must either be served at a berth either in any order of service at the home terminal or transfer to the other terminal for servicing. Constraint (3) enforces that every berth serves only one vessel at a time. Constraint (4) assures the vessels berthed at terminal should wait less than the waiting time limit. Constraint (5) makes sure the vessel will not berth before the completion of its pervious vessel at the same berth. Constraint (6) ensures no vessel should berth before its arrivals. Constraint (7) ensures that the total number of quay cranes assigned to the berths cannot exceed the total number of quay cranes in the terminal.

3.2 Proposed Two-Level Genetic Algorithm (TLGA)

Berth allocation problem always come with quay crane assignment because they are interrelated. In order to have a good cooperation among them, a Two-Level Genetic Algorithm (TLGA) is proposed. It is capable of solving the two problems simultaneously. TLGA involves two GAs. The GA in the first level, hereafter called 1st level GA, is used to determine the number of quay cranes assigned to a berth. The chromosomes will be individually input to the GA in the second level, hereafter called 2nd level GA, for solving the corresponding BAP. The berth allocation solution determined would then pass back to the 1st level GA. The iterations will stop when it reaches the stopping condition, and the best solution of the vessel schedule with crane assignment will be recorded during the evolution.

Figure 1 demonstrates the encoding and decoding of chromosome in the 1st level GA. The position of each gene represents a berth number, increasing from the left to the right. The value of the gene represents the number of QCs being assigned to that berth. Example in Figure 1 shows 18 QCs being assigned to 3 berths, in which 3 QCs are assigned to Berth 1.

Encoding:	3	4	11								
Decoding:	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px 10px;">Berth</td> <td style="text-align: center; padding: 2px 10px;">1</td> <td style="text-align: center; padding: 2px 10px;">2</td> <td style="text-align: center; padding: 2px 10px;">3</td> </tr> <tr> <td style="padding: 2px 10px;">No. of QC assigned to berth</td> <td style="text-align: center; padding: 2px 10px;">3</td> <td style="text-align: center; padding: 2px 10px;">4</td> <td style="text-align: center; padding: 2px 10px;">11</td> </tr> </table>			Berth	1	2	3	No. of QC assigned to berth	3	4	11
Berth	1	2	3								
No. of QC assigned to berth	3	4	11								

Figure 1: Encoding and decoding of 1st level GA chromosome

The chromosome in the 2nd level GA is used to represent the Vessel-Berth assignment and the service order of each vessel in the assigned berth. A character “0” to represent Q berths. The example in Figure 2 shows 5 vessels allocated to 3 berths, in which Vessel 4 is assigned to Berth 1, while Vessels 2 and 3 are assigned to Berth 2 and so on. The service order is defined from the left to the right. Therefore, in Berth 3, Vessel 1 will be served then Vessel 5. In the case if Vessel 5 has to wait longer than the waiting time limit, it will be transferred to other terminals.

Encoding:	4	0	3	2	0	1	5	0																		
Decoding:	<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px 10px;">Berth</td> <td style="text-align: center; padding: 2px 10px;">1</td> <td style="text-align: center; padding: 2px 10px;">2</td> <td style="text-align: center; padding: 2px 10px;">2</td> <td style="text-align: center; padding: 2px 10px;">3</td> <td style="text-align: center; padding: 2px 10px;">3</td> </tr> <tr> <td style="padding: 2px 10px;">Service Order</td> <td style="text-align: center; padding: 2px 10px;">1</td> <td style="text-align: center; padding: 2px 10px;">1</td> <td style="text-align: center; padding: 2px 10px;">2</td> <td style="text-align: center; padding: 2px 10px;">1</td> <td style="text-align: center; padding: 2px 10px;">2</td> </tr> <tr> <td style="padding: 2px 10px;">Vessels assigned to berth</td> <td style="text-align: center; padding: 2px 10px;">4</td> <td style="text-align: center; padding: 2px 10px;">3</td> <td style="text-align: center; padding: 2px 10px;">2</td> <td style="text-align: center; padding: 2px 10px;">1</td> <td style="text-align: center; padding: 2px 10px;">5</td> </tr> </table>								Berth	1	2	2	3	3	Service Order	1	1	2	1	2	Vessels assigned to berth	4	3	2	1	5
Berth	1	2	2	3	3																					
Service Order	1	1	2	1	2																					
Vessels assigned to berth	4	3	2	1	5																					

Figure 2: Encoding and decoding of 2nd level GA chromosome

The goodness of the chromosomes will be evaluated by fitness function, after evaluation of the chromosomes, the chromosomes in the initial pool will be selected to form the mating pool according to their fitness value. After that, the genetic operations including crossover and mutation would be carried out for the chromosome in the mating pool. Single-point crossover is applied in the 1st level GA and multi-point crossover is applied in the 2nd level GA. For mutation operation, single-point mutation is applied for both 1st and 2nd level GAs.

