ABSTRACT: This paper presents a framework of simulation model that can be used to solve berth allocation problem (BAP) and Quay Crane assignment problem (QCAP) in Port Said container terminal. The aim is to assign ships to berthing area alongside a quay with an appropriate number of quay cranes taking into consideration convoy time schedule. The proposed model logic will be implemented using discrete event simulation. This is a unique problem to that container terminal due to its presence on the Northern entrance of the Suez Canal that will have a significant impact on terminal performance and on container ships calling the port.

Keywords: Port Said port, Suez Canal, Berth Allocation, Quay Crane Assignment, simulation.

1. INTRODUCTION:

Containerized sea-freight transportation has grown dramatically over the last two decades, much faster than other sea transportation modes. World container trade, expressed in 20-foot equivalent units (TEUs), grew by 7.1 percent in 2011, down from 12.8 percent in 2010 as shown in figure1 [1].

This rapid growth is explained by several factors, such as reduced transit time, reduced shipping costs, increased reliability and security, multi-modality. Containers are nowadays the main type of tools used in intermodal transport: any container has a standardized load unit that is suitable for ships, trucks and trains and can be transferred very quickly from one transport mode to another.

In this context, container terminals are crucial connections between different transportation modes and cargo handling represents a critical point in the transportation chain. Moreover, they also represent the site where several market players involved in maritime transportation (such as the terminal itself, the port authority, and the shipping companies) trade for their business.
Port Said port is situated on the Northern entrance of the Gulf of Suez. It is considered one of the main Egyptian ports due to its distinguished location at the crossroad of the most important world sea trade route between the East and Europe via the Suez Canal, and the most extensive transshipment port in the world [2]. The port is bordered, seaward, by an imaginary line extending 0.5 nautical miles from the western breakwater boundary till the eastern breakwater end. And from the Suez Canal area, it is bordered by an imaginary line extending transversely from the southern bank of the Canal connected to Manzala Lake, and the railways arcade livestock as shown in Figure 2.

The port traditionally serves for transshipment cargo bound to the North African region (Egypt, Libya, Algeria), the East Med-Levant region (Israel, Jordan, Lebanon, Syria, Cyprus, lower Turkey), Aegean region (Greece), even as far as the Adriatic (Italy, Slovenia, Croatia, Albania) and the Black Sea region.
Starting operation on October 1988, Port Said Container Terminal (PSCT) is managed by Port Said Container & Cargo Handling Company (PSCCHC) which is majority owned by the Egyptian Ministry of Investment. PSCCHC unique location facilitates handling container vessels calling PSCT and joining the convoy. Port Said container quay and terminal are located at the extension of Abbas basin south Port-Said port & west canal navigation course. PSCT is complete pool of quayside and landside resources include the following units: 9 Gantry cranes, 7 Rubber Tired Cranes (RTG), 29 reach stackers and 50 Tractors & Semi-Trailers [3]. The breakdown by resource type and characteristics is represented in table 1.

<table>
<thead>
<tr>
<th>Terminal and Facility</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quay Length</td>
<td>950 m</td>
</tr>
<tr>
<td>Max Draft</td>
<td>13.20 m</td>
</tr>
<tr>
<td>Vessel Operation</td>
<td>9 x Gantry Cranes</td>
</tr>
<tr>
<td>Yard Operation</td>
<td>7x RTG + 29 Reach Stacker</td>
</tr>
<tr>
<td>Tractors &amp; Semi - Trailers</td>
<td>50</td>
</tr>
<tr>
<td>Warehouse</td>
<td>13,000 m²</td>
</tr>
<tr>
<td>Terminal Throughput Capacity</td>
<td>900,000 TEU</td>
</tr>
<tr>
<td>Total Yard Area</td>
<td>460,000 m²</td>
</tr>
<tr>
<td>Reefer Plugs</td>
<td>650 Fixed on Dedicated Yard</td>
</tr>
</tbody>
</table>

Container handling activity started since 1988 with a handling volume 25479 TEU. It began to grow year after year as a result of the continuous development incurred in the terminal including quays, yards, equipment, and computer system until it reached 1026023 TEU in 2005/2006. Container handling activity represents 90% of the company activities. The production volume of container handling activity is represented in Table 2 from 2000/2001 till 2008/2009.

