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An Integrated Operational Research and System Dynamics Approach for Planning Decisions in Container Terminals

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***Abstract*—**This paper focuses on the operational and strategic planning decisions related to the quayside of container terminals. We introduce an integrated operational research (OR) and system dynamics (SD) approach to solve the Berth Allocation Problem (BAP) and the Quay Crane Assignment Problem (QCAP). A BAP-QCAP optimization modeling approach which considers practical aspects not studied before in the integration of BAP and QCAP is discussed. A conceptual SD model is developed to determine the long-term effect of optimization on the system behavior factors like resource utilization, attractiveness to port, number of incoming vessels to port and port profits. The framework can be used for improving the operational efficiency of container terminals and providing a strategic view after applying optimization.

***Keywords*—**Operational research, system dynamics, container terminal, quayside operational problems, strategic planning decisions.

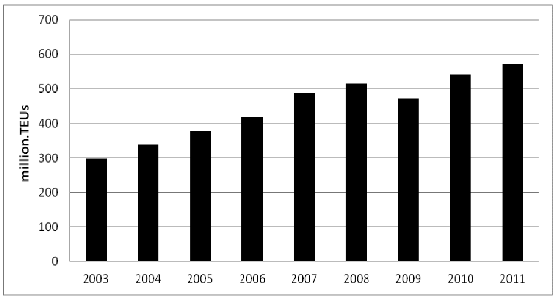
I. Introduction

THE global containerized trade increased dramatically from 2003 up to 2011with an average annual rate of 10.3% as shown in Fig. 1 (a) [1]. However, as a result of the financial crisis, the growth of global container traffic decreased with a drop of 8.5% during 2008.

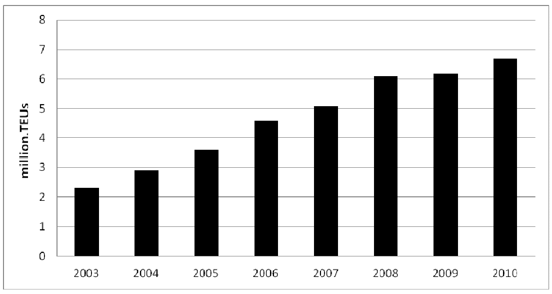
The increasing growth of global container traffic induced port traffic growth in most of developing countries. For example, the container traffic in Egyptian ports increased sharply from 2003 to 2010 with an average annual rate of 23.9% as shown in Fig. 1 (b) [2]. The main reason for this growth is the rapid increase in the number of transshipped containers. The percentages of transit, import and export containers, handled in the Egyptian ports in 2010, were 62%, 18% and 20% respectively as shown in Fig. 2 [2].

The competitiveness of a container terminal depends mainly on the length of the service time for vessels as Vessel operators want their vessels to be discharged and/or loaded as fast as possible. However, Fast service operations are constrained by the limited assets of ports. Consequently, optimization of handling operations at the container terminal received great attention in both the developed and developing countries.

Many Operational research models were proposed to improve the productivity and the operational efficiency of the port by the best use of port resources and infrastructures [3]. Other techniques like Simulation and queuing theory were also used for the evaluation of investment decisions and berthing policies [4]. Limited System dynamic models have been also used in container terminal management as a strategic decision tool [5]-[8].



(a)



(b)

Fig. 1 Global container port traffic (a) and Egyptian container port traffic (b)

The remainder of this paper is organized as follows: Section II provides a review of works related to container terminal in recent years. Section III discusses the research gap in the existing literature; the frame-work of our proposed model is in Section IV. The conclusions and recommendations are in the last section.

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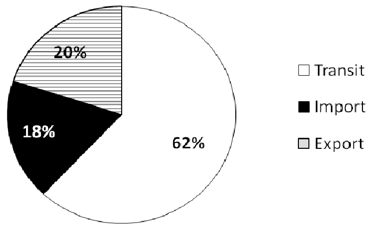

Fig. 2 Types of container handled in the Egyptian port.

