SIMULATION OF VESSEL BERTHING USING ARENA: CASE OF BEIRUT CONTAINER TERMINAL

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SUMMARY

The main objective of this research is to analyze the current situation of Beirut Container Terminal. The proposed methodology is to mimic current terminal operations using a simulation model using ARENA software in order to identify causes of queueing occurring at berth allocation. Field research was conducted and both qualitative and quantitate data were collected using interviews, on–site observations, and online vessel tracking. A base model is developed to simulate the current operations at Beirut Container Terminal. Then, three different feasible scenarios are proposed to minimize the total time spent by the vessel at the quay side. Proposed scenarios take into consideration physical and resources expansion subject to political and financial constraints. The aim of this research is to provide a tool for the decision maker at Beirut Container Terminal in formulating an investment strategy for future expansion.

NOMENCLATURE

AGVS:	Automated guided vehicle systems
BCT:	Beirut container terminal
CMA-CGM:	Compagnie Maritime d'Affretement – Compagnie Generale Maritime
FIFS:	First in first served
FMEA:	Failure mode and effect analysis
LMCS:	Linear motor conveyor systems
MV:	Mother vessel
MSC:	Mediterranean Shipping Company
POD:	Port of discharge
RTG:	Rubber Tired Gantry
STS:	Ship to shore
TEU:	Twenty feet equivalent unit
TT:	trailers
VISCOT:	Visual Interactive Simulation of container terminal

1. INTRODUCTION

The expansion of international trade during the last five decades led to the growth of maritime transportation. Currently, container transportation dominates the sea freight transportation (Nehme *et al.*,2016). Ports and container terminals are competing in order to attract more shipping agencies by optimizing their investment strategies (Kaysi & Nehme., 2016).

There are four main ports in Lebanon: Port of Beirut, Port of Tripoli, Port of Sidon and Port of Tyre. Port of Sidon and Port of Tyre are used for fishing activities and for accommodating small freighters. Thus, only Port of Beirut and Port of Tripoli are currently used for international trade. Port of Tripoli is the second most important port in Lebanon, and it accommodates about 450 vessels per year. However, most vessels berthing in Port of Tripoli carry general goods and dry discharge (BankMed, 2014). This paper focuses on Port of Beirut, as the main port in Lebanon, and specifically on Beirut Container Terminal. Beirut Container Terminal (BCT), located in Lebanon, is considered to be one of the most important terminals in the Middle East and Mediterranean coast countries due to (i) its location between three continents and (ii) its ability to accept all types of vessels especially large vessels known as mother vessels, in addition to feeder vessels. In year 2017, Port of Beirut accepted more than 3,000 vessels (Port of Beirut, 2018) and BCT handled more than 1.3 million TEUs containers (Beirut Container Terminal, 2018). Based on an average TEUs containers growth of 4.23% per year between years 2008 and 2017, the projected future demand is expected to exceed 2 million TEUs containers in year 2027. Currently, BCT is considering a major expansion to accommodate the growth in maritime trade especially that the reconstruction of Syria cost at least 1 Trillion dollars, and BCT will be a major hub for maritime trade between Syria and the international contractors and suppliers.

The main objective of this research is to analyze the current situation of BCT, and to identify weaknesses that exist within the berthing operation of vessels and that have an impact on the terminal productivity. The proposed methodology is to mimic the current situation of BCT using a simulation model in order to identify causes of queueing occurring at berth allocation. Then, an analysis is conducted and alternative scenarios are proposed to enhance terminal's productivity.

Several researches have used simulation techniques to mimic container terminals worldwide. However, none of them took into consideration the case of BCT, where it differs from other terminals in two main factors: (i) mother vessel (MV) has a higher priority over feeders to berth and (ii) a simulation model via ARENA software will be developed for the first time for BCT in order to mimic the current situation and propose suitable development techniques.

This paper is structured as follows: Section 2 presents a brief review of relevant literature related to simulation techniques used in a maritime container terminal. Section 3 discusses the characteristics of Beirut Container Terminal and the simulation model developed. Section 4 presents alternative scenarios for expansion. Section 5 discusses the insights and observations of the current situation and proposed alternative scenarios. Finally, Section 6 summarizes the paper and proposes future research.