The Suez Canal is considered to be the shortest link between the east and the west due to its unique geographic location; it is an important international navigation canal linking between the Mediterranean Sea at Port Said and the red sea at Suez. The unique geographical position of the Suez Canal makes it of special importance to the world and to Egypt as well. This importance is getting augmented with the evolution of maritime transport and world trade. The maritime transport is the cheapest means of transport, whereas more than 80% of the world trade volume is transported via waterways (seaborne trade).

The number of vessels passing through the Suez Canal over the period 2006-2012 is presented in figure 3[4]. As shown in the figure 3, the main vessels to use the canal are container ships; accounting for 38% of the total number of vessels passing through the canal in 2010. There was a growth in the number of Container and General Cargo ships between 2006 and 2008 by 15% and 19% respectively. Although there was a decline in numbers for all types of ships passing through the canal due to the economic crisis in 2009, the numbers from 2010 show that there is a potential increase in the number of vessels passing through Suez Canal in the next years.
Table 2: Total containers (Thousand TEU) handled in Port Said port from 2001 – 2009.

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Vessels</th>
<th>Actual Handling</th>
<th>Increasing Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOCAL</td>
<td>TRANSIT</td>
</tr>
<tr>
<td>2000/2001</td>
<td>1439</td>
<td>129736</td>
<td>423690</td>
</tr>
<tr>
<td>2001/2002</td>
<td>1545</td>
<td>127142</td>
<td>441806</td>
</tr>
<tr>
<td>2002/2003</td>
<td>1493</td>
<td>117345</td>
<td>449125</td>
</tr>
<tr>
<td>2003/2004</td>
<td>1660</td>
<td>121439</td>
<td>700097</td>
</tr>
<tr>
<td>2004/2005</td>
<td>1351</td>
<td>146726</td>
<td>699960</td>
</tr>
<tr>
<td>2005/2006</td>
<td>1384</td>
<td>193090</td>
<td>727976</td>
</tr>
<tr>
<td>2006/2007</td>
<td>1261</td>
<td>231895</td>
<td>794128</td>
</tr>
<tr>
<td>2007/2008</td>
<td>1144</td>
<td>269644</td>
<td>716228</td>
</tr>
<tr>
<td>2008/2009</td>
<td>1209</td>
<td>240674</td>
<td>497324</td>
</tr>
</tbody>
</table>

As stated earlier, PSCCHC unique location facilitates handling container vessels calling PSCT and joining the convoy. To achieve this goal, integrated berth and quay crane allocation problem must be solved. The analytical approach has been used to solve this problem, but due the complexity of the integrated problem, discrete event simulation will be used to solve this problem and proposed logic framework model will be presented.

Discrete Event Simulation (DES) is probably the most widely used simulation technique in Operational Research. As the name suggests it models a process as a series of discrete events. This means that entities (the general name for what is being considered; e.g. “ships”) are thought of as moving between different states as time passes. The entities enter the system and visit some of the states (not necessarily only once) before leaving the system.
When simulating, authors consider a container terminal as a system; therefore, instead of concentrating on a single terminal problem the entire flow of containers are considered and optimized (Nevins et al., 1998).

Simulation techniques are widely used in the analysis of port and terminal planning process and container handling system. Simulation studies have not only assisted in understanding the details of the processes, but the graphical modelling tools and animated runs like those in ARENA also ease the involvement of the management in the development and the decision making processes.

As an outline for the rest of the paper, we will give the literature review in Section 2. Section 3 describes the BA and QCA problem. In Section 4 we describe the solution method. Section 5 presents the proposed logic flowchart. Lastly, main conclusions and future work are addressed.

2. Literature review

2.1 Berth Allocation Problem :

The Berth Allocation Problem can be identified as a problem of allocating ships to berths or to quays. In the berth allocation problem the aim is to plan and assign ships to berthing area along a quay in order to achieve the maximum utilisation possible. The objective is to minimise the total service time for all ships which is defined as the time elapsed between the arrival in the harbour and completion of handling (Cordeau et al., 2005). There are many constraints and issues when allocating ships to berth. The constraints and issues includes the length of ship, depth of berth, time frame, priorities assigned to the ship, and shippers favourite berthing areas (Imai et al., 2007; Lee & Chen, 2009; Legato & Mazza, 2001; Vacca et al., 2007).

The berth allocation problem can be modelled either as a discrete or a continuous event. Cordeau et al., (2005) considered two versions of berth allocation problem in their studies: the discrete case and the continuous case. The discrete case worked with a finite set of berthing points and in the continuous case ships berthed anywhere along the quay. Two formulations and a tabu2 search heuristic are presented and tested on realistic traffic and berth allocation data obtained from the port of Gioia Tauro, Italy.

