An Integrated Approach for Optimization of Resource Utilization at Seaports

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Abstract
Equipment resources at container terminal are used to transfer containers from ships to yards and vice versa. Although these resources are related to each other, many researches tackled these problems separately. This paper aims to develop a methodology using discrete event simulation to optimize resource utilization at container terminal. An integrated approach that combines all container terminal equipment resources for container handling process is considered in this research. The proposed approach is applied on a real case study data of container terminal at El-Dekheila port in Egypt. The computational results show that the proposed approach is effective and efficient for optimization of resource utilization where 41% improvement in quay crane utilization is achieved.

Keywords: *optimization, discrete event simulation, resource utilization, container terminal***.**

1. INTRODUCTION

Nowadays, 90 percent of global trade is carried by sea. Container ships carry an estimated 52 percent of global seaborne trade in terms of value [10]. Containerized sea-freight transportation has grown dramatically over the last two decades, world container trade, expressed in 20-foot equivalent units (TEU). Containerized trade volumes expanded in 2013 to reach 164 million TEUs shown in Fig. 1; Egyptian ports transported 7.74 million TEUs in 2011 [10]. Seaport container terminals are essential nodes in sea cargo transportation networks. As such, the operational efficiency of container terminals in handling containers passing through them plays a critical role in a globalize world economy.

In container terminals, quay cranes, yard cranes and trucks are used in different parts of a container terminal to transfer or transport containers from one location to another. Quay cranes handle containers by running at the berth to transfer containers between ships and trucks. Yard cranes are move in the yard to transfer containers between trucks and the container yard for container storage or retrieval. Trucks are highly mobile devices for transporting containers from one location to another [2].

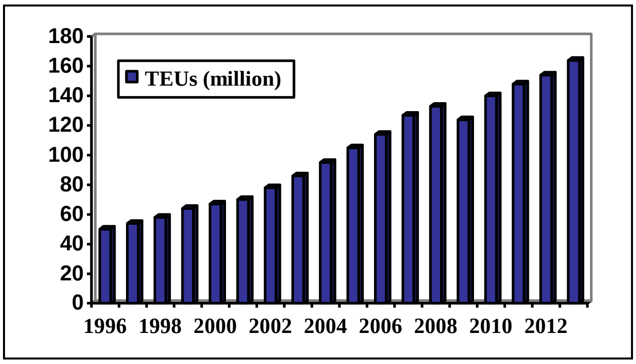

Fig. 1 Global container trade, 1996-2013

The flow of containers in terminal operations is presented in Fig. 2. Container handling problems at container terminals are NP-hard, stochastic, nonlinear, and combinatorial optimization problems. Generally, each problem is managed independently due to the fact that these problems are combinatorial problems so their complexities remain exponential [14].

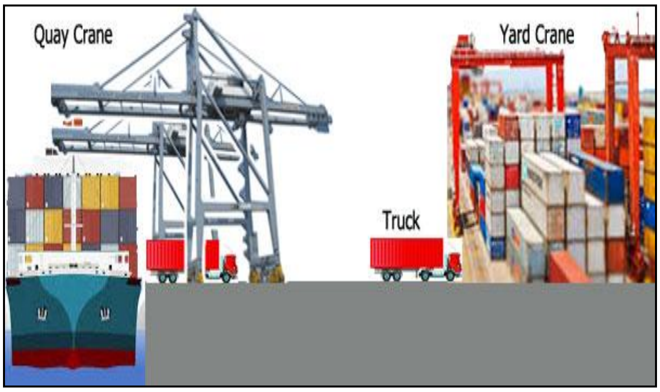

Fig. 2 Container Terminal Operations

In vessel handling times, the number of resources that the planner can allocate to a vessel is not always constant over time. Container terminal problems, like the berth allocation problem (BAP), storage space allocation (SSAP), quay crane assignment problem (QCAP), yard crane assignment problem (YCAP) and truck assignment problem are multi objective optimization problems, so operation of container terminal has the feature of uncertainty, multi-objectives and complexity, therefore, the optimization of the operation is too complex to be solved by mathematical programming model only. In addition, the rising com- petition among ports has compelled them to improve their service, which makes the efficiency of port operation an important factor to succeed in the fierce competition [7]. The whole terminal operation is very complex and involves different types of equipments. A terminal can therefore be ideally divided into two areas, the quayside and the yard. The quayside is made up of berths for vessels and quay cranes (QC) which move containers. The yard serves as a buffer for loading, unloading and transshipping containers and it is typically divided into blocks: each container block is served by one or more yard cranes (YC) [20]. Terminal operation and logistics at large terminals are already very complex. Therefore, the need for 'integrated' optimization is becoming more and more relevant. The transport process between quay and yard is broken into separate phases because different types of equipment are engaged for the whole transport chain [6].

