Simulation Models for Evaluation of Terminal Operations and Traffic Flow on Adjacent Road Network

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Abstract: The goods movement via terminals at ports is a complex operation as it involves use of different modes of transport that includes surface and marine. In this paper, we present three simulation models which can be used to understand and evaluate these operations. The macroscopic simulation model simulates the flows in and out of terminals and ports and it is integrated with a microscopic simulation model of the adjacent road network. A terminal cost model receives inputs from these two models to evaluate the cost associated with the processing of containers inside the terminal. The use of the three models is demonstrated by evaluating the impact of terrorist attack scenarios on a container terminal in LA/LB Port complex.

Keywords: Terrorism, Terminal Simulator, Terminal Cost Model, VISSIM, ACC

1. INTRODUCTION

The ports of Long Beach and Los Angeles are the largest container ports in the United States and together the 5th busiest container terminals in the world. In 2000 these ports handled about 9.5 million twenty-foot equivalent units (TEUs) (Mallon and Magaddino, 2001). In 2004, the combined ports handled roughly 13 million TEUs and it is expected to reach about 16 million TEUs by 2010 (AAPA, 2009). Annual growing rate of container trade is about 6% in the United States. Terminals’ authorities are trying to accommodate new technologies to improve terminal facilities. Since 1960’s ship’s capacities have increased from 400 TEUs to 8000 TEUs (Nye L.W., 1998). A container terminal with two berths and ten cranes requires 250 moves per hour to load a ship in 24 hours (Evers and Boonstra, 1996). The performance of cranes characterised by the loading/unloading container rate is an important measurement for evaluating the productivity of a terminal. Ship turnaround time is the time that a ship spends at berth in order to get loaded and/or unloaded. The ship turnaround time is one of the important factors that influences the total transportation cost of containers. The goal in each terminal is to reduce the ship’s turnaround time in order to minimize the overall transportation cost of containers (Toth, 1999). The operations within the terminal also affect the flow of traffic in the adjacent road network. A large proportion of containers arrive at the terminals via trucks using the road network. This interdependence of traffic efficiency with that of terminal operations such as delays at the gates, ship turn-around times, inspections inside and outside the terminals demonstrates the complexity of goods movement via a terminal. Delays due to processing, inspection, traffic etc impact the overall cost of moving containers through a terminal.

The average cost of trucks used by trucking industry is about $75 per hour which includes maintenance and labour costs (Frankel, 1987, Jones, 1996). Trucking industries take into account the overall transportation cost of containers and would often select terminals which serve trucks in short time in an effort to keep the cost low. The cost of moving containers within terminals depends on various factors that include labour cost, infrastructure, equipment, etc. Terminals desire to keep the terminal cost to the minimum possible in order to meet their specifications and competition. Performance, cost and competition put a lot of pressure on container terminals to operate within very tight constraints. Unpredictable events such as a terrorist attack at the twin ports would cost billions of dollars to the United States economic. Since 9/11, the Department of Homeland Security (DHS) has improved the terminal ports security by increasing inspection of trucks and containers, information gathering etc. These inspection measures add to the delay in moving containers from origin to destination and increase cost.

The purpose of this paper is to present three models to analyse the effect of inspection of trucks on performance and cost to the terminal. The microscopic urban traffic simulation model simulates the flow of traffic on the road network adjacent to the twin ports. The macroscopic terminal simulation model simulates the flows of containers in each terminal. The cost model takes inputs from the terminal model to generate the cost of moving containers through the terminal. The paper is organized as follows: In section 2 we present the microscopic urban traffic simulation model, and the macroscopic terminal simulation model. The terminal cost model is presented in section 3. Section 4 describes the economic effects of the terrorist attack scenario at one
specific container terminal in the twin ports. The paper is concluded in section 5.

2. SIMULATION MODEL FRAMEWORK

2-1 Urban Traffic Simulation Model

Various urban traffic simulation models have been developed to simulate and analyze traffic flow on highways and surface streets. These simulation models are developed using software tools such as Corsim, Paramics, VISSIM and others. Various studies present comparisons of different software packages for microscopic traffic simulation (Bloomberg and Dale, 2000, Tian et al., 2002, Panawi and Dia, 2002). In this paper, we use VISSIM to simulate the traffic flow of the road network adjacent to the twin ports shown in Figure 1 and integrate it with the terminal simulation model. VISSIM is a commercial software package that allows the development of microscopic traffic flow simulation models of selected roadway networks. Microscopic traffic simulation models allow the evaluation of different road configurations, traffic flow control techniques, vehicle and infrastructure technologies etc without having to build them and/or perform actual experiments which are costly and may significantly disrupt traffic in an adverse way.