2. LITERATURE REVIEW

There is a scarcity in publications addressing Beirut Container Terminal (BCT), and none formulated a simulation model as presented in this paper. Starting with Kaysi *et al*. (2007), the authors proposed an approach for optimizing truck appointments and Rubber Tired Gantry (RTG) crane deployment in the case of BCT, with the objective of maximizing yard productivity (Kaysi *et al.* 2007). Then, Kaysi *et al*. (2012) formulated a mathematical model as a linear integer programming and solved it using GUROBI solver via AMPL compiler to optimize the allocation and scheduling of cranes used in transshipment operations. The model included a large number of binary and integer variables which increased the complexity of the model, so the authors used heuristics and approximate solution methods to reflect the real situation. The main goal of the model was to determine the number of quay and yard cranes needed at every period from a set of available resources in order to give the complete location assignments and the schedules of quay cranes and yard cranes (Kaysi *et al.,* 2012). Yousefi *et al.* (2012) studied causes of delay during loading and unloading operations at BCT using FMEA (failure mode and effect analysis), in addition to the application of SIPOC model and Pareto analysis (Yousefi *et al.*, 2012).

Interested readers can refer to Steenken *et al.*, Stahlbock and Voß (Stahlbock & Voß, 2008), Islam and Olsen (Islam & Olsen, 2013), and Bierwirth and Meisel (Bierwirth & Meisel, 2015), for a comprehensive review of all papers published in the area of operations research techniques for seaside operations planning at container terminals.

In this section, we restrict our review to publications related to simulation techniques used in a maritime container terminal. Easa (1986) developed the first-generation simulation model on PORTSIM which incorporates the operation of grain terminals only applied to the port of Thunder Bay in Canada. The logical activities of the model included all the subroutines that are called during simulation such as ship arrival, number of berthing ships, and grain loading capacity. The objective was to determine (i) average waiting time, (ii) average queue length, (iii) berth utilization, (iv) port throughput, and (v) maximum queue length. This information helped in assessing future improvements in the port (Easa, 1986).

Ballis and Abacoumkin (1996) introduced a computer simulation model with on-screen animation graphics, the model is named VISOCT (Visual Interactive Simulation of Container Terminal) and it was applied at the port of Piraeus in Greece. Data related to equipment's' velocities, acceleration, and handling time were collected as an input for the model. The output generated that recorded trucks and equipment activities for each of the proposed scenarios by the authors (Ballis & Abacoumkin, 1996).

Legato and Mazza adopted a queueing network model related to the logistic activities related to a vessel's arrival and departure to evaluate waiting time experienced by the vessels. The model was developed on visual SLAM based on an object-oriented approach and focused on berth planning subsystem of the container terminal. Data were collected from the port of Gioia Tauro in Italy, regarding characteristics of secondary vessels, such as arrival rate and container moves, and for the primary vessels, a uniform distribution function for arrival rate and triangular function for container moves were assumed respectively (Legato & Mazza, 2001). Henesey *et al.* (2004) developed a berth allocation management system in order to increase the container terminal performance by enhancing the efficiency of resources without any physical expansion. Preliminary data were collected from the analysis of 30 international sea ports and container terminals to generate correlation between (i) quay length, (ii) number and size of berths and (ii) ship turnaround time and throughput of containers. Data were collected from Skandia Harbour located at the port of Gothenburg, Sweden in addition to data collected from Norfolk International Terminal in Norfolk, USA and Seagirt Terminal in Baltimore, USA (Henesey *et al*, 2004).

Zeng *et al.* (2015) proposed the use of dual-cycling where quay cranes perform loading and unloading operations simultaneously in the same ship bay. Due to the complexity of the process, the model was divided into a bi-level genetic algorithm, in addition to a simulation optimization method integrating the intelligent decision mechanism of the optimization algorithm and evaluation function of simulation model. The main goal was to improve the operation efficiency of quay crane dual-cycling scheduling by minimizing the operation time of quay cranes and reshuffling time of outbound containers (Zeng *et al.,*2015).

