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INTEGRATED OPTIMIZING OF BERTH ALLOCATION AND YARD SPACE ASSIGNMENT IN CONTAINER TERMINALS

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Abstract. *In this paper, issues of berth allocation and storage space assignment considering the transhipment operations in container terminals are addressed. Considering the interrelationship between berth allocation and yard space assignment, an integrated optimization model is developed to minimize total operation cost which consists of container transportation cost and vessel delay penalty. To solve the model, a heuristic algorithm based on genetic algorithm and bottom left algorithm is designed, and CPLEX is also applied to solving a decoupled model. Numerical experiments are provided to validate the proposed model and algorithms. Results indicate that the designed algorithm can obtain the berth and storage plan effectively. The integrated optimization model can reduce total operational cost, and provides an efficient method to schedule the transshipment operations in container terminals.*
Keywords: Container terminals, Berth allocation, Yard space assignment, Integrated optimization, Transhipment operations

1. **Introduction.** Containerized transportation played an important role in the global logistic network in the last few decades. To reduce operation cost, lane companies introduced mega-container ships as well as Hub and Spoke (H&S) network. As a result, transhipment operations in hub terminals increased rapidly (from 18% of the total throughput in 1990 to 28% in 2009 according to Drewry Shipping Consultants Report). Complexity of terminal planning also increased as transhipment operation consists of both loading and unloading procedures.

Berth allocation problem (BAP) is always an essential part of terminal operation planning for both loading and unloading procedures. The yard position to hold transhipment containers affects both loading and unloading procedures. Yard space assignment problem (YSAP) emerges.

In many studies of BAP, best berth position of a vessel is determined by the yard space assignment, which is assumed known data before optimizing berth schedule. Meanwhile, studies of yard management usually consider berth position and berth time as input parameters. These two problems are interrelated.

In this study, integrated optimizing of BAP and YSAP is proposed. The paper is organized as follows. In Section 2, a brief review of the previous literature is provided. Section 3 gives the model formulations. Section 4 demonstrates the developed heuristic which is based on genetic algorithm. Numerical experiments are provided in Section 5 to validate the proposed model and algorithms. Conclusions of this paper are presented in Section 6.

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2. Literature Review. Issues related to berth have been receiving much attention. Many models and algorithms have been developed. It was first proposed as discrete berth allocation problem by Lai and Shih [1], Brown et al. [2,3]. Then researchers realized that the berth should be treated as continuous resource and the continuous berth allocation problem is studied by Lim [4], Li et al. [5], Guan et al. [6], Park and Kim [7,8], Kim and Moon [9], Guan and Cheung [10], Imai et al. [11] and Chang et al. [12].

Among these researches, there are different ways dealing with the vessels' 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 depend on both the deviation of berth position and the number of quay cranes.

Liu and Teng [13] proposed a heuristics for rectangle cutting stock problem combining BL-algorithm and genetic algorithm. The problem they studied is similar to continuous BAP without arrival, deadline, best berth position and other features.

Fewer papers discuss the integration of berth allocation and yard management. Hammadi and Diabat [14] studied the integrated optimization of berth and yard for bulk ports. Moorthy and Teo [15] introduced the concepts of berth template and yard template for container terminal. Cordeau et al. [16] considered the integration as a generalized quadratic assignment problem and managed to linearize it. Zhen et al. [17] introduced the factor of quay crane assignment into the integration, and set the handling times related to the number of quay cranes assigned to the vessels. Tao and Lee [18] proposed a multi cluster stacking strategy and a mixed integer quadratic programming model for the joint optimization and considered workload balance.

This paper follows the trend on integrated optimization of quay-side operations and the yard-side ones. The aim of this study is to help port manager reduce operational cost considering not only cost in yard side but also the overdue cost in berth side. A mixed integer program model is proposed minimizing the sum of vessel overdue fee and container transport cost. And a deep integration solution method without feedback looping is developed through the combination of genetic algorithm, BL algorithm and CPLEX.

3. Model Formulations.

3.1. Problem descriptions. In container terminals, the handling procedure is like a combination of both import and export procedures. After discharged from vessels, transhipment containers will be stacked in the yard before they got loaded onto the other vessel. Both transportation from and to the yards is carried out by yard trailers. And the cost of the transportation is directly decided by the route length which depends on the stacking position and the berth positions of both vessels.

The berth position is given by BAP which decides the berth time and position for each vessel arrival in the future. BAP can be treated as rectangular cutting stock problem which is also called two-dimensional cutting stock problem as the quay treated as one dimension and the time treated as the other. Thus, solving the BAP will just be like cutting small rectangles from a large rectangle material. Notice that every vessel has its own schedule. If the terminal fails in the deadline, certain overdue fee has to be paid to the shipping company.

