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A DISCRETE EVENT SIMULATION FOR THE LOGISTICS OF HAMAD'S CONTAINER TERMINAL OF QATAR

Mariam Kotachi
Ghaith Rabadi

Department of Engineering Management and Systems Engineering
Old Dominion University
2101 Engineering Systems Building
Norfolk, VA 23529, USA

Mohamed Kais Msakni
Mohammad Al-Salem

Department of Mechanical and Industrial Engineering
Qatar University
P.O. Box 2713
Doha, QATAR

Ali Diabat

Engineering Systems and Management
Masdar Institute of Technology

Masdar City, Abu Dhabi, UAE

ABSTRACT

A discrete even simulation is developed for the first container terminal of Hamad's new port of Qatar which is anticipated to start its operations by the end of 2016. The model is based on the operational knowledge of experts from the current port of Doha and Qatar's port authority (Mwani). The challenge in this paper is validating a simulation for a system that has not started its operation. Nonetheless, data and configuration of the current port has been utilized to partially validate the output of the simulation. The preliminary analysis shows promising results and indicate the validity of the model.

1 INTRODUCTION

In 2013 the world container port throughput increased by an estimate of 5.1% which is about 651.1 million 20-foot equivalent units (TEUS) or containers, according to the United Nations Conference on Trade and Development (UNCTAD 2014). Maritime container terminals are always impacted by the global economic growth since most world trade takes place by sea. Terminals of all types are constantly undergoing expansions and enhancement, and consequently, compete to have the most efficient and highest utilized resources and equipment. Ports are composed of multiple facilities with specific and complex operations which, consequently, create problems, delays and eventually bottlenecks. Therefore, port officials tend to relay on computer software and algorithms to provide optimal solutions and improved scheduling scenarios to increase port efficiency and decrease container delay.

A container terminal is one of many facilities in a port, where containerized cargo is temporarily stored and transported. Upon the arrival of a container vessel, it must find a berth to dock, then quay cranes at the shore side are assigned for container loading and unloading processes. Yard trucks (a terminal transporter) move the containers to the storage area or container yard, where another yard crane or rubber tyred gantry (RTG) crane adds them to container stacks. Issues such as berth allocation, quay crane scheduling and

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assignment, storage yard layout configuration, container re-handling and risk analysis are some of the challenging problems that are typically studied.

Annual container throughput, resources utilization, and process completion times are generally considered the most significant measures of performance. Maximizing container throughput is essential for terminal and vessel operators, since higher throughput means more vessels can be serviced which increases the utilization of resources at the terminal, which in turn increase revenues for both terminals and shipping companies. Terminal operators tend to rely on simulation models to aid with predications, identifying bottlenecks, understanding system complexities, and measuring the impact of new operational policies, terminal design modifications, and new technology deployment.

This work is motivated by an ongoing research on simulating the logistics of the first newly constructed container terminal system of Hamad's new port of Qatar, which is expected to start its operations by the end of 2016. The objective is to develop, test and validate the simulation for the container terminal and to study the effectiveness of its operational policies and resource allocation prior the start of its operations. Although the design of the terminal is set, its policies and the operations management can still be influenced by rigorous models. The challenge, however, is in populating the model with data for a system that has no historical data. Therefore, the simulation model is constructed based on what is known about the new terminal and on data collected from the current Doha port and from open sources and other port research studies (Kotachi, Rabadi, and Obeid 2013; Kotachi and Rabadi 2014). This paper focuses on the simulation design and development effort, and presents some validation aspects of the model's output. Other types of container terminals exist like automated, semi-automated and transshipment container terminals, yet the focus of this paper would be on a manually controlled import/export container terminal.

2 RELATED WORK IN CONTAINER TERMINAL SIMULATION

Bielli, Boulmakoul and Rida (2006) created a container terminal simulator for the improvement of management decisions where they evaluated policies that were generated by optimization algorithms. They used distributed discrete event simulation in their model by applying multithreaded programming in Java. They analyzed the container terminal system based on object oriented paradigm where they identified different classes and diagrams to describe the system; they represented these diagrams by using the Unified Modeling Language.