Actually, modeling and simulation are essential tools for the design and analysis of container terminals. A computer model can emulate the activities at various levels of details and capture the essential interactions among the subsystems. Analysis based on the simulation is particularly useful for designing new terminals, making modifications to existing terminals, and evaluating the benefits of new resources or impacts of operation policies [1]. Quay cranes are a limited resource and will handle almost every container passing through the terminal; thus sophisticated approach must be established to ensure resource utilization is optimized. There are a maximum number of cranes available along the quay, cranes are operated on a single rail, so they cannot cross each other and the maximum number of cranes for each vessel is limited by the length of the vessel, this means that a crane can be assigned to a vessel if the crane can reach the vessel along the quay. The quay crane assignment problem aims to efficiently assign quay cranes to vessels [4].

Container terminals problems are interrelated so an optimized solution of a problem could restring the possibility of obtaining a better solution in a related problem than before. Cranes are a scarce resource and handle container movements. An integrated approach for container handling process is considered in this research. This research seeks to develop an efficient methodology to optimize resource utilization at container terminal.

The rest of this paper is organized as follows: Section 2 provides a literature review for optimization of resource utilization at container terminal. Section 3 discusses the proposed methodology developed for optimization of resource utilization at container terminal based on discrete event simulation. Computational results are given in section 4. Finally, in section 5 the conclusions and the future direction of the study will be presented.

2. LITERATURE REVIEW

Cranes along the quay called quay cranes. In view of the increasing importance of marine transportation systems, issues related to container terminal operations are getting more and more attention. Important features of a terminal are related to the location of equipment and resources over the terminal. This refers, e.g., to resource allocation problems. The need for optimization in container terminal operation has become more and more important in recent years. This is because the logistics especially of large container terminals has already reached a degree of complexity that further improvements require scientific methods [6]. Because Quay Cranes (QCs) are the most expensive equipment utilized at container terminals, their performance largely affects the container throughput and handling efficiency. Complexity of the different seaport operations often results in difficulties in using analytical tools as a method of investigation. In such a situation, computer simulation provides a powerful tool to analyze the port performance [12]. In the last decades, researchers have studied different types of problems in container terminals. A comprehensive review of the Methodologies for solving the problems of quay crane assignment problem are provided in this section.

(Bierwirth and Meisel, 2005) provide a heuristic approach for the integrated solution of Berth Allocation Problem (BAP) and Crane Assignment Problem (CAP), and present computational results based on real world data. The paper introduced a new objective function for the integrated BACAP occurring at seaport CTs. It considers the terminal operator's labor cost by minimizing the idle time of QCs. The problem was solved heuristically by a priority-rule based method [15]. (Wong and Kozan, 2006) presents MIP model for storage allocation. This paper investigates container storage location, and the sequencing and scheduling of machine operations in the port. An integrated approach is proposed to minimize ship service time. Meta-heuristic algorithms are developed to solve the problem. Numerical investigation is also presented [19]. (Kulak et al., 2008) explains the simulation model allows analyzing some pre-defined performance criteria such as average productivity, average resource utilization and average waiting time of the resources to identify potential bottlenecks of the operational areas, namely the quay cranes and the storage yard [11].

In reality, quay crane scheduling significantly affects the makespan of a container vessel since quay cranes are the interface between land side and water side in any port container terminals [9]. (Froyland et al., 2008) propose an integer programming-based heuristic This paper concerns the problem of operating a landside container exchange area that is serviced by multiple semi-automated rail mounted gantry cranes (RMGs) that are moving on a single bi-directional traveling lane and present a three stage algorithm to manage the container exchange facility, including the scheduling of cranes, the control of associated short-term container stacking, and the allocation of delivery locations for trucks and other container transporters [3]. Raa et al. (2011) present an integrated BAP-QCAP model, while taking into account many real-life features as well, such as vessel priorities and preferred berthing locations [16]. (Ambrosino and Tànfani, 2012) proposes an integrated use of optimization and simulation to study the seaside operations at terminal containers. A 0/1 MIP model is developed in order to determine the optimal assignment, on a shift basis, of QCs to bays of each ship served by the terminal during a given planning horizon, referred as Bay_QCAP. The optimization model solutions are used as input parameters for a Discrete Event Simulation (DES) model able to reproduce the system behavior taking into account its stochastic nature and complexity. The main expected results regard the possibility to constrain the resources and compute various performance statistics including: berth and quay utilization, average ship berthing time, QCs delays time, trucks' utilization rate [5].

