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Simulating port logistics operations using 3D visualization technology

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Abstract

Ports are one of transportation's logistic components crucial to supporting international trade and economic growth. Increasing at an average annual rate of 16%, the Port of Savannah has been America's fastest-growing port since 2001. Because of this rapid growth, there is a need to develop a cost-effective means to explore and evaluate new productivity improvement alternatives (e.g. a facility capacity increase) before they are implemented. This paper presents a low-level, detailed, 3D simulation model that was developed to simulate the Port of Savannah's berth operation and evaluate the productivity. The actual layout, traffic management, and operation flow in Berth 8 of the Port of Savannah were used to evaluate the impact of the quay crane's capacity on berth productivity. One of the values of using 3D visualization in this study is to provide better visibility on the operation flow for identifying the processes to be improved. For example, the idle quay crane can be easily identified visually in a 3D simulation. It also identifies any bottlenecks that may be caused by insufficient resources, such as jockey trucks. The 3D simulation model determines the amount of resources required to minimize the quay crane idleness and maximize berth productivity. Results show that the developed 3D simulation model can effectively evaluate the impact of the quay crane on berth productivity and determine the amount of resources needed for achieving the desired berth productivity improvements.

Keywords: container-terminal operations, 3D simulation.

1 Introduction

Ports are one of transportation's logistic components crucial to supporting international trade and economic growth. In the United States (U.S.) business logistics costs were $1,305 billion in 2006. During this same year U.S. ports handled 2.1 million twenty-foot equivalent units (TEUs), an 8% increase from the previous year and 30% increase over the past three years. The Port of Savannah is a major seaport in the U.S. It is operated by the Georgia Ports Authority. Between 2000 and 2005, the Port of Savannah was the fastest growing seaport in the U.S. During this period, while the national average annual growth rate was 9.7 %, the Port of Savannah grew at an average rate of 16.5%. Also the Port of Savannah handled more than 2.3 million TEUs of container traffic in 2007, making Savannah the fourth-busiest and fastest-growing container terminal in the U.S.

As a result of this rapid growth, there is a need to develop a cost-effective means to explore and evaluate new alternatives for increasing productivity (e.g. facility capacity increase) before implementing them. Because port operations are complex, simulation technology is a good means to evaluate the impact of different changes on the performance of the container terminal. This paper presents a low-level, detailed, 3D, container terminal simulation model based on FlexSim CT, a commercial container terminal simulation package. The actual layout, traffic management, and operation flow in Berth 8 of the Port of Savannah were used to evaluate the impact of increasing facility capacity to improve berth productivity. While other studies using container terminal simulation are carried out by modeling with a rather high level of detail in general, our model focuses on reproducing every detail of container-terminal equipment behavior, including the movements of Jockey trucks and cranes.

Low-level detailed representation in container-terminal simulation has been overlooked because the objective of simulation usually has been the evaluation of planning schemes and/or dispatching rules for operating container terminals (Kim et al. 2004; Yang et al. 2004). When the purpose of simulation is to assess the correlation between the productivity of container terminals and the capability of equipment used (Legato and Mazza 2001; Yun and Choi 1999), it is critical to take the detailed operational performance of equipment into consideration. Ha (Ha et al., 2007) has developed a low-level simulation to model container-terminal operation. As noted in Rohrer (Rohrer, 2000), high-quality animation can aid simulation processing in the following areas: verification and validation, understanding of results, communication of results, securing buy-in from nonbelievers, and achieving credibility for the simulation. This paper uses the actual port layout and traffic operation in Berth 8 of Port of Savannah to evaluate the feasibility of developing a low-level, detailed, 3D simulation model for evaluating the impact of quay crane capacity increases on berth productivity. The corresponding resources, such as the number of Jockey trucks, rubber tyred gantrys (RTG), needed to achieve the desired berth productivity are also analyzed using this model. This paper is organized as follows: Section 1 presents the background and the need for 3D port simulation. Section 2 presents the container-terminal operation and the developed 3D port simulation model. Section 3 presents the case studies to explore alternatives to improve berth productivity. Finally, conclusions and recommendations for future research are given in the last section.