Petering (2009) was the first to introduce the direct connection between the containers' block width and the long run performance at a container terminal. A discrete event simulation model written and compiled in Microsoft Visual C++ 6.0 was designed to consider this study, where four different cases were studied: a small terminal and a large terminal, and two different container size configurations: less equipment and more equipment. Nineteen different layout scenarios were tested for each of the small terminal configurations, whereas fourteen were tested for each configuration case of the large terminal. In each of these different scenarios, the total yard storage capacity, the number of storage zones, as well as the number of containers in each zone was manipulated in order to introduce changes to the system. Ten simulation replications were performed for the small terminal configuration and six replications for the large terminal.

Yuan, Zhang and Yang (2010) created a discrete event simulation model using Arena software in addition to optimization methods in order to analyze some issues in a raw material inland terminal. The issues they were dealing with are cargoes transportations, vessle berthing and handling machinery performance, since this is a special kind of terminal, it also faces some issues regarding raw material stock piling and production of material. After analyzing the current state of the port, they were able to improve performance in the terminal operations due to their simulation and optimization measures.

Jie, Wan, Meng Qing-yu, and Wen (2010) used the Arena software to build a conceptual and simulation model for a container terminal, that includes port resources, like quay cranes, container truck and Yard Crane. They utilized "OptQuest" add-on to Arena to find the optimal allocation of the port resources within a given constraints in order to minimize operation times and increase utilization. They have concluded that their results were realistic and practical; however since their model was created for teaching purposes, it still has some limitations and they intend to avoid these restrictions in their future work by building a model with more details and parameters.

Petering (2011) conducted nine different and independent studies in a vessel to vessel transshipment container terminal by creating a fully integrated discrete event simulation model that was designed to imitate the real system. He was able to analyze the various impacts of these studies on the long run of quay crane and the decisions made by the container terminal experts. The studies focused on finding the optimal yard capacity for a terminal, investigating finding the ideal number of Yard Cranes and Yard Trucks for a container terminal, studying the impact of substituting the Yard Cranes by Yard trucks, studying the processing speeds of the Yard Cranes and Yard Trucks, addressing the processing time variability of Yard Trucks and Yard Cranes on the Quay Crane Rates, as well as the minimum required yard crane separation distance, and the substitutability of Yard Trucks traveling to the same location.

Arango et al. (2011) created a discrete event simulation model using the Arena software for solving some of the berth allocation problems in the inland port in Seville, Spain. The port under study was considered a multi-purpose terminal where different types of cargo are being transferred and also this terminal has different specialties terminals for handling these different cargos. They also used heuristic algorithms like genetic algorithms to solve the berth allocation problem based on first come first served strategy, by aiming to reduce the service time for vessels. Their results confirm that simulation by optimization is indeed a good solution strategy and it did improve the performance in the port of Seville.

Yu, Zhang and Wang (2011) presented a simulation based optimization model for job sequencing scheduling-optimization of a container terminal. They developed a mathematical model based on Hybrid Flow Shop Scheduling Problem, to optimize the operations of quay cranes, yard cranes and yard trailers. They also developed a simulation optimization model based on Genetic Algorithms to find a solution for this problem. They have concluded that their proposed method is successful in managing job sequence optimization.

Said and El-Horbaty (2015) developed a methodology using discrete event simulation to optimize resource utilization at El-Dekheila port in Egypt, with regard to the integration of equipment resources used in the container terminal. Data was collected from the port in Egypt, where they were also able to validate their proposed model and conclude its efficiency and effectivity where the quay crane utilization was increased by %41.

Ji et al. (2015) considered a continuous and dynamic berth, where they integrated the berth allocation and the crane assignment problem. They created a continuous model using Monte Carlo simulation with different performance indicators. Their research is one of the few that considered the continuous nature of the berth system, with multiple different vessel sizes and random arrivals. They applied sensitivity analysis and double factors variance analysis to evaluate the operational efficiency of their model. Their results demonstrate the relationship between the crane assignment and the performance strategies considered at the terminal, and they suggested applying their optimal solutions in order to reduce waiting time and increase the resources utilization.