Imai et al. (2005) presented a continuous model of the berth allocation problem to minimise the total service time of ships. The authors presented a heuristic algorithm which solves the problem in two stages, by improving the solution for the discrete case. Lee & Chen (2009) present an optimisation based approach for the berth scheduling problem. The main purpose of the study was to determine the berthing time and space for incoming ships. The neighborhood-search based heuristic treats the quay as a continuous space. In addition to the basic physical requirements, the model they presented takes several factors important in practice into consideration, including the first-in-first-out (FIFO) rule, clearance distance between ships, and the possibility of ship shifting.

Imai et al. (2007) address the berth allocation problem at a multi-user container terminal with indented berths for fast handling of small containerships. The problem is formulated as an integer linear problem and the formulation is then extended to model the berth allocation problem at a terminal with indented berths, where both mega-containerships and feeder ships are to be served for higher berth productivity. The berth allocation problem at the indented berths is solved by genetic algorithms. The solutions are evaluated by comparing the indented terminal with a conventional terminal of the same size. Legato & Mazza (2001) propose a queuing network model of the logistics activities related to the arrival, berthing and departure process of vessels at container terminals. Wang and Lim (2007) propose a stochastic beam search scheme for the berth allocation problem. The implemented algorithm is tested on real-life data from the Singapore Port Terminal.
2.2 Quay Crane Scheduling Problem :

The Quay Crane Scheduling Problem refers to the allocation of a fixed number of quay cranes to a ship or to a task and it also refers to the scheduling of loading and unloading container moves (Vacca et al., 2007). The quay crane scheduling problem aims at finding a schedule for the quay cranes with respect to a given objective function (Bierwirth & Meisel, 2009). This helps in assigning a particular quay crane and a starting time to every intended loading and unloading operation. Most often, the purpose is to minimise the vessel service time (J. Liu et al., 2005).

Ng, (2005) examines the problem of scheduling multiple yard cranes to perform a given set of jobs with different ready time in a yard zone. The research develops a dynamic programming based heuristic to solve the scheduling problem and an algorithm to find lower bounds for benchmarking the schedules found by the heuristic. Computational tests are carried out to evaluate the performance of the heuristic. The results demonstrate that the heuristic can find efficient solutions for the scheduling problem.

Imai et al., (2007) propose a dynamic programming algorithms and a probabilistic tabu search to solve the quay scheduling problem. The algorithms are tested on the actual situation in the port of Singapore. Park and Kim, (2003) discuss the problem of scheduling quay cranes using a mixed integer programming model which considers various constraints related to the operation of quay cranes. The study proposes a branch and bound method to obtain the optimal solution of the quay crane scheduling problem and a heuristic search algorithm called greedy randomise adoptive search procedure. Both solutions are tested on generated instances.

2.3 Integrated Berth allocation and Quay Crane Assignment Problem :

The integration of berth allocation and quay cranes assignment has received less attention in the scientific literature; however, a few studies on this specific topic have been recently published.

Park and Kim (2003) have firstly integrated the BAP in the continuous case with the QCAP, also considering the scheduling of quay cranes. The integrated problem is formulated as an integer program and a two-phase solution procedure is presented to solve the model. In the first phase, the berthing time and position of vessels and the number of quay-cranes assigned to each vessel at each time step are determined using Lagrangean relaxation and a subgradient optimization technique; the objective is to minimize the sum of penalty costs over all ships. In the second phase, cranes are scheduled along the quay via dynamic programming, with the objective of minimizing the number of setups. Up to 40 vessels are scheduled over a time horizon of one week, with a berth of 1200m and 11 QCs available.

With respect to the problem formulation, authors take into account some practical aspects such as favourite berthing positions of vessels, maximum and minimum number of cranes to be assigned to each vessel, penalty costs due to earlier or later berthing time, and later departure time (with respect to previously committed time).

Meisel and Bierwirth (2006) investigate the simultaneous allocation of berths and quay cranes, focusing on the reduction of QCs idle times, which significantly impact on terminal’s labor costs. A heuristic scheduling algorithm based on priority-rules methods for the resource-constrained project scheduling is proposed and tested on six instances, based on real data, which consider up to 18 vessels to be served in two days. Preliminary results, compared to the manually generated schedules which have been used in practice, are encouraging. In this approach, each vessel represents an activity which can be performed in 8 different modes, each mode representing a given QC-to-Vessel assignment over time. The concept of “mode” seems analogous to the concept of profile we have introduced so far; however, no detailed description of these modes is available in the paper.