4. Results and Discussion

The numerical experiments is used to demonstrate the significances of the proposed approach (A) in simultaneously considering customer importance and handling volume to the service quality of the terminal. For comparison, two other approaches are used for benchmarking, hereafter named (B) and (C). In literatures, since one research stream considers only customer importance, approach (B) is created. Similarly, since there is another stream considers only handling volume, approach (C) is created.

Twelve sets of test data are generated in this experiment. The number of vessel $T = 10$, the number of Berth $Q = 3$, and number of QCs = 18. In comparison, it is based on different vessel arrival intervals, which are randomly generated as presented in Table 1 to represent from Loose to Normal to Tight situations. Each interval will have 4 sets of test data generated listed in Data Sets 1 – 12.

Table 1: Vessel arrival intervals

Data Set	Vessel Arrival Interval (R) (min)
1-4	$80 < R \leq 160$
5-9	$40 < R \leq 80$
10-12	$0 < R \leq 40$

It was assumed that no QC breakdown and the average QC rate is 2 minutes, meaning that one QC uses 2 minutes for handling one TEU container. The waiting time limitation at the original terminal is 2 hours. The proposed TLGA is programmed in JAVA language and run on a PC with CPU 1.33GHz and 4GB RAM. The solution pool size (n_1 and n_2) for the 1st and 2nd level GA are both 10. The number of evolutions for the 1st GA is 30, while for the 2nd level GA is 5000. It is long enough to obtain a steady solution.

This paper proposed that important customers are referring to those at high customer level and with large handling volume. The percentage of important customers being served is indicated by a proposed Customer Importance Fulfillment Index (CIFI). Each customer (vessel) will have a value, calculated by its customer level multiplied by its handling volume. CIFI is the total summation of those vessels being serviced. The weighting of the customer level is subjective and can be decided by terminal operator. In this experiment, the weighting of the customer level are set to be $w_1 = 1$, $w_2 = 2$, and $w_3 = 10$. The weighting of the service time and the vessel transfer are set to be $\alpha_1 = 0.1$ and $\alpha_2 = 0.9$ respectively. Figure 3 shows the results of the CIFI for the three approaches. It shows the percentage of fulfillment decreases along when the interval getting tighter in all approaches, meaning that more vessels cannot be served in the original terminal and has to be transferred. However, the proposed approach (A) performs better than other approaches in achieving higher fulfillment. It represents that more important customers defined in this paper can be served.

5. Conclusion

It is difficult to schedule Berth Allocation Problems and Quay Crane Assignments because they are known as NP-hard problems. Since the schedule determines the productivity and profitability of a terminal, it is recognized as one of the critical tasks. In addition, it determines the service quality provided to the customers. In literature, researchers give priority to vessels based on the two main streams (i) customer level, and (ii) customer's handled volume. In this paper, an integrated approach is proposed to consider them simultaneously. To optimize that, a Two-Level Genetic Algorithm (TLGA) is proposed to simultaneously dealing with BAP and QCA. Twelve sets of test data have been created in the experiment to test the significance of the proposed approach and the benefits obtained. Two additional common approaches have been created to compare with the proposed approach, including approach (B) in considering customer level and approach (C) in considering handled volume. The results demonstrated that the proposed approach is able to serve more important customers.

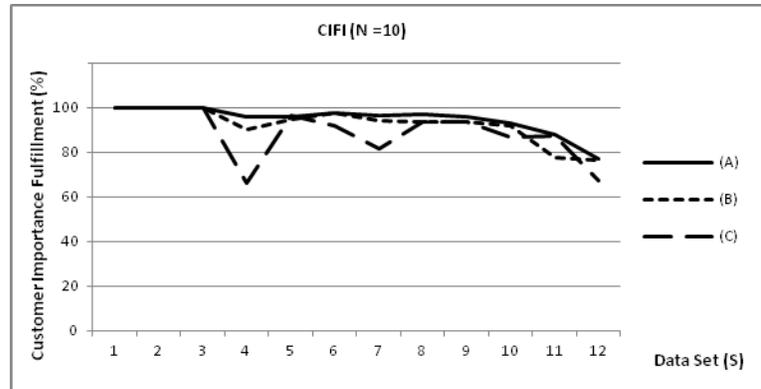


Figure 3: CIFI of 3 approaches in 10 vessels problem

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