While computer simulation and analysis has become a standard approach for evaluating the operation and designs of a complex container terminal ports in the literature, the body of knowledge appears to lack information about simulating a container terminal that is under construction or nonexistent. The work presented in this paper addresses this issue. In this study, we introduce the problem, present a system for making real-time container terminal decisions for a non-existent system; describe the simulation model used for experimentation, and describe the results and analysis of the simulated container terminal model."

3 MODEL DEVELOPMENT

The simulation model was developed based on the information obtained on the new terminal as well as through studying container terminals in general as there are a lot of similarities between container terminals.

The specific design information is obtained through discussions with managers, operators and staff of the new terminal under consideration, as well as the operational management of the current port.

3.1 Conceptual model

In the context of terminal simulations, a conceptual model is a logical flow diagram that represents the flow of vessels, trucks, and containers between sea side and land side and identifies decision nodes and resources necessary for the movement of containers and transport systems.

The conceptual model in Figure 1 was developed after studying the newly constructed container terminal system and the expected flow of its operations. In this abstract model, vessels arrive to the anchorage area at the port and wait for a berth. Once an available berth is allocated, the vessel moves to it via an access channel and docks at its assigned berth. Quay Cranes or Ship-to-Shore (STS) cranes are assigned to the vessel and start unloading containers to Yard Trucks that transport the containers to the Container Yard at which containers are stacked. Yard Cranes, which in our case are rubber tyred gantry cranes (RTGs) pick up the containers from the Yard Trucks and place them in blocks of containers at the Container Yard. Yard Trucks then return to the Quay to pick up more containers and bring them back to the Container Yard. In case of export containers, Yard Trucks take containers in the opposite direction for the STS cranes to load on the vessel. This process continues until the vessel is unloaded and export containers, if any, are loaded on the vessel. Multiple vessels can berth simultaneously and be serviced by the STS cranes.

In the truck cycle, external trucks come from land side and enter the port area through the security gates to the Container Yard to pick up containers and transport them inland. RTGs are used to load containers on the external trucks which then go through customs and exit the port area through the security gates. In the case of exporting containers or returning empty containers, external trucks bring these containers from the land side and drop them off at the Container Yard.

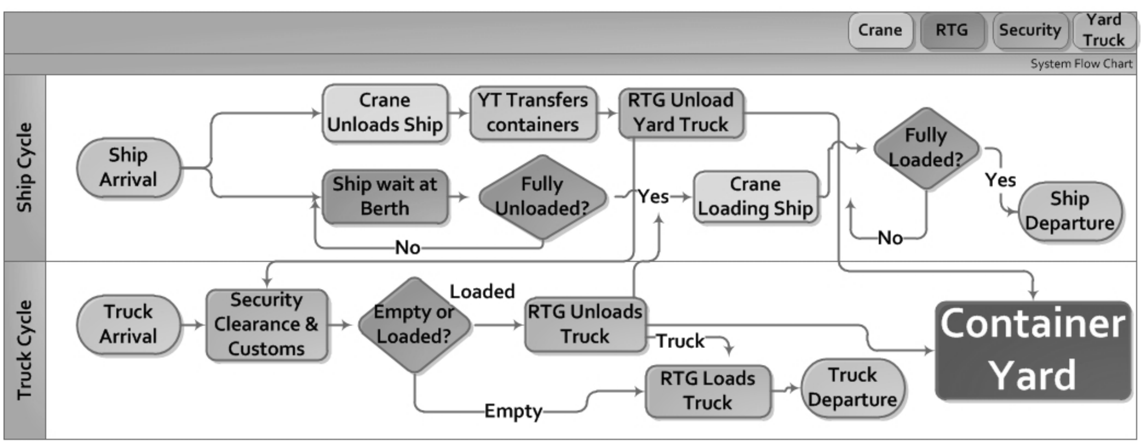


Figure 1: Conceptual model.