II. Literature Review

Considerable surveys [3], [4], [9] have reviewed the different methods used in the study of container terminal operational decision making. Analytical and simulation models are the most used methods as the majority of researchers focus on operational and tactical planning decisions. On the other hand, strategic planning methods like system dynamics models are rarely found in existing surveys.

As shown in Fig. 3, the general layout of a container terminal consists of three areas, namely the quay side, yard and gates. The internal transportation among the three areas is indicated by dashed lines. The investigated problems of container terminal can be classified according to the three areas of container terminal into: problems related to the quay side, yard, gates operations area and transfer operations among quay, yard and gate.

This paper focuses on the integration of quay side operations more specifically, the integration between the Berth Allocation Problem (BAP) and the Quay Crane Assignment Problem (QCAP). Other problems are beyond the scope of this paper, and a detailed description of the remaining problems can be found in the work of D. Steenken et al. [4].

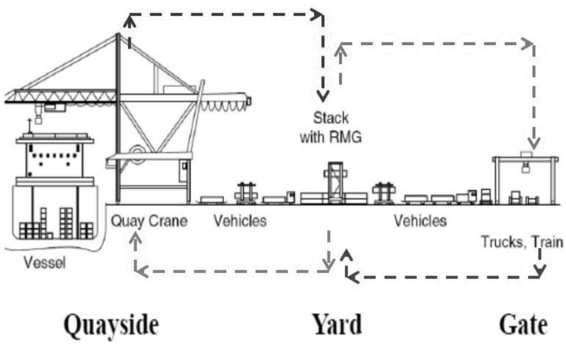

Fig. 3 Schematic representation of a container terminal layout [10]

The remainder of this section is organized as follows: First, a review and classification of BAP and QCAP integration approaches is presented. Second, system dynamics models related to container terminal are reviewed.

Quay side operations involve three main problems, namely the Berth Allocation Problem (BAP), the Quay Crane Assignment Problem (QCAP) and the Quay Crane Scheduling Problem (QCSP). The BAP aims at finding berthing positions and berthing times for incoming vessels while, the QCAP determines the assignments of quay cranes for each vessel. QCSP determines the schedules of the assigned quay cranes by providing the sequence of discharging and loading operations that a quay crane will perform.

In literature, the work related to quay side operations can be classified into two main categories as follows:

I. Work investigating single operational problems such as BAP, QCSP or QCAP [9].
II. Work investigating the integration of single operational problems. Proposed models involve the integration of the BAP and QCAP, the BAP and QCSP or the QCAP and the QCSP.

Recently, integration of quay side operations problems received increasing interest in literature due to high interdependence among them. C. Bierwirth et al. [3] reviewed the contributions on this topic and classified the integrated models according to the planning approaches, arrival time of ships and berth space. Planning of quayside operations includes sequential method and integrated approaches. The integrated approach includes simultaneous and functional integration. Simultaneous integration is realized by merging the two sub problems in one formulation. While, functional integration depends on a computational sequence for solving sub-problems and data exchange between the lower and the upper level. A further classification of integrated models is according to berth space. In this case the problem is classified into discrete, continuous berth or hybrid one. In the discrete case, the quay is viewed as a finite set of berthing positions while in the continuous case, vessels can berth anywhere along the quay. The arrival time of ships category, is further classified into static or dynamic arrival of ships. The static case assumes that all ships are already in the port when the berth allocation is planned, whereas the continuous case allows for ships to arrive during planning of berth allocation. *Generally, the planning approach of quay side operations can be classified as shown in Fig.4.*

