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16. Abstract

One of the prominent issues container terminal operators in the US are seeking to address is how to effectively reduce truck turn time. Historically, truck turn time has received very little attention from terminal operators because port congestion has never been a barrier to their operations. However, with the recent explosive growth in containerized trade, terminals are straining to accommodate the truck traffic that moves through them. The heavy intermodal truck traffic is not only causing problems for terminal operators but for the public as well. The emissions from idling trucks are a hazard to people working and living in and around the terminals. With containerized trade volume expected to double in the next ten years, the problems associated with port congestion could get worse if measures are not taken to address the source of the problems.

Terminals in some areas of the US are now required by state law to expedite the flow of trucks through their terminals. In California, any truck that idles for more than thirty minutes will result in a $250 fine to the terminal operator. This law has prompted terminal operators to look for ways to move trucks through their terminals faster, not just to avoid paying the fine, but also to lower the inland transportation cost of shipping a container via their terminals to remain competitive.

This research investigates the two measures terminal operators are taking to reduce their terminals' truck turn time. The first measure is investing in additional yard cranes to facilitate the handling of containers. To this end, this research seeks to assist terminal operators in deciding whether or not to make the investment. Statistical and simulation methodologies are developed to better understand the availability of yard cranes versus truck turn time. The second measure is implementing a truck appointment system to regulate the number of trucks into the terminal. To this end, this research seeks to assist terminal operators in evaluating the consequences of limiting truck arrivals into the terminals. Furthermore, this research develops a methodology to assist terminal operators in implementing the truck appointment system, should they decided to have one.

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METHODOLOGIES FOR REDUCING TRUCK TURN TIME AT MARINE CONTAINER TERMINALS

by

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Research Report SWUTC/05/167830-1

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ABSTRACT

One of the prominent issues container terminal operators in the US are seeking to address is how to effectively reduce truck turn time. Historically, truck turn time has received very little attention from terminal operators because port congestion has never been a barrier to their operations. However, with the recent explosive growth in containerized trade, terminals are straining to accommodate the truck traffic that moves through them. The heavy intermodal truck traffic is not only causing problems for terminal operators but for the public as well. The emissions from idling trucks are a hazard to people working and living in and around the terminals. With containerized trade volume expected to double in the next ten years, the problems associated with port congestion could get worse if measures are not taken to address the source of the problems.

Terminals in some areas of the US are now required by state law to expedite the flow of trucks through their terminals. In California, any truck that idles for more than thirty minutes will result in a $250 fine to the terminal operator. This law has prompted terminal operators to look for ways to move trucks through their terminals faster, not just to avoid paying the fine, but also to lower the inland transportation cost of shipping a container via their terminals to remain competitive.

This research investigates the two measures terminal operators are taking to reduce their terminals' truck turn time. The first measure is investing in additional yard cranes to facilitate the handling of containers. To this end, this research seeks to assist terminal operators in deciding whether or not to make the investment. Statistical and simulation methodologies are developed to better understand the availability of yard cranes versus truck turn time. The second measure is implementing a truck appointment system to regulate the number of trucks into the terminal. To this end, this research seeks to assist terminal operators in evaluating the consequences of limiting truck arrivals into the terminals. Furthermore, this research develops a methodology to assist terminal operators in implementing the truck appointment system, should they decided to have one.

EXECUTIVE SUMMARY

Economic projections on containerized trade were based on models of the past that did not include countries like China and India. As a result, trade forecasts were way below the actual figures, which failed to give ports adequate warning. Even when the forecasts became a reality, ports were slow to react, creating what is now known as port congestion which negatively affected many in the intermodal chain. Most terminals are now taking measures to increase their throughput and capacity by (1) introduce existing and new technology, (2) reduce equipment dwell times (by increasing demurrage fees and/or limiting the advance delivery of export cargo), (3) move empties and chassis to off-dock sites, (4) increase storage density (by stacking containers four or five high), and (5) reduce truck turn time. This study is focused on item five - reducing truck turn time at marine container terminals. Truck turn time is the time it takes a truck to complete a transaction such as picking up an import container.