Sheikhleslami *et al.* (2013) investigated an integrated decision problem that deals with the concurrent simulation of berth allocation and dynamic quay crane assignment by using discrete event-driven simulation on ARENA software. A variety of data was collected from the Rajae Port in Iran and it includes the tides height observations for 90 days, and the berth numbers and capacity, in order to identify the bottleneck in the process and perform scenario analysis to improve the port performance (Sheikhleslami *et al*., 2013).

Liu *et al.* (2000) studied using simulation model the differences between using manual operations and automated operations particularly LMCS (Linear Motor Conveyor systems) and AGVS (Automated Guided Vehicle Systems). The base scenario depended on Norfolk International Terminal, USA (Liu *et al.*, 2000).

Petering and Murty (2009) developed a discrete event simulation model of operations inside a seaport container terminal by using the professional edition of Microsoft Visual C++ 6.0 in order to present the effect of block length and yard crane deployment systems on overall performance at a seaport container transshipment terminal. The model had over 100-user defined input parameters in order to compute the average gross crane rate and berth occupancy (Petering & Murty, 2009).

Gambardelaa and Rizzoli (2000) presented a review of how simulation and optimization techniques have been applied to help and improve the management of intermodal container terminals is presented. The authors highlighted the following ideas: dividing management tasks along a time scale, importance of data availability, trends in optimization and simulation in intermodal terminals, the need for integrated terminal management, and the role of simulation in port operations (Gambardelaa & Rizzoli, 2000). Hansen and Henesey (2007) presented an overview of transshipment operation and description of methods and techniques for using simulation, where they stated all the steps of modeling in order to have a robust simulation model. The authors discussed a case study related horizontal transport systems at a transshipment container terminal using simulation modeling techniques (Hansen & Henesey, 2007).

Later on, Huang *et al.* (2008) developed a simulation system consisting of six modules to present the different operations at a container terminal in order to find the essential factors influencing the container terminal productivity. The system was used to model three ports in Southeast Asia. The authors concluded that the increase in the berth capacity increases the port throughput more than yard improvements (Huang *et al.*, 2008).

A similar work to what is presented in this research was accomplished by Adam (2009), in his thesis at Lincoln University, where he studied the container terminal at Male. Adam developed a simulation model using ARENA to find the bottleneck existing at the port. Then he proposed a berth extension to increase the berth capacity (Adam, 2009). However, this research differs from ours since the port of Male is a small port and it is dedicated for import containers only, since Male is a small island that needs to import most of its needs, while Beirut Container Terminal is considered as a hub for the Middle East and Mediterranean coast countries, and it covers all types of maritime operations.

3. SIMULATION MODEL

In this section, a simulation model is developed using ARENA software to mimic the complexity of daily operations occurring at Beirut Container Terminal (BCT). This section is divided into three parts: (1) BCT Operations, (2) Simulation Model, and (3) Assumptions and Data Input.

3.1 BEIRUT CONTAINER TERMINAL OPERATIONS

Operations at BCT can be divided into three steps:
(a) berth allocation
(b) (un)loading of containers, and (c) yard planning

Each step is briefly discussed below.

3.1(a) Berth Allocation

Only one quay is allocated for the Beirut Container Terminal Consortium with maximum capacity of 2 mother vessels and 2 feeders. The quay includes 12 STS (Ship-To-Shore cranes) for loading and unloading of containers. There is no specific place allocated for the vessel before its arrival. The queue system used is FIFS (First In-First Served), except for mother vessels operated by the two shipping lines, CMA and MSC, that have specific windows for them, so when they reach the port they use these windows that are located at a new constructed quay. If these windows were serving other vessels, mother vessels have the right to stop them from working and start their operation.

3.1(b) (Un) loading of Containers

Once the vessel reaches the quay side, two processes are in progress. The first process is the unloading of containers (transshipment and import) and the second is the loading of containers (export and transshipment) into the vessel.

