PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 26 No. 4 pp: 77-88

Berth Allocation and Crane Assignment Problem in Continuous Berth Containers Vessels Terminals

Abir Hussein [1], A. Elkharbotly [2], T. Ismail [3], [*]

[1] *Mechanical Engineering Dept., Faculty of Engineering, Fayoum University, Cairo, Egypt, email: ame09@fayoum.edu.eg*

[2] *Design & Production Engineering Dept., Faculty of Engineering, Ain-Shams University, Cairo, Egypt, email: amin_elkharbotly@eng.asu.edu.eg,*

[3] *Basic and Applied Sciences Department, Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt,*

[*] ***T. Ismail**, tamer.ismail@aast.edu,* *DOI: 10.21608/pserj.2022.172091.1201*

Received 8-11- 2022,
Revised 16-12- 2022,
Accepted 19-12- 2022

ABSTRACT

This research addresses the problem of optimizing simultaneously the container vessels berthing schedule and quay cranes assignment for each berthed container vessel. A mixed integer linear programming (MILP) mathematical model is developed to achieve the lowest total flow time of the group of anchored vessels waiting for service, considering port resources usage constraints. The research extended to study the efficiency of the use of port resources such as berth length, number of available quay cranes in the port and the maximum allowable quay cranes that can serve a vessel. Experiments were carried out using the developed model to study the effect of number of quay cranes, berth length and the maximum allowable cranes per vessel on vessels total flow time as well as the interaction between these factors in affecting the total flow time. The utilization of berth and quay cranes were studied at the berthing schedule that minimizes the total flow time. It was concluded from the results that increasing the number of quay cranes will not contribute to improving the total vessel flow time unless a sufficient berth that can accommodate more vessels is present. Moreover, a reduced quay crane utilization will occur with increasing the number of quay cranes. Also, increasing the maximum allowable quay cranes for vessels in service contribute to improving vessels total flow time and quay carne utilization.

Keywords: Berth scheduling, Continuous berth, Quay crane, Ports Scheduling

1. INTRODUCTION

Seaside operations faces many challenges that reflect on seaport efficiency. Seaside problems can be divided into three main categories which are: the berth allocation problem (BAP), the quay crane assignment problem (QCAP), and quay crane scheduling problem (QCSP) Hsu et al. [1]. The berth allocation problem (BAP) can be defined as the problem of determining the appropriate time and place for the berthing of vessels coming to the port. The problem of assigning quay cranes (QCAP) appears after vessel berthing due to the need to determine the appropriate number of cranes for each vessel according to vessel length, vessel workload, and the number of quay cranes available in the port. The quay crane scheduling (QCSP) is the process of scheduling the loading and unloading operations of containers using assigned quay cranes Al-Dhaheri et al. [2]. Some researchers, were interested in solving seaside problems in an integrated way [3,4,5,6,7].

Optimization models have been widely used to improve the efficiency and utilization of the port [8,9]. The researchers' goals varied to reach the best efficiency and high utilization of the port resources. Examples of optimization objectives are minimizing total service time [10] , turnaround time [11], make-span [12], weighted flow time [13], waiting time [5,14,15] and total tardiness [16].

2. LITERATURE REVIEW

Scheduling problems faced by the seaside area at container terminals is a topic that deserved the study of many researchers. In the past period, many researchers have discussed these problems and suggested methodologies for improvement. Bierwirth and Meisel [17] explained the overlap between these problems and the shortcomings of each problem. They stated that the main problem is how the service time is affected while allocating the berth and cranes to vessels.

Different solution approaches have been put out to address the three operational problems and their integration at the seaside. Imai et al. [9] used the genetic algorithm to solve the problem of discrete berth allocation (BAPD) in a multi-user container terminal to minimize the total service time. Prencipe and Marinelli [14] propose a mixed integer Linear Programming model to solve a dynamic and discrete berth allocation problem (DDBAP). A comparison between the Bee Colony Optimization (BCO) algorithm and CPLEX was performed, and the results show the effectiveness of (BCO). The authors developed a Biased Random Key Genetic Algorithm to solve the tactical berth allocation problem to minimize the total vessel's staying time in the port. The results ensured that the algorithm is very effective to solve this complicated problem. Lee et al. [13] proposed a Greedy Randomized Adaptive Search Procedure (GRASP) in a continuous and dynamic berth allocation problem (BAP) in order to minimize the total weighted flow time. Ting et al. [15] proposed practical swarm optimization (PSO) approach to minimize total waiting time in berth allocation problem (BAP). This approach was checked with two different size benchmark problems and proved its efficiency. Skaf et al. [18] Studied a quay cranes scheduling problem (QCSP) case at Tripoli-Lebanon port. A mixed integer dynamic programming model was formulated to minimize make-span. The proposed algorithm has the capability to minimize the make-span compared with the Tripoli-Lebanon port. Chung and Choy [12] Formulated a modified genetic algorithm to solve the quay crane scheduling problem (QCSP) to minimize make-span. The algorithm is compared with another benchmark problem and the results show that the genetic algorithm is more effective. Chen et al. [19] proposed a mixed integer programming model to solve the quay crane scheduling problem (QCSP) and minimize make-span. They developed new heuristic and the numerical test was used to evaluate the heuristic performance.

Some researchers such as [20,4] have focused on the effect of increasing the vessel's time in port on the amount of quay crane fuel consumption. Junliang He [4] formulated a mixed integer programming model to minimize the total departure delay time and the cost of quay crane energy consumption in the integrated berth allocation (BAP)and quay crane assignment (QCAP) problem. The results of experiments show how the model is more effective. Duan et al. [20] proposed a multi-objective optimization mode to schedule the berth and quay crane in the container terminal. The authors suggested a multi-objective optimization model for scheduling quay crane and berth at the container terminal. The research paper discussed that competition between ports does not depend only on achieving the shortest service time and highest port productivity, and proved that it is essential to take fuel quay crane consumption and pollution reduction into consideration.

Charguri et al. [21] developed an artificial neural network (ANN) predictive model in order to minimize the make-span. The author proved that the increase in quay crane productivity rate would affect the optimization model of quay crane scheduling problem (QCSP). Malekahmadi et al. [5] Developed an integer programming model to solve the case of integrating the three seaside problem berth allocation (BAP), quay crane allocation (QCAP), and quay crane scheduling (QCSP). The model was classified as NP-hard, thus a random topology particle swarm optimization algorithm was used to minimize the total waiting time. Shang et al. [22] developed a deterministic optimization model to solve the integrated berth allocation (BAP) and quay crane assignment (QCAP) problem. The genetic algorithm was used to minimize total weighted handling time and total waiting time. Iris et al. [6] proposed the generalized set partitioning model to minimize the overall cost in the integrated berth allocation (BAP) and quay crane assignment (QCAP) problem. Jiang et al. [3] developed a nonlinear mixed integer programming model, an improved genetic algorithm was used to minimize the cost. The results ensure that the algorithm gives effective berth and quay crane scheduling. Elwany et al. [11] formulated an integrated heuristics-based solution methodology in order to minimize the turnaround time. The results of the proposed heuristic-based approach are highly efficient and practicable. Xiang and Liu [7] addressed the integrated berth allocation and quay crane assignment problem to minimize the total cost. The proposed approach was more effective than benchmark approach.

