A Knowledge-based System for Berth Allocation in a Container Terminal

Junliang He[1,2,*], Youfang Huang[1], Daofang Chang[1], Weimin Zhang[2]

[1]Engineering Research Center of Container Supply Chain Technology, Shanghai Maritime University,
1550 Haigang Avenue, Shanghai 201306, P. R. China, +86 21 38282674
[2]School of Mechanical Engineering, Tongji University
4800 Caoan Road, Shanghai 201804, P. R. China,
Corresponding author, e-mail: jlhe@shmtu.edu.cn, yhuang@shmtu.edu.cn, dfchang@shmtu.edu.cn,
iamt@tongji.edu.cn

Abstract

Both of berth allocation and quay crane assignment are one of the most complex parts in container terminal operations, which significantly affect the operational efficiency, energy consumption and operational cost of the entire container terminal. Therefore, it is necessary to develop an efficient strategy for integrated berth allocation and quay crane assignment (BACP) from the perspective of knowledge, which aims at energy-saving and improving operational efficiency. In this paper, knowledge acquisition for BACP is initially conducted. And then, knowledge sorting process for BACP, including taxonomic tree generation and organization of acquired knowledge, is performed. After that, rules for BACP are extracted using the IF and THEN clause. Furthermore, a knowledge reasoning mechanism is designed. Finally, numerical experiments are used to illustrate the proposed knowledge-based system and verify the effectiveness and reliability.

Keywords: container terminal, berth allocation and quay crane assignment, knowledge-based system, knowledge sorting process

1. Introduction

As the a hinge between shipping and land transportation, container terminal with high efficiency, low energy consumption and low operational cost, plays more and more important role in the global trade growth. Automotive operation of container terminal requires a high-level intelligent scheduling. The appropriate planning and schedules of quay crane, yard crane, internal truck, berth and yard are the important decisive factors for the energy consumption and efficiency. BACP is one of the most complex parts in container terminal operations, which significantly affects the operational efficiency, energy consumption and operational cost of the entire container terminal. Currently, plenty of researches have been focused on improving the operational efficiency of container terminals, but a few literatures on container terminal operations considering energy-saving. Furthermore, most previous studies are referred to mathematical optimization methods, not the knowledge-based system. To address the abovementioned problem, a knowledge-based scheduling system for BCAP has been developed to enhance the port operation efficiency and reduce the total energy consumption.

BACP includes berth allocation and quay crane assignment. For obtaining then optimal solution, most investigations are using heuristic algorithm, genetic algorithm and other mathematical models, based on integer optimization, dynamic planning, and quadratic programming. However, as a complex NP problem with multiple objectives and factors, BACP problem cannot be solved analytically till now. Recently, knowledge engineering has been successfully used to solve problems with multiple objectives and factors. Due to its optimal adaptive selection among many schemes, it is worth to develop knowledge-based system for resolving BACP. The near optimal solution of BCAP can be obtained in short CPU time based on the novel approach of container terminal operation.

In open literatures, plenty of researches have referred to new operational approaches that can help exert the productivity of terminal. Amongst them, many methods were proposed to solve BACP. Imai et al. proposed a dynamic berth allocation method based on continuous berth

location [1]. Kim et al. tried to find out the berth allocation for the shortest delay of ship departure by using simulated annealing algorithm, respectively [2]. Du et al. developed a model on berth allocation considering energy consumption, and a mixed integer second order cone programming model is employed for overcoming the nonlinear complexity [3]. Guan et al. proposed a heuristic algorithm for berth allocation for the shortest berth time [4]. By using heuristic algorithm & simulation techniques, Chang et al. proposed an integrated container yard and berth allocation scheme [5]. Peterkofsky et al. developed a static quay crane allocation scheme for the shortest delay of arriving & departing [6]. Park and Kim integrated the berth allocation and QC scheduling problem, and employed mixed integer programming model and sub-gradient optimization technique to resolve the integrated problem [7]. Han et al. considered the uncertainties of the arrival time and handling time of the ships, and presented a non-linear programming model [8]. Furthermore, Chang et al. also integrated a berth allocation and QC assignment model based on a rolling-horizon, and developed an objective programming model which is aimed at minimizing berthing location deviation, total penalty and the energy consumption of QCs [9]. Similarly, Meisel et al. developed a construction heuristic, local refinement procedures, and two meta-heuristics to resolve a combined problem of berth allocation and crane assignment in container terminals [10]. Zhou and Kang proposed a combined berth and quay crane allocation model based on the genetic algorithm [11]. However, to our best knowledge, following issues have not been well addressed:

(1) Most previous investigations focus on improving efficiency while ignore the energy-saving

(2) Lacking of high-efficient algorithm for resolving the BACP.