3.1(c) Yard Planning

The yard is divided into several blocks: import, export, empty, and transshipment. Each block is divided into rows and columns. In each column a maximum of 5 containers could be stacked. When a container is unloaded from the vessel using the Ship-to-Shore crane (STS), it is moved to the yard by trailers (TT). The yard planner is then notified on all the information related to the container such as: weight of the containers, type (import, export, transshipment), status (empty, full), POD (port of discharge), feeder, and customer label.

Currently, Beirut Container Terminal is equipped with 12 Ship-To-Shore (STS) Post Panamax gantry cranes, 2 Mobile Harbor Cranes; 39 Rubber Tired Gantry (RTG) cranes; 14 Reach Stackers; 4 Top Loaders; and 8 Empty Handlers found to only hold empty containers; in addition to 58 Terminal Trucks, 4 Terminal Tractors, 5 Six-Wheel Trucks, 4 Goose Necks, and 69 Trailers (including 6 Mafi Trailers and Flat Beds) that are used to transport containers from vessels to yard and vice versa and to perform moves in the port premises (Beirut Container Terminal, 2018).

3.2 SIMULATION MODEL

Figure 1 illustrates the flow chart used in the simulation model via ARENA software to mimic all operations for BCT. The first step is the vessel arrival presented by a create module, then a decision module is used to differentiate between mother vessel and feeder. If the vessel is a mother vessel, we have to specify the availability of berths through another decide model that compares the number of occupied berths with the maximum capacity of berths. If a berth space is available, then mother vessel is allowed to berth, if not then we have to empty a berth space. Unloading of containers starts by a process module; when service is completed, the berth (in this case the resource) is released, which means it is empty again (idle), and the vessel leaves the system by the dispose module.

If the vessel is a feeder, we also check the availability of a berth through a decide module. However, if there is no berth space available, the feeder has to wait until a berth space is empty, then after berthing the process will be similar to mother vessel until finally the vessel is served and exits the system.

3.3 ASSUMPTIONS AND DATA INPUT

Qualitative and quantitative data were collected based on (i) on-site observations for two months at BCT, to mimic the sequence of sea and land activities related to containers' operations, and (ii) online-tracking for vessels, provided by BCT, to track and collect information such as time of arrival, time of berthing, vessel length, containers types and final point of destination. Then curves fitting techniques, by minimizing the mean squared error, were used to generate mathemactical distribution fucntions to mimic (i) arrival rate, (ii) berthing time, and (iii) operation time. Data were collected for 40 days, and based on that, several assumptions were made in this simulation model:

- The container terminal accepts 2 types of vessels: Mother vessels and feeders. MV have priority over feeders.
- The STS cranes perform loading and unloading operations seperately.
- Both containers types of 20 and 40 feet are being served.
- The operations at BCT is 24 hours per day, 7 days per week.
- The model is run for 960 hours (40 days) similar to the period of collected data.
- The model takes into account the vessel process from arrival to departure only. The hinterland processes are considered as one process.
- Delays arising from problems such as weather and strikes are not considered, since during data collection none of these problem occured.
- Quay side Length: the main quay is divided into two quays of length 500m and 600m respectively. The dimension of mother vessel (MV) is between 275m and 367 m.The dimension of feeders is between 141 m and 300 m. Therefore, the capacity of the quay is either (i) 2MV, (ii) 1MV and 2 feeders, or (iii) 4 feeders, based on daily activities. If we consider that each MV is equivalent to 2 units and feeder is equivalent to 1 unit, then the capacity of berth is equivalent to 4 units.
- A new variable is defined in order to control berthing spaces. The maximum number of available berths is considered to be 4 units computed from the dimension of the quay where vessels are officially allowed to berth.
- To perform the unloading operation MV needs 6 STS which also means 6 TT and 6 RTG, while feeders need 3 STS which also means 3 TT and 3 RTG.
- The percentage of MV is computed by dividing the number of MV by the total number of vessels during the analysis period.
- The percentage of feeder is computed by dividing the number of feeders by the total number of vessels during the analysis period.
- In order to compute the duration of berthing: for MV, subtract the actual time of arrival from the time of berthing. For feeder vessel, the berthing time is considered to be equal to that of MV since if we use the previous assumption to calculate the berthing time for the feeder vessel, it will include the waiting time to be served in case there is no empty berthing spaces.
- The duration of operation is calculated by subtracting time of berthing from time of departure.