Many approaches have been developed to solve container terminal problems. (Diabat et al., 2014) presents a Genetic Algorithm (GA) to solve Quay Crane Assignment problem, the performance of the GA in terms of solution quality was compared to the exact solution. Computational results indicate that the GA produces solutions with a small gap from the optimal solution. The most important characteristic of the developed model is the integration of the assignment and scheduling problem for quay cranes, which yields better results than solving these problems independently. Utilization Measures allow management to determine how intensively the production resources are used. Equipment utilization: Because the terminal's investment in cargo-handling equipment is very costly, equipment utilization is an extremely important performance measure [8]. G. Ilati et al. (2014) presented an effective evolutionary to find a globally good solution for the problem. A dynamic berth allocation problem was studied. It takes into account the vessel type, tidal effect, and allocation of tugboats to transfer vessels, and quay crane assignment planning. A simulation-based optimization is proposed to deal with stochastic processes and dynamic tides. The effectiveness of the proposed evolutionary algorithm is tested on RAJAEE Port as a real case. The result demonstrates the effectiveness of the proposed simulation-based optimization approach to find the near optimal solution within a reasonable time [18]. Abd El-Nasser et al. (2014) presented a simulation model that can be used to optimize operations in Container Terminal using simulation methodology, minimize ship's turn-around time. The proposed approach is applied on a real data at El-Dekheila port. Computational experiments were conducted to analyze the performance of container terminal operation. The results show that the proposed approach reduced the ship turnaround time in port [17].

In container terminals, many combinatorial related problems and the solution of one of the problems may affect to the solution of other related problems. For instance, the berth allocation problem can affect to the crane assignment problem and both could also affect to the Container Stacking Problem. Due to the complexity, it is very difficult if not impossible to build a mathematical model for analytical optimization of the whole terminal operation. Hence computer simulation models, emulating the activities of a terminal to capture the interactions between the individual subsystems, are essential tools [1].

Extensive research has been carried out with effectively allocating key resources, such as berths, yards, quay cranes and yard cranes separately not as a whole. As such, they are unable to ensure optimal solution for container handling in container terminal. This paper aims to develop a methodology to improve quay cranes utilization at container terminal using simulation methodology. The proposed approach is applied on a real case study data of container terminal at El-Dekheila port.

3. METHODOLOGY

Parameters of the container terminal problems are discrete. Container terminal problems are normally expensive and time-consuming. In order to deal with such problems, sophisticated tools and techniques are needed which can efficiently solve such problems. The objective of simulation model that was developed to simulate the container terminal at El-Dekheila port is to evaluate and optimize quay crane utilization. El-Dekheila container terminal consists of 1040 meters of quay length with a depth of 12-14 meters, terminal area is 406000 m2. The terminal equipments are, 8 quay cranes, 12 RTG, 16 Top Lift Trucks, 1 Mobile Crane, 5 Empty Handler Side Spreader, 45 truck, and 450 reefer plugs.

Discrete-event simulation tool (FlexsimCT) is employed for implementing the simulation model. The motivation for adopting a simulation tool for the study is as follows. Firstly, systems can be modeled as discrete model with Flexsim. In this study, the problems being studied are stochastic, dynamic and discrete, so this discrete-event simulator is suitable. Secondly, a distinct advantage of Flexsim software over similar software like Arena is that it comes with flexsim CT, a library specifically designed for simulating container terminal operation.