In this paper we developed a microscopic traffic simulation model of a road network that includes three interstate highways and two state highways namely I-710, I-405, I-110, CA-47 S, and CA-103 S. Which are part of the road network adjacent to the twin ports. The layout of our constructed model is presented in Figure 1. We implement some Data Collection Stations (DCS) in the constructed model to collect simulation data. The level of traffic flow rates used as inputs to the network are calculated using real traffic data from the Performance Measurement System (PeMS). The Vehicle Detector Stations (VDS) measure traffic flow and other transportation parameters used for network evaluation. The VDS of the PeMS are indicated with white arrows in Figure 1.

2.2. Terminal Simulation 1.1 Model

The Terminal Simulator 1.1 is an object-oriented simulation system developed using C# programming language and can be executed on a Microsoft .NET platform. It is a macroscopic model and focuses on the flows of containers in and out of terminals rather than individual pieces of equipment. The Terminal Simulator 1.1 is used to simulate all the 14 container terminals of Los Angeles and Long Beach port simultaneously. The simulator takes inputs from the roadway network as well as trains, ships and generates output flows to the road network, ships, and trains.

The simulation executive is comprised of container terminal object and three other objects used to generate trucks, ships and trains. Other major components such as import and export yards, train and ship cranes, and inbound and outbound gates are contained within the terminal object.
The Terminal Simulator model emulates the actual operation of shipping terminal. The exact processes in container terminal are controlled by parameters set by the user.

The Macroscopic Terminal Simulator Model could be modified to create a new Terminal Simulator package which would be able to track individual trucks and containers as they enter the inbound gate and follow them through the yard. This process enables the user to record wait and cycle times at different junctions in the terminal, obtain useful statistics, and create more sophisticated and complex scenarios. Figure 2 presents the inter-component connections of a container terminal in Terminal Simulation Model.

![Figure 2. Seaport container terminal](image)

This simulation does not track individual trucks or containers as they are processed by the terminal but instead the flow of containers or trucks. For example, to track individual trucks or containers, the object is instantiated, assigned a unique ID and placed in a queue or buffer as the situation demands. If there are 30 trucks in queue at the entrance gate, then there are 30 unique objects in memory. In the “flow” paradigm, it is only necessary to determine how many trucks or containers are in a queue or a buffer.

In a flow based implementation it is not possible to determine how long a particular truck or container has been within the terminal (or a particular station within the terminal). However, benefits include a simplified design that is easier and faster to implement and a final product that executes more quickly and utilizes less memory. In fact, in order to study the cause and effect of congestion within the terminal, the latter design choice is sufficient since data regarding queue length and container inventory is readily available.

Shipping containers are transported to and from the terminal by truck, train and ship. Trucks and trains bring containers for export and take away imported containers. Conversely, a ship brings containers for import and carries away containers for export. Several structures that exist in the physical terminal are also represented in the “virtual” terminal, including an inbound and outbound gate for processing trucks, an import and export yard for storing containers, a pier for loading and unloading ships, and a station for loading and unloading trains.

2.3. Integration of Microscopic and Macroscopic Models

The VISSIM based microscopic traffic simulation model of the adjacent to the twin ports road network has to be integrated with the macroscopic terminal model in order to generate the volumes of trucks entering and leaving the twin ports. COM interface allows VISSIM to work as an automation server to import and export data. COM interface collects data from traffic simulation model and generates input for the terminal simulation model. On the other hand, it provides input for the traffic simulation model from the output of the terminal simulation model. COM interface generates inputs for both terminal and urban traffic simulation model in each clock event.

3. Terminal Cost Model

One useful measure often used for economic evaluation of container terminal operations is the Average Cost per Container (ACC). ACC is the average cost to move a container through a terminal. It is calculated as the ratio of the total yearly cost of a terminal by the number of containers processed in a year. The terminal cost model used to calculate the ACC calculates the following elements which contribute to the total cost.