Recently, knowledge-based approach has been as an efficient method for resolving some scheduling problem. Nasution *et al.* proposed a scheduling strategy using their knowledge in the form of linguistic rules to analyze the energy for air conditioning [12]. Chanda *et al.* developed a differential evolution optimization technique based domain knowledge for congestion management cost optimization of contingent power networks [13]. Thereby, a knowledge-based approach for BCAP has been developed in this paper.

2. Problem Description

The operators of a container terminal will determine the berth time, berth location and the number of quay cranes for the arriving ships. The appropriate BACP schedules could reduce the transportation distance during loading & unloading, the serving time and energy consumption. The berth allocation is a discrete dynamic stochastic process which is very important to the overall planning of port operation. Specially, the berth allocation should be properly arranged with a suitable berth length, and should not be conflicted with other ships. The ship can be berthed at the planning location only when the berth length is longer than the length of ship, otherwise it must wait at anchorage. On the other hand, the quay crane assignment is the key factor to determine the loading and unloading time. To improve the operational efficiency to attract more ships, a container terminal must reduce the energy consumption and the total delay of all ship's departure time. The efficient BACP could reduce the total service time and lower the total energy consumption while to satisfy the total loading & unloading tasks.

3. Knowledge-Based System for BACP

Knowledge-based system for BACP includes 4 parts: (1) knowledge acquisition model, (2) knowledge sorting model, rules extracting model and knowledge reasoning model. The procedure is as following, first, to obtain the basic knowledge of BCAP from the related documents and experts, and then find out the relationship among the classified knowledge domains, followed by extracting the allocation/assignment rules from the organized knowledge base for system implementation. Finally, a practical knowledge reasoning model is proposed for a high-efficient, convenient and appropriate schedules based on the extracted rules.

3.1. Knowledge Acquisition Model

To find out the approximated solutions in short CPU time with high efficiency, the knowledge of BACP must be firstly examined in details. Therefore, how to obtain the useful

knowledge from the available sources is especially important, which can be named as knowledge acquisition. Knowledge acquisition is to extract the knowledge from the sources of a specified knowledge domain and convert the extracted knowledge into a certain representation. The source could be domain experts of BACP, or related documents and database. The important steps of knowledge acquisition include collection, interpretation and analysis.

Knowledge acquisition of BACP is a recycle processing, whereas the acquired knowledge could be more comprehensive and effective. Knowledge acquisition includes collection, analysis, modeling, validation and finally the development of collection methodology. The details of knowledge acquisition of BACP are shown as Figure 1.

3.2. Knowledge Sorting Model

Knowledge sorting is needed after knowledge acquisition. In the present study, KSP (Knowledge sorting process) model and algorithm are employed frequently. Generally, the tremendous knowledge extracted from experts and documents is normally ambiguous and large scale. Therefore knowledge sorting is necessary before knowledge representation, which is used to facilitate extracting the effective rules from the source knowledge. Knowledge sorting model of BACP includes the following 2 steps:

(1) Create the taxonomic tree by using the normal general sorting.
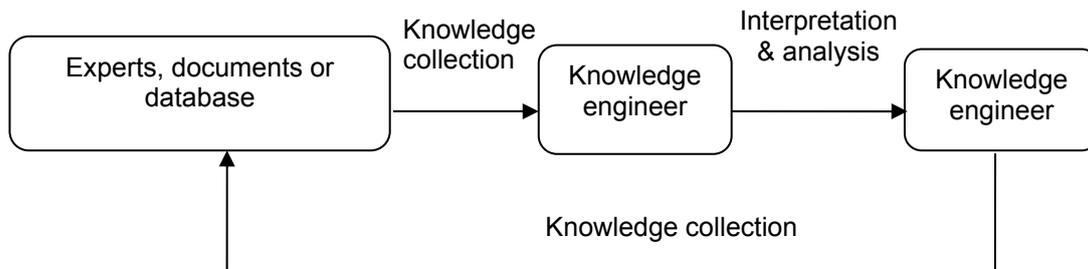(2) Organization the acquired knowledge of BACP.

