

Quay Crane Allocation of Container Terminal Based on Cluster Analysis

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Abstract—Quay crane allocation is one of the most important scheduling plans in the container terminal. A large of production data is stored in the database of the terminal. This paper utilizes the method of data mining to analyze the problem of quay crane allocation by using these data. From the mining, valuable information has been gotten from the database. The paper chooses the fuzzy c-means cluster algorithms to study the data of quay crane allocation in database. Data mining model of quay crane allocation has been designed by learning plan of quay crane in order to improve the production efficiency of container terminals. And the case study shows that the method using in the paper is effective.

Index Terms—container terminal, quay crane allocation, fuzzy c-means algorithms, cluster analysis

I. INTRODUCTION

The amount of information has been stored in databases, and knowledge can be discovered from these information. Data mining is the useful method which can dig out valuable information from databases[1]. Data mining is widely used in different fields, such as customer relationship management[2], business decision[3], digital library[4], quality improvement in manufacturing industry[5] and so on. The techniques of data mining had developed well in the recent years[6]. Using data mining to analyze the scheduling of manufacturing is the popular way, especially in job shop scheduling, manufacturing process, maintenance and so on[7]. Quay crane allocation is also one of the important

scheduling in container terminal. So using the method of data mining to study the problem of quay crane allocation is feasible.

The production efficiency of the container terminal mainly depends on stevedoring system operating efficiency, so good scheduling plan for container terminal is essential[8]. New container terminal handling technology had also been proposed, and simulation is also a important way to analyze the container terminal[9]. As one of the details, more and more researches have paid attentions to the studies on quay crane allocation in global trade. Goodchild et al. established handling double-cycle model, the purpose was to reduce the quay crane scheduling and improve the quay crane operation efficiency[10]. Lee et al. provided a mixed integer programming model for the quay cranes assignment and proposed a genetic algorithm to obtain near optimal solutions[11]. While Tavakkoli-Moghaddam et al. proposed a genetic algorithm to solve the problem for the real-world situations[12]. Meisel et al. studied on the single container quay crane job sequencing problem[13]. Chang et al. studied on quay crane allocation by minimizing the summation of the delay berthing penalty cost and late departure penalty cost, and the total consumption[14]. Zhang et al. established the smallest cost model to study the ship berthing position, the operating time and the number of assigned quay crane[15]. Chao et al. developed a two-phased method to deal with the quay crane problem[16]. Chen et al. proposed heuristic framework by considering the unique features at indented berth is formulated[17]. Kaveshgar et

al. proposed the means by using of genetic algorithm to obtain the solution in reasonable time[18]. Chung et al. proposed a modified genetic algorithm compared with other well known existing algorithms to solve the problem[19]. Legato et al. provided a rich model for quay crane scheduling and employed a branch-and-bound scheme for the problem[20]. Lu et al. proposed the concept of contiguous bay operations with considering the moving time and interference constraints and developed a heuristic to generate schedules[21].

These researches above are basically from the angle of the quay crane scheduling optimization, however, with the rapid development of database technology, container terminal stevedoring scheduling progress also involves a lot of data records and statistics. For container terminal quay crane allocation, the huge database undoubtedly plays a key role. Therefore, this paper will use the method of cluster analysis of data mining to analysis the container terminal quay crane allocation with the historical data, get the container terminal quay crane allocation plan, let the container vessels to reduce the time and cost of docked in the port.

II. PROBLEM DESCRIPTION

The layout of the quay side of the container terminal is shown in Fig. 1. Usually, the terminal staff assigns the berth and quay crane equipment of incoming vessels according to the experience or the actual situation. But due to the influencing factors such as the ship stowage amount, the sailing date and the container type, the work efficiency is low if the terminal staff makes the plan based on the first feeling of determining the berth allocation strategy. So it is very necessary to get a reliable berth allocation strategy in container terminal by finding association rules from the berth allocations on the basis of historical data.

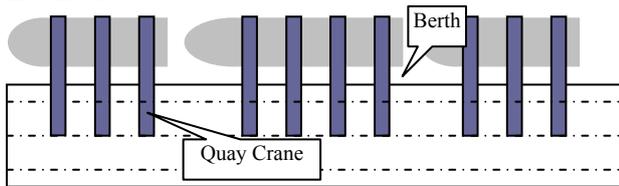


Figure 1. Quay side of the container terminal.