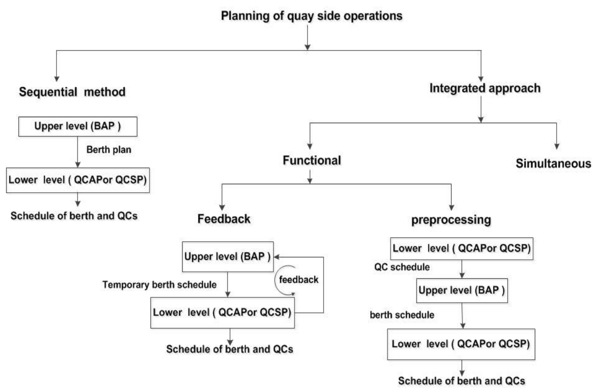

Fig. 4 Classification of planning approaches for quay side operations

TABLE I
COMPARISON OF PLANNING METHOD AND APPROACHES

Approach/method	Advantages	Disadvantages
1) Sequential method	Consider performance of sub-problems	Ignore interactions of sub-problems
2) Integrated approach		
a) Functional (feed back)	Consider interactions and performance of sub-problems	Depends on Assumed variables Need experience with value of variables
b) Simultaneous	Consider interactions of sub-problems	More complex Sometimes, unsolvable Not ensure the performance of all sub-problems

For more comparative analysis of the quay side planning methods and approaches, Table I shows the advantages and disadvantages of the different planning methods and approaches. The sequential planning method focuses on the performance of sub-problems individually, as each problem has its own objective function which ensures the good performance of each problem. However, such planning method ignores the interaction between sub-problems. Functionally integrated approach with feedback structure focuses on the interaction as well as the performance of sub-problems. The simultaneously integrated approach considers only the interaction between sub-problems, for example, in simultaneous integration of BAP and QCAP, the QCAP is inserted to estimate the handling depending on the QCs assigned to each ship and no guarantee for the performance of QCAP. A reasonable schedule should include both the interaction and the performance of sub-problems. In functionally integrated models with feedback loop, obtaining a reasonable schedule depends highly on the algorithm which builds feedback loop between the sub- problems. Simultaneous integration usually ensures effective schedule. However, it can provide reasonable schedule if the performance of the sub-problems is considered in the model formulation [10].

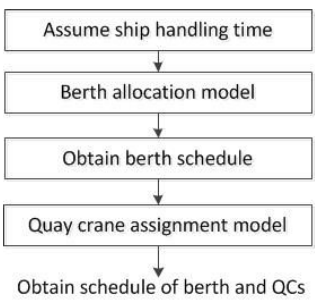

Fig. 5 Flow chart of sequential planning method

Figs. 5-7 show the basic flow charts of the planning method and approaches most frequently used for the integration of BAP and QCAP in literature. Simultaneous integration of BAP and QCAP has received much interest of researchers [10]-[12].

