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Simulation Modeling and Analysis of Complex Port Operations with Multimodal Transportation

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Abstract

World trade has been increasing dramatically in the past two decades, and as a result containers exchange has grown significantly. Accordingly, container terminals are expanding to meet this increase and new container ports have opened. Ports with one or more container terminals are considered complex systems in which many resources, entities and transporters interact to achieve the objective of safely moving containers delivered by ships inland as well as loading containers delivered by trucks and rail onto ships. Ports with multimodal transportation systems are in particular complex as they typically operate with ships arriving to one or more terminals, multiple quay cranes, rubber tyred gantry cranes, trains, and trucks delivering containers of different types to terminals.

With several resources of different types working and interacting, the system can be so complex that it is not easy to predict the behavior of the system and its performance metrics without the use of simulation. In this paper, a generic discrete-event simulation that models port operations with different resource types including security gates, space, rubber tyred gantry cranes, trains, quay cranes, and arriving and departing ships, trucks, and trains is presented. The analysis will entail studying various scenarios motivated by changes in different inputs to measure their impact on the outputs that include throughput, resource utilization and waiting times.

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Keywords: Port Simulation; Complex Multimodal Transportation ; Container Terminal; Arena Simulation

1. Introduction

Ports are considered the main intermodal point where different types of transportation modes (ships, trucks and rail) meet to exchange cargo. The United States alone has 361 seaports which are the gateways for more than 80% of the foreign trade; the United States is the world's largest importer and exporter [1].

The basic process in the ports starts by the arrival of ships trucks and rails. All cargo and containers get inspected upon arrival. Containers are then removed by cranes or other methods and sometimes exchanged by

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loaded or empty ones, loaded containers are either moved to storage area or container yard by yard trucks or rubber tyred gantry cranes (RTG) or moved from one transportation method to another [2] [3].

Security measures and customs delays significantly influence port's operations and might lead to spoiling schedules, longer queues and delays in flow of materials throughout the port. Government agencies including customs administrations and control have faced many challenges regarding managing the increasing growth trade, because they have to simultaneously guarantee law compliances and facilitate lawful trades. In such cases, it is very difficult to keep track of gatekeeping and law compliance due to fast growth of the international trade volume given the limited resources of custom and port administrations and that some of the new customs control systems follow selectivity approach and risk management [4].

Many researches have been conducted to perform safety measures on ports by creating simulating models to anticipate the current situation in order to prevent delays and reduce cost. Studies have been conducted in schedule loading operations in container terminals to integrate optimization algorithms and evaluate performance via functions in the simulation model. For example, in a research done in [4], the main events are: initializing container sequence according to some dispatching rule, then the sequence will be improved by a genetic algorithm, and the objective function of a given scheduling scheme will be evaluated using a simulation model. Another model is designed to foresee the objective function and to remove poor solutions in order to decrease the simulation model running time. Many tests have shown that scheduling problem of container terminals can be solved by simulation optimization methods [3].

Another popular port problem is the berth allocation problem, which is the assignment of quay space and service time to containers that need to be unloaded or loaded at the terminal. A study was conducted to analyze the berth allocation under uncertain arrival time and operation time. For example, [5] studied the proactive approach to develop an initial schedule that incorporates a degree of uncertainty expectation during schedules' execution and also studied the reactive recovery strategy, which adjusts the initial schedule to handle accurate situations with the lowest penalty cost of deviating from the initial schedule.

Simulation studies are usually used to develop approaches for improving the performance of dynamic and complex systems like an intermodal terminal ports. Simulation helps imitate the port operations and provide predictions of outcomes and performances. Different scenarios can also be tested in a simulation model and the results can be studied and analyzed [6].

This paper addresses the simulation of terminal operations in general, but mainly focuses on modeling a modern ports with modern resources, where cargo changes modes of transportation from a ship to an inland transport mode and vice versa. Data was collected from different papers and ports around the world in order to accurately develop a generic simulation model that can be used with new port terminals without much effort in customization of the model.

The overall objective behind this work is to reflect the overall interactions in the real system in a simulated environment, to create a platform that would allow sensitivity analysis, and to develop a tool that would be able to give numeric outcomes of the current system highlighting areas and opportunities of improvement. The proposed simulation model makes analysing some measures simpler, like average resource utilization, the total number of containers that pass through the port, average waiting time in queues among others.

2. Methods

A discrete event simulation model was developed using Arena 14.0 to model generic port operations as well as the movement of incoming and outgoing ships, trucks, trains and containers. Principally, the aim is to model the path of containers starting from their arrival and ending with their departure.

2.1. The Real System

To build a conceptual model, the system is to be thoroughly explored. The real system consists mainly of ships, trucks and rail. In addition, container-handling equipment including quay cranes, yard trucks and rubber tyred gantry cranes (RTG) are used to move containers at the terminals. RTG is a rubber tyred mobile gantry crane used for stacking containers within the stacking areas or container yard and transfer containers from trains or trucks to the stacking area and vice versa. They are also used to straddle multiple lanes of rail and road and container storage [7].