- Cost of activities
- Cost of land
- Cost of equipment
- Cost of labours

3.1. Cost of activities

Gates, berths, storage yard, maintenance area, and central controller are locations considered as activities in seaport terminals. Cost of activities is included variable cost and fixed cost. Consumption cost of electricity is considered as variable cost of activities and fixed cost of activities calculated as the following formula.

\[
\text{Location Fixed Cost} = \frac{\text{investment}}{\text{accounting life}} + \left( \text{\textquoteleft repair\textquoteright} + \text{\textquoteleft insurance\textquoteright} + \text{\textquoteleft interest\textquoteright} \right)
\]

Hence, the total cost of activities is calculated by adding up all variable costs and fixed costs for all locations.
3.2. Cost of land

The cost of land is calculated by considering all locations of container terminal that include storage yard, berth, gate area, train. It is calculated by multiplying the area of the land (in acre) by land cost per acre. Annual cost of land is calculated as follows (Park and Park, 1997):

\[ A = P \times R \times \left( \frac{(1 + R)^n}{(1 + R)^n - 1} \right) \]

Where \( A \) is the annual land cost, \( R \) is the inflation rate, \( P \) is the initial land investment, and \( n \) is the accounting life. Annual cost of land is calculated as follows:

\[ \text{Total annual land cost} = P \times IR + A \]

Where \( IR \) represents lost investment opportunity which is the average (over 25 years) annual interest rate.

3.3 Cost of equipment

The number of vehicles, quay cranes, yard cranes, management infrastructure and other equipment of the container terminal are used to calculate the cost of equipment. Energy consumption is considered as variable cost in equipment cost and is calculated as follows:

\[ \text{Equipment Variable Cost} = \text{working hours} \times \text{price of energy per hour} \times \text{number of equipment} \times \text{utilization factor} \]

The equipment fixed cost is calculated the same way as activities fixed cost i.e.

\[ \text{Equipment Fixed Cost} = \text{`investment'} / (\text{`accounting life'}) + \text{`investment'} \times \text{(`repair'+`insurance'+`interest')} \]

The total cost of equipment is calculated by adding up the variable costs and fixed costs for all locations.

3.4. Cost of labours

Overtime working hours are calculated as the total scheduled working hours subtracted from the number of shifts multiplied by regular working hours.

\[ \text{Overtime working hours} = \text{`scheduled working hours'} - \text{`Regular working hours'} \times \text{(number of shifts)} \]

The total labour cost is calculated as the sum of all the salaries of the people operating the container terminal.

3.5. Average cost per container (ACC)

The average cost per container is calculated by dividing the total annual cost for the yard by the total annual container volume. The total annual cost for the yard can be obtained by adding up total cost of land, activities, labour and equipment.

4. Terrorist Attack Scenario

As mentioned earlier most terminals operate under tight constraints due to pressures for performance due to rising demand, pressure for lower cost in order to meet competition. Any event that disturbs the normal operations of the terminals could lead to high cost and disruption of the transportation chain that can be felt all over the world. In this section we demonstrate how to use the models we described in previous sections to evaluate the effects on the operation of a particular terminal due to certain security measures taken, in response to a terrorist attack scenario. The terrorist attack scenario is provided by CREATE-LAB at the University of Southern California, Los Angeles (USC) and assumes a commando attack at the Cruise terminal in the Los Angeles port. We are considering the economic impact of the terrorist attack scenario on the Pier 400 container terminal in the Los Angeles port. Since the terrorist attack happened at the cruise port, there is no direct economic loss to the Pier 400 container terminal. Previous terrorist attacks such as the 9/11 give more information how the United States responded to such threats. Based on this information it is natural to expect that an intense inspection of containers entering the port complex will be carried out immediately after an attack. We assume four inspection cases including different inspection technologies for all containers. We place three check points on the bridges at the Terminal Island in the port complex as presented with the white crosses in the Figure 1. Each case generates delay to the steady flow of containers into and out of the Terminal Island. The traffic and terminal simulator models are used to evaluate the traffic flow characteristics of the adjacent road network to the Pier 400 container terminal. Economic consequences on the Pier 400 container terminal due to inspection delays are calculated using the terminal cost model. In the following, we present four cases using different inspection technologies and the economic consequences on the Pier 400 container terminal.