Different from the whole quay crane scheduling problem, the study based the quay crane allocation of data mining to solve the main problem is the analysis of the historical data to find the association rules and attain the container terminal quay crane allocation strategy. In this context, this paper selected the expected sailing date of arriving ships, workloads and other data in a container terminal in a period of time as a case to study. Assume that the parameters of all the terminal quay crane operations are the same without regard to the limitations of the quay crane operations. Analyzes of historical data related to the crane allocation, including the number of each ship loaded containers, the number of each ship unload containers and the sailing date.

III. DATA SELECTION

The goal of data mining is to find the association between all types of ship schedules and workloads demand, it can provide the basis for the further development of the quay crane scheduling scheme. This paper selects the expected sailing date of arriving ships, workloads and other data, the data selected from the database of the terminal. The information in the database includes the basic information of the ship, the information of the amount of ship loading and unloading, the information of ship docked operations and the information of quay crane allocation. Through the collection and collation, the main data table of ship loading and unloading terminal is as follows:

(1) Table of ship information

In this table, the main data contents of the ship name, ship length, ship layer, ship multiple and other information is included.

(2) Table of ship loading and unloading information

In this table, the main data contents of the ship name, the number of the import 20 feet container, the number of the import 40 feet container, the number of the export 20 feet container, the number of the export 40 feet container and other information are included.

(3) Table of ship locked information

In this table, the main data contents of the ship name, entrance time, leaving time, on berth time and other information are included.

(4) Table of quay crane allocation information

In this table, the main data contents of the ship name, prediction berth, the number of quay crane and other information are included.

For the collection and collation data, the range is too wide and some data in the data mining is no direct significance. Therefore, reducing the scope of the contents of the four data table is essential to obtain information data table related to data mining. The data in the narrow range of data mining is accurate and effective, in this way to avoid blind mining. These data may have a negative impact on data mining quality and efficiency. In order to ensure that research scientific and practical, the principle of narrow the scope of data is to ensure that the data is accurate and complete to cover all types of ships and quay crane in and out of the container terminal. Therefore, the tables are not the original table in the table. The table which is closely related to the data mining can be gotten from the tables above through connecting the different tables according to the factors selected. The main fields of the table can be seen in Fig. 2. Its contents include as follows: ship number, ship name, entrance time, leaving time, the number of the import 20 feet container, the number of the import 40 feet container, the number of the export 20 feet container, the number of the export 40 feet container, the number of the quay crane. According to the above clustering index selection as well as the structure of the database table, the SQL statement is used to statistical summary.

Information for data mining	
PK	ship number
PK	ship name
	entrance time leaving time the number of the import 20 feet container the number of the import 40 feet container the number of the export 20 feet container the number of the export 40 feet container the number of the quay crane

Figure 2. Information for data mining.

IV. MODEL OF QUAY CRANE ALLOCATION BASED ON CLUSTER ANALYSIS

A. Cluster Algorithms Selection

The problem of quay crane allocation is rely on the equipment of quay crane with port ship, it do not have certain advantages and disadvantages, only according to the carrying capacity and the sailing date, the amount of quay crane is determined. Therefore it is more suitable for using division method. Considering the pros and cons, the use and application extent of the various algorithms, this paper selected fuzzy C-means clustering (Fuzzy C-Means, FCM) algorithm as cluster analysis algorithm.

In the fuzzy C-means clustering algorithm of clustering progress, it need to find y_1, \dots, y_c as the center of c clusters respectively, FCM algorithm is to minimize the objective function value, the objective function is defined as follows:

$$I_f = \sum_{j=1}^n \sum_{i=1}^c x_{ij}^\beta d_{ij}^2; z_i \in R^n, 1 \leq i \leq c$$

x_{ij} in the above equation means the value of the membership degree matrix; $d_{ij} = \|z_i - x_j\|$ is the Euclidean distance between the i -th cluster center z_i and the j -th data point x_j ; β is the fuzzy control parameter.