Imai et al. (2007) address the simultaneous berth-crane allocation and scheduling problem, taking into account physical constraints of quay cranes, which cannot move freely among berths as they are all...
mounted on the same track and cannot bypass each other. A MIP formulation which minimizes the total service time is proposed and a genetic algorithm-based heuristic is developed to find an approximate solution. Computational experiments have been performed on generated instances, which consider between 34 and 88 ships calling over a period of one week, with 4-5 berths and between 8 and 18 QCs available. As authors recognize, the relationship between the number of cranes and the handling time is not investigated in the paper; indeed, a reference number of cranes needed by each ship is assumed to be given as input of the problem.

Meisel and Bierwirth (2008) study the integration of BAP and QCAP with a focus on quay cranes productivity. An integer linear model is presented and construction heuristic, local refinement procedures and two meta-heuristics are developed to solve the problem. Authors compare their approach to the one proposed by Park and Kim (2003) over the same set of instances and they always provide better solutions. More complex instances are generated, taking into account a time horizon of one week, a berth length of 1000m and 10 QCs available to serve up to 40 vessels. Vessels are divided in 3 classes (Feeder, Medium and Jumbo) with different technical specifications and cost rates. Only small instances (20 vessels) are near-optimally solved by a commercial solver, whereas the proposed heuristics perform relatively well also on bigger instances. An analysis of quay crane’s productivity losses, mainly due to interference among QCs and to the distance of the vessel berthing position from the yard areas assigned to this vessel, is also presented and their impact on the terminal’s service cost is evaluated.

3. Problem description:

The location of Port Said port on the Northern entrance of Suez Canal as illustrated in fig 4 puts constraints on arrival and departure of ships, especially those will join the southbound convoy.

Fig 4: Suez Canal map

Ships transit the Suez Canal in three convoys daily as illustrated in fig 5:
To the best of our knowledge, there is no studies addressed this problem and its relationship with berth allocation and quay crane assignment.

However, to reduce the waiting time for ships after completion of handling operation, the ship's service time at berth must be controlled. This time depends on the number of cranes assigned to each ship. When the number of cranes assigned to a ship increases, the ship's time at berth decreases. This is why the Berth-allocation and the crane-assignment problems will be solved simultaneously in this study.

As stated earlier, the berth allocation problem consists of assigning and scheduling ships to berths (discrete case) or to quay locations (continuous case) over a given time horizon. Constraints usually taken into account include the ship's length, the berth's depth, and time windows on the arrival and departure times of vessels, priority ranking, and favorite berthing areas. The typical time horizon is up to one week for operational berth allocation and up to one month for tactical berth allocation.

The quay crane assignment problem aims to efficiently assign quay cranes to vessels that have to be operated over a given time horizon. The assigned number of quay cranes must be sufficient to complete the workload within the given time window. In this study the number of quay cranes assigned to each ship will depend on the time needed to complete container handling (unloading/loading) before the time of the convoy. The quay crane assignment problem is more operational: planners must assign specific quay cranes to specific tasks (set of containers) and produce a detailed schedule of the loading and unloading moves for each quay crane. Issues related to interference among cranes, precedence and operational constraints, such as no overlapping, must also be taken into account.

According to Meisel and Bierwirth (2006), the BAP and QCAP strongly interact. The QCAP determines the ship's time in port which, at the same time, is an input for BAP. Moreover, the BAP determines the ship's time at berth which, again is an input for the QCAP. Therefore, solving of both problems, which refers to as the Berth allocation & Quay Crane Assignment Problem (BAQCAP) simultaneously will be presented in this study.

The following is considered for formulation of the problem:

1. Each vessel has a maximum and a minimum number of cranes to be assigned. Sometimes, contract terms between terminal operating companies and shipping companies specify the minimum number of cranes to be assigned to a vessel. The maximum number of cranes that can be simultaneously assigned to a vessel is limited by the length of the vessel.

2. The duration of berthing of a vessel is inversely proportional to the number of cranes assigned to the vessel. Therefore, the number of assigned quay crane for a ship can be changed depending on the time left to join the convoy.
3. Vessels, PSCCHC and Suez Canal Authority continuously communicate with each other for adjusting the arrival/departure schedule. Delayed arrival or departure of a vessel beyond the committed time may lead to a trouble in meeting the schedule of the convoy.