Following data collection and the use of curves fitting techniques, by minimizing the mean squared error, the below input data were used;

- Arrival Rate: is computed by calculating the time interval between 2 consecutive ships during the studied period. 101 different input data distributed over 10 intervals with minimum value of 0.17 hours and maximum value of 39 hours were used. The distribution function used is Gamma (8.9, 1.14) with a squared error of 0.00357.
- Berthing Time: is calculated by subtracting the actual time of arrival from the actual time of berthing. The distribution function used is Lognormal (0.621, 0.392) with a 0.1 squared error.
- Operation Time: in order to calculate the time needed to perform all operations, the actual time of berthing is subtracted from the estimated departure time. It differs from mother vessel (MV) and feeders. For MV, the distribution function is Triangular (15, 28.3, 33) with a 0.021 squared error. For feeder vessel, the distribution function is Erlang (5.51,3) with a 0.016 squared error.

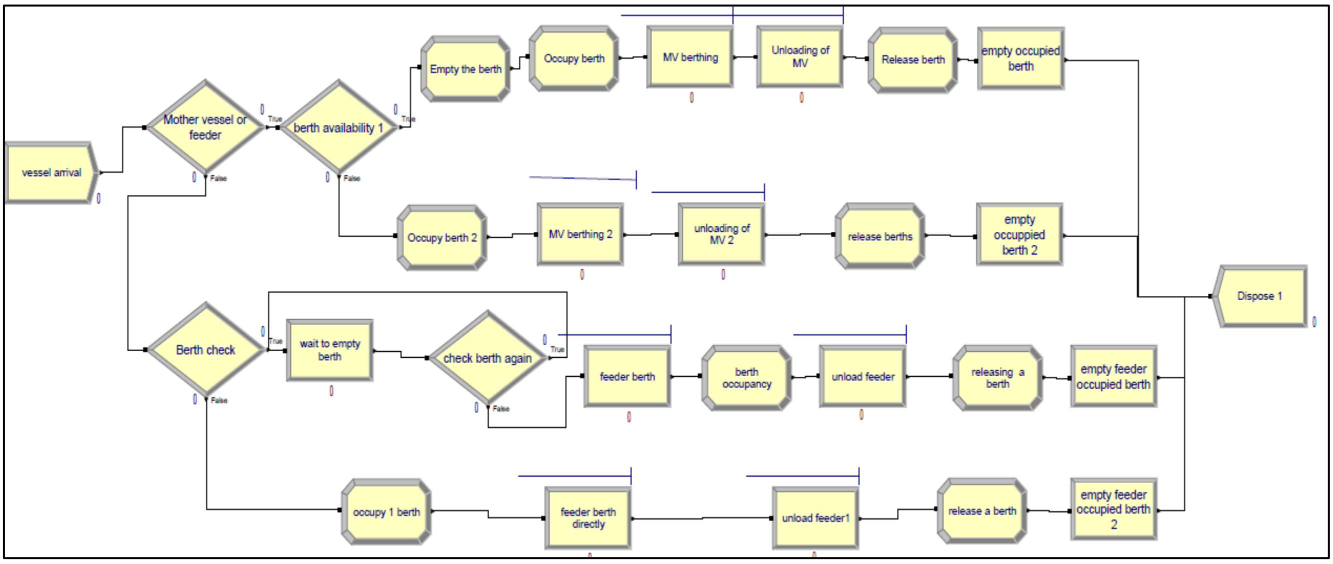

Figure 1: Flow Chart of Beirut Container Terminal on ARENA

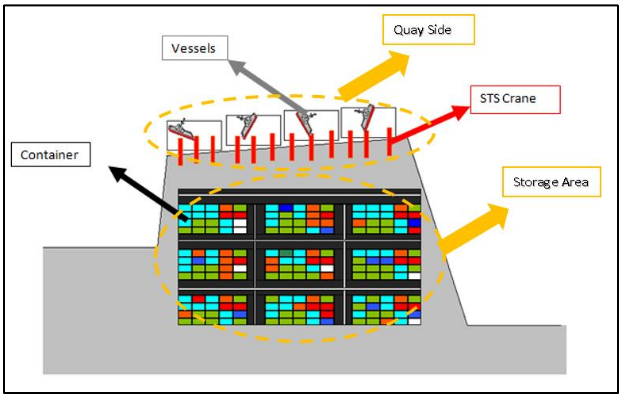

Figure 2: Terminal layout on ARENA

Figure 2 illustrates the layout of the Beirut Container Terminal including the quay side and the storage area side as represented in the ARENA software.

4. PROPOSED ALTERNATIVE SCENARIOS

Three alternative scenarios are presented to assess the possibility of any expansion or enhancement at Beirut Container Terminal (BCT). The first two scenarios, Scenario A and Scenario B, are proposed by BCT, while the third Scenario C is proposed after analyzing the base scenario and reviewing the literature. In this section, the three alternative scenarios are presented in order to be compared with the current situation referred in this paper as base scenario. The objective is to select the optimal scenario that will maximize the container terminal productivity by decreasing the total time of the vessel at the berth. The three scenarios, in addition to the base scenario, are described and discussed as follows.

4.1 BASE SCENARIO

It represents the current status of BCT, as described in Section 3. It is the base of comparison with other proposed alternative scenarios.

4.2 SCENARIO A: QUAY EXPANSION WITH LIMITED RESOURCES

In this proposed scenario, the berth capacity will be increased by expanding the current quay length to 2,300m instead of the current quay of 1,100m. In this case, the capacity of the berth will be 8 instead of 4 units. All other parameters will remain the same without any addition of resources such as (STS, RTG and TT).