Imai et al. [10] discussed the problem of minimizing the total service time at berth allocation and quay cranes allocation and the genetic algorithm was used to solve the problem. They found that it is not possible to reduce the service time without the presence of sufficient resources such as berths and quay cranes. Liang et al. [23] Used hybrid evolutionary algorithm to locate a vessel's berth and determine the suitable number of cranes to reduce handling time, waiting time, and idle time for each vessel. An approximate solution to the problem was found, explaining the factors that affect the handling time and waiting time, such as the location of the berth and the number of cranes. Han et al. [24] proposed a two-stage model for berth allocation and quay crane allocation to minimize the total staying time of vessels and to minimize the cost resulting from the increase of quay crane movements. The swarm optimization method was used to solve the proposed model. Skaf et al. [18] showed the effect of increasing the quay cranes in the port and neglecting the effect of increasing berth length. Imai et al. [25] addressed the problem of berth allocation in a multi-user container terminal. A heuristic algorithm was developed to minimize the total service time with a dynamic arrival time. The results showed that the increase in the number of berths affects the proposed solution negatively, in addition to the fact that the increase in the number of vessels causes an increase in the total service time. Liu et al. [16] studied quay crane scheduling problem and proposed a mixed integer linear programming model to minimize the maximum relative tardiness of vessels. The problem was divided into two level because of its large size to vessel level and berth level. The authors assumed that the vessels arrival time is different. The results showed that the proposed system is more effective. Ganji et al. [26] formulated a nonlinear mixed integer programming model and used a genetic algorithm to minimize total service time in the berth allocation problem (BAP). Genetic algorithm results were compared with branch and bound algorithm results. The results show that the service time decreased according to berth length increase.

From the previous literature it can be concluded that most of the previous research focused in developing techniques for solving different scheduling problems in seaport terminals. While only few research addressed the problem of studying and analysing the factors affecting port performance in terms of vessels waiting time, mean flow time and resources utilization. The objective of this paper is to investigate the different factors affecting the port performance in terms of vessels total flow time and the utilization of both berth and quay cranes. A linear programming model for berth and quay crane assignment is developed to provide optimum berthing schedule and quay crane assignment with the objective of minimizing vessels total flow time. The model is used to analyze the effect of berth length and the number of available quay cranes on the achieved total flow time and the resulting berth and cranes utilization under different combinations of vessels length and workload distribution represented by the maximum allowable quay cranes per vessel.

The rest of this paper is organized as follows: section 3 includes the problem definition and the proposed integer linear programming model for the problem. Section 4 includes design of experiments (that includes different parameters and their effect on the port performance), results of the experiments and discussion. Section 5 includes the conclusion and suggested future work.

3. PROBLEM DESCRIPTION AND FORMULATION

Sea-side scheduling problems start with the arrival of the vessel at the seaport where each incoming vessel has certain length that requires to occupy on the berth. The problem of berth and quay crane allocation to container vessel (B&CAP) includes both BAP and CAP types of simultaneous occurring problems. Thus, berth allocation problem is concerned with the location at which the vessel will berth for service and determining the allowable time to berth. Appropriate number of quay cranes should be assigned to each berthed vessel according to each vessel workload. This number of assigned quay cranes will determine the service time of each vessel. Meanwhile, the number of assigned quay cranes can vary throughout service time based on the need of other berthed vessels which optimizes the total flowtime. Thus, quay crane assignment problem will be concerned with assigning available quay cranes in the port terminal to all berthed vessel according to their workload and according to the minimum and maximum number of quay cranes that can be assigned to each vessel. Moreover, the total time spent by the vessel is divided into waiting time until a place in the berth is available to accommodate the vessel length and service time according to the number of quay cranes assigned to this vessel to perform unloading and loading tasks and leave the port which will in turn affects berth availability to accommodate other vessels to receive required service. Consequently, berth allocation problem (BAP) and quay crane scheduling problem (QCSP) should be solved simultaneously. Figure 1 shows an example for berth allocation and crane scheduling for four vessels. In this example, a 600m berth length and five quay cranes are available in the seaport. According to the figure, the first vessel of 400m length and having a workload of 13 time units being served for four time units with 3 cranes in the first three time units and four cranes in the fourth time units. At the same time, another vessel of 200m length is being served as the berth length can accommodate both vessels. The workload of 6 time units will performed fulfilled through assigning two cranes for three time units. The remaining two vessels are of 300m length, therefore none of them can start its service until the 400m vessel is finished. By the end of four time units, the berth is vacant to accommodate the two 300m vessels where two cranes are assigned to the first 300m vessel and three cranes are assigned to the other vessel. In this research, a mathematical model is developed for berth allocation quay crane scheduling problem with the following assumptions:

- A continuous berth where vessels can berth at any position.
- Ready time for all vessels at the beginning of the time horizon is known.
- Vessel's berthing position cannot be changed during service time.
- The maximum number of quay cranes that can be allocated to each vessel is determined by the length of the vessel, and the distribution of workload over the length of the vessel.
- Service time is function of both vessel workload and number of allocated quay cranes
- Safety distance between vessels is included in the ship length
- The berthing position of vessels do not affect the number of quay cranes that can be assigned to each vessel.

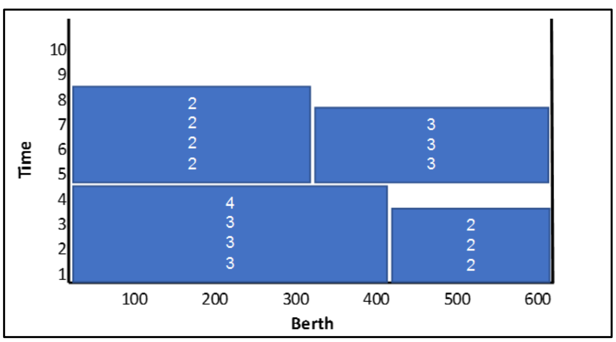

Figure 1: Berth Allocation and crane scheduling for four vessels and 600m berth length

The model was built to achieve the predefined objective which is to minimize the total flow time of the set of ready containers' vessels for service. The model constraints are mathematically formulated while considering the previously determined problem assumptions. The developed model was solved by LINGO optimization software using Core i5 4.3 GHz computer.