3.2 Simulation Model Design and Implementation

The design of the simulation model is intended to be at the macro level in order to study operations policies such as the impact of resource allocation and scheduling on the terminal's performance. The model was developed using ARENA simulation modeling environment. The vessels (with different lengths), containers, and external trucks are modeled as dynamic entities that flow through and drive the simulation according to the conceptual design discussed earlier. The resources modeled include the vessel access channel, quay berth area, the STS cranes, RTGs, and security gates. Yard Trucks are modeled as transporter resources to accurately model their functions. The external trucks were not, however, modeled as transporters because they do not belong to the port; they are instead treated as entities that are attached to other entity type which are the containers. It is assumed in this model that personnel are readily available to operate the modeled resources and the impact of their unavailability is captured within the data.

Many processes that take place at the terminal were modeled by seizing the necessary resources, delaying the entity by a certain time, and then releasing the resources. Processing times are based on historical data of the current terminal for validation purposes. Data that is not historically available are estimated from similar ports and experts in the field Qatar's port authority Mwani.

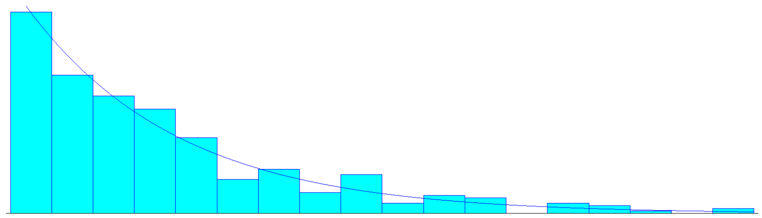
The berth allocation and crane assignment problems are very difficult optimization problems that are not solved within the simulation. Instead, simple heuristics such as First Come First Served are used at this stage of the research. More advanced optimization methods will be attempted at a later stage of the project. The berth area is considered continuous and vessels are allocated to berth areas based on the vessels' lengths.

3.3 Input Analysis and Data Fitting

Vessel historical data was collected from the current container terminal which is expected to reflect a comparable demand levels and material flow that the new terminal will undergo in the first a few years of operations. The data was analyzed and appropriate distributions were fitted to it. This included vessel lengths, vessel interarrival times, number of containers (full, empty, import and export), delay times from arrival to the start of operations, loading/unloading times, and delay times from the end of operations to a vessel's departure. We recognize that the resource types and terminal design differ between the new and current port; however, the objective in this paper is to validate the simulation model and therefore, we populated the model with data based on the current port to be able to validate against the historical data. For example, the STS crane types in the new terminal are capable of moving more containers per hour, and hence, are expected to service a vessel faster; however, we used crane movement rates that resemble those of the current crane types to validate the simulation output. Another example is the access channel, which does not exist for the current port; therefore, the time for the vessel to pass through it (in the model) was set to zero. Similar assumptions have been made to accommodate the differences between both systems.

One year worth of historical data was analyzed. To conduct proper validation analysis, data only for six months were used to fit the distribution and the remaining six months were used for testing purposes. To further remove any biases due to possible trends and seasonality in the data, the historical data of the full year was randomized and then half of the dataset was drawn randomly for input analysis, while the other half was used for validation after running the model and comparing its outcome. After the data is fitted to theoretical statistical distributions, both of the Chi Square and Kolmogorov-Smirnov (K-S) tests were used assess the goodness of fit. The null hypothesis in this case is that the fitted distribution and the theoretical one are the same, and when we reject the null hypothesis (p-value > 5%) it means that there is no difference between both distributions (i.e., the fit is acceptable).

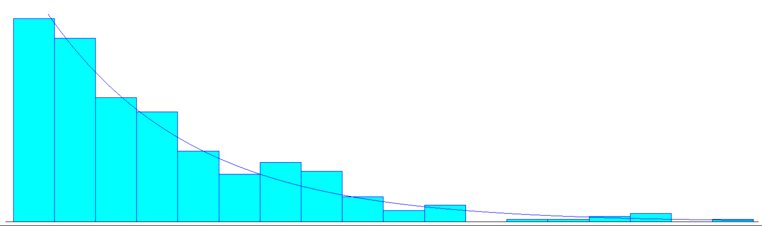
Figure 2 is an example of fitting the vessel interarrival times over six months of randomized data using ARENA's Input Analyzer which shows that the best fit is an Exponential distribution with a mean of 13.7 hours and shows that this distribution passes both tests as the p-values is large (> 0.05). This means that the null hypothesis that both distributions are the same cannot be rejected and therefore the fit is acceptable. Other simulation inputs were conducted similarly and empirical distributions (based on six month worth of data) were used whenever fitting to a theoretical distribution failed the hypothesis testing.