There are two common measures terminal operators are looking at to reduce the truck turn time at their terminals. One is adding yard cranes and the other is employing a truck appointment system. The issue surrounding measure number one (adding yard cranes) is whether or not to invest. In particular, terminal operators want to know if there is any benefit to adding cranes, and if there is benefit, how many cranes are needed to achieve their objectives. The issues surrounding measure number two (employing a truck appointment system) are should it be used, what impact will it have, and how to properly use it.

This study developed methodologies to assist terminal operators evaluate and apply the two aforementioned truck-turn-time reducing measures. To assist terminal operators in deciding whether or not to purchase additional cranes and how many, this study developed two different methodologies to study the availability of cranes versus truck turn time. The first methodology employed statistical modeling, in particular, regression models, and the second methodology employed simulation. To assist terminal operators understand the benefits or consequences of the truck appointment system, this study developed a simulation model to help evaluate its impact on factors such as truck turn time and utilization of cranes. In addition, this study developed a framework which terminal operators could use to run the truck appointment system optimally. The methodology is a combination of mathematical formulation and simulation. It

seeks a solution that is beneficial for both the terminal operator and truckers. Moreover, it is formulated to yield robust solution to account for truckers with appointments showing up late or not show up at all.

To study the availability of cranes versus truck turn time, the first approach was to employ statistical models. They include multiple regression models, polynomial regression models, and non-linear in parameter regression models. The non-linear in parameter model yield the best fit (i.e. highest R-squared). Through the estimating procedure, it was identified that truck turn time is primarily affected by the ratio of road moves to be performed and the number of road cranes available.

The second approach to analyzing the availability of cranes versus truck turn time was to use a simulation model. This study developed a simulation model that aimed to model the precise movements of trucks and yard cranes. Truck movements are modeled by identifying the processes each truck must follow for a particular transaction type and moving the truck through the process via a road network. Transaction types include trucks picking up import containers and/or chassis and trucks dropping off export containers and/or chassis. Trouble transactions are accounted for in the model; a trouble transaction refers to the situation where the trucker's paper work is invalid. Trucks are modeled to use the shortest paths to their destinations and are modeled to move at different speeds based on a specified distribution. Yard cranes are modeled by identifying the procedure in which they go about the yard providing service to the trucks and moving them accordingly on a crane network. Cranes are also modeled to use the shortest paths to get to their destinations, moving at a specified velocity, turning velocity and acceleration.

The developed simulation model provided more insight about the relationship between the number of road cranes and truck turn time. It indicated that adding an additional road crane does not necessarily lower truck turn time. The reason for this is because of the randomness in various processes. For example, it could be that ship cranes consistently serve fewer road trucks. So, even with an additional road crane, it is conceivable that the overall average truck turn time could be higher. Another reason why adding another road crane does not necessarily lower truck turn time is because of where the crane is placed in the yard. That is, it could be placed where it does not have the opportunity to perform more moves because work is closer to other cranes.

This study examined two issues related to the use of a truck appointment system at marine container terminals to smooth out demand. The first is the effect of limiting truck arrivals into the container yard on truck turn time and crane utilization. Experiments carried out using the developed simulation model and data from the Port of Houston Barbours Cut Terminal indicate that some smoothing of the truck arrivals to the terminal can be beneficial. Beyond a certain level, in particular, setting the caps too low can be counter productive to both the terminal (lower crane utilization) and truckers (higher turn time). The second issue this study addressed is finding the maximum number of trucks a terminal could allow into a specific area of the yard per time window without violating resource constraints and meeting the specified desired average truck turn time. To achieve this, this study developed a methodology that is based on robust optimization and simulation. The robust formulation was employed to account for truckers with appointments showing up late or not show up at all. An ad-hoc search heuristic was used in this study to solve the developed formulation. Results from the experiments corroborate intuition that some slack can be built into the solution for the scenario that a great majority of truckers with appointments will not show up.