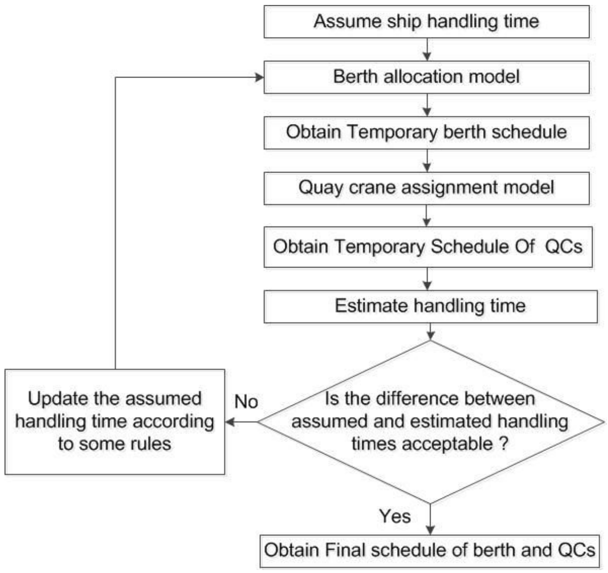

Fig. 6 Flow chart of functional integration with feed back

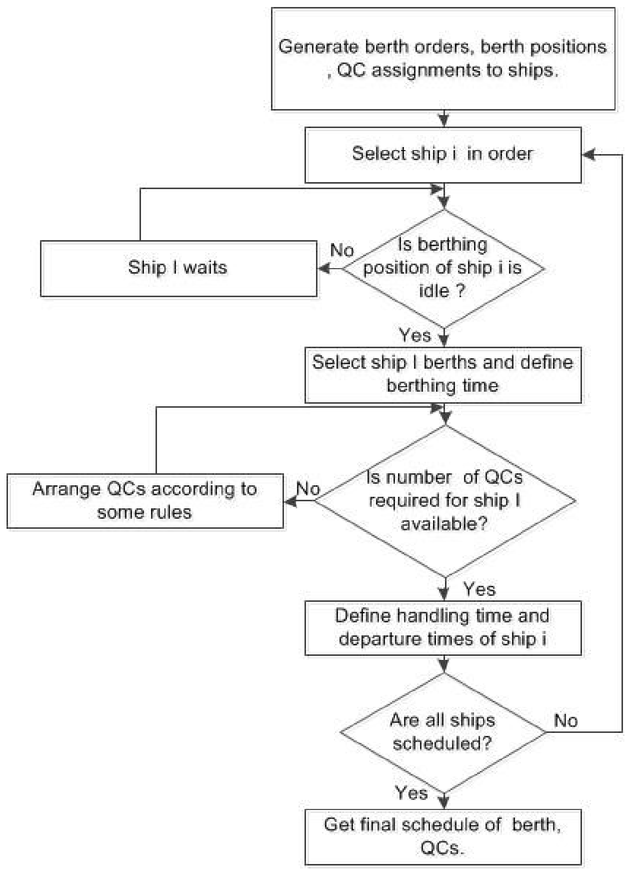

Fig. 7 Flow chart of simultaneous integration

Y. M. Park et al. [11] proposed an integer programming model considering continuous berth and static arrival of ships. The proposed model could simultaneously provide the berthing time, berthing positions and assignment of quay cranes to ships. The model was solved by a two phase solution procedure through which a Lagrangian relaxation based heuristic and dynamic programming was used in the first and second phase respectively. F. Meisel et al. [10] contributed to literature by considering the productivity of the quay cranes in their mathematical formulation of the integrated BAP-QCAP model with continuous berth and dynamic arrival of ships.

More recently, D. Chang et al. [12] proposed a MIP model using multi objective programming. They employed hybrid parallel genetic algorithm which combined parallel genetic algorithm and heuristic algorithm, was employed to solve the proposed model. Limited researchers [13], [14] studied functional integration of BAP and QCAP. This approach is most frequently studied in the integration of BAP and QCSP due to the difficulty of developing simultaneous models for these sub-problems. In a recent paper of C. Yang et al. [13], they functionally integrated the BAP and the QCAP with a feedback loop structure and proposed an algorithm which consists of three loops. Two inner loops for solving BAP and QCAP and an outer one acting as a feedback loop.

Simulation optimization is a recent approach for integrating sub problems in quay side at container terminal. This approach depends on combining discrete event simulation with OR techniques. Recently, C. Arango et al. [15] formulated a BAP model, using first-come-first-served rule, and developed heuristic procedure based on genetic algorithm for solving the model, then they integrated the BAP model with a simulation model. They illustrated that their proposed approach improves the performance of container terminal compared to the existing policy. One advantage of simulation optimization is the ability to consider real aspects that are usually neglected when analytical models are used.

System dynamics (SD) is a recent strategic planning technique used to analyze the effects of policy by modeling the structure of a system using a computer-based simulator. Few studies [5]-[8] have investigated SD techniques at container terminal. For example, H. R. Choi et al. [5] suggested the factors that affect competitiveness of a container terminal and the relationship among them. A System Dynamics method was used then to analyze the effect of these factors in the long term. Recently, G. Yeo et al. [6] investigated the impact of increasing security level in Korean ports on the handling container cargo handling volumes. They developed a causal loop diagram among evaluation factors and then a SD model was proposed. They concluded that increasing the security level leads to an increase in processing time due to complicated security procedures, and this will decrease the attractiveness and number of incoming vessels to ports.