As transportation cost is decided by berth position and yard position, yard space assignment problem should be addressed.

YSAP is a problem of assigning space for a series of vessels. When a vessel is berthed at the terminal, yard space for import containers has to be assigned and occupied. And space for the export containers of this vessel will be released and emptied after its departure. The main constraint in YSAP is the capacity constraint of each yard. And its aim is to minimize transportation cost between yard and quay.

Noticing that BAP and YSAP are interrelated, separately making decisions in either order (BAP first, or YSAP first) can only obtain partial optimization rather than total optimization. This study integrates BAP and YSAP, to minimize the total cost of transport cost and overdue cost simultaneously.

3.2. **Assumptions.** 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, because this study focuses on operation planning in mega-terminals which usually have plenty quay cranes and yard-trailers.

The second assumption is that the transportation cost per container between the same berth position and the same yard block is fixed. The cost is mainly decided by the trailers route. When the precise stacking position is modified inside the block, the trailers route will stay the same. Thus the decision variable in YSAP should be number of contains from each vessel to stack in each block.

The third assumption is that the corresponding stacking space is occupied or released the moment the moment a vessel is berthed. The space for import containers has to be occupied before stacking in, meanwhile space for export containers does not have to remain occupied till the vessel departed, because the loading and unloading procedures can be dealt simultaneously with multiple yard cranes.

3.3. **Mathematical model.** The parameters will be noted as the following: QL represents quay length; M represents an enormous number; L_i represents the length of vessel i; H_i represents the handling time of vessel i; A_i represents the arrival time of vessel i; D_i represents the deadline of vessel i; OC_i represents the overdue fee rate of vessel i; X_i^k represents the number of export containers from block k to vessel i; TC_{pk} represents the transportation cost rate from berth position p to yard block k; F_k represents the full stacking capacity of block k; TS_i represents the total import containers from vessel i; TW_{ij} represents the total transhipment containers from vessel i to vessel j.

The decision variables are T_i, P_i and S_i^k. They represent berth time of vessel i, berth position of vessel i and number of import containers from vessel i and will be stacked in block k respectively. B_i^+ is also variable and represents the overdue time of vessel i. Several binary variables are also needed. If vessel i is berthed left to the tail position of vessel j, $OH_{ij} = 1$, else $OH_{ij} = 0$. If vessel i is berthed earlier than the departure time of vessel j, $OV_{ij} = 1$, else $OV_{ij} = 0$. If vessel i is berthed earlier than vessel j, $\lambda_{ij} = 1$, else $\lambda_{ij} = 0$. If vessel i is berthed at quay position p, $BA_{ip} = 1$ else $BA_{ip} = 0$.

The integrated model can be formulated as follows:

$$\min \sum_{i \in V} \left\{ C_i \times B_i^+ + \sum_{k \in B} \left\{ TC_{pk} \times BA_{ip} \times \left[S_i^k + X_i^k + \sum_{j \in V} \left(W_{ij}^k + W_{ji}^k \right) \right] \right\} \right\} \tag{1}$$

$$\text{s.t. } T_i \geq A_i,\ \forall i \in V \tag{2}$$

$$P_i + L_i \leq P_j + M \times (1 - OH_{ij}),\ \forall i, j \in V,\ i \neq j \tag{3}$$

$$T_i + H_i \leq T_j + M \times (1 - OV_{ij}),\ \forall i, j \in V,\ i \neq j \tag{4}$$

$$OH_{ij} + OH_{ji} + OV_{ij} + OV_{ji} \geq 1,\ \forall i, j \in V,\ i \neq j \tag{5}$$

$$T_i + H_i \leq D_i - B_i^+,\ \forall i \in V \tag{6}$$

$$P_i + L_i \leq QL,\ \forall i \in V \tag{7}$$

$$P_i \geq 0,\ \forall i \in V \tag{8}$$

$$\sum_{i \in V} X_i^k \lambda_{in} + \sum_{i \in V} S_i^k \lambda_{ni} + \sum_{i \in V} \sum_{j \in V} W_{ij}^k \lambda_{in} \lambda_{nj} \leq F_k,\ \forall k \in K,\ \forall n \in V \tag{9}$$