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CHAPTER 1. INTRODUCTION

1.1 MOTIVATION

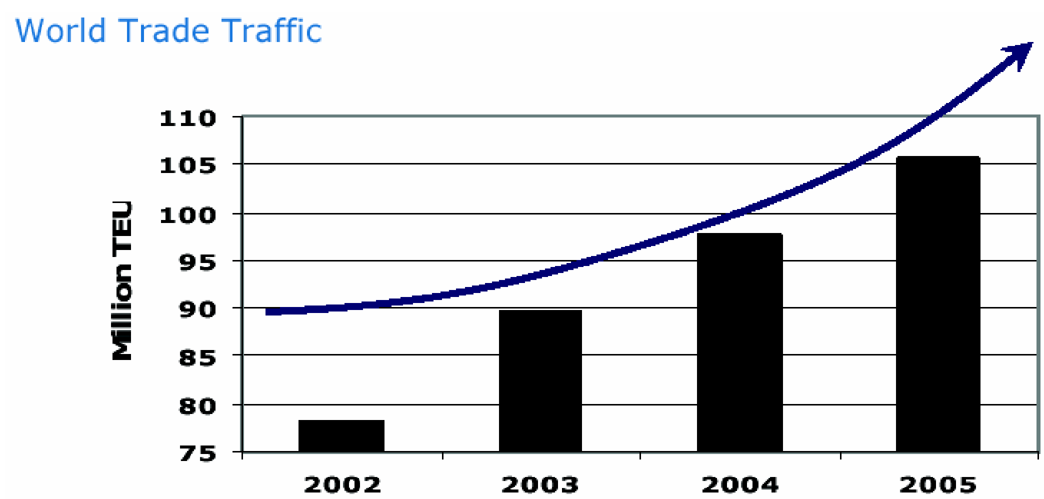
World trade traffic has steadily risen over the past few years and is forecasted to double in 2010. Figure 1.1 shows such forecast measured in terms of containers handled. The impact of this growth is already affecting US marine container terminals and there is a growing concern about the ability of US marine terminals to keep supply chains moving during the next several years (Mongelluzzo, 2005). Most terminals are now taking measures to increase their throughput and capacity: (1) introduce existing and new technology, (2) reduce equipment dwell times (by increasing demurrage fees and/or limiting the advance delivery of export cargo), (3) move empties and chassis to off-dock sites, (4) increase storage density (by stacking containers four or five high), (5) reduce truck turn time.

This research is focused on item five in the above list – reducing truck turn time at marine container terminals. Truck turn time is the time it takes a truck to complete a transaction such as picking up an import container. There are a few factors that are driving terminal operators to reduce the truck turn time at their terminals: (1) reduce environmental impacts, (2) reduce landside shipping cost, (3) improve national economy. The driving factors are discussed in the following.

Trucks are spending more and more time idling at ports because of congestion (Figure 1.2). A concern with trucks idling for an extended period of time (especially older trucks) is the emissions they are generating – an exhaust that is responsible for causing cancer, triggering asthma, and accelerating heart disease. At risk are the truck drivers, terminal workers, and local communities who breathe the polluted air. Moreover, idling trucks contribute to global warming and deplete our oil supply.

A consequence of trucks delayed at terminals is the additional cost of goods to consumers. When trucks are held up at ports, the drivers lose money and in turn the trucking companies. As a result, trucking companies charge their customers (e.g. Wal-Mart, Home Depot) a higher rate for shipping. The increased costs in shipping are then transferred to consumers. By reducing the truck turn time and thereby the landside shipping cost, terminals gain a competitive advantage.