III. Current Gaps in Literature

Many researchers have investigated the integration of BAP and QCAP in different approaches. However, the following issues are not addressed in literature:

1. Traffic Congestion and fuel consumption issue: traffic congestion occurs on the quay side due to the interference of Quay Trucks (QTs). This traffic congestion increases fuel consumption of quay trucks and also affects the performance of quay cranes. The reduction of traffic congestion and fuel consumption of quay trucks aren't tackled in the integrated BAP-QCAP models.
2. Limited number of quay trucks: in literature, no restriction on the availability of the quay trucks used for handling containers between quay side and yard. However, the problem of limited availability of quay trucks may occur due to many issues, such as maintenance or breakdown. The number of trucks assigned to QC affects its productivity and as a result, the handling time of ships will be also affected.
3. Long term-effect of operational optimization policy: a container terminal should consider the long term-effect of applying optimization on different factors like attractiveness to port, resource utilization, port profits and average waiting time of ships.

IV. The Proposed Model Frame Work

A. Problem Description

Egyptian ports mainly depend on handling transshipped containers (see Fig. 2). In transshipment terminals, most of handling operations are loading and /or discharging of ships as well as transferring containers between the quayside and the yard. The traffic congestion, on the quay side, increases due to interference of truck flows. Fig. 8 shows the traffic congestion resulted from allocating containers of ship A to yard 2 while that of ship B to yard 1. Traffic congestion leads to increase fuel consumption of trucks as well as increasing the total service time of ships.

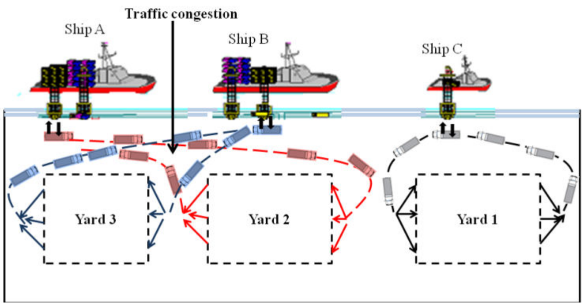

Fig. 8 Traffic congestion on the quay due to interference of truck flows

The second issue is to allocate berths and assign QCs to ships under limited number of quay trucks. Fig. 9 shows how the service rate of QC is affected by its assigned quay trucks. In the case of assigning two trucks for QC (Fig. 9 (a)), the idle time of QC will be less than the idle time in the case of assigning one truck to QC (Fig. 9 (b)), given that all other factors remain constant So, the handling time of ship doesn't only depend on the number of quay cranes assigned to ship but also depend on the number of quay trucks assigned to theses QCS.

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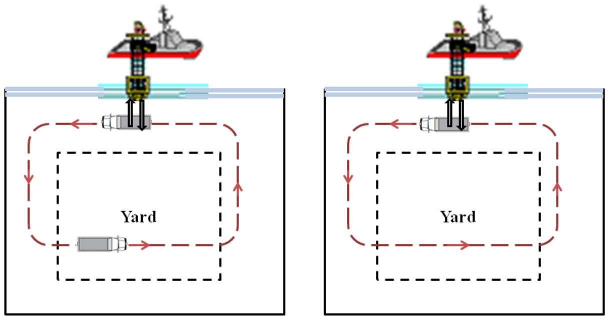

(a) (b)

Fig. 9 Assigning two trucks to QC (a) assigning one trucks to QC (b)

Another issue is related to strategic planning decision. Container terminal management must have a tool to determine the long term-effect of optimizing handling operations. Optimization leads to decrease in the average service time of vessels which increases attractiveness of vessels to the port. Increasing demand will increase utilization of resources which in turn will increase average waiting time of ships. By the time, the port will lose its customers due to excessive increase of waiting time. So, the terminal management should know the suitable time to increase its resources to avoid excessive waiting time. Especially, the setup of some quay resources requires from 1 to 2 years to be set up on land. In summary, we have three issues as following:

1. Traffic congestion and fuel consumption of quay trucks.
2. Allocate berths and assigning QCs to ships under limited availability of quay trucks.
3. Determine the long term-effect of operational improvement on resource utilization, waiting time, port growth, port attractiveness, port profits and the suitable time to increase resources.