4. Solution method:

Complexity of the different container terminal operations often results in using mathematical models as a method of investigation as illustrated in figure 6. BAP and QCAP have been solved by using analytical approaches (Park and Kim, 2003; Meisel and Bierwirth, 2008 and Imai et al., 2008).

According to Park and Kim (2003), berth and crane-scheduling procedure can be decomposed into two phases as illustrated in fig 7. In the first phase “berth-scheduling phase” the berthing position and the arrival time of vessels and the number of cranes allocated to each vessel are determined. In the second phase “crane-assignment phase” which is based on the results of the first phase, the starting and the ending times of the operation by each crane for each vessel are scheduled. In the second phase, the objective is to minimize the number of setups which include travels by cranes and assistants from one vessel to another, various delays for the preparation to start the operation in a different vessel. Illustrations of output of the Berth and crane-scheduling phase are given in Figure 8. Figure 8a illustrates the output of the first phase. Each rectangle represents the Berthing schedule of a vessel. The positions of the horizontal sides represent the Berthing locations, and the lengths of the horizontal sides correspond to the lengths of the corresponding vessels. Also, the position of a vertical side corresponds to the duration from the starting to the ending time of the operation of a vessel.

**Figure 6: Research approaches to model a system**

**Phase I: Berth-Scheduling**
Determine the berthing time and position of each vessel and the number of cranes to be allocated to the vessel.

**Phase II: Quay crane- assignment**
Schedule the assignment of individual cranes.

**Figure 7: Berth and quay crane scheduling procedure**
Figure 8b illustrates the output from the second phase based on the same example as the one in Figure 8a. The numerical values on the left-hand side of each rectangle denote the number of cranes allocated to
each vessel at each time segment. In Figure 8b, specific cranes are assigned to each segment of the operation time for each vessel. In the example shown in Figure 8b, cranes $1 \rightarrow 5$ are assigned to vessel A for 4 time segments, cranes $1 \rightarrow 3$ are assigned to vessel B, and cranes $4 \rightarrow 5$ are assigned to vessel C. However, crane 3, which was assigned to vessel B, stops serving vessel B at the last time segment for vessel B. Cranes $2 \rightarrow 5$ are assigned to vessel D. However, crane 5, which was assigned to vessel D, stops serving vessel D at the last 2 time segments for vessel D. Finally, cranes $1 \rightarrow 2$ are assigned to vessel E for 6 time segments.

![Figure 8a: Sample output of the Berth-scheduling phase.](image1)

![Figure 8b: Sample output of the crane-assignment phase](image2)

Figure 8a, b: An illustration of output from the two phase procedure

As stated earlier, a simulation can be used to solve complex realistic problem and help the ultimate decision-maker solve a given problem. Therefore, a proposed logic flowchart to solve BAQCAP will be presented in the next section.

5. **Proposed logic flowchart:**

When a ship arrives at Port Said Port it waits until the berth is available. If the berth is available and the assigned number of QCs according to ship class is available, the ship proceeds to berth and sets up for loading/unloading containers as illustrated in the proposed logic flowchart. But in case the berth is not available the ship anchors at the waiting area and waits for the availability of the berth. Upon accomplishing the loading/unloading operation, the ship leaves the port to join the southbound convoy. During unloading/loading the QCs assigned to the ship can be changed according to the remaining number of TEUs and time left to join the convoy. Arena software can be used to build the simulation model and solve the problem of BAP, QCAP as well QCSP considering convoy time schedule.
6. Conclusion:

This paper focuses on efficient scheduling and use of the berths and quay cranes to increase the competitiveness of Port Said port. Mathematical solutions are restricted to the integrated/hierarchical approach to solve the problem. In this study, we proposed a simulation framework that simultaneously solves the BAP, QCAP as well QCSP considering convoy time schedule. The proposed model logic will be implemented using discrete event simulation.

We can conclude that the port facilities are able to serve the ships to join the southbound convoy but for this to be achieved current berths systems must be improved. For future work is necessary to make proposals focused on managing the handling equipment such as forklifts and Reachstackers. This equipment is used mainly by the quayside transport and the landside transport, and should be consider in order minimizing the costs, handling operations time, bottlenecks, etc.
7. References: