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Dynamic configuration of QC allocating problem based on multi-objective genetic algorithm

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Abstract Solving the problem of allocating and scheduling quay cranes (QCs) is very important to ensure favorable port service. This work proposes a bi-criteria mixed integer programming model of the continual and dynamic arrival of several vessels at a port. A multi-objective genetic algorithm is applied to solve the problem in three cases. The results thus obtained confirm the feasibility and effectiveness of the model and GA. Additionally, the multi-objective solution considering both the total duration for which vessels stay in the port and QCs move is the best, as determined by comparing with considering only the total time for which vessels stay in the port or QCs move, as it considers, and it balances these two objectives.

Keywords Port facilities · Multi-objective genetic algorithm · Quay crane scheduling · Pareto optimal solution

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Introduction

Marine container terminals are critical components of global supply chains, and their operators face various challenges in seeking to keep their daily operations efficient and competitive. Most of these challenges are associated with the interactions between operations and facilities in the terminals. Operations and facilities, which mainly include quay cranes (QCs), yard trucks (YTs) and yard cranes (YCs), must be allocated to vessels before they enter the port (Han et al. 2008). Among these three facilities, the QC is the most expensive and the most important. The quay container crane is the most important machine for transporting containers in a port. As the speed of the QCs increases, and the loads become heavier, the dynamic responses of the QCs become urgent and their effects on QCs allocation and scheduling cannot be neglected. To remain competitive, terminal operators must develop accurate and reliable QC schedules.

Research on the impact and dynamic characteristics of cranes on quay cranes allocation and scheduling both domestically and abroad is extensive. Kim and Park solved the problem of single-vessel QC scheduling using the branch and bound method (Kim and Park 2004). Moghaddam et al. (2009) constructed a mixed integer programming model of the quay crane scheduling and allocating problem (QCSAP) and solved it using genetic algorithm (GA). Der-Horng Lee and Hui Qiu Wang et al. developed a sequence of allocating QCs to container vessels taking into account interference between QCs. Jin and Li (2011) discussed the problem of dynamically scheduling QCs based on berth planning, mainly under the limited of QCs and considered the priorities of loading and unloading tasks. Qin et al. (2013) researched the relationship between allocation and scheduling of QCs oriented multi-vessels, developing a mixed integer model whose

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objective function is to minimize the total fee of operators. These authors considered the interference among QCs and safe distance between QCs. Zhang (2012) studied the static and dynamic scheduling of QCs based on workload balance, considering the interference among QCs, and comparing and analyzing the two results of the static and dynamic scheduling.

Most current researches in the QC scheduling problem seek to minimize the total time vessels stay in port or to minimize the delaying time. This study considers two targets, i.e., minimizing the total time of vessels staying in the port and minimizing the number of moves of multiple QCs. And Pareto method is applied to obtain better results considering both the two targets.

Definition of problem

QCs load and unload containers into or from vessels when they arrive at a port. Their efficiency is important to the port. A port is competitive if QCs are scheduled properly. The QC allocating and scheduling problem is the appropriate assigning of QCs to finish operators to offer an efficient service to vessels. The goal is to determine the sequence of operators (Fan and Le 2013). Most of the working time is taken by the work and move of the QCs and little time is taken by waiting both QCs wait for YTs and YTs wait for QCs. Since QCs are huge machines, their moves take a long time and disturb the facilities around them. Therefore, the moving of QCs must be considered in providing favorable port service.

In this study, given information about multiple QCs and vessels, the QC allocating solution is obtained, which minimizes the total time vessels staying in the port and the number of moves of the QCs. In this paper, the berth plan is known, and a dynamic model of QCs allocating that is based on continuous time is constructed, accounting for the dynamic arrival of vessels at the port. The allocation and working sequences of the QCs are obtained by solving the bi-criteria mixed integer programming model.

For convenience, berths are divided into one unit per 100 m, and 1 day is composed of 24 periods. In Fig. 1, the horizontal axis represents time and the vertical axis represents berth position:

Figure 1 provides the information on the arrival of vessels at the port and their berthing positions. For example, vessel 1 berths at [0,4], which is the position of berth 1 if the berths are ordered from small to large and the arrival time of the vessel is time 0. QCs operate on the first batch vessels which arrive in the port at the first time—vessel 1, vessel 2 and vessel 3, and then on the second batch—vessel 4, vessel 5, and vessel 6—and so on.

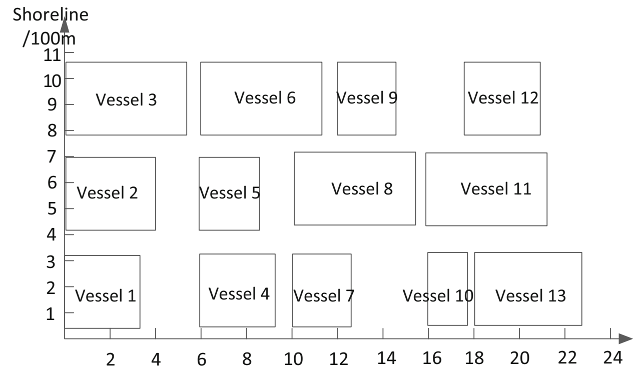

Fig. 1 Berth-time of vessels

Mathematical model of multiple QC scheduling

Assumptions

Before the mathematical formulation of QC allocating and scheduling is proposed, we discuss the assumptions for formulating a model as follows.

1. Available berths as well as QCs are uniformly distributed along a coastline. In the coordinate system, the horizontal axis represents time and the vertical axis represents the initial position of vessels.
2. All of the loading and unloading tasks in each vessel should be handled continuously, which means all the tasks in the same vessel should be finished in continuous time unit.
3. The berth plan as well as the unloading lists of all vessels are given. To reduce the complexity of the problem, only unloading tasks are considered.
4. All the QCs work at the same efficiency.
5. All the containers are 20-foot containers.

Parameters

Vessel:	set of vessels to be served in a planning period, $\{1, 2, \ldots V\} \in Vessel$;
QC:	set of available QCs in a container port, $\{1, 2, \ldots Q\} \in QC$;
T:	set of periods, $\{1, 2, \ldots nT\} \in T$;
Q:	number of available QCs;
nT:	planning period. If the planning period is 3 days and 1 day is divided into 24 periods, one planning period is composed of 72 periods, so nT = 72;
v:	working speed of QCs;
nB:	total number of available berths;
AR_j:	arrival time of vessel j;
r_j:	maximum number of QCs that can work on vessel j simultaneously;

S_j: the total number of container need to be operated of vessel j, measured in twenty-foot equipment unit (TEU);

M: a large positive number.

Decision variables

AV_j: starting time of operators of vessel j;

CV_j: finishing time of operators of vessel j;

NQ_{tj}: number of QCs assigned to vessel j in period t;

$h_{j_1 j_2}$: sequence of operators of vessel j_1 and vessel j_2; if tasks of vessel j_2 cannot be started until tasks of vessel j_1 have been completed, then $h_{j_1 j_2} = 1$; otherwise $h_{j_1 j_2} = 0$. Therefore,$h_{j_1 j_2} = 0$ when tasks of vessel j_2 begin before tasks of vessel j_1 are completed; tasks of vessel j_1 and vessel j_2 begin at the same time or tasks in vessel j_1 start after those in vessel j_2.

X_{tj}: if vessel j is operating in period t ; $X_{tj} = 1$; otherwise, $X_{tj} = 0$;

Y_{tqj}: if QC q is working on vessel j in period t, then $Y_{tqj} = 1$; otherwise, $Y_{tqj} = 0$;

θ_{tqj}: if QC q is moving toward vessel j in period t, then $\theta_{tqj} = 1$; otherwise, $\theta_{tqj} = 0$.

Model formulation by bi-criteria mixed integer programming

After analyzing a multi-ship quay crane (QC) and dynamic configuration of QC scheduling problem and by using parameters and decision variables defined, we can formulate the following bi-criteria mixed integer programming model:

Objective functions:

$$\min f_1 = \sum_{j=1}^{V} (CV_j - AR_j) \tag{1}$$

$$\min f_2 = \sum_{t=1}^{nT} \sum_{q=1}^{Q} \sum_{j=1}^{V} \theta_{tqj} \tag{2}$$

Constraints:

$$AV_j \geq AR_j, \quad \forall j \in Vessel \tag{3}$$

$$AV_j = min \left\{ (t-1) * X_{tj} \middle| X_{tj} = 1 \right\} \quad \forall j \in Vessel, t \in T \tag{4}$$

$$CV_j = max \left\{ (t+1) * X_{tj} \middle| X_{tj} = 1 \right\}, \quad \forall j \in Vessel, t \in T \tag{5}$$

$$NQ_{tj} \leq r_j, \quad \forall j \in Vessel, t \in T \tag{6}$$

$$\sum_{j=1}^{V} NQ_{tj} \leq Q, \quad \forall t \in T \tag{7}$$

$$\sum_{t=1}^{nT} NQ_{tj} = S_j / v, \quad \forall j \in Vessel \tag{8}$$

$$\sum_{j=1}^{V} Y_{tqj} \leq 1, \quad \forall t \in T, q \in QC \tag{9}$$

$$NQ_{tj} = \sum_{q=1}^{Q} Y_{tqj}, \quad \forall j \in Vessel, t \in T \tag{10}$$

$$X_{tj} \geq Y_{tqj}, \quad \forall j \in Vessel, t \in T, q \in QC \tag{11}$$

$$\sum_{j=1}^{V} X_{tj} \leq nB, \quad \forall t \in T \tag{12}$$

$$CV_{j_1} - AV_{j_2} \leq M * \left(1 - h_{j_1 j_2}\right), \quad \forall j_1, j_2 \in Vessel \tag{13}$$

$$CV_{j_1} - AV_{j_2} + M * h_{j_1 j_2} \geq 0, \quad \forall j_1, j_2 \in Vessel \tag{14}$$

$$h_{j_1 j_2} + h_{j_2 j_1} \leq 1, \quad \forall j_1, j_2 \in Vessel \tag{15}$$

$$\mathrm{M} * \left(h_{j_1 j_2} + h_{j_2 j_1}\right) \geq \sum_{k=1}^{Q} k * Y_{tkj_1} - \sum_{q=1}^{Q} q * Y_{tqj_2} + 1$$
$$\forall k, q \in QC, j_1, j_2 \in Vessel, \ j_1 < j_2 \tag{16}$$

$$h_{j_1 j_2}, X_{tj}, Y_{tqj}, \theta_{tqj} \in \{0, 1\},$$
$$\forall \mathrm{j}, j_1, j_2 \in Vessel, \ t \in T, q \in QC \tag{17}$$

Objective function (1) minimizes the total time for which all vessels staying in port; objective function (2) minimizes the moving times of all QCs. Constraint (3) ensures that the QCs can work on vessels only after those vessels have arrived at the port. Constraint (4) defines the starting time of operators in vessels. Constraint (5) defines the finishing time of operators in vessels. Constraint (6) ensures that the number of QCs that are assigned to each vessel does not exceed the maximum number of QCs that can work on a vessel simultaneously. Constraint (7) ensure that the number of working QCs in a period does not exceed number of available QCs in the port. Constraint (8) ensures that all the tasks are completed. Constraint (9) ensures that a QC can service at most one vessel in one period. Constraint (10) specifies the relationship between NQ_{tj} and Y_{tqj}; and constraint (11) expresses the relationship between X_{tj} and Y_{tqj}. Constraint (12) ensures that the number of working vessels does not exceed the number of berths. Constraints (13)–(15) define the working sequence of QCs as $h_{j_1 j_2}$. Constraint (16) prevents interference among QCs. If $h_{j_1 j_2} + h_{j_2 j_1} = 0$, $\mathrm{k} - \mathrm{q} + 1 \leq 0$, $\mathrm{q} \geq \mathrm{k} + 1$, $j_1 < j_2$. Constraint (17) ensures that variables $h_{j_1 j_2}$, X_{tj} and Y_{tqj} are binary variables.

In this paper, the presented mix-integer programming model, which comprises a lot of binary variables and integer variables, cannot solved by standard optimization solver in reasonable time. Therefore, a multi-objective genetic algorithm (MoGA) is applied to solve the problem.

V_1	V_2	V_3	V_4
5	0	0	0
4	3	0	0
0	6	4	0
0	1	5	4
0	0	0	6

Fig. 2 Representation of chromosome

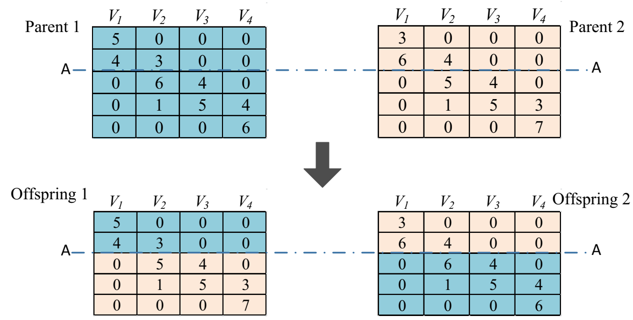

Fig. 3 Illustrative example of proposed crossover operator

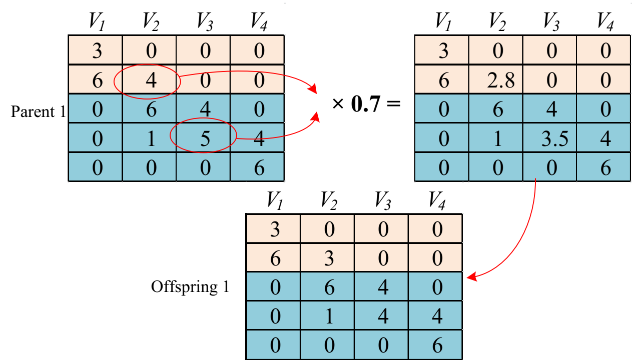

Fig. 4 Illustrative example of proposed mutation operator

Genetic algorithm

Chromosomes and initial population

The chromosomes and initial population is the basic elements of a GA. A (V × nT) matrix, as shown in Fig. 2, is specified in which V is the number of vessels in port in a planning period, and nT is the duration of each planning period. The gene is the number of QCs that are assigned to each vessel during each period. Therefore, the total number of genes in a row cannot exceed the number of available QCs, and the total number of genes in a column cannot be more than the working time of every vessel. Each chromosome represents a QC-scheduling plan in a planning period.

As is well known, the initial population is very important to the efficiency of a GA (Gen and Cheng 2000). Generating chromosomes randomly is used in most situations. It can be described as follows:

Step 1: For the jth column of chromosomes, determine whether QCs must be allocated to vessels during the ith period. If QCs must be allocated to vessels during the ith, then go to step 2; otherwise assign the gene zero and determine the vessel $j + 1$;
Step 2: If a QC in a port is available, then go to step 3, otherwise, the gene is zero and then determine the row $i + 1$;
Step 3: If the number of available QCs exceeds the maximum number of QCs that can work on a vessel the same time, then its gene is generated from random integers in $[r_j/2 + 1, r_j]$, otherwise its gene is generated from random integers in $[1, n_i]$, where r_j is the maximum number of QCs that can work on vessel j at the same time, and n_i is the number of available QCs. Then, update n_i and the completed tasks in vessel j, which are represented by c;
Step 4: Repeat step 2 until c $> S_j$, and then adjust the genes using c $= S_j$. Update n_i, such that all the other genes in the jth column of chromosomes are zero.
Step 5: Generate genes in column $j+1$; repeat steps 1–4.
Step 6: Generate the next chromosome when a chromosome is finished. The initial population is generated until M chromosomes are finished.

Crossover operator

Maintaining a population is important and a simple crossover method, single-point crossover, is utilized to do so. M arrays are generated randomly and they are crossed with their neighbors, as presented in Fig. 3.

Mutation operator

The mutation operator ensures that the next generation retains excellent individuals in the search for the optimal solution. Generally, all genes are examined and as presented in Fig. 4.

Some chromosomes as shown in Fig. 4, the sum of genes in the third column are fewer than the tasks in vessel 3. That is, not all of the tasks are completed by the end of the planning periods. In such a situation, the genes must be repaired as follows.

Step 1: If the total number of genes in column j exceeds the number of tasks of vessel j, then go to Step 2. Otherwise, go to Step 3.
Step 2: Add the difference of the total number of genes and the number of tasks to the total number of genes in row i; if the sum does not exceed the number of available QCs, then the gene is r_j when the new sum of the difference and the number of genes in row i and column j exceeds the maximum number of QCs that can work

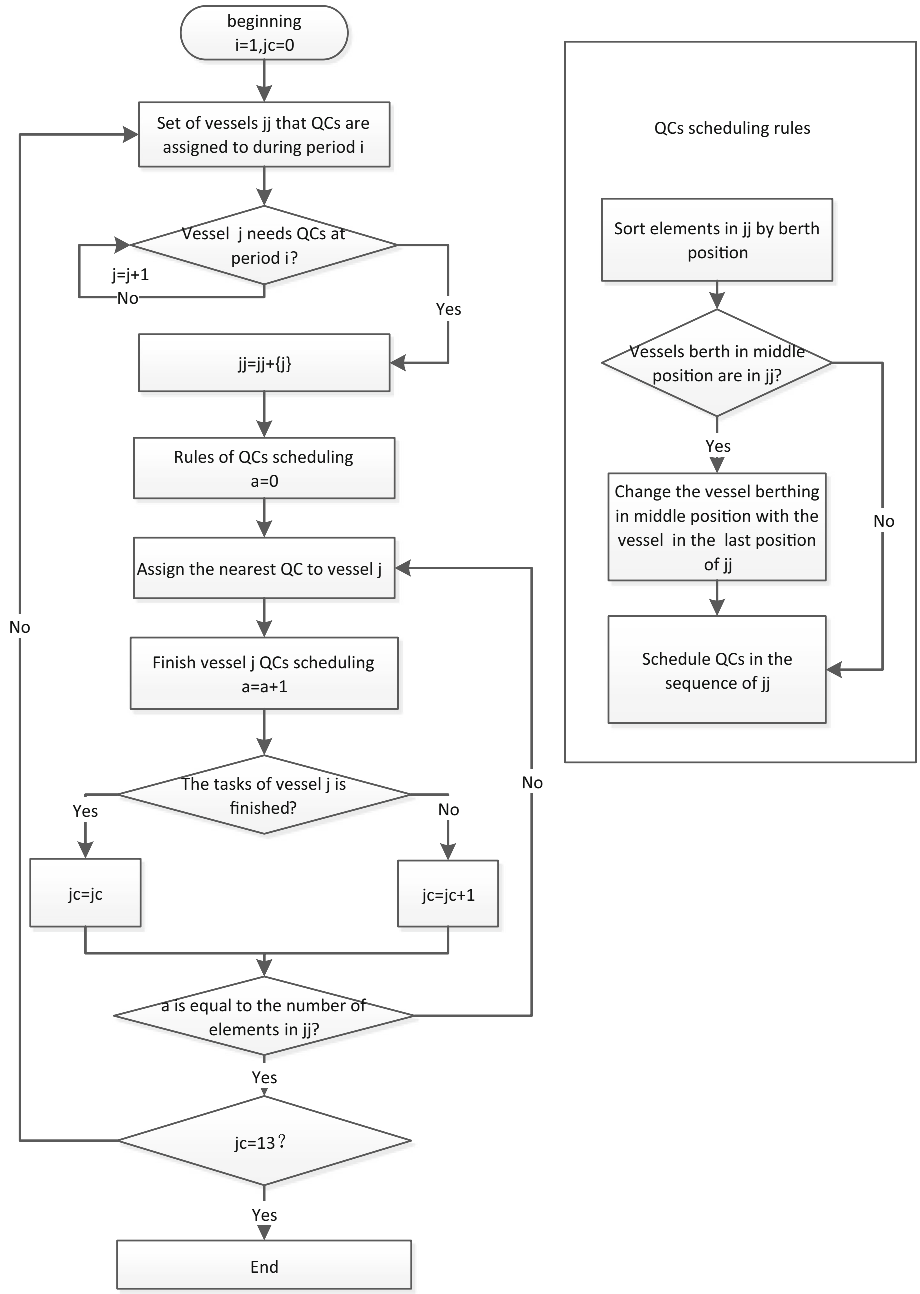

Fig. 5 Heuristic algorithm for allocating QCs

on vessel j simultaneously. Update difference and repeat Step 2 until the number of genes in column j equals S_j;
Step 3: If the row i minus the difference is not less than 1, then assign the number of its gene minus the difference to it. Otherwise, make the first non-zero gene 1, then update the difference and repeat the Step 3 until the difference is zero.

Selection operator

The chromosome is designed for solving the problem of allocating QCs, whereas the heuristic algorithm is used to solve the problem of scheduling QCs when their allocation is known, as presented in Fig. 5.

The QC scheduling plan can be determined using GA algorithm to solve. The fitness function is the objective function in the GA, and it is used to determine the fitness of all individuals. The top of M make up a new generation.

Pareto fitness-optimized solution

The method of Pareto fitness optimization is used when multi-objectives that consist of two single objectives are considered (Gen and Lin 2014). The method is effective in solving multi-objectives in a GA. Two weights are introduced to transform a multi-objective problem to a single-objective problem.

In the population in iteration t, f_1^{min} (or f_2^{min}) is the minimum of the two objectives and f_1^{min}(or f_2^{mean})is their average. Compare these values with those in iteration t − 1 and choose the better one in each case.

$$f_q^{\min(t)} = min\left\{f_q^{\min(t-1)}, f_q\left(v_k\right) \middle| k = 1, 2, \ldots, pop_{size}\right\}, \quad q = 1, 2 \tag{18}$$

$$f_q^{mean(t)} = \min\left\{f_q^{mean(t-1)}, \left(\sum_{k=1}^{pop\_size} f_q\left(v_k\right)\right) / pop\_size\right\}, \quad q = 1, 2 \tag{19}$$

$f_q^{\min(t)}$ and $f_q^{mean(t)}$ are the minimum and the average of the qth objective of all the individuals in iteration t respectively. v_k is the kth feasible solution in the population.*pop_size* is the total number of feasible solution.

The weights in the fitness function is set as (20) :

$$\omega_1 = \frac{f_1^t - f_1^{\min(t)}}{f_1^{mean(t)}}, \omega_2 = \frac{f_2^t - f_2^{\min(t)}}{f_2^{mean(t)}} \tag{20}$$

The fitness function is:

$$\text{eval}\left(v_k\right) = \omega_1 * f_1 + \omega_2 * f_2 \tag{21}$$

The Pareto selection and mutation operator are used in this method as in the previous one, and the optimal solution is thus obtained.

Numerical experiments

Input data

In this paper, the number of berths is three and the berth plan is known. Ten QCs are available and every QC operating speed is 50TEU/h (Tang 2011). Tables 1–4 presents the information of the vessels, such as the positions of their berths, the numbers of tasks, their arrival times, and their leaving time. The number of individuals in a generation is set to 150 and the mutation rate is set to 0.1. The GA computation performed up to a limit of 500 generations.

Results

(1) Applying the data in Table 1 to MoGA, Table 2 presents the results of the objective function that minimizes the total time of all vessels in the port. Figure 6 presents the planned scheduling and Tables 3, 4 presents the working sequence.

Table 1 The information of vessels in planning period

V.N	N.T	M.N.Q	A.T	L.T	B.P
1	400	4	09:00	20:00	3
2	450	5	09:00	21:00	1
3	300	3	00:00	13:00	1
4	150	2	21:00	24:00	3
5	700	7	00:00	24:00	2
6	350	4	08:00	21:00	1
7	450	5	07:00	24:00	3
8	350	4	11:00	24:00	2
9	200	2	21:00	24:00	1
10	150	2	22:00	24:00	2
11	350	4	09:00	24:00	2

V.N number of vessels, *N.T* the number of tasks, *M.N.Q* the max number of QCs in the vessel, *A.T* arrival time, *L.T* the latest time to leave port, *B.P* berthing position

Table 2 Single objective 1 (minimizing total time for which all vessels stay in port)

V.N	A.T	B.T	S.T	F.T	Time (h)
1	09:00	10:00	10:00	12:00	3
2	09:00	10:00	10:00	13:00	4
3	00:00	00:00	00:00	02:00	2
4	21:00	21:00	21:00	23:00	2
5	00:00	00:00	00:00	02:00	2
6	08:00	08:00	08:00	10:00	2
7	07:00	07:00	07:00	09:00	2
8	11:00	12:00	12:00	14:00	3
9	21:00	21:00	21:00	23:00	2
10	22:00	22:00	22:00	24:00	2
11	09:00	09:00	09:00	10:00	1

V.N number of vessels, *A.T* arrival time, *B.T* berthing time, *S.T* time work begins, *F.T* time work ends, *Time* total time of vessels in port

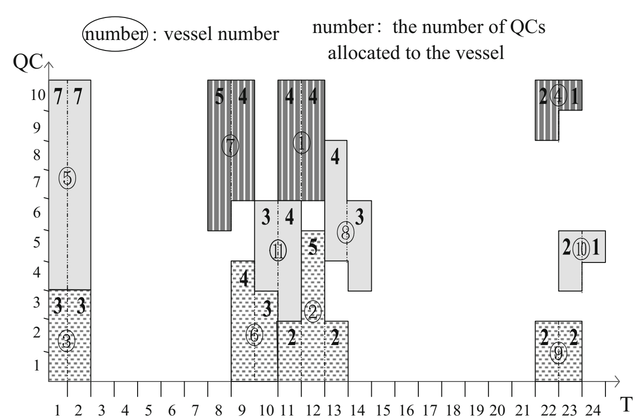

Fig. 6 Single objective 1 (minimizing the total time for which all vessels stay in port): allocation of QCs

Table 3 Single objective 1 (minimizing total time for which all vessels stay in port)—sequences of QCs operators

QC.N	Vessels sequence	QC move
1	3-6-2-9	0
2	3-6-2-9	0
3	3-6-11-2	2
4	5-6-11-2-8-10	4
5	5-11-2-8-10	2
6	5-7-11-8	2
7	5-7-1-8	2
8	5-7-1-8	2
9	5-7-1-4	1
10	5-7-1-4	1
Total		16

QC.N number of QCs, *Vessel sequence* the sequence in which QCs work on vessels, *QC move* number of QC moves

Table 4 Single objective 2 (minimizing the number of times that all QCs move)—results concerning other decision variables

V.N	A.T	B.T	S.T	F.T	Time (h)
1	09:00	10:00	10:00	13:00	4
2	09:00	11:00	11:00	14:00	5
3	00:00	00:00	00:00	02:00	2
4	21:00	21:00	21:00	23:00	2
5	00:00	00:00	00:00	03:00	3
6	08:00	08:00	08:00	11:00	3
7	07:00	07:00	07:00	10:00	3
8	11:00	12:00	12:00	15:00	4
9	21:00	21:00	21:00	23:00	2
10	22:00	22:00	22:00	24:00	2
11	09:00	09:00	09:00	12:00	3

V.N number of vessels, *A.T* arrival time, *B.T* berthing time, *S.T* time when work begins, *F.T* time when work ends, *Time* total time for which vessels are in port

From the data in the above figure and table, the total time for which the vessels stay in the port is 25 h, and the QCs move 16 times. Hence, all 11 vessels arrive in the port 1 day (one planning period) stay in the port for 25 h. From the above, all of the vessels leave the port before their allowed time and no delay occurs. Also, the total number of working QCs is limited to the maximum number of QCs that can work on a vessel at the same time. In the busy time, at least 50 % of the vessels are working. These results explain that the model promotes the utilization of QCs, and better results are achieved made if the QCs move fewer times.

(2) Table 4 presents the results of the objective function that minimizes the number of times that the QCs moves take. Figure 7 presents the scheduling plan and Table 5 presents the working sequence.

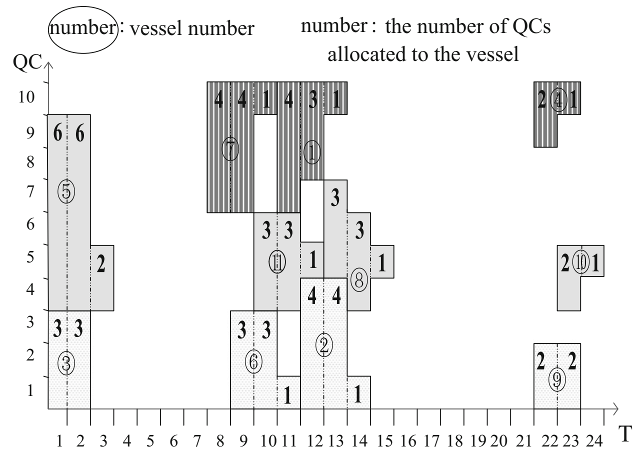

Fig. 7 Single objective 2 (minimizing the number of moves by all of the QCs)—allocation of QCs

Table 5 Single objective 2 (minimizing the number of moves by all of the QCs))—sequences of QCs operators

QC.N	Vessels sequence	QC move
1	3-6-2-9	0
2	3-6-2-9	0
3	3-6-2	0
4	5-11-2-8-10	2
5	5-11-8-10	0
6	5-11-8	0
7	5-7-1-8	2
8	5-7-1	1
9	5-7-1-4	1
10	7-1-4	0
Total		6

QC.N number of QCs, *Vessel sequence* the sequence in which QCs work on vessels, *QC move* number of moves made by QCs

From the results in the figures and tables above, the vessels spend 31 h in port, and the QCs move six times. Therefore, all 11 vessels arrive in the port in 1 day (one planning period) stay in the port for 31 h and QCs move six times. Accordingly, all of the vessels leave the port before their allowed time and no delay occurs, and the total time that vessels are in port is increased by 24 % and can be improved.

(3) Multi-objectives results and analysis

The total time for which vessels stay in port in single objective 2 (which minimizes the number of times all of the QCs move) increases by 24 % compared with the total time in single objective 1 (which minimizes the total time of vessels staying in port), while the number of times the QCs move is reduced by 62.5 %. The two objectives both have important roles in improving the utilization and efficiency of QCs. The solution is improved by considering both of these objectives.

Table 6 Pareto optimal solution of QCs operators

	Time (h)	QC move	Distance
1 (a)	34	6	8
2	30	7	4.12
3 (c)	28	8	2.83
4	27	10	4.12
5 (b)	26	13	5

Time total time for which all vessels are in port, *QC move* Number of QC moves, *Distance* distance from ideal point (the best solution in theory)

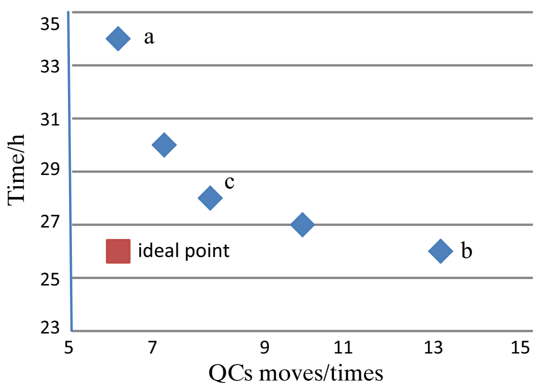

Fig. 8 Pareto-optimal solution. Time: total time for which all vessels are in port, QC move: Number of QC moves

Table 7 Multi-objectives (minimizing the total time spent by all vessels in the port and minimizing the number of moves by all of the QCs)—results concerning other decision variables

V.N	A.T	B.T	S.T	F.T	Time (h)
1	09:00	10:00	10:00	13:00	4
2	09:00	10:00	10:00	13:00	4
3	00:00	00:00	00:00	02:00	2
4	21:00	21:00	21:00	23:00	2
5	00:00	00:00	00:00	03:00	3
6	08:00	08:00	08:00	10:00	2
7	07:00	07:00	07:00	10:00	3
8	11:00	11:00	11:00	13:00	2
9	21:00	21:00	21:00	23:00	2
10	22:00	22:00	22:00	24:00	2
11	09:00	09:00	09:00	11:00	2

V.N number of vessels, *A.T* arrival time, *B.T* berthing time, *S.T* time work begins, *F.T* time work ends, *Time* total time of vessels in port

A Pareto optimal solution genetic algorithm is applied to work out the solution and the computing time is acceptable. The solution is as Table 6 and Fig. 8.

From Fig. 8, point c, where objective 1 is 28 h and objective 2 is 8, is the best. Therefore, the total time of all vessels in the port is 28 h; the operating time is 25 h, and all of the QCs move eight times in total. The relevant information is presented in Table 7; Fig. 9 displays the schedule and Table 8 presents the working sequence.

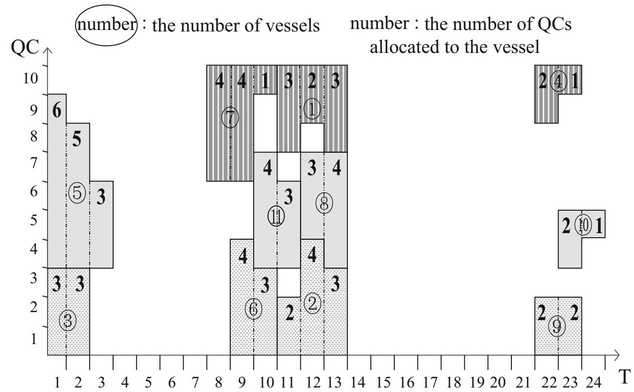

Fig. 9 Multi-objectives (minimizing the total time spent by all vessels in the port and minimizing the number of moves made by all QCs)—allocation of QCs

Table 8 Multi-objectives (minimizing the total time spent by all vessels in the port and minimizing the number of moves mad by all QCs)—sequences of QCs operators

QC.N	Vessels sequence	QC move
1	3-6-2-9	0
2	3-6-2-9	0
3	3-6-2	0
4	5-6-11-2-8-10	4
5	5-11-8-10	0
6	5-11-8	0
7	5-7-1-8	2
8	5-7-1	1
9	5-7-1-4	1
10	7-1-4	0
Total		8

QC.N number of QCs, *Vessel sequence* the sequence in which QCs work on vessels, *QC move* number of moves made by QCs

The total time spent by vessels in the port is easily determined to be 28 h, and the QCs move eight times. All vessels leave the port before the latest time they are allowed to do so and no delay occurs. Also, the total number of working QCs is limited to the maximum number of multiple QCs that can work on a vessel at the same time. QCs exhibit a high utilization during the busy time. In the result of considering both minimizing the total time of vessels staying in port and minimizing the number of QCs moves, the total time for which vessels stay in port is 9.68 % less than in the solution to single objective 2 (minimizing the number of moves made by all QCs), and the number moves made by QCs is almost 50 % less than that in the solution to single objective 1 (minimizing the total time spent by all vessels in the port). The multi-objective result is the best of the three and can be utilized in allocating and scheduling multiple QCs.

Conclusions

The paper studies the allocating and scheduling of multiple Query Cranes (QCs) to several vessels, considering the continual and dynamic arrival of such vessels in port. The concept of dynamic planning is applied to describe the arrival of vessels at a port. The optimal plan for allocating and scheduling multiple QCs is based on the arriving vessels berth plan. A bi-criteria mixed-integer model consists of two objective functions, one of which minimizes the total time spent by all vessels in the port and the other of which minimizes the number of moves made by all the QCs. The two single-objective functions are solved using a multi-objective genetic algorithm (MoGA), and multi-objective function is solved by finding the Pareto optimal solution. The final computational results confirm the feasibility of the proposed model and the algorithm MoGA. The multi-objective yields the best results, balancing the two objectives conflicting each other.

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