B. The Proposed Solution Methodology

The Solution methodology is based on the integration between operational research (OR) techniques and system dynamics (SD) techniques as shown in Fig. 10, in the first phase, a BAP-QCAP model will be developed. In the second phase, the solution of the optimization model will be the input to the proposed system dynamics model.

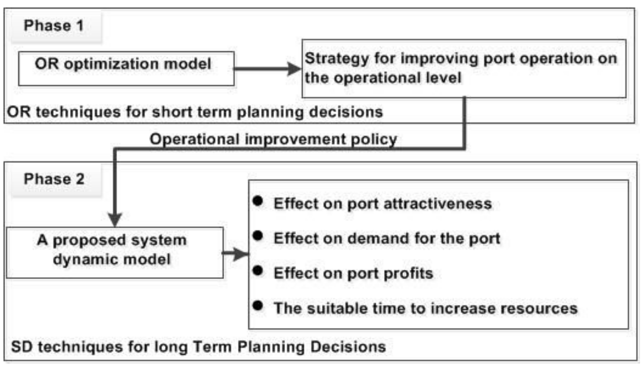

Fig. 10 The proposed solution methodology

C. The OR Modeling Approach

The contributions of this model are:

1. Development of a BAP-QCAP model sustaining customer, port operator and the environment using goal programming.
2. Establishment of a new objective function that minimizes traffic congestion as well as fuel consumption of quay trucks.
3. Consideration of the limited availability of quay trucks in BAP-QCAP modeling.

The model is established based on the following assumptions:

1. Each ship has been previously planned for a best berthing location which is closest to the yard allocated for this ship
2. There is a limited number of quay trucks to handle containers between quay and yard.
3. All quay cranes have the same service rate expressed in (TEUs per time per one quay truck).
4. Ship handling requires a specific number of QCs and it can't begin until this number is available.
5. Each QC can't be used until at least the minimum number of quay trucks is available for it.

Fig. 11 shows the basic structure of the proposed modeling approach: (1) generate the berthing order, the berthing positions, the number of quay cranes for all the ships and the number of quay trucks for all quay cranes simultaneously , (2) determine the ship berthing time according to berthing constraints, (3) assign quay cranes for the ships based on some rules, (4) assign quay trucks for the quay cranes based on some rules, (5) gain the handling time and the departure time of ships and (6) obtain the final berth, quay crane schedule and the number of quay trucks assigned to each quay crane.

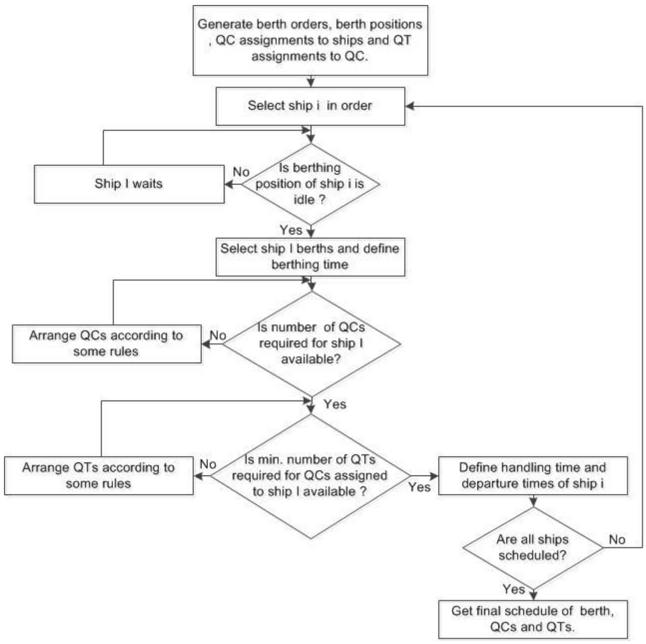

Fig. 11 Basic flow chart of the proposed modeling approach

D. The Proposed System Dynamics Model

In this section, an attempt has been made to develop a conceptual SD model. Fig. 12 shows the proposed causal loop diagram which consists of reinforcing (R) and balancing (B) loops. The reinforcing loop illustrates how optimization positively impacts number of incoming vessels to port while the balancing loop (B) illustrates negative impacts of increased resource utilization and average waiting time on number of incoming vessels to port.

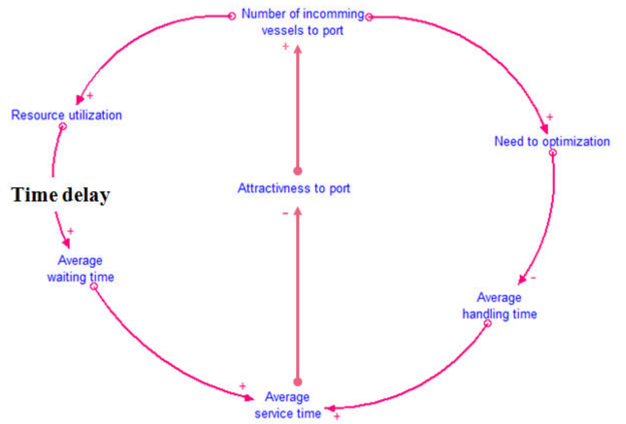

Fig. 12 Causal loop diagram of the proposed system dynamics model

The data used in the simulation are hypothetical (see Table II in appendix). The conceptual model is shown in Fig. 13. Fig. 14 shows the results obtained from running simulation for 7 years after directly applying optimization. The vertical axis represents variation of different factors on a dimensionless scale. After a period of 2.75 years from applying optimization of handling operations, the service time decreased from 1to 0.77. This decrease in the service time leads to increase both of attractiveness to port and number of incoming vessels from 1 to 1.3 and from 1 to 1.25 respectively. The utilization of resources reached its maximum value 1.2 after four years from applying optimization. As a result of excessive resource utilization, service time increased due to increasing waiting time of ships. The rapid increase in service time negatively affects attractiveness to port, number of incoming vessels and port profits. The growth of Port profits decreases after 4 years as a result of losing customers, increased salaries and paying penalty cost for late departure of ships. In order to avoid negative impacts of excessive utilization of resources , terminal management should increase resources after two years from applying optimization assuming that some resources need about two years to be set up on land. Knowing this time will help management to consider investment in resources in its port plan for future.

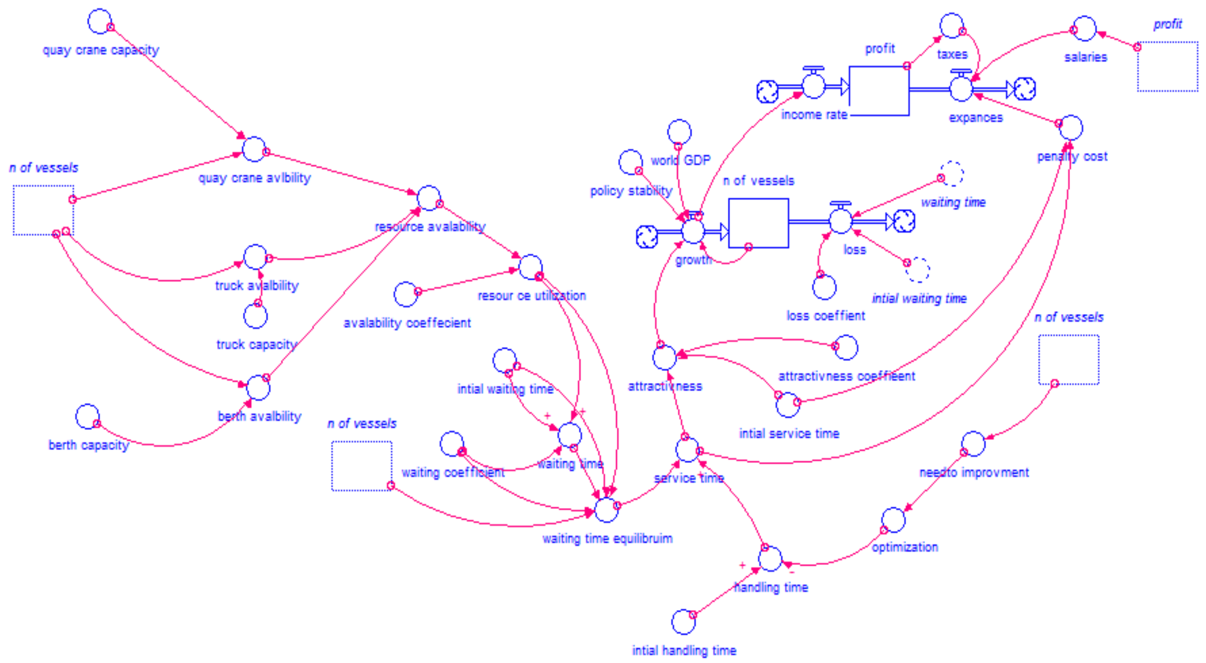

Fig. 13 Stock and flow diagram of the proposed model

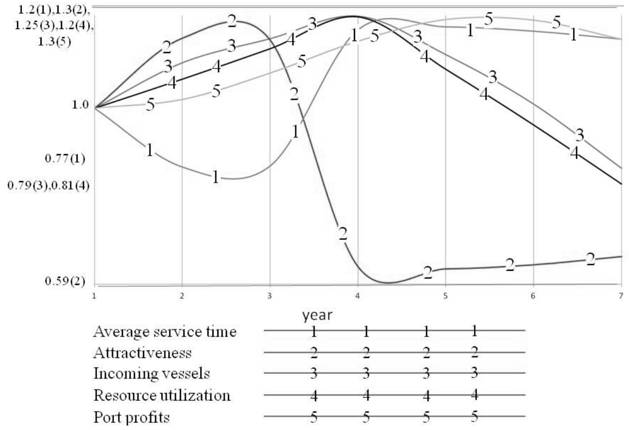

Fig. 14 Variation of average service time, attractiveness to port, number of incoming vessels, resource utilization and port profits

V. Conclusion and Future Work

In this paper we propose an integrated approach of optimization and system dynamics to study the quayside operations at container terminals. A BAP-QCAP optimization modeling approach is proposed by considering traffic congestion, fuel consumption and limited availability of quay trucks. A conceptual system dynamics model is developed to evaluate the long term effect of optimization on average service time, resource utilization, attractiveness to port number of incoming vessels to port and port profits.

At present, the main efforts are aimed at developing and verifying the optimization model as well as collecting data for the SD model. Afterwards, particular attention will be given to the validation of the SD model. The proposed approach is intended to be applied for a real case study in Alexandria Container Terminal (ACT). As a future work, the SD model may be extended to provide more analysis of resource utilization such as determination of how much the terminal management should invest in resources to reduce waiting time.

Appendix

TABLE II
Hypothetical Data Used in the Proposed SD Model

parameters	value
1. number of QCs	11
2. number of QTs	65
3. berth capacity	1600 m
4. handling time improvement	20% over the original value
5. time delay	3 years

Assumptions:
1. Political issues affect port traffic volume
2. World GDP affects port traffic volume
3. Salaries and taxes increases as port profits increase
4. Results of optimizing operations depend on experience, so the best improvement of handling time is reached after a specific period of time through which experience with applying optimization increases

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