4.3 SCENARIO B: QUAY EXPANSION WITH ABUNDANT RESOURCES

This proposed scenario is similar to Scenario A, with an increase in the quay length to 2,300m (increase the capacity of berth to 8 vessels), and the addition of new resources at the quay side by increasing the number of available STS from 12 to 24 units.

4.4 SCENARIO C: DUAL CYCLING CRANES

In this proposed scenario, all quay side cranes are replaced by dual cycling cranes. Dual-cycling quay cranes perform the loading and unloading operations simultaneously at the same ship bay. Therefore, the capital cost required for the replacement is almost negligible from accounting perspective. In this scenario, all the assumptions of the base scenario are applied except the operation time for mother vessel and feeder vessel. In this scenario, the operation time is decreased by 20% compared to the base scenario, as supported by the work of Zeng *et al.* (2015).

5. ANALYSIS RESULTS AND INSIGHTS

In this section, we present our results for the base scenario presented in Section 3 and the three proposed scenarios in Section 4. Seven output parameters were selected to assess the new scenarios and to reflect the level of service for vessels inside the container terminal. The seven output parameters are:

- Service Time: the actual mean time spent by the vessel while being served, in hours.
- Waiting Time: the mean waiting time spent by the vessel before being served, in hours.
- Time-in-System: the mean total time spent by the vessel in the container terminal. It includes the service time and waiting, in hours.
- Berth Utilization: the percentage of time the berth is actually busy (not empty) with respect to the total spent in the container terminal, in percentage.
- STS Utilization: the percentage of time a STS (quay side crane) is busy or not idle with respect to the total time of availability, in percentage.
- RTG Utilization: the percentage of time a RTG (yard side crane) is busy or not idle with respect to the total time of availability, in percentage.
- TT Utilization: the percentage of time a TT (trailer) is busy or not idle with respect to the total time of availability, in percentage.

The model was run for 960 replications with 24 hours per day for all the above four scenarios. The total time availability of all resources in the proposed scenarios is assumed to be constant.