2 Container terminal operation and modeling

This section presents the spatial components of the Port of Savannah and the container flow we have modeled. The simulation process is then presented. The Port of Savannah is represented with four major spatial components. They are Berth, Yard, Gate, and Rail. The following briefly describes each component and how it relates to simulation modeling. *Berth* is a place in which a vessel is docked where nearby a quay crane loads or discharges the ship's containers. In our simulation process, berth has a broader coverage. It includes the physical place a vessel docks at and leaves from, the space the quay crane is working in to load and discharge containers, and the route Jockey trucks use to serve the vessel. *Yard* is the area used for the storage and switching of containers. The yard can be described as a large, organized buffer for containers. The yard is one of the largest components in the terminal and the most challenging to handle. *Gate* is the entrance and exit for all container cargo operations. It includes truck inspection, ticket issuing, etc. The operation of the gate determines the traffic condition inside and outside of the terminal. This is important to the connection between the local network and the terminal operation. *Rail* is another mode of transportation in the Port of Savannah. This rail component includes the area for changing containers to different transportation modes (e.g. freight to rail).

There are three management components in the Port of Savannah. They are traffic management, resource management, and data management. They are used to establish the relationship among different spatial components in the flow of containers. The resource includes equipment, such as the quay crane, RTG, and Jockey trucks. Examples are shown in Figure 1. This equipment is crucial to ensure the efficient flow of containers.

Quay Crane RTG Jockey Truck

Figure 1, Equipment resource in container terminal

Container terminal operation is a complicated process. After studying the container flow in the Port of Savannah, we divided the container flow into six major processes: 1) truck-to-ship: the containers for export are brought in by road trucks through the gate; 2) ship-to-truck: the containers for import are discharged by a quay crane from a container ship and transported to the designated location in the import yard by Jockey trucks; 3) ship-to-rail: the containers for import are discharged by a quay crane from a container ship and transported to the designated location in the rail yard by Jockey trucks; 4) rail-to-ship: the containers for export are brought in by trains and temporarily piled in the rail yard. The Jockey trucks pick up the containers and place them in the export yard together with other containers from the road; 5) truck-to-rail: the containers are brought in by road trucks through the gate. With the drop-down ticket provided by the gate, the containers will be transported directly into the rail yard; 6) rail-to-truck: the containers are brought in by the train and then discharged to the rail yard.

The following paragraph describes the process of developing the 3D-container-terminal simulation model. In this paper, we simulate only the container flow between two components (berth and yard) to demonstrate the benefits of using the developed 3D-simulation model. After the simulation model is developed, we validate the model by checking the results, such as berth productivity, to ensure they are reasonable. The model is validated before conducting a what-if analysis. Based on the real geographic setting of Berth 8, we have created the layout of Berth 8 and the yard using FlexSim CT Ver 2.0.2 function of Berth Planer and Yard Planner. Using actual operating parameters, we separately set berth, yard, and gate using the Berth Planner, Yard Planner, and Gate Planner of FlexSim CT software to make sure all the strategies, operations are reflective of the real case. Based on the traffic flow in Berth 8 yard, including all the trucks and facilities, the traffic route was created using Nodes and Links in the simulation model. Figure 2 shows the actual Berth 8 traffic management. We calibrated the input parameters, truck speed, block number, capacity, allocation strategy, etc., to make sure the results are correct. For example, the berth performance is reasonable based on our discussion with Port of Savannah's engineer. We then use the developed model to perform simulation analysis.