Figure 1. Recycle processing of knowledge acquisition of BACP

3.2.1. Generation of taxonomic tree

Taxonomic tree can be generated by 3 continuous steps:

(1) Obtain the terms used for BACP. By discussion with experts or reviewing literatures, the basic terms, the serious terms and conceptions used in BACP are obtained.

(2) Sort the terms with certain standards. Classify the obtained terms in details until they cannot be decomposed any further. The combination or separation of the terms of BACP depends on the characteristics or attributes.

(3) Generate taxonomic tree. Based on the general sorting and attributes of the knowledge of BACP, the taxonomic tree is finally generated. A sample taxonomic tree of BACP is shown in Figure 2.

3.2.2. Knowledge Organization

For conveniently extracting the BACP rules, the KSP method is employed for knowledge organization. Three main steps are involved as follows.

Step1: Determine the relationship between the factors and attributes of BACP. The factors and attributes will be determined firstly. The factors mean the basic factor which will influence BACP. The attributes mean the features which affect the final BACP schedules. For a clearly understanding of relations between factor and attributes which influences each other, their relationships are shown in Table 1. The solid circle means the factor affects the attribute while the hollow one means attribute affects factor.
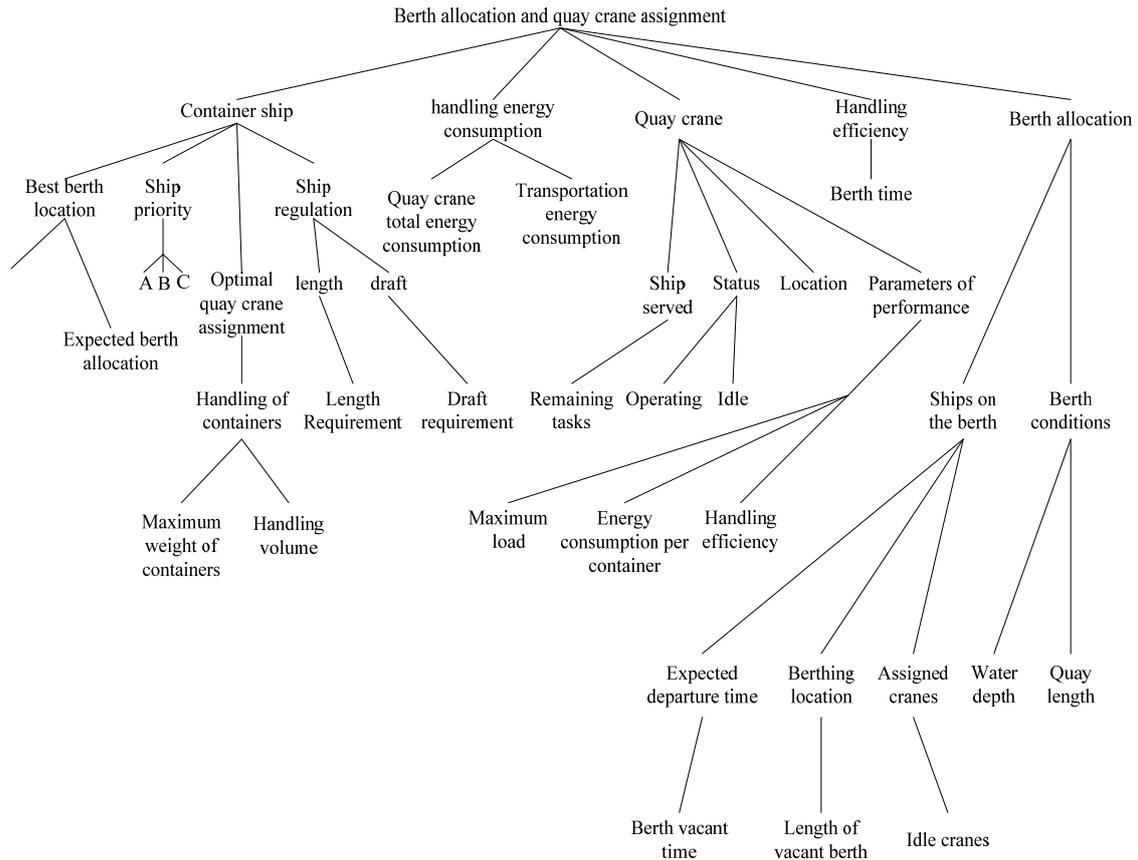
Berth allocation and quay crane assignment

