การแก้ปัญหาการจัดสรรท่าเทียบเรือตู้คอนเทนเนอร์ ซึ่งมีลักษณะการเทียบท่าแบบผสมโดยใช้แบบจำลองทางคณิตศาสตร์

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บทคัดย่อ

ปัญหาการจัดสรรท่าเทียบเรือ (Berth Allocation Problem) เป็นกิจกรรมหนึ่งที่มีผลต่อประสิทธิภาพการดำเนินงานของท่าเรือ การจัดสรรท่าเทียบเรือนั้นเป็นการกำหนดตำแหน่งและเวลาในการเทียบท่าให้กับเรือที่เข้ามารับบริการของท่าเรือ ในงานวิจัยนี้ได้พิจารณาท่าเทียบเรือที่มีหลายผู้ใช้ (Multi-User Container Terminals , MUT) โดยศึกษาการวางผังท่าเทียบเรือแบบผสม (Hybrid Layout) โดยพิจารณาลำดับในการเข้าเทียบท่าของเรือและมีวัตถุประสงค์เพื่อลดเวลารวมที่เรือเข้ามาเทียบท่า ทำการกำหนดปัญหาขึ้นมา 3 ขนาดได้แก่ ขนาดเล็ก กลาง และใหญ่ จากการหาคำตอบโดยการคำนวณแม่นตรง (Exact Solution) พบว่าปัญหาขนาดกลางบางปัญหาและขนาดใหญ่นั้นใช้เวลานานและได้คำตอบที่เหมะสม (Local Optimal Solutions)

คำสำคัญ : การจัดสรรท่าเทียบเรือ , ท่าเรียบเรือแบบผสม , ท่าเทียบเรือหลายผู้ใช้

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A Mathematical Programming Model for Hybrid Layout Berth Allocation Problem

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Abstract

Berth allocation problem is the key factor strongly affecting the port performance. Berth allocation generally deals with the berth space and service time assigned to the ships receiving service at the quay. This present research studied the Multi-User Container Terminals (MUT) with hybrid layout and investigated the service order of each ship with the major aim to minimize the total service time. The small, medium, and large problem instances were determined and then solved with the exact solutions method. The results indicated that some medium and large scale problems took long computational time to achieve local optimal solutions.

Keyword: Berth Allocation Problem (BAP), Hybrid Layout, Multi-User Container Terminals

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1. Introduction

Transportation activities have currently played important role in the national economic development. They help facilitate domestic and international distribution of goods, which contributes to increased market share, higher sales revenues, and greater business expansion. Marine transportation is a transportation method that usually encounters the problems of delay in ports and container terminals. However, it has prominent ability to reduce production costs. During production process, raw materials need to be transported from their sources to manufacturing plants. Thus, transporting raw materials in large quantities at a time will effectively save cost in this process. Marine transportation can also reduce transportation costs because its shipping rate is lower than that of other transportation methods. Moreover, it can ensure safety shipping since cargo ships generally travel at low speeds.

Port authority is a significant agency in marine transportation. The port can be divided into two main parts, which are quay and yard. The quay consists of two components, including berth and crane. The berth mainly serves vessels and ships while crane loads and unloads containers. This present research focuses on effective berth allocation that can optimize berth scheduling and reduce waiting time. Berth Allocation Problem (BAP) is relevant to the allocation of berth space and time assignment for each ship according to the primary goals of berth management. [1] suggested that there were generally three types of berth layout, namely discrete layout, continuous layout, and hybrid layout.

When dealing with large scale problems of berth allocation, it is essential to apply computer and technology to find the appropriate solutions. This is consistent with the objective of this research, which is to solve hybrid berth allocation problem with mathematical programming model.

2. Literature Review

This part discuss the previous research related to berth allocation problem in terms of time and position. The input that needs to be considered includes the length of ship (including the space between each ship), estimated arrival time of each ship, and total service time assigned to each ship. There is also a restriction that each ship must be moored in the quay and cannot be simultaneously berthed at the same position. [1] classified berth allocation problem based on spatial constraints into 3 categories: discrete, continuous, and hybrid.

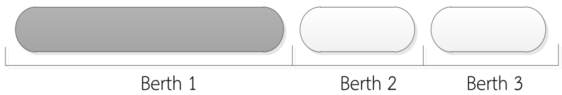

Figure 1. The discrete layout

According to the discrete layout shown in Figure 1, the quay is divided into a set of berths. Only one ship can be served at each single berth at a time.

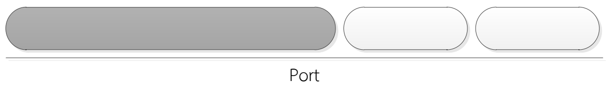

Figure 2. The continuous layout

The continuous layout illustrated in Figure 2 suggests that the quay is not partitioned into berths. A ship can occupy any position on the quay. This continuous layout gives better result than the discrete layout when the same problem is assigned because it can better utilize the quay space.

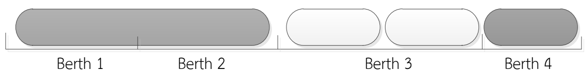

Figure 3. The hybrid layout

As shown in Figure 3, the hybrid layout is similar to the discrete layout. The quay is divided into definitive berths. A ship can occupy multiple berths and a berth can serve more than one ship. [2] studied the continuous berth allocation problem and found that the arrival time of each ship was dynamic. The handling time was found to depend on the position of the ship in the quay. In other words, once the ship was berthed at the appropriate position, the handling time would be considerably reduced. Their study aimed to reduce the total service time of all ships with Lagrangian Relaxation method and to propose the Mixed Integer Nonlinear model to solve the continuous berth allocation problem. [3] also explored the continuous berth allocation problem by using a genetic algorithm. In addition, [4] investigated the continuous berth allocation problem, dealing with dynamic arrival time and fixed handling time, with an aim to assign the position and arrival time of each ship by using Stochastic Beam Search. Later, [5] introduced the research about indented berth allocation, which was considered a hybrid berth layout. The aim of this research was to minimize the total service time, which was waiting time plus handling time, when the arrival time and service time was static. All of the previous research made the researchers interested to further study and develop the mathematical programming model to solve the hybrid berth allocation problem.

3.Berth Allocation Problem Characteristics

The hybrid berth allocation model in this present research was adapted from the model of [2]. The preliminary assumptions and the depth of water were taken into account in order to ensure practical results. The solution of hybrid berth allocation is generally presented in graph format, illustrating berthing time and berthing position of each ship. The horizontal axis shows the start and end of berthing time, whereas the vertical axis shows the number of berths, as can be seen in Figure 4.

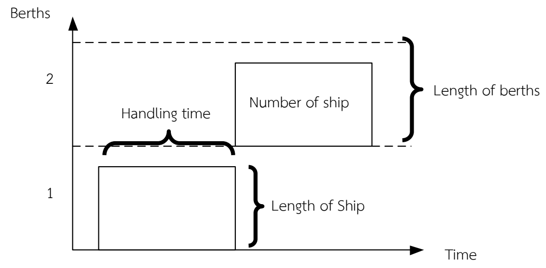

Figure 4. The planning for the ship

3.1 Preliminary Assumptions of Hybrid Berth Allocation

1. Handling time must be assigned by the port
2. A single berth can serve a maximum of two ships. The length of ship should not be longer than the length of berth.
3. The order of arrival times is disregarded. Ships can be simultaneously berthed.
4. One ship can occupy only one berth.
5. Ships are divided into 2 types: small and large. Small-sized ship must be 135 meters long and has a draft of 4 meters. Large-sized ship must be 305 meters long and has a draft of 8 meters. The berth length must be 310 meters with alongside depth of 7 and 8 meters.
6. Equal service time is given to each ship at each berth. The service time is the average time of all tasks, which includes container loading and unloading.
7. There is no entry and exit obstacle that blocks incoming and berthing ships.

3.2 Parameter

$i\ (=1,......,I) \in B$ set of berths

$j\ (=1,......,T) \in V$ set of ships

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

TM a very large number

A_j arrival time of ship j

BL_i length of berth i

L_j length of ship j

S_i time when berth i becomes idle

C_{ij} handling time spent by ship j at berth i

Depth_i the depth of berth

$Drown_j$ the drown of ship

The detail of time for ship service in berths show in Figure 5.

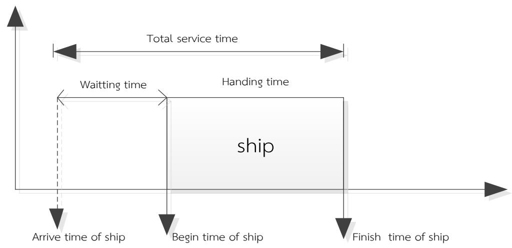

Figure 5. Total service time

The detail of Depth_i and $Drown_j$ while the ship to service in berths. If Depth_i more than $Drown_j$ the ship can service. else ship can't service. that show in Figure 6.

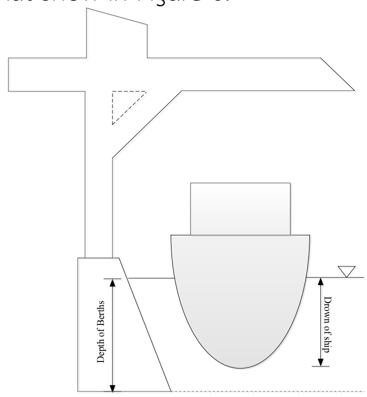

Figure 6. 2D view of the ship to service

3.3 Decision Variables

x_{ijk} { 1 if j is served as the k th ship at berth i; 0 otherwise

$\tau_{ijj'}$ { 1 if both the ships j and j' are served in berth i where j is earlier than j'; 0 otherwise

$\omega_{ijj'}$ { 1 if both j and j' are served at the same time in berth i; 0 otherwise

b_{ij} start time of handling ship j at berth i

f_{ij} completion time of handling ship j at berth i

3.4 Mathematical Model for Hybrid Berth Allocation Problem

$$Minimize\ Servicetime = \sum_{j \in V} \left\{ \sum_{i \in B} \{ f_{ij} - A_j \} \right\} \quad (1)$$

$$\sum_{i \in B} \sum_{k \in U} x_{ijk} = 1 \ \forall j \in V \quad (2)$$

$$\sum_{j \in V} x_{ijk} \le 1 \ \ \forall i \in B, k \in U \quad (3)$$

$$\sum_{j \in V} x_{ijk} \ge \sum_{j \in V} x_{ijk+1} \ \ \forall i \in B, k \in MaxU \quad (4)$$

$$b_{ij} \ge \sum_{k \in U} \max\{S_i, A_j\} x_{ijk} \ \ \forall i \in B, j \in V \quad (5)$$

$$f_{ij} = b_{ij} + \sum_{k \in U} C_{ij} x_{ijk} \ \ \forall i \in B, j \in V \quad (6)$$

$$\sum_{k \in U} k x_{ijk} \le \sum_{k' \in U} k' x_{ij'k'} + (1 - \tau_{ijj'}) TM \ \ \forall i \in B \ \forall j, j' \in V \quad (7)$$

$$b_{ij} \le b_{ij'} + (1 - \tau_{ijj'}) TM \ \ \ \forall i \in B \ \forall j, j' \in V \quad (8)$$

$$f_{ij} < b_{ij'} + (1 + \omega_{ijj'} - \tau_{ijj'}) TM \ \ \forall i \in B \ \ \forall j, j' \in V \quad (9)$$

$$\omega_{ijj'} (L_j + L_{j'}) \le BL_i \ \ \forall i \in B \ \ \forall j, j' \in V \quad (10)$$

$$\omega_{ijj'} \le \tau_{ijj'} \ \ \ \forall i \in B \ \ \forall j, j' \in V \quad (11)$$

$$\sum_{k \in U} (x_{ijk} + x_{ij'k}) - 1 \le \tau_{ijj'} + \tau_{ij'j} \le \frac{\sum_{k \in U} (x_{ijk} + x_{ij'k})}{2} \ \ \forall i \in B \ \ \forall j, j' \in V \quad (12)$$

$$\sum_{j'} \omega_{ijj'} \le 1 \ \ \forall i \in B \ \ \forall j \in V \quad (13)$$

$$\sum_{i \in B} \sum_{k \in U} (\mathrm{Depth}_i - Drown_j) X_{ijk} \ge 0 \ \forall j \in V \quad (14)$$

$$x_{ijk} \in \{0,1\} \ \forall i \in B, j \in V, k \in U \quad (15)$$

$$\tau_{ijj'} \in \{0,1\} \ \forall i \in B \ \ \forall j, j' \in V \quad (16)$$

$$\omega_{ijj'} \in \{0,1\} \ \forall i \in B \ \ \forall j, j' \in V \quad (17)$$

$$b_{ij} \ge 0, \ f_{ij} \ge 0 \ \ \ \forall i \in B \ \forall j \in V \quad (18)$$

Constraints: (1) The minimum service time is equal to the sum of the difference between the minimum service time and the arrival time. (2) Each berth can serve only a single ship in chronological order. (3) Each ship can occupy only one berth at a time. (4) If the service order of any ship is k+1, the previous service order of that ship at the same berth must be k. (5) The time when the first ship starts receiving service must be higher or equal to the maximum of the berth's idle time and the ship's arrival time. (6) The service finishing time should be equal to the sum of the handling time and the service starting time. (7) The service order of ship j must be less than that of ship j' when ship j is served earlier than ship j' at the same berth. (8) The starting time of ship j must be less than the starting time of ship j' if they receive service at the same berth. (9) The finishing time of ship j must be less than the starting time of ship j' if they receive service at the same berth. (10) When two ships simultaneously receive service at the same berth, the total ship length must not be longer than the length of berth. (11) The decision variable must be less than or equivalent to at the same berth, which can occur in 3 cases: 1) two ships receive service at the same time without overlapping service order = 1, = 1, 2) ship j is served earlier than ship j' = 0, = 1, 3) no ship is served at the berth. (12) The decision variables and can occur in 3 cases: 1) ship j is served earlier than ship j', 2) ship j' is served earlier than ship j, 3) no ship is served at the berth. (13) When ship j is served at any berth, only ship j' can be simultaneously served. (14) A ship can be served only when the depth of berth is greater than the immersed volume of the ship. (15) (16) (17) All variables are equal to 0 and 1. (18) The variables and are greater than or equal to 0.

4. Experimental Design and Results

The small, medium, and large problem instances were determined to examine and ensure that the proposed mathematical model is valid and able to solve hybrid berth allocation problem according to the preliminary assumptions of the model. The details are shown in Table 1.

Table 1. Problem instances with different numbers of berths and ships

Problem						
Size	Depth of berth		berths	Number of ship		Ship
	12 m.	7 m.		Big size	Small size	
small	1	2	3	3	5	8
				4	8	12
				5	9	14
medium	3	2	5	6	10	16
				7	11	18
				8	12	20
Large	4	3	7	12	18	30
				14	21	35
				18	27	45

4.1 Procedure

The computer program, called A Mathematical Programming Language (AMPL), was used to find the solution. This program was developed by Fourer et al. [6] to modify a mixed-integer linear programming model. This procedure applied the Branch and Bound technique, which initially dealt with the large scale problem and then divided it into sub-problems. The bounding was also taken into account. The solutions of sub-problems were also compared with the solutions resulting from the simplex method in order to find the sub-problems with the best solutions.

4.2 Results

Considering the results calculated by the computer program, which was set to find the solutions within 16 hours, it was found that the best solutions of small scale problems could be immediately found. On the other hand, it took a long computational time to find the appropriate solutions for the medium and large scale problems.

Table 2. Solutions of the problems

Problem No.	Result (hr.)	Handling time (hr.)	Wait time (hr.)	Solution time (hr.)
1	70(Optimal)	55	15	0.1
2	92(Optimal)	80	12	0.1
3	150(Optimal)	95	55	0.3
4	123(Optimal)	110	13	11.4
5	137(Local)	125	12	16
6	164(Local)	140	24	16
7	279(Local)	210	69	16
8	476(Local)	245	231	16
9	601(Local)	315	286	16

The solution of small scale berth allocation problem with 3 berths and 8 ships can be exemplified in Figure 5. The service time is shown in Table 3.

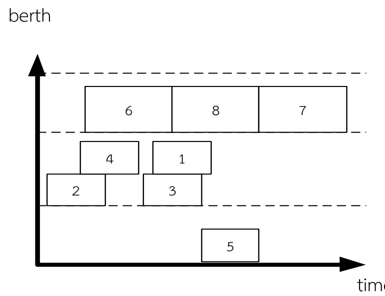

Figure 7. Allocation plan for 3 berths and 8 ships

Table 3. Service time of each ship

Ship	Arrive	Start	Handling time	Finish	Wait time
5	24	24	5	29	0
2	5	5	5	10	0
4	9	9	5	14	0
3	15	15	5	19	0
1	16	16	5	21	0
6	10	10	10	20	0
8	12	20	10	30	8
7	23	30	10	40	7

Table 3 indicates that the berths need to maintain the operations for 70 hours, of which 55 hours are handling time and 15 hours are waiting time. The service order and position of the ships should be assigned according to Figure 7.

5. Conclusions

The mathematical programming model for hybrid berth allocation problem, which was adapted from the original version, could find the solutions and was found to be valid according to the preliminary assumptions and the determined scope of the problem. The Branch and Bound method, one of heuristic approaches, was applied to find the solution. The results showed that the solutions of small scale problems could be found instantly, whereas the medium and large scale problems took longer time to find the solutions than expected. In addition, their best solutions could not be found because the number of decision variables immensely increased.

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