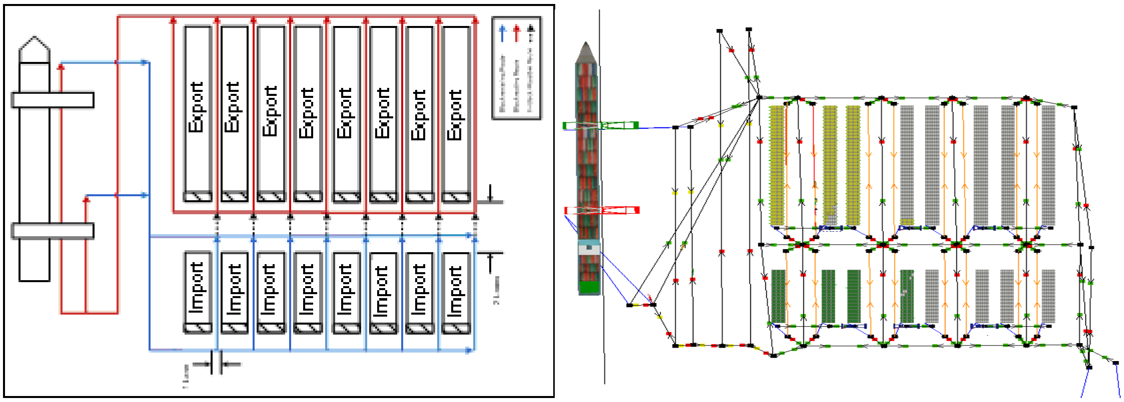

Figure 2, Traffic flow of Berth 8 (Left: sketch drawing; Right: FlexSim drawing)

3 Case study

This section presents two cases using the developed 3D container-terminal simulation model to evaluate different alternatives for improving berth productivity (i.e. increasing quay crane speed). The actual data from the Port of Savannah, including yard layout, traffic management, and operation flow in Berth 8, are used to develop the simulation model. The focus of the case studies is to evaluate the impacts of quay crane speed and jockey trucks on the berth productivity. Therefore, a baseline case was created using a combination of actual layout and some hypothetical data. Figure 3 shows the developed 3D visualization model used to simulate Berth 8 operations. It includes the quay crane, Jockey trucks, actual berth and yard layouts, traffic management, and RTG. The parameters for the baseline case are as follows:

- Two quay cranes serve Berth 8, each with a speed of 30 moves/hr;
- Six RTGs for 16 blocks are arranged in the yard. The utilization of the RTG depends on the stevedore's strategy (i.e. how the containers are allocated in the blocks). In our case study, it is assumed the RTG can be utilized efficiently and there is no bottleneck at the RTG. Therefore, we can focus on analyzing for the optimum number of jockey trucks.
- Three Jockey trucks for each quay crane with a total of 6 Jockey trucks;
- The demand is 4000 TEUs throughput per week, including loading and discharge.

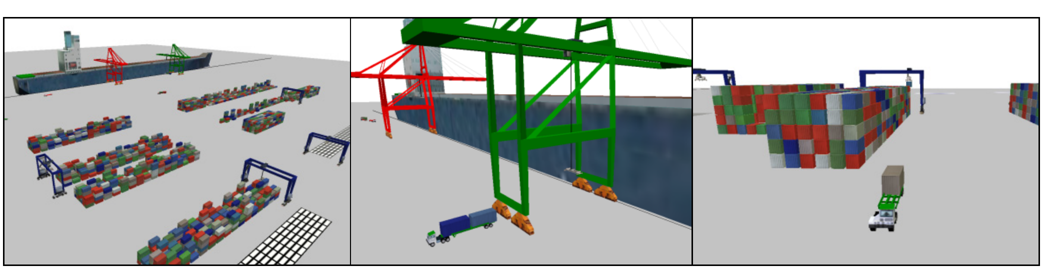

Figure 3, 3D low-level container terminal simulation model

The baseline case shows the crane operating at 26 moves/hr with 6% waiting time (the percentage of time a crane is idle waiting for a Jockey truck during the working period). To analyze productivity (i.e. container throughput) for Berth 8, two cases were explored. The first case increased quay crane capacity and another increased the number of Jockey trucks. As expected, in the first case, increasing quay crane speed, did increase the berth productivity. However, the quay crane was observed idling frequently. In order to minimize the quay crane idling there is a need to increase the number of trucks. One quay crane can cost more than $10 million dollars and is one of the most expensive assets in the port. It should not be idle but should be utilized efficiently. Case 2 simulates the increase of corresponding number of Jockey trucks. Different numbers of Jockey trucks are simulated to determine their impact on berth productivity and quay crane idleness. From these simulations, the optimum number of Jockey trucks necessary for efficient operations can be determined. These two cases are presented below.