4.1. Case 1: Inspecting all containers: 10 seconds per container

In this case we assume the use of a scanning technology that takes 10 seconds to inspect a container. The base line Pier 400 container terminal throughput is 144 containers per hour and Average Cost per Container is $171.34. A 10 second delay per container due to inspection will have an economic impact on the terminal. The traffic simulation model was modifying to include inspection points and delays. The container volumes entering the terminal are of course affected due to the delays which in turn affect the productivity of the terminal. The traffic simulator generates 138 containers per hour at the inbound gate of Pier 400 container terminal which is an input to the terminal simulator. We assume that the terminal 400 operates 260 days in a year 16 hours per day. The terminal simulator shows that an additional 45 minutes per day are needed in order to serve all
containers in one operational day and accommodate the inspection delay. The simulation parameters for export yard, import yard, truck arrivals, ships arrivals and train arrivals inside pier 400 container terminal were taken into consideration. Out of the 32 parameters for the Terminal-Port simulation, the parameters considered for this scenario were outflow and inflow rates of traffic for export yard and import yard, truck arrival rate at inbound gate of the terminal, ship arrivals at the terminal and the train arrivals. The results generated indicate that the effect of the 10 second inspection delay per container forces the terminal to operate an additional 195 hours per year in order to accommodate the inspection delays. The economic impact data in form of Average Cost per Container is calculated to be $171.40 using the cost model and the output obtained from the terminal simulator.

4.2. Case II: Inspecting all containers: 30 seconds per container

In the second case, we assume a scanning technology that takes an average of 30 seconds per container for all arriving trucks at the Terminal Island in the port complex. Implementing 30 seconds delay in the traffic simulator generates 96 containers per hour for the Pier 400 container terminal throughput. Based on previous assumption of Pier 400 operational hours, the terminal simulator shows that an additional 1430 hours of operation are needed in order to accommodate the inspection delay. This leads to an ACC calculated by the terminal cost model of $180.43.

4.3. Case III: Inspecting all containers: 60 seconds per container

In the third case, we assume a more thorough inspection that takes 60 seconds per container. The integrated traffic and terminal simulator model generates a volume of 74 trucks per hour at the inbound gate of Pier 400 container terminal. This reduced volume leads to additional 2080 hours of terminal operation annually in order to accommodate the delay. This in turn leads to an ACC of $185.18 generated by the cost model.

4.4. Case IV: Using different inspection technologies

We consider the effect of different inspection technologies. We assume that during the first month after a terrorist attack, improved inspection technologies together with physical inspection will be used to ensure a secure containerized freight system. It is assumed that this thorough inspection will take 60 seconds average per container. Then after five months the inspection time will be reduced to 30 seconds due to improved inspection technology or relaxed measures for about a month and then reduced further to 10 seconds inspection delay for the following six months. The traffic and terminal simulators showed that an additional 862.5 hours of operation in one year are required in order to accommodate the inspection delay. This leads to an ACC of $177.34 generated by the cost model.

The ACC value for all four cases is summarized in Table 1.

<table>
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<tr>
<th>Cases</th>
<th>ACC</th>
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<td>Base Line</td>
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<tr>
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<td>$185.18</td>
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<td>4</td>
<td>$177.34</td>
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</table>

Table 1: Economic Impact of Terrorist Attack Scenario on Pier 400

5. Conclusion

In this paper, we presented three simulation models which include a microscopic traffic simulator, a terminal simulator and a terminal cost model and demonstrated how they can be used to evaluate the impact of container inspection on the roadside on a particular terminal. For different cases of inspection delays are assumed. For each case the integrated traffic and terminal simulators generate the number of additional hours the terminal has to operate annually in order to accommodate the inspection delays whereas the cost model is used to calculate the corresponding average cost per container (ACC) value for comparison purposes. The terminal Pier 400 is used to demonstrate the results.

ACKNOWLEDGMENT

This research was supported by the United States Department of Homeland Security through the National Center for Risk and Economic Analysis of Terrorism Events (CREATE) under grant number 2007-ST-061-000001. However, any opinions, findings, and conclusions or recommendations in this document are those of the authors and do not necessarily reflect views of the United States Department of Homeland Security.

We would like to thank Dr. Isaac Maya, Dr. Michael Orosz, Dr. Onur Bakir, Dr. Anthony Barrett, Carl Southwell and Jennifer Chen for their constant support and inputs.


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