Container ship — handling energy consumption — Quay crane — Handling efficiency — Berth allocation

Best berth location — Ship priority — Ship regulation — Quay crane total energy consumption — Transportation energy consumption — Berth time

A B C — Optimal quay crane assignment — length — draft — Ship served — Status — Location — Parameters of performance

Expected berth allocation

Handling of containers — Length Requirement — Draft requirement — Remaining tasks — Operating — Idle — Ships on the berth — Berth conditions

Maximum weight of containers — Handling volume — Maximum load — Energy consumption per container — Handling efficiency

Expected departure time — Berthing location — Assigned cranes — Water depth — Quay length

Berth vacant time — Length of vacant berth — Idle cranes

Figure 2. Taxonomic tree of BACP

Table 1. Relationships between the factors and attributes of BACP

Factors		BACP schedule				Energy consumption		Efficiency
		Berthing location	Berthing time	Assigned QCs	Handling volume of QCs	Energy of QCs	Transportation energy	Turnaround time
ship	Arrival time	●	●	●				●
	Predicted berth allocation	●				○	○	●
	Ship priority	●	●					●
	Maximum weight of containers			●				
	Handling volume			●	●	●	●	●
	length	●						
	Loading/ unloading draft	●		●				
Berth	Berth length	●						
	Water depth	●						
	Berthing Location	○	○					●
	Predicted departure time	○	○	○	○			●
	Vacant berth	●	●				●	●
	QCs for the			●	●	●		●

QC						
	ship served					
	QC status		●			
	QC location	○	●			
	Max volume of QC		●			
	Energy Consumption per container				●	
	QC efficiency		○			●
	Ship in service		●	●		
	Remaining task of QC		●	●		●

Step 2: Determine the interrelationships between factors of BACP. The triangle relations are further shown in Figure 3. Referring to this table, the information is depicted in a graphical format (Figure 4). It can be seen that Factor 2 and13 (respectively denote the berth allocation and assigned QC for the berthed ship) have more interrelationships with other factors, i.e. Factor 2 and13 will affect more factors. More concerns of the two factors are needed, which also is confirmed by the port operation experts.

Step 3: Determine the relationships between the dependent variables and independent variables of BACP. The two types of variables will be determined firstly. Correlation variables means the variables used to evaluate the performance of BACP while independent variables means the factors influence the BACP schedules. Dependent variables and independent variables are listed in Table 2. Dependent variables will vary with independent variables accordingly. The solid circle means the close relationship between the 2 variable. The more the solid circles the more the influences of independent variables on correlation variables.

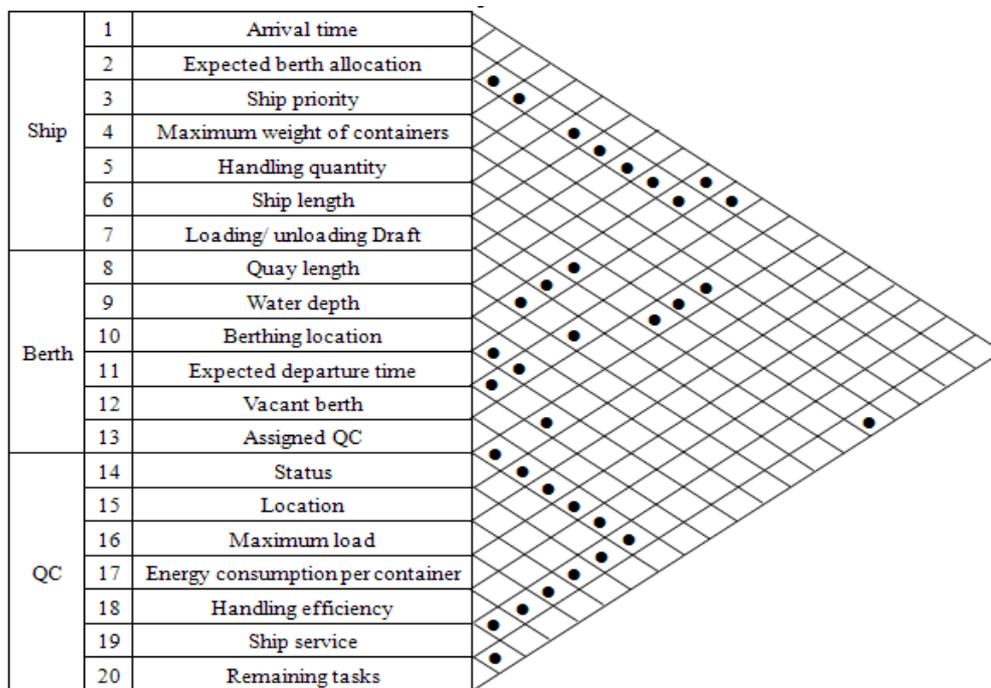|		
Ship	1	Arrival time
	2	Expected berth allocation
	3	Ship priority
	4	Maximum weight of containers
	5	Handling quantity
	6	Ship length
	7	Loading/ unloading Draft
Berth	8	Quay length
	9	Water depth
	10	Berthing location
	11	Expected departure time
	12	Vacant berth
	13	Assigned QC
QC	14	Status
	15	Location
	16	Maximum load
	17	Energy consumption per container
	18	Handling efficiency
	19	Ship service
	20	Remaining tasks

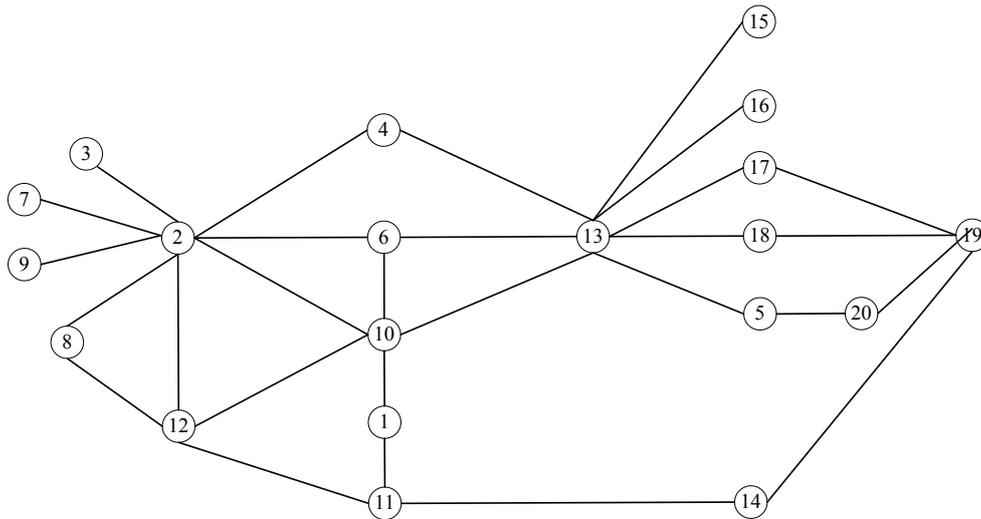Figure 3. Interrelationships between the factors of BACP

Figure 4. Grouping the results from Figure 3

Table 2. Relationships between the dependent variables and independent variables of BACP

Independent variables	Dependent variables						
	Turnaround time	Waiting time	Delay	Energy of QCs	Transportation energy	Transportation distance	QC efficiency
Handling quantity	●●●			●●●	●●●	●●	
Berthing time	●	●	●●				
Berth location	●●●	●●	●●●		●●●	●●●	
Number of QC assigned for the ship being served	●●●		●●●	●●●			●
Assigned handling volume for each QC	●●		●●	●●			●
Single-recycle of QC efficiency	●●●		●●				●●●
Energy consumption of each QC				●●●			
Remaining volumes for QC	●		●				●

Knowledge sorting model is very useful for the extraction of knowledge from different sources. The basic knowledge of BACP can be obtained from Table 1, and the interrelationships between the factors are investigated in Figures 3-4, by which the importance of the factors for BACP can be clearly determined. The influence of independent variables on the planning efficiency is further examined in Table 2. By the abovementioned procedure and steps, the detailed understandings on the relations of the knowledge are obtained, which make it easier for the extraction of rules of BACP.

3.3. Rules Extracting Model
By the means of the knowledge sorting process and the updated information, the rules are extracted from the organized knowledge for BACP. In addition, these rules are expressed using an IF-THEN clause, and computing formulas are employed.

3.3.1. Rules for Berth Allocation
Rule 1: If the berth time conflicted/crossed/overlapped
Then the berth location cannot be conflicted/crossed/overlapped
Rule 2: If the berth location conflicted/crossed/overlapped
Then the berth time cannot be conflicted/crossed/overlapped
Rule 3: If berth location outside of the quay length
Then berth location not valid
Rule 4: If the berth time smaller than the arrival time
Then berth time invalid
Rule 5: Berth allocation computation rules are as follows:
Step 1: update the current decision *DP*, *t* = 1;
Step 2: if *t* ≤ *DP*, go to Step 3; otherwise, stop;
Step 3: get all the ships within time *t*, sorted by the arrival time. N_t is the totally number of the ships, *i* denotes each ship, *i* = 1;
Step 4: if *i* ≤ N_t, go to Step 5; otherwise *t* = *t* + 1, then go the Step 2;
Step 5: find out the location of the available berth;
Step 6: by employing the Rules 1 & 3 to find out the suitable berth location for ship *i* within time *t*, then go the Step 7; otherwise, ship waiting in sequence in the mooring area;
Step 7: Find out the best & nearest berth location for ship *i* within time *t*, then go the Step 9
Step 8: Assign the random berth location for ship *i* within time *t*, then go the Step 9
Step 9: Assign the random berth time for ship *i* within time *t*. Berth time should be larger than T_{it} (AT_{it} is the expected arrival time for ship *i* within time *t*), applying Rules 2 & 4 simultaneously to make sure that the berth time will be conflicted when berth location conflicted.

3.3.2. Rules for QC Assignment
Rule 1: If the max weight of the container in the ship greater than the maximum loading capacity of all the QCs assigned
Then QC assignment failed
Rule 2: If QCs assigned not neighboring to each other
Then QC assignment failed
Rule 3: If the sum of the assigned loading/unloading volume not equal to the sum of the ship loading/unloading volume
Then QC assignment failed
Rule 4: QC assignment computation rules, which are as follows:
Step 1: Calculate the bay-number $bayNum_{it}^{40}$ for 40-feet-container for ship *i* within time *t*;

Step 2: Calculate the maximum number of the QCs available for assignment, $Q_{it}^{Max} = ceil\left(bayNum_{it}^{40}/2\right)$, Q_{it}^{Max} means max number of the QCs;

Step 3: Calculate the minimum number of the QCs available for assignment, $Q_{it}^{Min} = \left(NC_{it} \cdot \overline{\eta}\right)/\left[\left(DT_{it} - AT_{it}\right) \cdot 3600\right]$, Q_{it}^{Min} denotes the minimum number of the QCs, DT_{it} denotes the expected departure time, AT_{it} denoted the arrival time, NC_{it} means the ship capacity, $\overline{\eta}$ means the averaged loading/unloading efficacy;

Step 4: Find out the required number of QCs for ship *i* within time *t*, q_{it}, by $q_{it} = uniform\left(Q_{it}^{Min}, Q_{it}^{Max}\right)$;

Step 5: Find out remaining loading/unloading volume for each QC, qs_k^{it}, qs_k^{it} is the remaining volume for time at y_{it}, then assign q_{it} of QCs to ship *i* within time *t*. During QC assignment, Rules 1,2&3 must be satisfied. The QCs assigned cannot be conflicted with the QC for other ships, and the remaining volume of the assigned QCs should be less than unassigned QCs without confliction. If QC *k* assigned, A_k^{it} = 1; otherwise A_k^{it} = 0;

Step 6: Calculate the volume of QC *k* for ship *i* within time *t*, by
$$qn_k^{it} = \left(\sum_{k=1}^{q} A_k^{it} \cdot qs_k^{it} + NC_{it}\right)/q_{it}$$

3.3.3. Rules for Comprehensive Evaluation

Rule 1: Actual berth deviation includes the deviation of each ship and the total of all, i.e.
$\left| x_{it} - x_{it}^* \right|$ and $\sum_{t=1}^{DP} \sum_{i=1}^{N_t} \left| x_{it} - x_{it}^* \right|$, whereas x_{it}^{m} means the berth location for ship i within time t, x_{it}^* means the best berth location for ship i within time t;

Rule 2: Staying time of the ship in port, includes the staying time of each ship and the total of all, i.e. $y_{it} + \underset{\{k=1,2,...,q\}}{Max} \left(A_k^{it} \cdot qs_k^{it} / \eta_k + qn_k^{it} / \eta_k \right) - A_{it}$, and

$$\sum_{t=1}^{DP} \sum_{i=1}^{N_t} \left[y_{it} + \underset{\{k=1,2,...,q\}}{Max} \left(A_k^{it} \cdot qs_k^{it} / \eta_k + qn_k^{it} / \eta_k \right) - AT_{it} \right]$$

Rule 3: Energy consumption of each ship and the total of all, i.e.
$\left(qn_k^{it} \cdot \left(\eta_k / (q_{it})^g \right) \cdot C_{ke}^w \right)$ and $\sum_{t=1}^{DP} \sum_{i=1}^{N_t} \sum_{k=1}^{q} \left(qn_k^{it} \cdot \left(\eta_k / (q_{it})^g \right) \cdot C_{ke}^w \right)$, C_{ke}^w means the energy consumption of QC_k per unit time;

Rule 4: Delay time of ship departure time for each ship and the total for all, i.e. $Max \left(0, \underset{\{k=1,2,...,q\}}{Max} \left(A_k^{it} \cdot qs_k^{it} / \eta_k + qn_k^{it} / \eta_k \right) - (DT_{it} - AT_{it}) \right)$ and

$$\sum_{t=1}^{DP} \sum_{i=1}^{N_t} \left(Max \left(0, \underset{\{k=1,2,...,q\}}{Max} \left(A_k^{it} \cdot qs_k^{it} / \eta_k + qn_k^{it} / \eta_k \right) - (DT_{it} - AT_{it}) \right) \right).$$

3.4. Knowledge Reasoning Model

Forward knowledge reasoning model has been employed for BACP as follows:

Step 1: Explore the knowledge base of BACP to check if the related knowledge set available or not. If yes, work out he knowledge set, otherwise re-scan the knowledge database.

Step 2: If all the knowledge in pool has been used or solution has been obtained, stop; otherwise go to next step;

Step 3: Selection and implementation of knowledge, in the meanwhile update the current results

Step 4: Go to Step 1, search for the newly available knowledge database of BACP.

4. Numerical Experiments

To verify the effectiveness and reliability of the knowledge-based system for BACP in a container terminal, the numerical experiments with different scales are conducted for. The scales of the numerical experiments depend on the quay length and the number of total arrival ships. In this section, three sets experiments with different quay length of 800m, 1200m, 1600m and QC number of 8, 12, and 16, respectively, have been used for the tests. There are 3 groups of the total number of arrival ships for the terminal, i.e. 10, 20 & 30 for quay length of 800m, 15, 25 & 35 for 1200m, and 20, 30 & 40 for 1600m. There are 10 detailed instances for each testing group. The averaged results are used to evaluate the effectiveness and reliability of the knowledge-based system for BACP. Table 4 shows the ship length, loading/unloading volumes, and arrival percentages for different types of ships. The capacity of each ship in these tests is within the range of the corresponding uniformly distributed loading/unloading volume shown in Table 3. The proposed knowledge-based system (KBS) is compared with the real operation (RO). Tables 4-6 show the comparisons of quay length of 800m, 1200m and 1600m, respectively.

Table 3. Basic parameters for ships

Ship length	Handling volume (moves)	Rate
100	200-400	11.20%
155	400-1000	37.70%
200	1000-1800	24.20%
272	1800-2800	11.41%
282	2800-4000	9.85%
300	4000-8000	6.27%

Table 4. Comparison of quay length of 800m

Indices	Ships					
	10		20		30	
	KBS	RO	KBS	RO	KBS	RO
Berth deviation (m)	0	0	90	180	125	273
Penalty fee for the delay of departure ($)	0	0	220	500	510	725
Port staying time (h)	85.66	92.24	191.3	192.8	278.2	294.6
QC energy consumption(kwh)	38365.7	39567.8	80325.7	81388.6	122488.3	125331.6

Table 5. Comparison of quay length of 1200m

Indices	Ships					
	10		20		30	
	KBS	RO	KBS	RO	KBS	RO
Berth deviation (m)	180	447	253	735	259	757
Penalty fee for the delay of departure ($)	0	442	214	602	236	844
Port staying time (h)	144.78	144.5	220	250.26	348.25	346.43
QC energy consumption(kwh)	64216.72	66295.63	107689.9	117926.1	151696.3	150540.1

Table 6. Comparison of quay length of 1600m

Indices	Ships					
	10		20		30	
	KBS	RO	KBS	RO	KBS	RO
Berth deviation (m)	0	0	38	232	129	391
Penalty fee for the delay of departure ($)	0	0	271	728	344	1123
Port staying time (h)	168.94	176.67	238.63	242.34	359.45	370.97
QC energy consumption(kwh)	84297.61	76976.03	122521.3	120788.5	143639.3	171993.7

It can be seen from Tables 4-6 that the energy consumption of the proposed knowledge-based system for BACP are less than the real operation. The results indicate that the strategy and models proposed in the present study are appropriate for BACP of different scales of container terminals. The effectiveness and reliability of the knowledge-based system for BACP has been verified.

5. Conclusion
A knowledge-based system for BACP has been proposed aiming to save energy consumption and improve operation efficiency. The knowledge acquisition model is firstly proposed. And then, the knowledge sorting model has been conducted based on the taxonomic tree generation and knowledge sorting process. Subsequently, IF-THEN clause is employed to extract the rules of BACP. Finally, a practical knowledge reasoning model is proposed for a high-efficient schedules based on the extracted rules. The effectiveness and reliability of the

knowledge-based system for BACP has been verified by the numerical experiments. The main achievements of the present study are as following:

(1) Compared with traditional method, the total energy consumption has been considered in the proposed knowledge-based system for BACP, which is the mainstream of green transportation.

(2) Compared with such existing approaches as the operations research, heuristic algorithm and simulation modeling, the proposed approach could effectively avoid the large-scale computation and conveniently update the knowledge to improve the BACP.

However, there still existed a space for improvement in the future work, e.g. the trade-off between efficiency and energy-saving.

References

[1] Imai A, Sun X, Nishimura E, Papadimitriou S. Berth allocation in a container port: using a continuous location space approach. *Transportation Research Part B*. 2005; 39(3): 199-221.

[2] Kim KH, Moon KC. Berth scheduling by simulated annealing. *Transportation Research Part B*. 2003; 37(6): 541-560.

[3] Du YQ, Chen QS, Quan XW, Long L, Fung RYK. Berth allocation considering fuel consumption and vessel emissions. *Transportation Research Part E: Logistics and Transportation Review*. 2011; 47(6): 1021-1037.

[4] Guan Y, Xiao WQ, Chueng RK, Li CL. A multiprocessor task scheduling model for berth allocation: Heuristic and worst case analysis. *Operations Research Letter*. 2002; 30: 343-350.

[5] Chang DF, Yan W, Chen CH, Jiang ZH. A berth allocation strategy using heuristics algorithm and simulation optimization. *International Journal of Computer Applications in Technology*. 2008; 32(4): 272-281.

[6] Peterkofsky RI, Daganzo CF. A branch and bound solution method for the crane scheduling problem. *Transportation Research Part B*. 1990; 24(3): 159-172.

[7] Park YM and Kim KH. A scheduling method for berth and quay cranes, *OR Spectrum*. 2003; 25: 1-23.

[8] Han XL, Lu ZQ, & Xi LF. A proactive approach for simultaneous BACP problem with stochastic arrival and handling time. *European Journal of Operational Research*. 2010; 207: 1327-1340.

[9] Chang DF, Jiang ZH, Yan W, He JL. Integrating berth allocation and quay crane assignments, *Transportation Research Part E*. 2010; 46 (6): 975-990.

[10] Meisel F, Bierwirth C. Heuristics for the integration of crane productivity in the berth allocation problem. *Transportation Research Part E*. 2009; 45(1): 196-209.

[11] Zhou PF, Kang HG. Study on Berth and Quay-crane Allocation under Stochastic Environments in Container Terminal. Systems Engineering - Theory & Practice. 2008; 28 (1): 161-169.

[12] Nasution H, Jamaluddin H, Syeriff JF. Energy analysis for air conditioning system using fuzzy logic controller. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2011; 9(1): 139-150.

[13] Chanda S, De A. Congestion relief of contingent power network with evolutionary optimization algorithm. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(1): 1-8.