Distribution: Exponential	Chi Square Test
Expression: EXPO(13.7)	Number of intervals = 10
Square Error: 0.001987	Degrees of freedom = 8
	Test Statistic = 7.28
	Corresponding p-value = 0.507
Data Summary	Kolmogorov-Smirnov Test
	Test Statistic = 0.0438
Number of Data Points = 324	Corresponding p-value > 0.15
Min Data Value = 0	
Max Data Value = 66.4	
Sample Mean = 13.7	
Sample Std Dev = 12.9	

Figure 2. Vessel interarrival times distribution fitting of 6 month historical data (data included in the model).

To validate the distributions inputted into the simulation, the historical data of the remaining six months are fitted into a distribution and both distributions are compared. Figure 3 for example shows the interarrival time distribution fitting of the six month data that was used for testing. The result shows that an exponential distribution with an average interarrival time of 13.1 hours is the best fit which is very close to the result shown in Figure 2.



Distribution: Exponential	Chi Square Test
Expression: EXPO(13.1)	Number of intervals = 10
Square Error: 0.002313	Degrees of freedom = 8
	Test Statistic = 11.5
	Corresponding p-value = 0.19
Data Summary	Kolmogorov-Smirnov Test
	Test Statistic = 0.0361
Number of Data Points = 328	Corresponding p-value > 0.15
Min Data Value = 0.03	
Max Data Value = 66.5	
Sample Mean = 13.1	
Sample Std Dev = 11.7	

Figure 3. Vessel interarrival times distribution fitting of 6 month historical data (testing data).

4 VALIDATION RESULTS AND ANALYSIS

As was mentioned in Section 3.3, the one year data set was randomized to remove any trends or seasonality and was split into two six month data sets (training and testing). The training data set was used for input analysis and distribution fitting, while the testing data set was used for comparisons with the simulation output. A Summary of the simulation results for some of the measures compared to the historical data are shown in Table 1. Note that the Historical data column does not correspond to consecutive six months of the year but rather randomly selected days of the year that add up to six months.

The simulation was run for 25 replicates for six months each replicate. It was observed that with this number of replicates, the half width of the 95% confidence interval was about 5% of the mean for most measures. Hence, we were satisfied with this number of replicates. Furthermore, we noticed that the model goes into steady state after about 14 days; therefore, we used a simulation warm up period of 14 days. A Summary of the simulation results for some of the measures compared to the historical data are shown in Table 1.

Table 1: Simulation results vs. historical data.

Measure		**Historical Data**		**Simulation Output**	
		Mean	**95% C.I.**	**Mean**	**95% C.I.**
Vessel Turn Around Time (hrs)		36.5	[33.9, 39.1]	41.6	[40.46, 42.74]
Truck Counter (per month)		29,651	[28,255, 31,045]	29,921	[29,756, 30,086]
Number of Containers from different vessel lengths (in meter)					
116.5 m	**Imports**	251.7	[240.4, 263.0]	250.9	[247.74, 254]
	Exports	171.6	[138.1, 205.0]	159.1	[153.51, 164.77]
145 m	**Imports**	410.5	[400.0, 421.0]	406.2	[404.18, 408.20]
	Exports	141.6	[101.7, 181.6]	133.5	[127.71, 139.29]
68 m	**Imports**	61.81	[58.3, 65.3]	62.99	[62.47, 63.51]
	Exports	37.87	[30.4, 45.3]	41.14	[39.22, 43.06]

5 SIMULATION SCENARIOS

Running scenarios of interest via simulation can be very valuable to stakeholder and also aids in validating the model. Sample scenarios which some important assets and resources are manipulated. Two sample scenarios are included here. The first is reducing the number of RTGs and Yard Trucks by 20% and the second is reducing the Yard Trucks by 50%. In both scenarios, the turn Vessel Turn Around time is used as a performance measure. According to our simulation, the results in Tables 2 and 3 indicate that scenario 1 did not have major impact, but scenario 2 has a few hours of vessel turnaround time delay. These results were not too surprising since Hamad port is equipped with high level of resources especially when used with demand levels that are similar to those at the current port. The number of Yard Trucks was reduced to 50% for scenario number 2 as shown in Table 3.