Simulation results showed that for the base scenario, the mean total time spent by the vessel at the container terminal is 28.13 hours out of which 6.69 hours were spent waiting in queue, which is 23.8% of the total time spent in system. Berth Utilization is 69.63%, STS Utilization is 67%, RTG Utilization is 22%, and TT Utilization is 17%. For Scenario A, the mean total time spent by the vessel at the container terminal is 24.58 hours, out of which 2.87 hours were spent waiting in queue, which is 11.7% of the total time spent in system. Berth Utilization is 35.5%, STS Utilization is 59%, RTG Utilization is 20%, and TT Utilization is 16%. For Scenario B, the mean total time spent by the vessel at the container terminal is 21.13 hours with no queue line. Berth Utilization is 32%, STS Utilization is 30%, RTG Utilization is 20%, and TT Utilization is 16%. For Scenario C, the mean total time spent by the vessel at the container terminal is 19.53 hours out of which 2.07 hours spent waiting in queue, which is 10.6 % of the total time spent in system. Berth Utilization is 55.6%, STS Utilization is 52%, RTG Utilization is 18%, and TT Utilization is 14%. Table 1 summarizes all seven output performances for the four scenarios.

From table 1, Scenario B has zero queue waiting time but Scenario C has the lowest Time-in-System time. Since Scenario B has the same characteristics of Scenario A, but with more resources used at the quay, ipso facto it is a better scenario. However, the estimation of implementing Scenario A is 30 million dollars. In case Scenario B is implemented, it is estimated to be around 240 million dollars (Beirut Container Terminal, 2018). In Scenario C, the vessel waiting time is 11.7% of the total time spent inside the quay, but it has the minimal time among all other scenarios. In addition, the capital cost required to implement Scenario C is less costly compared to both Scenario A and Scenario B. This due to the absence of the infrastructure expansion cost required in scenarios A and B. Thus, Scenario C is currently the most feasible scenario to be implemented.

Table 1: Summary of output performance for the four scenarios

Output Performance	Base Scenario	Scenario A	Scenario B	Scenario C
Service Time (hours)	21.44	21.71	21.13	17.46
Waiting Time (hours)	6.69	2.87	0	2.07
Time-in-System (hours)	28.13	24.58	21.13	19.53
Berth Utilization (%)	69.6	35.5	32.0	55.6
STS Utilization (%)	67	59	30	52
RTG Utilization (%)	22	20	20	18
TT Utilization (%)	17	16	16	14

6. CONCLUSION AND FUTURE RESEARCH

Maritime trade is experiencing a dramatic development nowadays, especially containerized cargo. This makes container terminal productivity a crucial issue to be studied to optimize performance. Due to the complexity of container terminals, simulations are used to analyze ports bottlenecks and congestion.

In this research, a model simulation using ARENA software was developed to mimic the real situation of Beirut Container Terminal (BCT). To set up the simulation model, field research was conducted at BCT.

Qualitative and quantitative data were collected depending on on-site observation and online tracking. The model was divided into several modules to present realistically the situation at BCT. The model was run for 40 days. The results showed that currently the vessel spend about 24% of its total time waiting at the quay. The utilization of resources demonstrates that the berth utilization is the most utilized source. Furthermore, after checking the queue time, the major cause of queue was detected at vessel's berthing.

Thus, it was suggested to study three scenarios to decrease the queue at berthing. The first two were strategic scenarios based on increasing berths capacity by increasing the length of the quay, then adding more resources. The third scenario is an operational scenario where quay cranes are replaced by dual cycling cranes. Applying the third scenario is the most feasible and cost efficient scenario, which will minimize the total time spent by the vessel inside the quay to less than 20 hours, and the waiting time spent to be served is less than 11.7% of the total time spent inside the terminal.

For future research, it is beneficial to study the impact of the quay side improvement on the yard operations. In addition, a study to integrate dual cycling cranes at the quay side with the automated vehicles used at the yard side is another venue to consider to expand capacity at Beirut Container Terminal with minimizing the number of resources used. Finally, a benefit to cost analysis should be conducted to identify all capital costs and operational costs related to proposed scenarios, in addition to quantify financial benefits generated from enhancing the level of service in the proposed scenarios.

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