3.1. Nomenclature

Parameters:

V : Set of vessels on anchorage waiting for service; $\{v_i\}$ i = 1,2,.. V

T : Planning Horizon in unit time (The value of T is considered equal to the makespan upper bound value)

L : Berth length in meters

TQC : Total number of available quay cranes in berth

W_i : workload each vessel 'i', where i=1, 2… V

R_i : Ready time for each vessel 'i', $i \in V$

l_i : Length of vessel 'i', where $i \in V$

Min_i : Minimum number of quay cranes to be assigned to vessel 'i' =1

Max_i : Maximum number of quay cranes that can be assigned to vessel 'i'

Decision Variables:

ST : Vessels' service starting time matrix where, $St_{i,t}$ is a binary decision variable representing service start time for vessel i;

$$\begin{cases} 1 & \text{if vessel } `i\text{' start service at time } `t\text{'} \\ 0 & \text{Otherwise} \end{cases}$$

SST : Vessels service duration matrix where, $Sst_{i,t}$:A binary decision variable;

$$\begin{cases} 1 & \text{if vessel } `i\text{' is being served during time period } `t\text{'} \\ 0 & \text{Otherwise} \end{cases}$$

$Qc_{i,t}$: An Integer decision variable representing the number of quay cranes serving vessel 'i' during time period 't'

Ex: The matrices below shows an example for a problem of six vessels scheduled over a period of 7 time units. The decision matrices shown below indicate the start processing time, the service duration of each vessel and the number of cranes serving each vessel during its service time. For example, it can be observed that vessel six will start its service at period five and will be served for two time units with four cranes in the first period of service and four cranes in the second period of service.

$$ST = \begin{bmatrix} 1&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0 \\ 0&0&1&0&0&0&0 \\ 0&0&0&1&0&0&0 \\ 1&0&0&0&0&0&0 \\ 0&0&0&0&1&0&0 \end{bmatrix}, \quad SST = \begin{bmatrix} 1&1&1&1&0&0&0 \\ 1&1&0&0&0&0&0 \\ 0&0&1&1&0&0&0 \\ 0&0&0&1&1&1&1 \\ 1&1&1&0&0&0&0 \\ 0&0&0&0&1&1&0 \end{bmatrix},$$

$$QC = \begin{bmatrix} 2&2&2&2&0&0&0 \\ 3&3&0&0&0&0&0 \\ 0&0&3&4&0&0&0 \\ 0&0&0&2&4&4&4 \\ 3&3&3&0&0&0&0 \\ 0&0&0&0&4&4&0 \end{bmatrix}$$

3.2. Problem formulation

The problem is formulated as follows:

3.2.1. Objective function

$$Minimize\ \sum_{v=1}^{V}(\ Total\ Flow\ Time\ ) \quad (1)$$

$$\text{Min Z}=\sum_{i=1}^{V}\left\{\ \sum_{t=1}^{T}\left(St_{i,t}\ * ts_t\right)+\sum_{t=1}^{T}(Sst_t)-(Rs_i)\ \right\}$$

The objective function in equation (1) aims to minimize the total flow time for all vessels considered within the planning horizon where the difference between the finishing time of any vessel and its ready time is considered. The service start time for each vessel and the number of unit times for serving the vessel are considered in the calculation.

The first term of the above equation represents the start processing time for vessel i, where $St_{i,t}$ is equal to 1 at a single value of t. The processing duration of vessel i is represented in the second term of the equation, where the summation of $Sst_{\mathrm{i,t}}$ throughout the planning horizon represents the number of periods at which vessel i is being processed.

3.2.2. Constraints

$$\sum_{t=1}^{T} st_{i,t}=1 \qquad \forall\ i\ \in V \quad (2)$$

The constraint in equation (2) ensures single start time for each vessel. The above constraint guarantees a single start time for each vessel i, as the value of $st_{i,t}$will be equal to one at a single value of t and zero otherwise.

$$\sum_{t=1}^{T}\ st_{i,t} * t\ \geq\ Rs_i \qquad \forall\ i\ \in V \quad (3)$$

The constraint in equation (3) guarantees that the start service time of any vessel does not exist begin before its given ready time. The left-hand side of the constraint converts the start processing time of any vessel i from a binary vector$st_{i,t}$ to a value that is compared to the ready time of the vessel. The value of t is multiplied by its corresponding binary value in the vector$st_{i,t}$, thus the summation will result in a single value representing the vessel service start time.

$$\sum_{i=1}^{V}(l_i *\ Sst_i)\ \leq L \qquad \forall\ i\ \in V \quad (4)$$

The constraint in equation (4) ensures that the total length of berthed vessels at any time t do not exceed the berth length.

$$\sum_{i=1}^{V} Qc_{i,t}\ \leq TQC \qquad \forall\ t\ \in T \quad (5)$$

The constraint in equation (5) ensures that the total number of cranes serving the vessels at any time does not exceed the total number of cranes available in the port.

$$\sum_{t=1}^{T} Qc_{i,t} \geq W_i \qquad \forall\ i\ \in V \quad (6)$$

The constraint in equation (6) ensures that the total number of cranes assigned to any vessel during its entire service exactly covers the required workload of the vessel.

$$-Sst_{i,t-1}+Sst_{i,t}-\sum_{n=1}^{t} st_{i,n}+\sum_{n=1}^{t-1}\frac{Qc_{i,t}}{W_i}\leq 1 \quad (7)$$

$$-Sst_{i,t-1}+Sst_{i,t}-\sum_{n=1}^{t} st_{i,n}+\sum_{n=1}^{t-1}\frac{Qc_{i,t}}{W_i}\geq -1 \quad (8)$$

$$Sst_{i,t}\ \geq\ Sts_{i,t} \qquad \forall\ i\ \in V\quad \&\quad \forall\ t\ \in\ T \quad (9)$$

The constraints in equation (7), (8) & (9) ensure that the vessel's service is not interrupted until vessel service is finished as the value of $Sst_{i,t}$ for any vessel i is one starting from time t at which $st_{i,t}$ (vessel service start time) is one and never return to zero as long as the summation of the cranes assigned to the vessel is less than the total processing time required.

$$Qc_{i,t}\ \geq\ min_i * Sst_{i,t} \qquad \forall\ i\ \in V\quad \&\quad \forall\ t\ \in\ T \quad (10)$$

The constraint in equation (10) ensures that while serving any vessel, the minimum number of quay cranes is provided. The left-hand side of the constraint represents the total number of cranes serving a vessel at any time t which should satisfy the minimum number of cranes required by the vessel but only during the processing of the vessel at which $Sst_{i,t}$ equals one. As $Sst_{i,t}$ is equal to zero when the vessel is not being served (i.e: either before its service start or after finishing the service) then $Qc_{i,t}$ will equal to zero.

$$Qc_{i,t}\ \leq\ max_i * Sst_{i,t} \qquad \forall\ i\ \in V\quad \&\quad \forall\ t\ \in\ T \quad (11)$$

The constraint in equation (11) to ensure that the maximum number of cranes that can be assigned to each vessel is not exceeded.

4. RESULTS AND DISCUSSION

Experiments are carried out to study the effect of different seaport terminals' resources and operating factors on vessels-berth scheduling performance. The factors under study are continuous berth length, total number of available quay cranes and the maximum number of quay cranes that can be assigned to each vessel. The performance of vessels berthing and quay cranes scheduling is measured by the total schedule flow time, berth utilization and cranes utilization. **The experiments were divided into two groups:**

The **first group** aims to study the impact of the available resources and seaport operating strategy on the effectiveness of the vessels' berthing schedules to receiving services and to assign berthing places on the quayside. It is assumed that all container vessels are waiting at the anchor at the same. This group imposes the following:

The study considered different combinations of vessel sizes. Berth lengths are taken 400, 600, 800, 1000 &

1200 meters as per assumed by Henesey et al.[27]. The study is conducted assuming a total number of 4, 8, 12 & 16 quay cranes available at the seaport. Two vessel sizes are considered, large size vessels of 400 meters length and small size vessels of 200 meters length. Different ratios are considered between the number of large size and small size vessels. For each vessel length representing there are a minimum and a maximum number of quay cranes that can be assigned depends on vessel length and distribution or vessel workload. Six sets of experiments are conducted for above mentioned combinations of berth length, number of quay cranes and the two levels of maximum number of allowable quay cranes for each vessel as shown in table 1.