Table 2: Reducing yard trucks and RTG by 20%.

Measure	**Original Output**		**Scenario 1**	
	Mean	**95% C.I.**	**Mean**	**95% C.I.**
Vessel Turn Around Time (hrs)	42.08	[33.9, 39.1]	42.7	[40.56, 44.84]

Table 3. Reducing yard trucks by 50%.

Measure	Original Output		Scenario 2	
	Mean	**95% C.I.**	**Mean**	**95% C.I.**
Vessel Turn Around Time (hrs)	42.08	[33.9, 39.1]	46.76	[44.43, 49.09]

6 CONCLUSIONS AND FUTURE WORK

Container terminals have complex logistical operations that are commonly studied by using simulation models. In this paper, we developed a discrete event simulation for the newly constructed container terminal of Hamad's new port of Qatar which is expected to become operational by the end of 2016. The model captures the flow of vessels, containers, and external trucks as well as important resources including STS cranes, Yard Trucks, and RTGs. The focus of this paper was on validating the simulation output by comparing it to historical data from the current port of Doha. Although there are major differences between both ports, the model was developed for the new terminal but configured to reflect the design of the current one. The preliminary results show confidence in the validity of the model. As more data become available from the new container terminal, further validation will be conducted.

Two scenarios were executed in which resources were reduced to reflect a policy change. Specifically the Yard Trucks and RTGs were moderately reduced in one scenario and the Yard Trucks were significantly reduced in another scenario. The results indicate that since the port is equipped with more resources than the necessary for the current demand levels and in anticipation of increases in future demands, the moderate reduction in resources did not impact the vessel turnaround time. However, significantly reducing the number of Yard Trucks will have more profound impact on the vessel turnaround time.

Future research includes developing more detailed processes for customs, inspection and Storage Yard. Optimization techniques can also be combined with the simulation for a more complex simulation optimization model.

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AUTHOR BIOGRAPHIES

MARIAM KOTACHI is a Ph.D. candidate and Graduate Teaching/Research Assistant at Old Dominion University at the Department of Engineering Management and Systems Engineering (EMSE). She received her B.S. degree in Biology from the University of Texas at Arlington; and her M.S. degree in Engineering Management from Old Dominion University. She is currently working on research areas including, among others, simulation optimization, discrete event simulation, and operations research. Her email address is mkotachi@odu.edu.

GHAITH RABADI is Professor of Engineering Management and Systems Engineering at Old Dominion University. He holds a Ph.D. and a M.Sc. degree from the University of Central Florida, Orlando, FL. His research interest include planning and scheduling, simulation modeling and optimization. His email address is grabadi@odu.edu and more information can be found at www.ghaithrabadi.com

ALI DIABAT is Professor of Engineering Systems and Management at Masdar institute of Science and Technology, Abu Dhabi. He received his MSc degree in Operations Research from North Carolina State University, USA (2003) and his PhD in Industrial Engineering from Purdue University, USA (2008). His research interest include mathematical programming and modeling and simulation. He can be reached at adiabat@masdar.ac.ae

M. KAIS MSAKNI is a post doc at Qatar University, Doha, Qatar and he is currently conducting research on terminal simulation and optimization model. He holds a Ph.D in Computer Science for Management from the University of Tunis. His research interest is optimization methods and scheduling and sequencing. He can be reached at msakni.kais@qu.edu.qa

MOHAMMAD AL-SALEM is Associate Professor of Industrial Engineering at the Mechanical and Industrial Engineering Department at Qatar University. He holds a Ph.D. in Industrial Engineering from the university of Central Florida, Orlando, FL and MSc degree from New Mexico State University. His research interest is operation research, sequencing and scheduling. He can be reached at: alsalem@qu.edu.qa