In the cluster iterative progress, anyone of the fuzzy clustering C_i do the following changes:

$$y_i^{(k+1)} = \frac{\sum_{j=1}^n x_{ij}^{(\beta)} x_j}{\sum_{j=1}^n x_{ij}^{(\beta)}}$$

(1) Parameters

n : the number of data objects;

m : evaluation index number; i.e. the number of attributes of the data objects;

c : the number of results cluster; $X = \{x_i\}, 1 \leq i \leq n$: p -dimensional space data set in R^p ;

N : the maximum number of iterations;

ϵ : the threshold value of the distance between the clusters;

β : the fuzzy control parameter.

(2) Target

$Y = \{y_i\}, 1 \leq i \leq c$: Results cluster center;

$(x_{ij}), 1 \leq i \leq c, 1 \leq j \leq n$: Results membership matrix;

it : the number of iterations.

(3) Steps

Step 1: Make terrible standardized processing of the data set $X = \{x_i\}$;

Step 2: Initialize membership matrix x_{ij} using the random number in the value $[0, 1]$, so as to satisfy the constraint condition, while normalize the membership matrix, and ultimately obtain the initial membership matrix;

Step3: Begin clustering iterative process, and termination condition is the number of no improvement of objective function reaching limited requirements N .

(4) Clustering iterative process

(a) Calculate clustering center according to the membership degree matrix

For $i = 1$ to c

$$y_i^{(k+1)} = \frac{\sum_{j=1}^n x_{ij}^{(\beta)} x_j}{\sum_{j=1}^n x_{ij}^{(\beta)}}$$

End for

(b) Calculate distance matrix of each clustering center i and all point j respectively

For $i = 1$ to c

For $j = 1$ to n

$$d_{ij}^{(k)} = \|x_j - y_i^{(k)}\|$$

End for

End for

(c) Calculate a new membership degree matrix according to the distance matrix

For $i = 1$ to c

For $j = 1$ to n

$$x_{ij}^{(k)} = \left[\sum_{l=1}^c \left(\frac{d_{ij}^{(k)}}{d_{lj}^{(k)}} \right)^{2/(\beta-1)} \right]^{-1}$$

End for

End for

(d) Calculate clustering objective function I_f to evaluate and judgment

If $I_f = \sum_{j=1}^n \sum_{i=1}^c x_{ij}^\beta d_{ij}^2 < \epsilon$ then

$$y_i = y_i^{(k+1)}, 1 \leq i \leq c$$

$$x_{ij} = x_{ij}^{(k)}, 1 \leq i \leq c, 1 \leq j \leq n$$

$it = k+1$

For $i = 1$ to c

Output y_i, x_{ij}, it

End for

Else

Return to (a) and restart clustering iteration

End if

B. Cluster Indicators Selection

The purpose of the ship quay crane number assigned is divided into several categories based on the ship sailing date and the amount of loading and unloading, assigning the same number of quay crane for the same sets and

meet all kinds of ship contains the sum of all the ships in and out of the container terminal, and ultimately improve the efficiency of container terminal operations.

According to the actual situation, as the cluster analysis of the characteristics of indicators to select clustering indicators for all ships, that is the initial data object attribute columns. Clustering index selection principle is to be able to reflect the influence. That is how the ship sailing date and the amount of loading and unloading container inflect the ship quay crane allocation and get the number of the quay crane. Therefore, selected the following Clustering indicators:

- (1) The number of the import 20-foot container in the j time of ship i ;
- (2) The number of the import 40-foot container in the j time of ship i ;
- (3) The number of the export 20-foot container in the j time of ship i ;
- (4) The number of the export 40-foot container in the j time of ship i ;
- (5) The ship dock time in the j time of ship i .

C. Initial Membership Matrix

According to the definition of membership matrix of the FCM clustering algorithm, the clustering object to the membership of the cluster center must be equal to 1, therefore, the selected initial membership matrix must meet the definition of constraints, it is assumed that the historical data of the quay crane allocation with n results, the number of clusters is c , then it needs to generate an $n \times c$ initial membership matrix.

As the common analytical tools used in data processing, the famous scientific computing software contains some mature algorithms such as fuzzy clustering analysis, FCM algorithm is one of them. Initial membership matrix should not be manually determined due to the large data size in this paper, therefore using MATLAB randomly generated initial membership matrix, the statement is as follows: $U = \text{initfcm}(\text{cluster_n}, \text{data_n})$.

U is the initialization membership matrix; cluster_n is the number of cluster centers; data_n is the initial number of data objects.