The process at the port starts by the arrival of one of the intermodal transporters, that is, vessel, rail or truck. When a ship arrives to the terminal and seizes a berth, quay cranes are used to unload the ship by moving the containers from the ship board to the mobile yard truck. The yard trucks are usually available to receive containers from the crane. However if no yard truck is available, the crane will have to wait for an empty yard truck. The yard truck transports the containers to the container yard or the storage area and parks in the assigned isle and waits for processing. An RTG transfers the container from the truck to the stack of containers. This process continues for several hours or a day until the ship is emptied from all the containers that must be unloaded. After unloading the ship, the loading process begins and follows the same steps explained earlier but in a reversed way; the RTG transfers container from the container stack onto the yard truck, which travels to the ship, and lastly the crane transfers the container from the yard truck to the ship's board until the ship is loaded with all the assigned containers before setting sail and departing the port.

The process of arriving containers from land is done through trucks or rail. When a train arrives, it stops underneath an idle RTG which moves vertically above the train allowing some isle space for the yard truck to park. The RTG then unloads the containers from the train to an idle yard truck. The yard truck then travels to the container yard where another RTG unloads the containers from the yard truck to the container stack and the empty yard truck travels back to the train unloading area to be loaded again. This process continues until the containers are unloaded from the train before the train loading process starts. Loading the train follows similar steps like unloading but in a reversed way. Yard trucks transfer containers from the container yard to the train loading area and the RTG loads them to the train. This process continues until all the assigned containers are on the train and the train departs the port.

For inbound trucks that bring containers, the handling process is a little different. Most arriving trucks come loaded with a container to be transferred to the container yard. However, there is some percentage of arriving trucks come empty, just to pick up containers and leave. Loaded trucks drive to the assigned container yard isle to be unloaded after going through some security check points. An idle RTG would transfer the containers from the truck to the stack of containers. The truck then either leaves empty or it drives to another container stack isle to receive another outbound container from an RTG. Arriving empty trucks that come for a pick up simply follow the same truck loading part mentioned above.

In this paper the port considered is a modern container terminal with a capacity of three berths and more than 3500 feet length and can handle the world's largest vessels. The terminal is equipped with eight quay cranes, 26 RTGs and 30 yard trucks. The container yard, or storage area, is divided into ten zones with two RTGs per zone and six RTGs are dedicated to the rail loading and unloading process. Such terminal is be able to handle around two million TEU (twenty-foot equivalent unit) a year.

2.2. Conceptual Model

After studying the real system and building an overall understanding of the on-going operations, a conceptual model can be inferred and constructed. Entities moving within the simulation model include ships, trucks, trains and containers. The resources in the model include quay cranes for loading and unloading, RTGs for stacking and unloading, ship berths, and storage areas or container yard. The processes in the model are constructed based on the operations that take place at the port including loading/unloading containers from sea or land and moving containers to the container yard or around the port to another transportation mode. Fig 1 shows the flow chart of the port and the processes involved.

The proposed simulation studies different scenarios regarding the number of cranes, RTG, and yard trucks to understand their impact on the port progression. Furthermore, the simulation model is set up as a platform to study the impact of customs and security check points on the port's operations and efficiencies.

2.3. Data Collection

Data was collected from five different container sea ports and from different research studies ([2] [6] [8] [9] [10]) and works that have been conducted on port simulations in order to help create this generic simulation model. Data collected can be categorized as follows:

- Arrivals: inter-arrival times of ships, trucks and rail
- Processing times: times it takes various transporters (cranes, RTGs, trucks) to load/unload
- Travelling times: distances and velocities for Yard Truck, ships, trucks and train
- Availability: number of Cranes, RTGs, and Yard Truck
- Capacity: Berth, Container Yard, ship capacity, train capacity.