Table 1. Vessels Lengths and Maximum Allowable Cranes for the Six Experiments

No. of experiment	Proportion of different vessels sizes $l_1 : l_2$	Vessels length (unit length) $l_1 - l_2$	Min and Max. quay cranes for each vessel l_1	l_2
Set of Exp. #1	(50-50)%	400-200	min.=2 max.=4	min.=1 max.=3
Set of Exp. #2	(50-50)%	400-200	min.=2 max.=6	min.=1 max.=4
Set of Exp. #3	(80-20)%	400-200	min.=2 max.=4	min.=1 max.=3
Set of Exp. #4	(80-20)%	400-200	min.=2 max.=6	min.=1 max.=4
Set of Exp. #5	(80-20)%	200-400	min.=1 max.=3	min.=2 max.=4
Set of Exp.#6	(80-20)%	200-400	min.=1 max.=4	min.=2 max.=6

The **second group** aims to test the effectiveness of applying the developed model to solve a more general case where the port is assumed to contain 24 anchored waiting vessels. Berth length is assumed to be 1200m. Vessel length is generated randomly from a set of 200m, 300m and 400m vessels. The workload and the maximum allowable quay cranes are assumed to be proportional to the vessel length. As in the case of the first group, it is assumed the availability of cranes to serve the loading and unloading operations are 8-10-12-16-20, and a minimum and maximum number of quay cranes allocated to each vessel are 4 and 6. The same study was carried out on this group as in the first group.

4.1. Results of first group of experiments

The results of set of exp. #1 are shown in figure 2. The effect of increasing the quay cranes on the total flow time is shown in Figure 2(a). It is observed that increasing the number of quay cranes at berth length of 400m does not contribute in improving the total flow time. Additionally, a deterioration in quay care utilization occurs as the number of quay cranes increases as can be seen in figure 2(b).

The interpretation of such behaviour can be concluded from Figure 3 which shows the berthing schedule of the vessels and the number of cranes serving each vessel at every time period. It is concluded that increasing the number of quay cranes available in the port, without increasing the capacity of the berth to accommodate more vessels at a time, will result in the same total flow time and makespan together with reducing the quay crane utilization to 22% when the number of quay cranes increases to 16 cranes.

For berth length 600m, an improvement in the total flow time can be depicted in Figure 2(a). As the number of quay cranes increased from four to eight, the total flow time has improved by 9.3% at TQC=4 as compared with that obtained with the same number of quay cranes at 400m berth length. As the number of quay cranes increases to 8, total flow time has improved by 25%. However, the improvement was also accompanied by a reduction in quay carne utilization as shown in figure 2(b). The reduction in crane utilization can be explained by figure 4. This means that, when the number of cranes increases from four to eight, the number of idle cranes increases despite of full occupancy of berth. The presence of idle cranes at the time the berth is fully occupied occurs due the fact that each berthed vessel utilizes the maximum allowable number of cranes.

On the other hand, further increase in the number of quay cranes will result in no improvement in the total flow time as well as a reduction in quay crane utilization. As neither the berth can accommodate more vessel nor can the vessel be served by more cranes at any given time. Also, the berth utilization shown in figure 2(c) remains constant with increasing the number of quay cranes, since the berth can always be fully utilized as the number of cranes is equal to or exceeds the requirements of the berthed vessels.

For 800m berth length, figure 2(a) shows that the same total flow time as 600m berth length is obtained when the number of quay cranes are four. As the number of quay cranes increases a higher improvement in the total flow time is obtained compared to that with smaller berth length. However, the total flow time remains constant with further increase in quay cranes.

The quay cranes utilization shown in figure 2(b) demonstrates the same behavior as that for smaller berth length. Figure 5 describes the effect of increasing the number of quay cranes. As the total quay cranes reaches eight and more, the berth is fully occupied with vessels and the maximum allowable quay cranes are assigned to berthed vessel. Thus, increasing the number of quay cranes for the given berth length leads to reduced crane utilization.

It is obvious from figure 2(c) that berth utilization is reduced compared to that for 600m berth length. This is accompanied with an increase in the utilization as the number of quay cranes increases up-to 12 quay cranes after which it remains constant. Figure 5 explain such

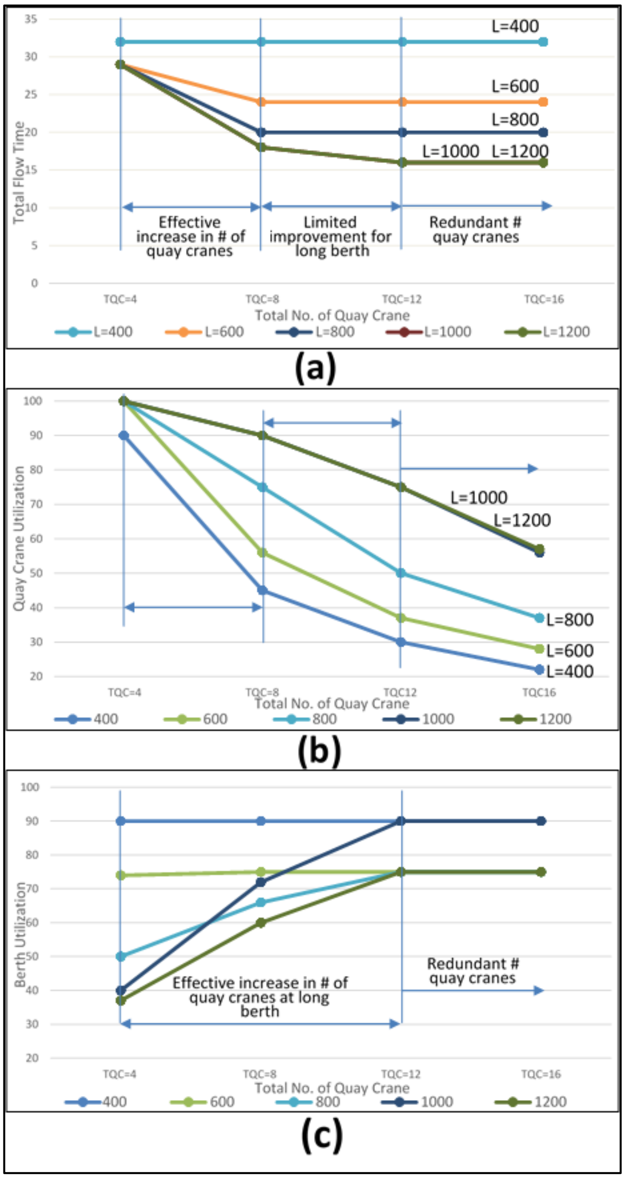

Figure 2: The Results of Exp. #1 (a) Total Flow Time (b) Quay Crane Utilization (c) Berth Utilization

behaviour as the berth is not fully occupied when the total number of quay cranes are 4 and 8 since the number of available cranes do not allow the berth to accommodate more vessels. As the number of quay cranes are 12 and more, the berth can accommodate more vessels to be served and the utilization is improved to its maximum value dictated by the vessel lengths with respect to berth length.

For berth length 1000m and 1200m in figure 2, the same behaviour is obtained as occurred in case of smaller berth length. As the total flow time at four quay cranes is equal to the similar case at smaller berth length while a sound improvement in the total flow time is obtained with increasing the number of quay cranes. Also, the same behaviour is obtained for crane utilization and berth utilization as obtained for smaller berth. Figures 6

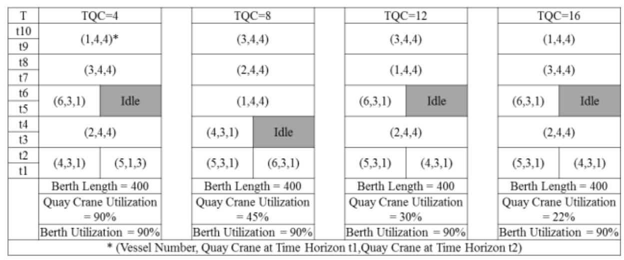

Figure 3: The Quay Crane Distribution at Berth Length 400m

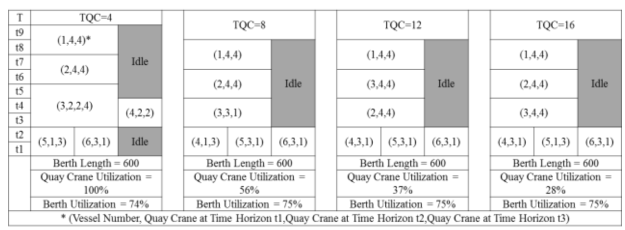

Figure 4: The Quay Crane Distribution at Berth Length 600m

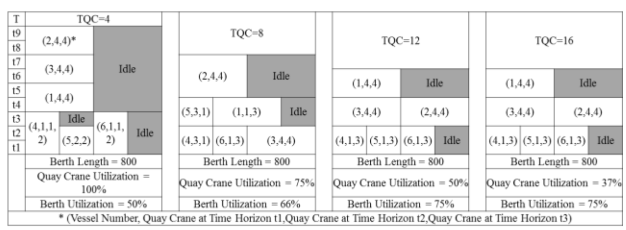

Figure 5: The Quay Crane Distribution at Berth Length 800m

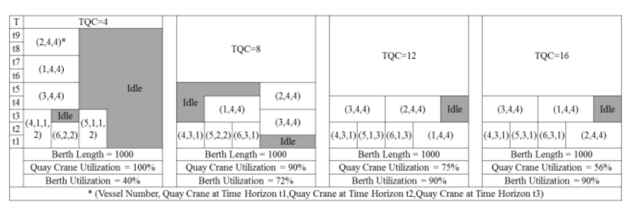

Figure 6: The Quay Crane Distribution at Berth Length 1000m

and 7 shows the berthing schedule for 1000m berth and 1200m berth respectively at different number of quay cranes. It can be observed that the same behaviour is obtained as smaller berth length.

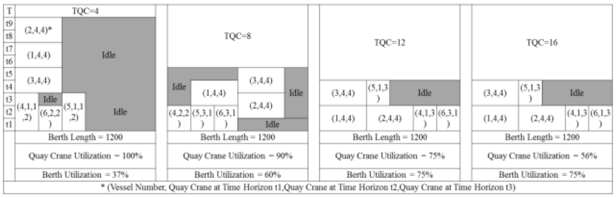

Figure 7: The Quay Crane Distribution at Berth Length 1200m

As shown in table 1, Exp. #2 is conducted with the same size and large size vessels. Figure 8(a-c) shows the berth length and number of quay cranes on: (a) total flow time, (b) quay crane utilization and (c) berth utilization in (c). It is evident from the figure that the same results patterns are obtained as in set of Exp. #1.

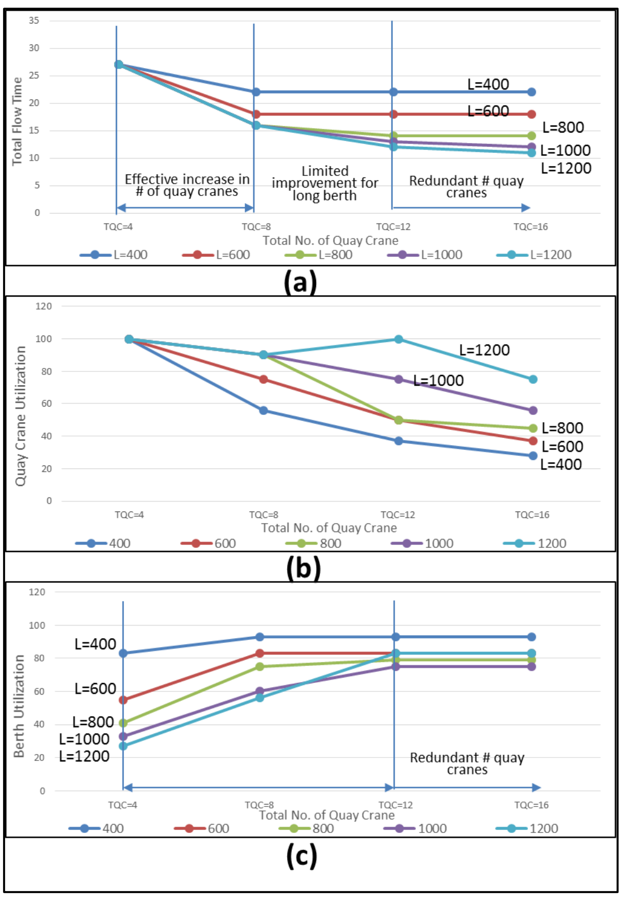

Figure 8: The Results of Exp. #2 (a) Total Flow Time (b) Quay Crane Utilization (c) Berth Utilization

Figure 9 shows a comparison between the total flow time obtained for Exp. #1 and Exp. #2. The figure shows that a typical behavior is obtained at all combinations of berth length and number of quay cranes with increased values as the maximum allowable quay cranes. It is obvious from the figure that the difference between the total flow time values increases at small values of berth length while the differences between the two values

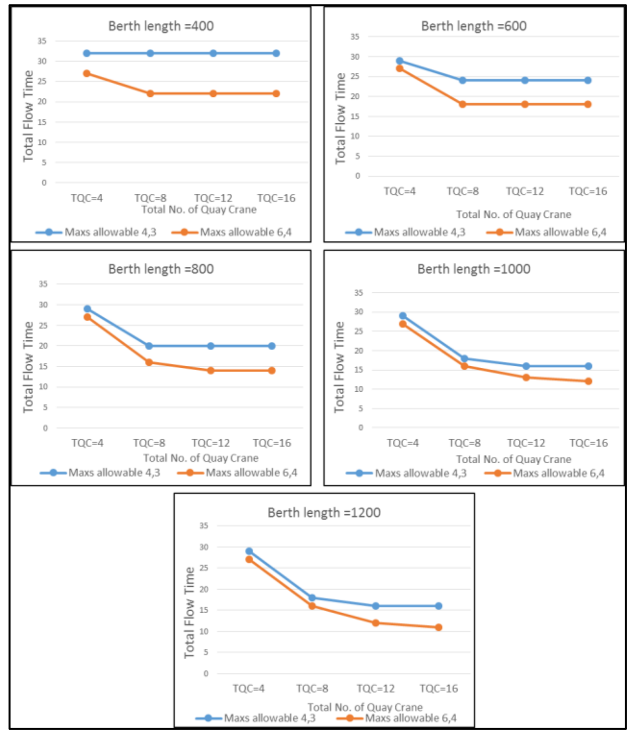

Figure 9: The Total Flow Time Difference between Exp. #1 and Exp. #2

decreases at larger values of berth length.

Different ratios between large and small size vessels are considered in Exp. #3 and Exp. #4 as shown in table 1. Large size vessels represent 80% of the vessel arriving to the port. Figure 10 shows the total flow time, quay crane utilization and berth utilization for Exp. #3 for the same combinations of berth length and number of quay cranes considered in the previous experiments. It can be concluded from the figure that the same behavior previously obtained in Exp. 1 & 2 can describe the behavior with regard to the number of quay cranes which increases for a given berth length.

Figure 11 illustrates the difference in total flow time obtained for Exp. #3 and Exp. #4 for each berth length. The difference is significant in the berth length 400m, and 800m at TQC= 8, 12 and 16. The difference will be small for berth length 600m, 1000m, and 1200m.

For Exp. #5 and Exp. #6, the ratio of large size vessels represents 20% of the total number of vessels waiting to berth. The results of Exp. #5 and Exp. #6 shows the same pattern of total flow time, quay crane utilization and berth utilization as previous experimental results. Figure 12 shows a comparison of the total flow time between Exp. #5 and Exp. #6 due to the increase of the maximum allowable cranes per vessel. Figure 12 shows the same behavior obtained in figures 9 & 11. An improved total flow time is obtained by increasing the maximum allowable quay cranes for each vessel.

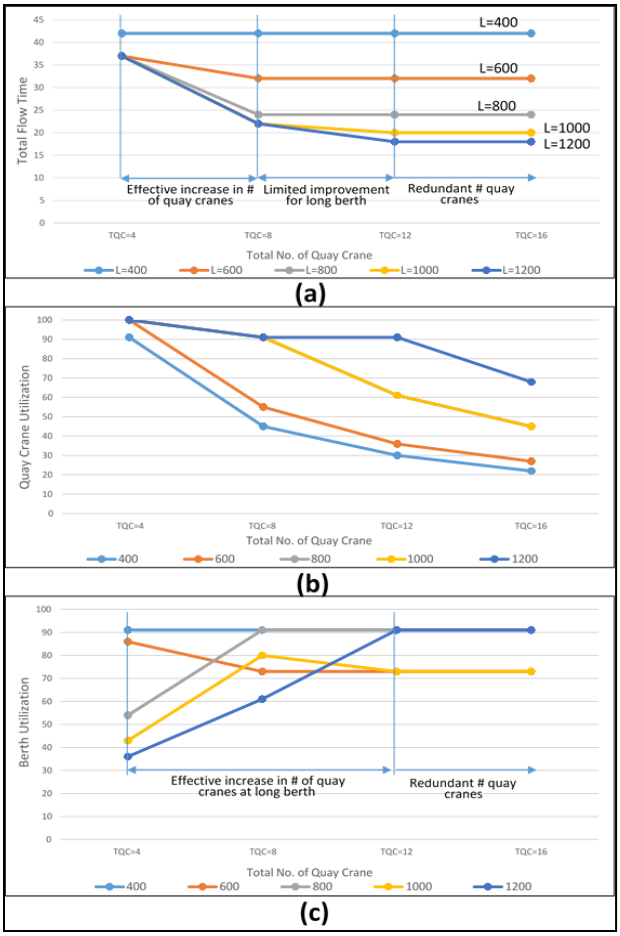

Figure 10: The Results of Exp. #2 (a) Total Flow Time (b) Quay Crane Utilization (c) Berth Utilization

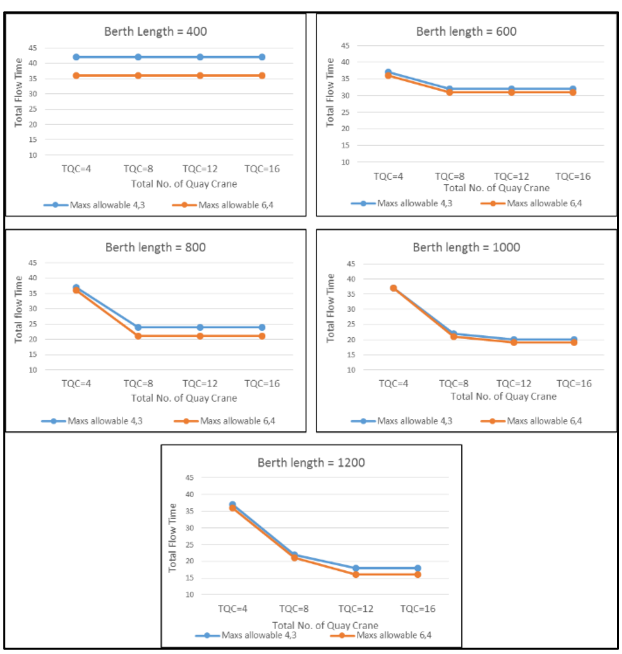

Figure 11: The Total Flow Time Difference between Exp. #3 and Exp. #4

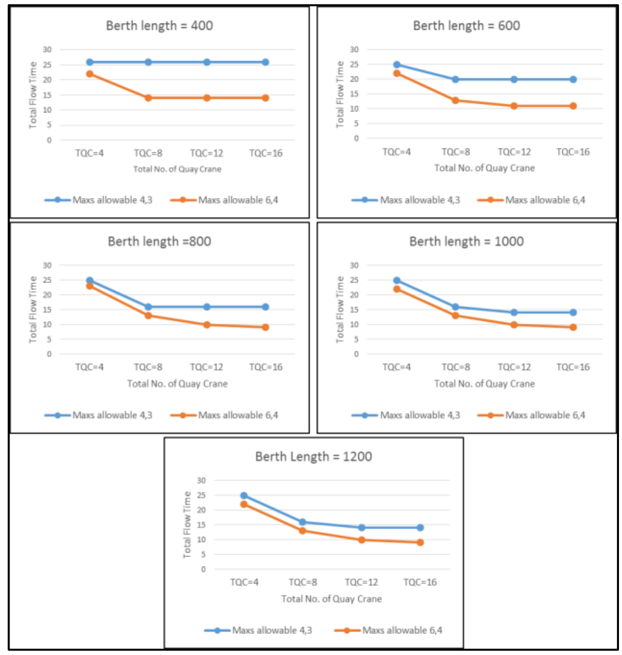

Figure 12: The Total Flow Time Difference between Exp. #5 and Exp. #6

Based on the observations from the previous sets of experiments; as the berth length increase, increasing the number of quay cranes will have a significant effect in improving vessels total flow time where this improvement is accompanied by an increase in berth utilization and a reduction in crane utilization. Also, as the maximum allowable quay cranes per vessel increase an improvement in the vessels total flow time is achieved where such improvement is significant as the number of quay cranes increases. Thus, a direct relation exists between the three influencing factors (berth length, number of quay cranes and maximum allowable cranes per vessel) and their effect on the total flow time, berth utilization and quay crane utilization. This the due to the fact that as the berth length increase it can accommodate more vessels to be served at the same time, also; as the workload of vessels is distributed over its entire length it can accommodate more cranes to perform the loading/unloading process. Hence, increasing the number of cranes will contribute significantly to improving the total flow time. On the contrary, as the number of cranes decreases; less number of vessels will be served leading to an increase in total flow time and the make span together with a reduced berth utilization since the number of vessels served at any time will decrease. For smaller berth length, increasing the number of cranes will not improve the total flow time since the berth is accommodating less number of vessels, therefore the cranes will be idle leading to a reduced quay crane utilization.

4.2. Results of second group of experiments

The results of total flow time, quay crane utilization and berth utilization are shown in figure 13(a-b). It is obvious from figure 13 that the same pattern as the six previously discussed experiments is obtained. An improvement in total flow time is obtained with increasing number of quay cranes till a certain number after which no further improvement occurs. Also, an improved berth utilization and reduced quay crane utilization is obtained as that observed in the previous six experiments. Figure 14 shows the berthing schedule for the 24 vessels and the number of quay cranes assigned to each vessel at every time period for the case of 12 quay cranes. It can be observed that for most of the time the berthed vessels are served by their maximum allowable number of cranes while the berth is fully occupied. Therefore, increasing the number of cranes to more than 12 will not contribute to improving the total flow time for the given berth length; moreover, quay cranes utilization decreases significantly due to increased number of idle cranes.

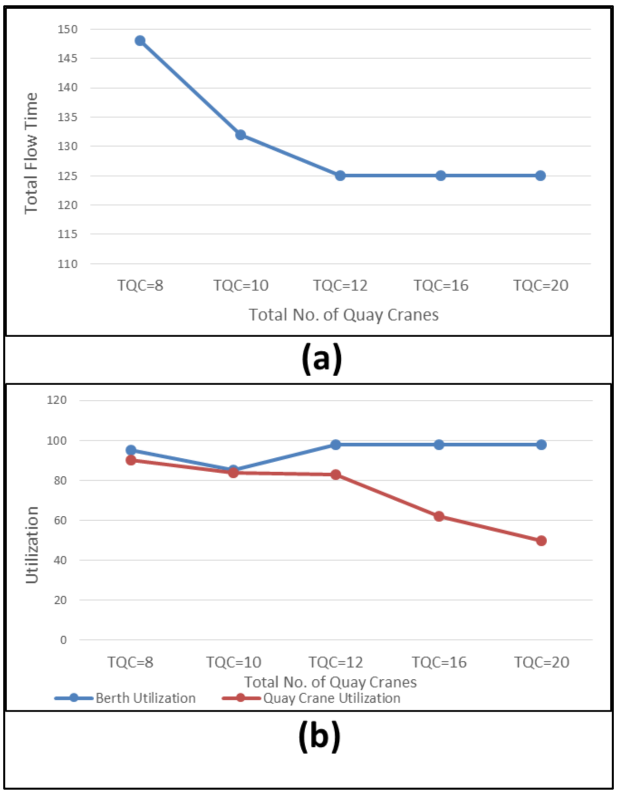

Figure 13: Total Flow Time and utilization of 24 vessel Experiment

5. CONCLUSION

Most of the previous research focused on developing solution techniques either exact methods or meta-heuristics in order to solve the integrated berth allocation quay care assignment problem and to evaluate the efficiency of developed models in terms of accuracy and time. Only few research discussed the factors affecting port performance. A linear programming model is developed to minimize the total flow time. The developed model is used to study the factors affecting vessels total flow time, cranes utilization and ports utilization as well as the interaction between these factors. Experiments have been conducted on hypothetical cases of limited number of container vessels considering multiple quay lengths and different numbers of quay cranes. The experiments led to the conclusion that increasing the number of quay cranes leads to a significant reduction in the total flow time up to certain limit of quay cranes. Increasing the number of cranes above this limit has insignificant effect on the total time of flow. It is found that this behavior and quay cranes limit depends on the length of the quayside and the maximum number of cranes allowed to serve each vessel workload. The results also demonstrated a deterioration in the rate of utilization of quay cranes and an increase in the rate of use of the berth as the number of available quay cranes increases. The effectiveness of the proposed model has been proven in achieving the required objectives for different port configuration and its efficiency in dealing with cases involving a larger number of container vessels, where the results show similar behavior to the cases previously tested. Future work may include considering dynamic vessels arrival and solving the problem with multiple objectives.

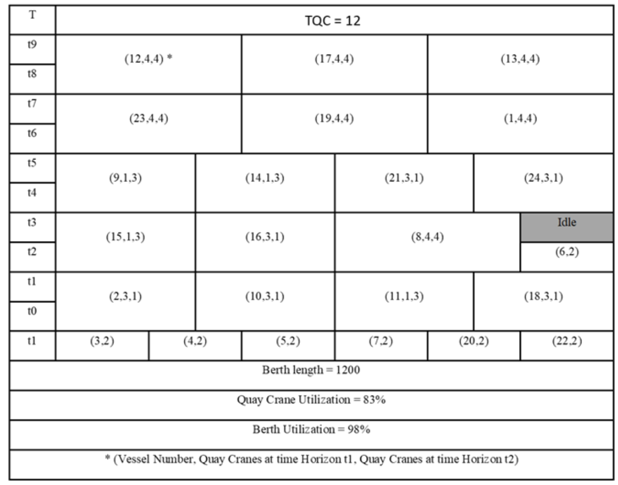

Figure 14: Quay Crane Distribution at 24 Vessel Experiment

6. REFERENCE

1. Hsu, H.P.; Wang, C.N.; Chou, C.C.; Lee, Y.; Wen, Y.F. Modeling and Solving the Three Seaside Operational Problems Using an Object-Oriented and Timed Predicate/Transition Net. *Appl. Sci.* **2017**, *7*, doi:10.3390/app7030218.
2. Al-Dhaheri, N.; Jebali, A.; Diabat, A. The Quay Crane Scheduling Problem with Vessel Stability and Nonzero Crane Moving Time. *Comput. Ind. Eng.* **2016**, *94*, doi:10.1016/j.cie.2016.01.011.
3. Jiang, M.; Zhou, J.; Feng, J.; Zhou, L.; Ma, F.; Wu, G. Integrated Berth and Crane Scheduling Problem Considering Crane Coverage in Multi-Terminal Tidal Ports under Uncertainty. *J. Mar. Sci. Eng.* **2022**, *10*, doi:10.3390/jmse10040506.
4. He, J. Berth Allocation and Quay Crane

Assignment in a Container Terminal for the Trade-off between Time-Saving and Energy-Saving. *Adv. Eng. Informatics* **2016**, *30*, 390–405, doi:10.1016/j.aei.2016.04.006.
5. Malekahmadi, A.; Alinaghian, M.; Hejazi, S.R.; Assl Saidipour, M.A. Integrated Continuous Berth Allocation and Quay Crane Assignment and Scheduling Problem with Time-Dependent Physical Constraints in Container Terminals. *Comput. Ind. Eng.* **2020**, *147*, 106672, doi:10.1016/j.cie.2020.106672.
6. Iris, Ç.; Pacino, D.; Ropke, S.; Larsen, A. Integrated Berth Allocation and Quay Crane Assignment Problem: Set Partitioning Models and Computational Results. *Transp. Res. Part E Logist. Transp. Rev.* **2015**, *81*, 75–97, doi:10.1016/j.tre.2015.06.008.
7. Xiang, X.; Liu, C. An Almost Robust Optimization Model for Integrated Berth Allocation and Quay Crane Assignment Problem. *Omega (United Kingdom)* **2021**, *104*, doi:10.1016/j.omega.2021.102455.
8. Boison, David King, Awudu, I.; Norbis, M. Optimizing the Use of Sea-Port Berthing Space : A Case Study of Tema Port in Proceedings of 8th Global Business Research Conference Optimizing the Use of Sea-Port Berthing Space : A Case Study of Tema Port in Ghana Iddrisu Awudu *, David Boison and Mario. **2017**, 1–23.
9. Imai, A.; Nishimura, E.; Hattori, M.; Papadimitriou, S. Berth Allocation at Indented Berths for Mega-Containerships. *Eur. J. Oper. Res.* **2007**, *179*, 579–593, doi:10.1016/j.ejor.2006.03.034.
10. Imai, A.; Chen, H.C.; Nishimura, E.; Papadimitriou, S. The Simultaneous Berth and Quay Crane Allocation Problem. *Transp. Res. Part E Logist. Transp. Rev.* **2008**, *44*, 900–920, doi:10.1016/j.tre.2007.03.003.
11. Elwany, M.H.; Ali, I.; Abouelseoud, Y. A Heuristics-Based Solution to the Continuous Berth Allocation and Crane Assignment Problem. *Alexandria Eng. J.* **2013**, *52*, 671–677, doi:10.1016/j.aej.2013.09.001.
12. Chung, S.H.; Choy, K.L. A Modified Genetic Algorithm for Quay Crane Scheduling Operations. *Expert Syst. Appl.* **2012**, *39*, 4213–4221, doi:10.1016/j.eswa.2011.09.113.
13. Lee, D.H.; Chen, J.H.; Cao, J.X. The Continuous Berth Allocation Problem: A Greedy Randomized Adaptive Search Solution. *Transp. Res. Part E Logist. Transp. Rev.* **2010**, *46*, 1017–1029, doi:10.1016/j.tre.2010.01.009.
14. Prencipe, L.P.; Marinelli, M. A Novel Mathematical Formulation for Solving the Dynamic and Discrete Berth Allocation Problem by Using the Bee Colony Optimisation Algorithm. *Appl. Intell.* **2021**, *51*, 4127–4142, doi:10.1007/s10489-020-02062-y.
15. Ting, C.J.; Wu, K.C.; Chou, H. Particle Swarm Optimization Algorithm for the Berth Allocation Problem. *Expert Syst. Appl.* **2014**, *41*, 1543–1550, doi:10.1016/j.eswa.2013.08.051.
16. Liu, J.; Wan, Y.W.; Wang, L. Quay Crane Scheduling at Container Terminals to Minimize the Maximum Relative Tardiness of Vessel Departures. *Nav. Res. Logist.* **2006**, *53*, 60–74, doi:10.1002/nav.20108.
17. Bierwirth, C.; Meisel, F. A Survey of Berth Allocation and Quay Crane Scheduling Problems in Container Terminals. *Eur. J. Oper. Res.* **2010**, *202*, 615–627, doi:10.1016/j.ejor.2009.05.031.
18. Skaf, A.; Lamrous, S.A.; Hammoudan, Z.; Manier, M.; Skaf, A.; Lamrous, S.A.; Hammoudan, Z.; Exact, M.M. Exact Method for Single Vessel and Multiple Quay Cranes to Solve Scheduling Problem at Port of Tripoli-Lebanon To Cite This Version : HAL Id : Hal-02991560. **2020**.
19. Chen, J.H.; Lee, D.H.; Cao, J.X. Heuristics for Quay Crane Scheduling at Indented Berth. *Transp. Res. Part E Logist. Transp. Rev.* **2011**, *47*, 1005–1020, doi:10.1016/j.tre.2011.04.004.
20. Duan, J.; Liu, Y.; Zhang, Q.; Qin, J. Combined Configuration of Container Terminal Berth and Quay Crane Considering Carbon Cost. *Math. Probl. Eng.* **2021**, *2021*, doi:10.1155/2021/6043846.
21. Chargui, K.; Zouadi, T.; El Fallahi, A.; Reghioui, M.; Aouam, T. A Quay Crane Productivity Predictive Model for Building Accurate Quay Crane Schedules. *Supply Chain Forum* **2021**, *22*, 136–156, doi:10.1080/16258312.2020.1831889.
22. Shang, X.T.; Cao, J.X.; Ren, J. A Robust Optimization Approach to the Integrated Berth Allocation and Quay Crane Assignment Problem. *Transp. Res. Part E Logist. Transp. Rev.* **2016**, *94*, 44–65, doi:10.1016/j.tre.2016.06.011.
23. Liang, C.; Huang, Y.; Yang, Y. A Quay Crane Dynamic Scheduling Problem by Hybrid Evolutionary Algorithm for Berth Allocation Planning. *Comput. Ind. Eng.* **2009**, *56*, 1021–1028, doi:10.1016/j.cie.2008.09.024.
24. Han, X.L.; Gong, X.; Jo, J. A New Continuous Berth Allocation and Quay Crane Assignment Model in Container Terminal. *Comput. Ind. Eng.* **2015**, *89*, 15–22, doi:10.1016/j.cie.2015.04.033.
25. Imai, A.; Sun, X.; Nishimura, E.; Papadimitriou, S. Berth Allocation in a Container Port: Using a Continuous Location Space Approach. *Transp. Res. Part B Methodol.* **2005**, *39*, 199–221, doi:10.1016/j.trb.2004.04.004.
26. Ganji, S.R.S.; Babazadeh, A.; Arabshahi, N. Analysis of the Continuous Berth Allocation Problem in Container Ports Using a Genetic

Algorithm. *J. Mar. Sci. Technol.* **2010**, *15*, 408–416, doi:10.1007/s00773-010-0095-9.
27. Henesey, L.; Davidsson, P.; Persson, J.A. Using Simulation in Evaluating Berth Allocation at a Container Terminal. *Proc. 3rd Int. Conf. Comput. Appl. Inf. Technol. Marit. Ind.* **2004**.