Case 1 Increase only quay crane capacity

With the basic settings and parameters described above, the quay crane design speed was changed from the baseline of 30 moves/hr to 50 moves/hr. Other parameters, including the number of Jockey trucks, remained unchanged from the baseline case. The results show the berth productivity was increased from 26 moves/hr to 34 moves/hr. It was observed that the individual quay crane utilization did not reach the design speed of 50 moves/hr, but instead due to an insufficient number of Jockey trucks only had an actual speed of 34 moves/hr. In the visualization of the simulation it was observed that the quay cranes were idle from time to time. This is shown as red shadows under quay cranes in Figure 4. This indicates the quay cranes are under-utilized, a situation that could be improved. In addition, the crane's waiting time increased from 6% before the quay crane speed was increased to 33% after it was increased. Therefore, in case 2 we increased the number of Jockey trucks.

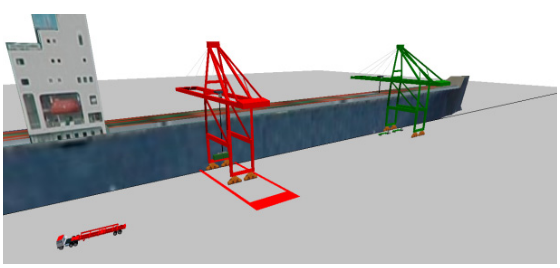

Figure 4, Quay crane idle shown by red shadow. Idle due to insufficient Jockey trucks

Case 2 Increase the number of Jockey trucks

We increased the number of Jockey trucks from 3 for each quay crane to different numbers to determine the optimum number of Jockey trucks needed. In order to focus on analyzing the number of Jockey trucks, we assumed there was sufficient RTG capacity in the yard to handle the increased number of Jockey trucks. Table 1 shows the simulated relationship between different numbers of Jockey trucks and berth productivity. The optimal number of Jockey trucks, 6, under this simulation setup can then be determined. The recommended optimum number of Jockey trucks is 7 (one for backup). Increasing the number of Jockey trucks will not necessarily improve the quay crane speed because a bottleneck may now be created by other resources, e.g. RTG. Although the actual operation is a lot more complicated because of the involvement of many other interrelated activities/processes (e.g. traffic management and RTG, etc.), the purpose of this case study is to demonstrate the feasibility of evaluating different proposed operation settings and determining what the optimum settings are before implementing actual costly changes.

Table 1. Impact of number of Jockey trucks on quay crane utilization

# of Jockey Trucks	3	4	5	6	7
Waiting Percentage	33.0%	23.6%	13.7%	8.9%	8.9%
Quay Crane Speed (moves/hr)	34	37	43	46	46

Using the developed 3D simulation model, these case studies demonstrate the capability and feasibility of evaluating the impact of increasing the quay crane capacity on the berth productivity. The quay crane idle time can be seen clearly in a 3D visualization environment. This helps to identify additional resources needed. In addition, we have simulated different numbers of Jockey trucks and determined the optimum number required to achieve the desired berth productivity. This study shows that the developed simulation model can effectively evaluate different alternatives before implementing costly changes, thereby minimizing any potential risk.

4 Conclusions

Ports are one of transportation's logistic components crucial to supporting international trade and economic growth. In order to sustain a port's continuous growth; it is important to explore alternatives to improve their productivity. There is a need to develop an effective means to evaluate these alternatives before their costly implementation. This paper explores the feasibility of developing and using a 3D simulation model to evaluate different operational changes. The actual layout, traffic management, and operation flow in Berth 8 of the Port of Savannah, are used to evaluate the impact of quay crane capacity increases on the berth productivity. Case studies have demonstrated that it is feasible and promising to use the developed 3D simulation model to perform the analysis. One of the values of using 3D visualization in this study is to provide better visibility on the operation flow for identifying the processes to be improved. For example, the idle quay crane can be easily identified visually in a 3D simulation. The optimum number of Jockey trucks can also be determined using the simulation model. It is recommended that the simulation test use the actual berth schedule, truck data, etc. It is also recommended to perform validation on the baseline comparison in the future although it is a costly process. In addition to evaluating the performance of new equipment, we can evaluate a) the gate operation and policy/incentives, b) the rapid dispatch yard operations (a unique operation in the Port of Savannah, designed to increase customer service and to maximize the asset utilization, and d) traffic management. Finally, besides normal operation, it is recommended to use this 3D simulation for modeling the exceptions, such as foggy weather prioritization and resource management.

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