$$\sum_{k\in K} S_i^k = TS_i,\ \forall i \in V \tag{10}$$

$$\sum_{k\in K} W_{ij}^k = TW_{ij},\ \forall i,j \in V \tag{11}$$

$$T_i > T_j,\ \forall (i,j) \in \{(a,b)\,|TW_{ab} > 0\} \tag{12}$$

$$T_i > T_j - \lambda_{ij} \times M,\ \forall i,j \in V \tag{13}$$

$$\sum_{p=1}^{QL} BA_{ip} = 1,\ \forall i \in V,\ p \le QL \tag{14}$$

$$\sum_{p=1}^{QL} (p \times BA_{ip}) = P_i,\ \forall i \in V \tag{15}$$

$$OH_{ij},\ OV_{ij},\ \lambda_{ij} \in (0,1)\,,\ \forall i,j \in V \tag{16}$$

$$T_i, P_i, B_i^+ \ge 0,\ \forall i \in V \tag{17}$$

$$S_i^k,\ W_{ij}^k \in Z^+,\ \forall i,j \in V,\ \forall k \in K \tag{18}$$

$$BA_{ip} \in (0,1)\,,\ \forall i \in V,\ p \le QL \tag{19}$$

The objective function to minimize is the sum of overdue fee and transport cost. Constraint (2) ensures vessels can only berth after they arrived. Constraints (3)-(5) are the non-overlapping restriction. If the berth positions of vessels i and j are too close, $O_{ij}^x + O_{ji}^x = 0$ and if vessels i and j are berthed at the same time, $O_{ij}^y + O_{ji}^y = 0$. Thus constraint (5) guarantees vessels are either berthed far apart or not berthed at the same time. Constraint (6) calculates vessels' overdue time. Constraints (7) and (8) make sure vessels berth within the quay. Constraint (9) 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. The total number of import, export and transhipment containers in each block should not exceed the block's capacity. Constraints (10) and (11) make sure all the discharged containers (both direct import and transhipment ones) will be stocked in the yard. Constraint (12) guarantees the berth order do not violate the transhipment relation. Constraint (13) calculates the intermediate binary variable λ_{ij}. Constraints (14) calculate the intermediate variable BA_{ip}.

4. **Solution Procedure.** As mentioned in Section 3.1, the BAP in the study is quite similar to the rectangle cutting stock problem which is an NP-complete problem. To solve the problem, a method based on genetic algorithm (GA) and bottom left algorithm (BL) is designed. Detailed procedure is shown in Figure 1.

For a randomly generated berth order by GA, BL algorithm is used to obtain the complete berth plan (including berth position and berth time). Because the handling time of vessels is known, getting berth time means getting overdue cost. The transport cost is calculated by CPLEX with information of berth order and berth position.

4.1. **BL algorithm.** Bottom left algorithm (BL) is first proposed to solve typical rectangle cutting stock problem. The idea is to cut rectangles one by one out of the large rectangle, and each rectangle's location should obey the "Bottom First and Left First" rule.

Given any cutting order BL-algorithm output the detailed cutting plan in the rectangle cutting stock problem. The most straight-forward way to solve the cutting problem is to enumerate all cutting order and input them into BL-algorithm to get detailed cutting plan for evaluation. However, the number of enumeration increases exponentially with the count of rectangles. Genetic algorithm will be applied to increasing the efficiency of BL algorithm.

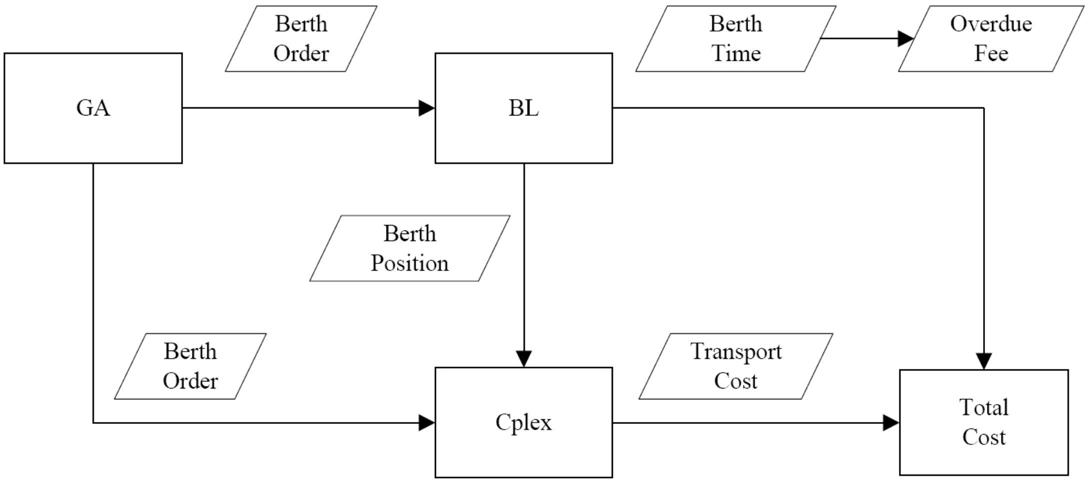

Figure 1. Overview of flow chart

4.2. **Procedures of GA.**

(1) Chromosome

As the chromosome of GA represents berth order of each vessel, integer string representation is used. Each locus represents a vessel while the number represents its berth order. An example is shown in Figure 2, in which the first berthed vessel is Vessel 6 for its number is 1, the second is Vessel 11, and the third is Vessel 1.

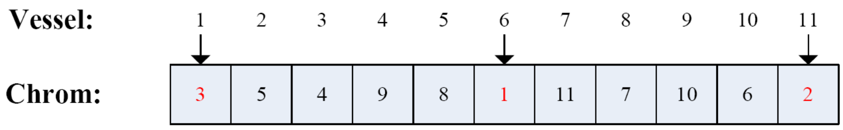

Figure 2. Presentation of chromosome

(2) Crossover

To keep the feasibility, the crossover operation is performed in the single crossover manner. Figure 3 shows a typical example of creating offspring by crossover.

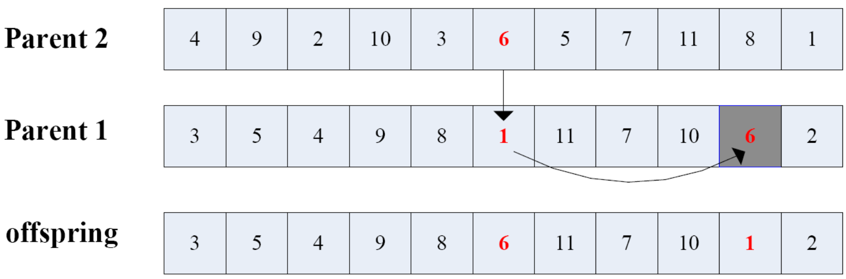

Figure 3. Presentation of crossover procedure

(3) Mutation

Mutation follows the same idea of crossover. After the number of a locus is changed, find the other locus having the same number and change it with the original number. The difference with crossover is that the change number is randomly generated rather than from the other parent.

4.3. **Obtaining yard space assignment by CPLEX.** With the GA and BL giving berth plan information, the yard space assignment model can be decoupled from the main model as follows:

$$\text{Min:} \sum_{i\in V,\, k\in B} \left\{ TC_{P_i k} \times \left[S_i^k + X_i^k + \sum_{j\in V} \left(W_{ij}^k + W_{ji}^k \right) \right] \right\} \tag{20}$$

$$\text{s.t.} \sum_{i\in V,\, Q_i>n} X_i^k + \sum_{i\in V,\, Q_i\le n} S_i^k + \sum_{i\in V,\, Q_i\le n} \sum_{j\in V,\, Q_j\ge n} W_{ij}^k \le F_k,\ \forall k\in B,\ \forall n\in V \tag{21}$$

$$\sum_{k\in B} S_i^k = TS_i,\ \forall i\in V \tag{22}$$

$$\sum_{k\in B} W_{ij}^k = TW_{ij},\ \forall i,j\in V \tag{23}$$

where X_i^k, Q_i, P_i, TS_i, $TC_{P_i k}$ and TW_{ij} are input data, and S_i^k, W_i^k are decision variables. Q_i is the berth order of vessel i and is given by the GA chromosome. Though the variables are integral, the structure of this model (18), (20)-(23) makes it easily solvable through branch-and-bound strategy. Thus we leave this model to CPLEX to solve.

5. **Numerical Experiments.** Numerical experiments are conducted to validate the proposed solution procedure which was programmed by C#.net VS2012 on a PC (Intel i3 2.3GHz, 4GB memory).

5.1. **Data setting.** Usually, the planning horizon of BAP is week. As the integrated optimization considers yard space which changes quickly, and the real rush hour of terminal is usually on weekends, the schedule period of the numerical experiments is set to 48 hours. Vessels in the experiments are distinguished with three classes: feeder, direct liner and main liner vessels. These vessels differ in several specifications as shown in Table 1.

TABLE 1. Parameters of the experiments

Class	Percentage	Length	Handling Time	Transhipment Containers	Import Containers
Feeder	50%	100-250m	6-8h	300-500 or 0	300-400
Direct Liner	30%	200-300m	8-10h	200-400 or 0	800-1200
Main Liner	20%	250-400m	10-12h	600-1500	400-600

Experiments were conducted in two scenes: medium terminal (12 vessels, 6 × 3 yard blocks, 1400m quay) and larger terminal (16 vessels, 8 × 3 yard blocks, 1800m quay). Each block has 30 bays, 5 columns and can stack up to 4 tiers. Thus maximum capacity of each yard block is 600 TEUs (twenty-foot equivalent unit).

5.2. **Convergence through generation.** Firstly, experiments in medium terminal scene are conducted to test the convergence of the proposed algorithm. The population was set to 50, and max generation was set to 20. Figure 4 shows the best and the average adaption values in the first 10 generations.

We can conclude that the algorithm can effectively optimize the integrated schedule problem. The best solution was found in the 6th generation, and then average adaption value of entire population is just 8% above the best solution. As generations after the 6th did not get better solution but just made the average nearer to the best found solution. To save computing time, we set an additional stop condition: when the difference between best and average adaption value is lower than 10%, iteration stops.

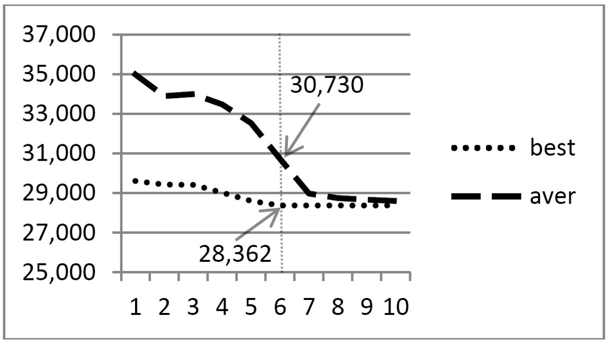

Figure 4. Adaption values in the first 10 generations

5.3. **Solution quality and computation speed.** Comparative experiments are conducted to test the solution quality. We introduce the separated solution for comparison which solves BAP and SAP separately. Thus the separated solution gives lower bound of the integrated solution. 10 experiments in both medium and large terminals scenes are conducted. Table 2 shows the result comparison and speed of the integrated solution.

Table 2. Results of integrated model and separated model

ID	Objective Value			Time (s)	ID	Objective Value			Time (s)
	Separated	Integrated	Gap	Integrated		Separated	Integrated	Gap	Integrated
Med_1	30152	28362	6.31%	142	Large_1	49512	40942	20.93%	318
Med_2	29741	28602	3.98%	154	Large_2	42354	38451	10.15%	331
Med_3	28496	26183	8.83%	141	Large_3	42818	41617	2.89%	297
Med_4	33584	29546	13.67%	128	Large_4	44981	40973	9.78%	345
Med_5	20104	18796	6.96%	122	Large_5	43514	42210	3.09%	336
Med_6	24656	24656	0%	168	Large_6	41983	39541	6.18%	401
Med_7	27414	26848	2.11%	162	Large_7	45641	39696	14.97%	247
Med_8	33180	28479	16.51%	158	Large_8	51920	45151	14.99%	188
Med_9	33042	27057	22.12%	142	Large_9	48413	37162	30.28%	423
Med_10	29501	28015	5.30%	138	Large_10	46748	38245	22.24%	405
Average	28987	26654	8.75%	146	Average	45788	40399	13.5%	329

Average gaps between the integrated optimization and the separated ones are 8.58% and 13.55%, for medium and large terminal scenes respectively. And the max gap of larger terminal scene (30.28%) is also bigger than that of medium terminal scene (22.12%). Thus, we can conclude that the larger the port is, the better the integrated solution severs.

Meanwhile, when more vessels involved, total computation time raised rapidly (Cases were conducted that when solving 30+ vessels, 50+ blocks, the computation will take more than 20 minutes). However, the speed is acceptable considering schedule period is usually no more than 48 hours and few terminals have quay longer than 4,000m.

6. **Conclusions.** In this paper, a model for integrated optimization of berth allocation and yard space assignment is developed. The model reflects the interrelationship between berth allocation problem and yard space assignment, which helps to decrease the total operation cost and provides an efficient method to schedule the transhipment operations in container terminals. A heuristic based on GA and BL is designed to solve the integrated optimization problem. Numerical experiments indicate that the designed algorithm can solve the model effectively. The computation time is around 5 minutes for large terminals, which indicates that the algorithm can be used to solve practical scheduling. Meanwhile, the integrated model decreases total operation cost compared with method optimizing BAP and YSAP separately.

The developed model supposes that the capacity of each yard zone is pre-determined. However, during the planning horizon, the number of containers stored in each yard zone changes with consignees' pickup and shippers' delivery. Therefore, the dynamic optimization of yard space assignment is needed, which is an interesting topic for further studies.

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