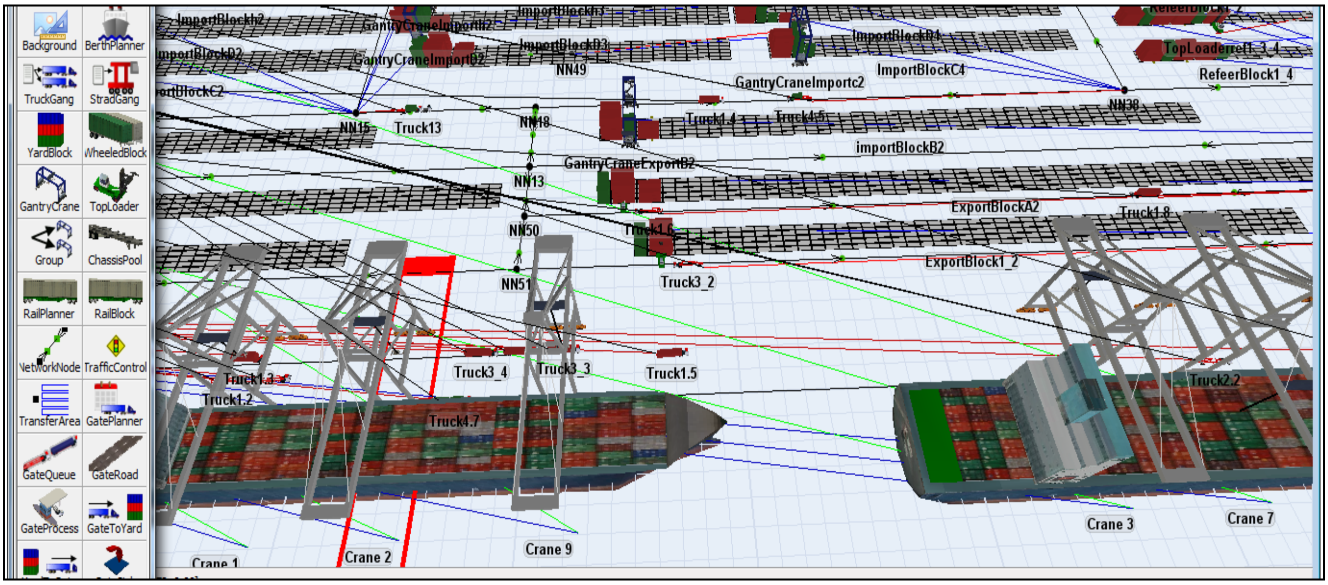

Fig. 3A snapshot of Container Terminal operation simulation model

The data used in this study was obtained from El-Dekheila container terminal. The daily “log sheets” of the planning department include the detailed information for each ship arrived to the port; every sheet contains the following data: ship Name, ship length, container size and number of containers (discharge/load) and the daily “log sheets” of the operation department include operation time (start/end) and quay cranes working hours. Actual data for one month operation from 01/03/2014 to 31/03/2014 were selected. A simulation model was developed and verified and validated using the terminal operational parameters. Our simulation model has been applied, including all major aspects of container operations (see Fig. 3).

Table 1: Quay Carnes Actual Operation

Quay cranes	No of containers		Cranes Working Time	
	load	discharge	Hours	Min.
Carne-1	743	1217	158	15
Carne-2	719	1953	185	45
Carne-3	1630	1841	289	45
Carne-7	3881	4052	374	45
Carne-8	3660	3512	379	0
Carne-9	2756	2952	316	45

4. COMPUTATIONAL RESULTS

The input data for simulation models are based on real data at the El-Dekheila port Container Terminal for one month from 01/03/2014 to 31/03/2014 (see table 1). The number of (discharge/load) containers (Throughput), cranes working time, total number of movements for each crane has been considered in this research. Implementation of the model was run on a Laptop with the following configurations: i3 CPU 2.4 GHZ, 4.0 GB RAM, Windows 7.

Experimental setting

1. All Cranes have the same specifications (single hoist).
2. Quay crane tasks must be finished without interruption once they get started.
3. Crane-4 and crane-5 are in maintenance.

Table 2: Quay Cranes utilization

Quay cranes number	Actual Operation (move/Hour)	Proposed Model (move/Hour)
Carne-1	12	19
Carne-2	14	24
Carne-3	12	27
Carne-7	21	31
Carne-8	19	31
Carne-9	18	32

The results shows that our proposed simulation model achieved quay crane utilization better than the actual operation (see table 2). Fig.4 illustrates a graph comparison between both actual and proposed model crane utilization. The computational results show that the proposed approach is effective and efficient for optimization of quay cranes utilization.

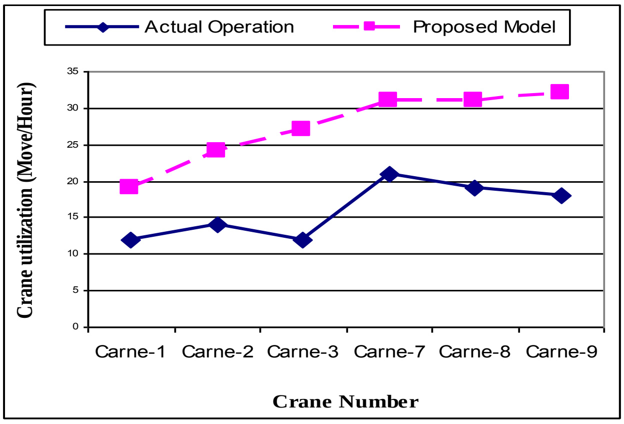

Fig. 4: A comparison between actual operation and proposed model Results

5. CONCLUSION AND FUTURE WORK

This study optimizes resource utilization using simulation model with regard to the integration of equipment resources used in container terminals. The actual workload of container terminal resources has been considered in this research. In this paper, we proposed a simulation model that is used to optimize resource utilization in container terminal using simulation methodology. An integrated approach for container handling process was considered in this research. The proposed approach was applied on a real case study data of container terminal at El-Dekheila port. The computational results show that the proposed approach is effective and efficient for Optimization of resource utilization where 41% improvement in quay crane utilization is achieved.

In the future, analytical and empirical evaluations will be develop a methodology to solve container terminals problems using simulation based optimization methodology and develop a computational framework for enhancing the computational efficiency of the proposed solution technique.

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