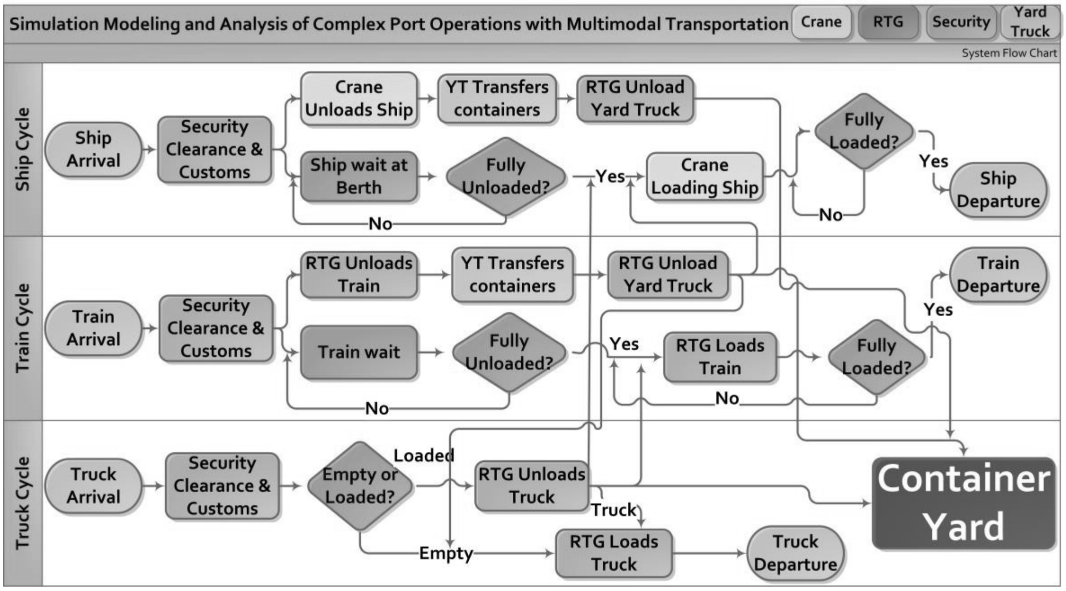

Fig 1. Flow chart of Port Operations

2.4. Key Modeling Techniques

During the development of the model, some obstacles were faced concerning modeling complex operations performed and decisions made in the port. A brief description of some of these obstacles is now introduced as well as how they were resolved.

In the simulation model, it is assumed that the three different means of container transportation arrive to the system already loaded with no regard to where or how these containers came from. In order to do that, a ship, train or truck is initially created as one entity until it reaches the port. At that instant, it is duplicated to produce the amount of containers that it should carry and these new duplicates are assigned a new entity type to make the model recognize them as containers. The Separate Module in Arena was used to perform the duplication.

In order to add fidelity to the model and to reduce complexity, an initial amount of containers was assigned to the Container Yard before the first event occurs. This was done by creating an external source of containers and sending them to the Container Yard without travelling time.

In order to make the transporting entity wait until all the containers have been unloaded or loaded, a counter was assigned to count all the containers that are being processed after drop off. The containers are then held (via Hold module) until all required entities are there.

To be able to distinguish between the different arriving and departing containers, their mode of transportation as well as the different ship types and sizes, Assign modules are used throughout the model to assign specific entity types as well as specify the required attributes to the entities.

Yard trucks were modelled as Transporters to simulate their movement around the port from the ship to the container yard and vice versa, and also from the container yard to the train and vice versa. Transporters in Arena are resource types that realistically represent a vehicle movement including its speed and distances between pick up and drop off locations.

2.5. Assumptions

When utilizing the conceptual model to build the simulation model, some assumptions had to be made in order to reduce some unnecessary details. These assumptions can in future expansions be relaxed when considering other aspects and details of a port. These assumptions include:

- Container yard capacity is infinite
- Personnel and staff running the port and some of the machines are considered embedded available whenever needed to reduce complexity
- At this stage, the port is not affected by holidays, weather or any down time delays. However, this will be accounted for in future work.
- Container Yard storage level is 5000 containers at initiation.

3. Results

The simulation model was run for 10 replications each of 100 days to conduct face validation for the model and check whether or not it realistically models the real system. A simulation day was modelled to have 15 working hours. The model averaged 94,618 total number of entities that were processed through the port operations and departed the system. Out of the total number of entities processed, a sum of 60,209 containers departed the port through the three different transportation modes. Table 1 shows the average total number of entities processed related to the other types of entities in the system.

Table 1. Number of entities per type that departed the system

Entity	Number Processed
Full Trucks	55,708
Empty Trucks	40,526
Ships	59
Trains	194,911

Regarding the resources operating the port, the utilizations varied from one process to another. The RTGs, however, reflected the highest utilization due to the congested demand on the RTG service for stacking containers in the yard as well as loading and unloading trucks and trains.

For each container that leaves via any of the three modes of transportation, the average flow time is defined as the time between its first arrival to the stack in the container yard and its departure from the system on a ship, a train or a truck. Table 2 shows the flow times in hours for the containers varying according to its transportation manner.

Table 2. Average Flow Time for containers leaving with the three modes of transportation

Mode	AVG. Flow Time (hours)
With Ship	73.1
With Train	407.7
With Truck	333.8

Upon running, the simulation model was initiated with 5,000 containers in the container yard. After the model was completely run, the container yard reflected a container count of 12,486. This increase is a result of the incoming containers arriving through ships, trains or trucks to the container yard.

4. Conclusion and Future Work

This paper is concerned with designing a generic discrete event simulation to model the flow of entities in any modern but typical port in the world. The process of the port starts by the arrival of ships, trains and trucks loaded with containers. The cranes, RTG and yard trucks provide the needed handling and transportation of containers around the port and from/to the three different kinds of transportation modes.

The main purpose of this study was to study the complex operations involved as well as the utilization of resources. Furthermore, the outcome of the port flow is studied and different scenarios are simulated.
This study is just the initial work for a larger scope in which the influence of other port functions such as customs and security that impact the port process will be studied and simulated further more.

In Future work, required data is to be collected and statistically analyzed to provide input distributions for arrival and service times as well as parameters for the different stations and scenarios. In addition, further detailed modelling will be done to include weather conditions, holidays and other variables. Furthermore, output analysis will be conducted on the results and sensitivity analysis will be used to determine the impact of each parameter on the overall flow and to provide a platform for what-if-scenarios. Also hypothesis testing will be performed and subject matter experts will be consulted.

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