The matrix needs to meet the following conditions:

$$\sum_{i=1}^c x_{ij} = 1, 1 \leq j \leq n, \quad 0 < \sum_{j=1}^n x_{ij} < n, 1 \leq i \leq c$$

D. Iterative Process of Cluster

To determine the quay crane allocation FCM clustering algorithm iteration input conditions according to the above initial preparation of the membership matrix.

In the clustering iterative process, FCM algorithm cluster centers and membership matrix constantly modified and adjusted until meeting the conditions of the termination of the clustering iterative. That is the objective function value is less than the inter-cluster distance threshold ε and the final output result is the membership matrix, the cluster center and the objective function value.

From the requirements of the FCM algorithm, it was known that in the quay crane allocation of clustering

analysis, selected the objective function value of the minimum for the final result, generated cluster centers in the case of the objective function value of the smallest, gave the quay crane allocation clustering class c center value, and got the number of the import 20-foot container, the number of the export 20-foot container, the number of the import 40-foot container, the number of the export 40-foot container and the port time (seconds).

Category Center can be get though the switch of the cluster center, that was the center of the number of the import 20-foot container, the number of the export 20-foot container, the number of the import 40-foot container, the number of the export 40-foot container and the port time (seconds) in the number of each quay crane. Finally came to the conclusion that each data object belonged to the results of cluster center membership. That was the results of the membership matrix.

According to the results of the membership matrix, took the maximum in a category of membership as the final membership category and generated the final partition matrix with the representation of (0, 1) matrix. Then got each of the ship belonged to what kind of quay crane allocation scheme, which can get the parameters of each distribution scheme. After the analysis of the final membership matrix, selected the parameter range in the membership greater than 0.8, removed the isolated values, and next got the parameter range of the container terminal quay crane allocation.

V. CASE STUDY

A. Initial Parameters

This paper used the actual data of a container terminal as a case study. The theory of data selection is used in the case, collected data of four data tables in the database associated with the data mining tasks. It is total about 30,254 data of 387 days.

After data preprocessing, it was known that ship number reached 2162. According to the container terminal equipment parameters, there were 11 quay crane of the same type available. Analysis of historical data showed that every time each ship equipped quay crane with at least 1, at most 6 units. Therefore, the clustering results can be divided into six categories, that was equipped with one quay crane, two quay crane, three quay crane, four quay crane, five quay crane, six quay crane. Thus, setting the number of the initial data object $n=2162$, the number of clusters $c=6$, the initial data set $X(U_{2162}, P_5)$.

The clustering algorithm herein relatively had large data objects, and belongs to the fuzzy clustering accuracy requirements of the data was not very high, so this paper set the maximum number of iterations $N=20$. Gorji Kandi S et al. studied the influence of different parameters on the performance of the FCM algorithm clustering to make color image clustering[22]. Finally the FCM algorithm parameters selected for fuzzy control parameters $\beta=2$, the inter-cluster distance threshold $\varepsilon = 0.01$.

B. Other Recommendations

$U=\{U_1, U_2, U_3, \dots, U_{2162}\}$ represents ship number, $P=\{P_1, P_2, P_3, P_4, P_5\}$ represents the cluster indicators, Treated to get a data sets of 2162*5 matrix, i.e. the initial

data set $X(U_{2162}, P_5)$, and obtained the range of parameters of container terminal quay crane allocation strategy is shown in Table I.

TABLE I
QUAY CRANE ALLOCATION STRATEGY OF CONTAINER TERMINAL

Quay crane number (Number)	Imports 20 feet container (Unit)	Imports 40 feet container (Unit)	Exports 20 feet container (Unit)	Exports 40 feet container (Unit)	Excepted in the port time (Hour)
1	[0,20]	[0,32]	[0,42]	[0,34]	[0,2.64]
2	[17,78]	[19,68]	[30,84]	[48,71]	[2.64,6.72]
3	[63,200]	[43,180]	[75,187]	[62,119]	[4.88,10.56]
4	[104,262]	[112,266]	[78,292]	[139,244]	[8.16,16.68]
5	[141,305]	[131,236]	[118,293]	[129,276]	[15.59,25.74]
6	>186	>230	>179	>235	>18.4

Among them:

Quay crane number means the number of the quay crane planned to equip;

Import 20 feet box quantity means the number range of 20 feet container needed to unload in his ship berthing;

Import 40 feet box quantity means the number range of 40 feet container needed to unload in this ship berthing;

Export 20 feet box quantity means the number range of 20 feet container needed to load in the ship this berthing;

Export 40 feet box quantity means the number range of 40 feet container needed to load in the ship this berthing;

The expected time of the ship in the port means a ship schedule requirements in this time.

Before the ship to the port, the system can plan the number of the quay crane according to the allocation strategy. The allocation chooses the appropriate standard of ship for quay crane distribution according to the actual situation.

Before the coming of the ship, the system can be allocated the number of units of the quay crane according to this strategic plan. It is based on the actual situation to select the appropriate standard.

C. Simulation Analysis

This paper used simulation software to test the above quay crane allocation strategy made by data mining. The interface is shown in Figure 3. The flow chart of the simulation model is shown in Figure 4. The simulation interface diagram can change based on different ship work conditions, interface operation can realize real quay crane operation dynamic demonstration. Finally, the total operating time can be calculated.

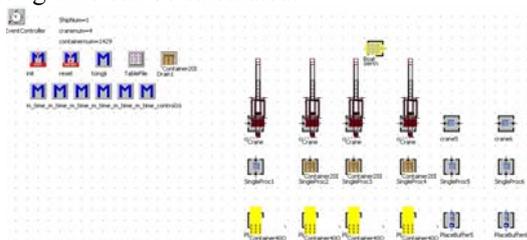


Figure 3. Simulation interface diagram.

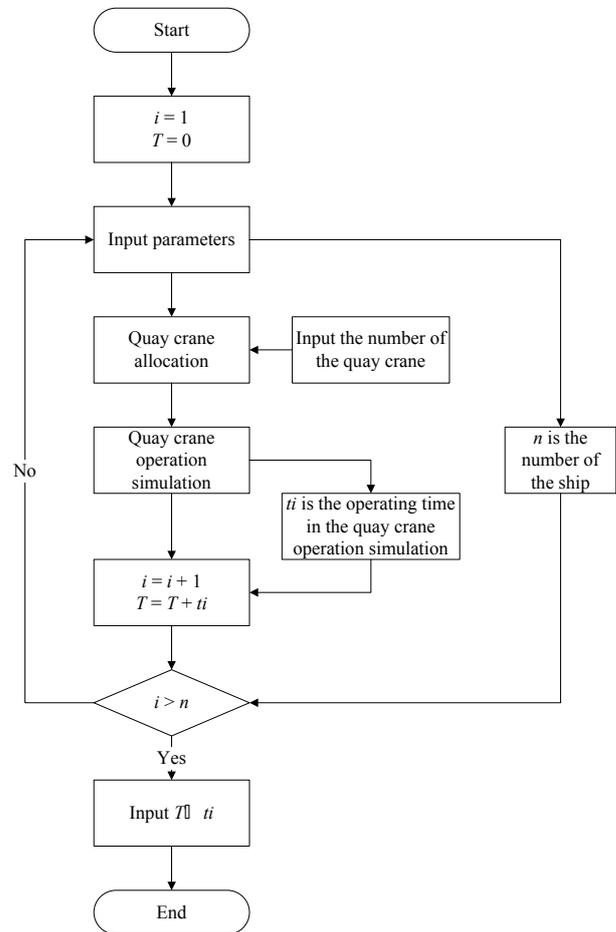


Figure 4. Flow chart of simulation.

The goal need to verity in this paper was to input the quay crane number of the original data and the data mining results. Two simulation results were obtained. Comparing the results draw the conclusion. The simulation selected the 20 records in the raw data randomly and intercepted the parameter value need to input. The input data is shown in Table II.

TABLE II
SIMULATION INPUT DATA

NO.	Imports 20 feet container (Unit)	Exports 20 feet container (Unit)	Imports 40 feet container (Unit)	Exports 40 feet container (Unit)
1	172	363	347	565
2	0	0	104	14
3	16	0	103	133
4	15	6	4	0
5	247	65	100	90
6	6	334	33	251
7	34	0	33	31
8	197	212	115	63
9	86	48	43	29
10	38	48	68	57
11	403	253	115	87
12	14	93	29	48
13	15	23	0	36
14	17	60	24	10
15	64	13	34	62
16	54	54	8	47
17	217	251	79	97
18	0	0	4	12
19	32	26	26	34
20	27	63	5	0

These 20 records of the quay crane number in the actual quay crane simulation are given by the original data sheet, such as shown in Table III.

TABLE III
THE ACTUAL QUAY CRANE ALLOCATION

NO.	Quay crane number	NO.	Quay crane number
1	4	11	3
2	2	12	2
3	2	13	2
4	2	14	2
5	2	15	2
6	3	16	2
7	2	17	3
8	2	18	2
9	2	19	2
10	2	20	2

Make the allocation of these 20 ships by using the container terminal quay crane strategies concluded in this paper. The quay crane allocation is shown in Table IV.

TABLE IV
THE QUAY CRANE ALLOCATION ACCORDING TO THE STRATEGY

NO.	Quay crane number	NO.	Quay crane number
1	4	11	6
2	3	12	2
3	4	13	2
4	3	14	2
5	1	15	3
6	3	16	3
7	1	17	5
8	4	18	1
9	3	19	2
10	1	20	1

According to the simulation, the result of comparison is shown in Table V.

TABLE V.
SIMULATION RESULTS

No.	Actual operating		Data mining	
	Quay crane number	Working time	Quay crane number	Working time
1	4	8:53:59.4607	4	8:53:59.4607
2	2	1:16:23.2694	3	51:18.3965
3	2	2:59:40.8715	4	1:30:55.8698
4	2	17:12.6273	3	12:20.4261
5	2	5:41:39.6842	1	11:22:43.9832
6	3	5:28:02.7698	3	5:28:02.7698
7	2	1:08:30.6832	1	2:15:43.9460
8	2	6:55:47.9046	4	3:29:24.6046
9	2	2:23:56.0393	3	1:36:15.7232
10	2	2:30:44.6927	1	4:58:52.8892
11	3	6:36:15.6275	6	3:18:39.2681
12	2	2:30:44.6927	2	2:18:29.3000
13	2	6:36:15.6275	2	57:06.1566
14	2	2:18:29.3000	2	1:22:39.5187
15	2	57:06.1566	3	1:22:14.0612
16	2	1:22:39.5187	3	1:19:50.4859
17	3	2:02:25.3173	5	3:05:28.0679
18	2	1:59:06.8460	1	24:11.0809
19	2	5:07:20.2723	2	2:47:54.7879
20	2	12:35.1991	1	2:17:47.4133
Total time:		2:12:47:00.2095		2:11:53:58.2102

In Table V, the total time under the new quay crane allocation strategy is 2 days 11 hours and 53 minutes, but the time of original data is 2 days 12 hours and 47 minutes. Under the new distribution strategy, the 20 boats saving the service time about one hour in total. According to the data in Table V, Fig 5 is drawn to show the results.

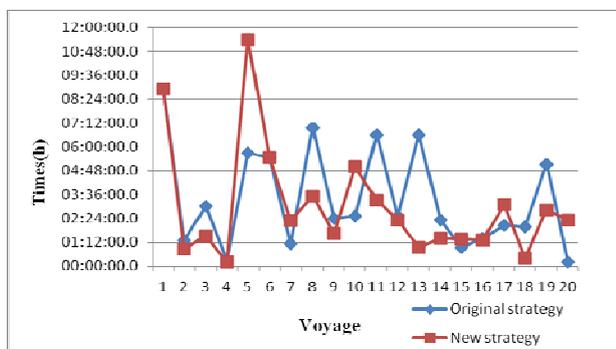


Figure 5. Comparing of simulation results.

In Fig. 5, the time for the working process is stable by using the new quay crane allocation strategy, and avoids the long time working for ship operating in one time. In this case, the total time is shorter than the original. Therefore, it proves that the data mining for quay crane allocation achieves the goal, reduces the service time and saves the costs of terminal operations.

VI. CONCLUSIONS

Quay crane allocation is an important plan in the container terminal, and this paper studies the application of the fuzzy clustering in data mining technology. It analyzes the quay crane allocation problem in container terminal by using the method of the fuzzy C-means analysis. The data mining model of the quay crane allocation is established based on association rules. Quay crane strategy for the models is obtained. Finally, simulation is established to test the new quay crane allocation strategy. Through the comparing, it is proved that the new quay crane allocation strategy made by data mining is useful.

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