Trucks delayed at terminals could affect the nation's economy as a whole. With the volume of U.S. trade with Asia expected to double in 2010, U.S. exporters and importers could face more delays, higher costs, and poorer service unless American ports can improve their productivity (Machalaba, 2001). If the costs of shipping through U.S. ports continue to rise, customers may eventually find it more cost effective to shift U.S.-bound cargo to ports in Mexico, Canada, or the Caribbean and transport it the rest of the way by trucks, rails, feeder ships, or barges. According to 21st Century Transportation (Transporte Siglo XXI), a Mexican logistics publication, Toyota is thinking of abandoning the Port of Long Beach in favor of Manzanillo due to Long Beach's congestion problems and lack of expansion space (Mireles, 2005). In that scenario, thousands of jobs and millions of dollars could be lost. The Port of Houston Authority alone in 2000 generated 287,454 jobs, $7,212,920 in personal income, $10,865,133 in business revenue, and $649,163 in state/local taxes (Martin Associates, 1999).



	TEU Millions	Demand Growth
2003	90.8	--
2004	102.4	12.8%
2005	111.8	9.2%

Source : Drewry Shipping Consultants, Container Market Quarterly June 2004

Figure 1.1: Growth of Worldwide Trade in Terms of Containers

Figure 1.2: Trucks Dominate 710 Freeway on a Morning Commute

1.2 PROBLEM STATEMENT

There are two common measures terminal operators are looking at to reduce the truck turn time at their terminals. One is adding yard cranes and the other is employing a truck appointment system. The issue surrounding measure number one (adding yard cranes) is whether or not to invest, after all each yard crane cost approximately 1.5 million US dollars. In particular, terminal operators want to know if there is any benefit to adding cranes because there is no clear understanding of how yard cranes affect truck turn time, and if there is benefit, how many cranes are needed to achieve their objectives.

The idea of a truck appointment system is to "flatten" the gate activity to an efficient and proportionate level to reduce the trucks' queuing time. It is a concept that is beginning to gain momentum in practice with terminal operators and the trucking community. Several terminals are currently employing the appointment systems (e.g. Yusen Terminals, Evergreen L.A. Terminal, Total Terminals International’s Pier T at Long Beach, West Basin Container Terminal at L.A., and Port of Miami). The issues surrounding measure number two (employing a truck appointment system) are should it be used, what impact will it have, and how to properly use it.

This research seeks to develop methodologies to assist terminal operators evaluate and apply the two aforementioned truck-turn-time reducing measures. To assist terminal operators in deciding whether or not additional cranes are needed and how many if needed, this research proposes to develop statistical models and simulation models to help explain the relationship between the availability of cranes and truck turn time. To assist terminal operators understand the benefits or consequences of the truck appointment system, this research proposes to develop simulation models to help evaluate its impact on factors such as truck turn time and utilization of cranes. In addition, this research proposes to develop a framework which terminal operators could use to run the truck appointment system optimally.

1.3 RESEARCH OBJECTIVES AND RESEARCH TASKS

As discussed, the goal of this research is to assist terminal operators evaluate and apply the two prevailing measures to reduce truck turn time at marine container terminals. Corresponding to these two measures are two research objectives. The steps associated with these two research objectives and how they will be carried out are outlined below.

1.3.1 Research Objective #1: Cranes Availability vs. Terminal Efficiency

1. Select a terminal as a case study and document that terminal's operations.
2. Collect data for analysis. This step involves identifying the relevant attributes for the study and obtaining actual data for those attributes.
3. Develop models (statistical and simulation) that would capture the relationship between the number of cranes and terminal efficiency.
4. Use the developed model to determine the number of yard cranes needed by a terminal to achieve the desired (or required) level of service.

1.3.2 Research Objective #2: Effect of Truck Appointment System

Part 1 (Evaluation)

1. Build a simulation model of selected terminal (from research objective #1).
2. Verify and validate simulation model.
3. Use the developed simulation model to evaluate the effectiveness of an appointment system.

Part 2 (Optimization)

4. Develop a methodology to calculate the number of trucks a terminal would allow into a specific area of the yard per time window. The methodology would seek a solution that is beneficial for both the terminal and truckers. Furthermore, the methodology would seek a robust solution to account for truckers with appointments showing up late or not show up at all
5. Devise optimization-simulation scheme.
6. Implement optimization scheme.
7. Use the developed optimization-simulation methodology to determine the optimal appointment system.

1.4 ORGANIZATION

The remainder of this report is organized as follows. Chapter two presents the literature review of studies related to this research and a basic introduction to container terminal operations. The review is divided into three parts. The first part summarizes the research performed on container terminal operations and logistics. The purpose of this part is to show the vast body of work that has been conducted and to show where this research fits in the area of container terminal modeling. The second part of the review presents studies closely related to this research. Lastly, the third part of the review presents simulation models developed to study container terminal operations. Chapter three begins with some background information on the Port of Houston's Barbours Cut Container Terminal, which is the terminal selected as a case study for this research. It then discusses the methodology performed and results obtained for research objective one. Chapter four discusses the development of the simulation model to address the two parts of research objective two. It also discusses results obtained from the simulation model on the availability of yard cranes versus truck turn time. Chapter five presents the simulation-optimization framework developed to determine the optimal scheduling of trucks for the appointment system. Simulation results obtained from the developed methodology are also presented. Lastly, chapter six summarizes key findings from this research, highlights its contribution, and discusses potential areas for future research.

CHAPTER 2. BACKGROUND AND LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the literature review and provides some background information on marine container terminals. The literature review section covers the research that has been done in the area of port operations and logistics. It also discusses topics closely related to this research. The goal of the review is two-fold. The first is to share the current body of literature on container terminal modeling, and the second is to show through the comprehensive review that few studies have examined the issues that are to be addressed in this research. The background section provides a basic introduction to marine container terminal operations. A good understanding of the operation of a container terminal is necessary to appreciate the intricacies of the work described in subsequent chapters.

2.2 LITERATURE REVIEW

In the following, an extensive list of studies related to port operations and logistics is presented; it builds on the list provided by Vis and De Koster (2003). The list is provided to show what has been done and to show that there is little if any documented research that examines the issues addressed in this report. However, there are a few related studies which are presented in the section titled "Review of Relevant Studies." In addition, there are some related topics and they will be discussed in the section titled "Review of Relevant Topics." Note that the focus of this review is on port operations and logistics, not port economics, port pricing, port competition, etc. There is a huge body of literature on maritime policy and management that addresses these very issues.

The various decision problems that arise at marine container terminals can be categorized into one of three planning and control levels 1) strategic, 2) tactical, and 3) operational. Strategic decisions are long-term decisions that involve terminal layout, handling equipment, and procedures. Tactical decisions are medium-term decisions that involve the number of wharf cranes, yard cranes, vessel trucks, etc. Lastly, operational decisions are short-term decisions that involve the process in which wharf cranes, yard cranes, vessel trucks, etc. follow. The following provides a summary by general classification of the various decision problems addressed for container terminals. Only the names, year, and title of the paper are given here, the complete reference can be found in the reference section.

2.2.1 Arrival of Ship

2.2.1.1 Strategic Level. When a ship arrives at the port, it has to moor in one of the available berths. The number of berths that should be available is one of the decisions that has to be made at the strategic level.

Edmond, E.D., Maggs, R.P. (1978). How useful are queue models in port investment decisions for container berths?

Nicolau, S. N. Berth Planning by Evaluation of Congestion and Cost (1969). ASCE Journal of the Waterways and Harbors Division.

2.2.1.2 Operational Level. Berth allocation can be done with the objective of maximizing the berth utilization. On the other hand, berth allocation can be obtained by seeking to minimize the sum of ship turn time. This problem is equivalent to a machine scheduling problem.

Imai, A., Nagaiwa, K., Tat, C.W. (1997). Efficient planning of berth allocation for container terminals in Asia.

Imai, A., Nishimura, E., Papadimitriou, S. (2001). The dynamic berth allocation problem for a container port.

Nishimura, E., Imai, A., Papadimitriou, S. (2001). Berth allocation planning in the public berth system by genetic algorithms.

2.2.2 Unloading and Loading of Ship

2.2.2.1 Strategic Level. To load and unload a ship, wharf cranes are often used. Thus, the decision at this level involves the determination of the type of wharf crane to use. No prior research or publications were found on this topic.

2.2.2.2 Tactical Level. The tactical decision involves deciding the number of wharf cranes to have on a ship and how the cranes should work the ship. This problem is known as the crane scheduling problem. The objective is to minimize the total delay of the ships.

Daganzo, C.F. (1989a). The crane scheduling problem.

Daganzo, C.F. (1989b). Crane Productivity and Ship Delay in Ports.

Peterkofsky, R.I., Daganzo, C.F. (1990). A branch and bound solution method for the crane scheduling problem.

2.2.2.3 Operational Level. The operational decision involves preparing the unloading and stowing of containers. The unloading plan indicates which containers are to be unloaded and where they are on the ship. Conversely, a stowage plan indicates for each container where it is to be placed on the ship. In general, the unloading and stowage plans seek to minimize the number of necessary moves to be performed on the ship at the current terminal as well as subsequent terminals.

Shields, J.J. (1984). Container stowage: a computer-aided preplanning system.

Wilson, I.D., Roach, P.A. (2000). Container stowage planning: a methodology for generating computerised solutions.

Avriel, M., Penn, M., Shpirer, N., Witteboon, S. (1998). Stowage planning for container ships to reduce the number of shifts.

Avriel, M., Penn, M., Shpirer, N. (2000). Container ship stowage problem: complexity and connection to the coloring of circle graphs.

2.2.3 Transport of Containers from Ship to Stack and Vice Versa

2.2.3.1 Strategic Level. To transport containers from ship to stack and vice versa, several types of equipment could be used (e.g. truck, straddle carrier). Thus, the decision at this level is concerned with the type of equipment best suited for that terminal. No prior research or publications were found on this topic.

2.2.3.2 Tactical Level. Given a particular type or types of transport vehicles, the tactical decision entails determining the necessary number of vehicles needed to carry out day-to-day operations.

Vis, I.F.A., De Koster, R., Roodbergen, K.J., Peeters, L.W.P. (2001). Determination of the number of automated guided vehicles required at a semi-automated container terminal.

Vis, I.F.A., De Koster, R., Savelsbergh, M.W.P. (2000). Estimation of the number of transport vehicles at a container terminal.

2.2.3.3 Operational Level. Given a certain number and type(s) of vehicles, the operational decision involves deciding the route these vehicles should take and how each vehicle should be used to transport containers. The objectives are to minimize empty-travel distances, delay of ships, or total travel time of the vehicles.

Bish, E.K., Leong, T.Y., Li, C.L., Ng, J.W.C., Simchi-Levi, D. (2001). Analysis of a new vehicle scheduling and location problem.

Chen, Y., Leong, Y.T., Ng, J.W.C., Demir, E.K., Nelson, B.L., Simchi-Levi, D. (1998). Dispatching automated guided vehicles in a mega container terminal.

Evers, J.J.M., Koppers, S.A.J. (1996). Automated guided vehicle traffic control at a container terminal, Transportation Research A 30(1), 21-34.

Kim, K.H., Bae, J.W. (1999). A dispatching method for automated guided vehicles to minimize delays of containership operations.

2.2.4 Stacking of Containers

2.2.4.1 Strategic Level. To stack and retrieve containers, several types of equipment could be used (e.g. gantry yard cranes, straddle carrier, top loader). The strategic decision is concerned with choosing the type of equipment best suited for the stack layout. The stack layout itself is another strategic decision, which greatly affects the efficiency of stacking. Factors involved in determining the stack layout are the stack height and strategies for storage and retrieval of import and export containers.

Chen, T. (1999). Yard operations in the container terminal - a study in the 'unproductive moves'.

De Castilho, B., Daganzo, C.F. (1993). Handling strategies for import containers at marine terminals.

Holguin-Veras, J., Jara-Diaz, S. (1999). Optimal pricing for priority service and space allocation in container ports.

Kim, K.H., Kim, H.B. (1999). Segregating space allocation models for container inventories in port container terminals.

Taleb-Ibrahimi, M., De Castilho, B., Daganzo, C.F. (1993). Storage space vs handling work in container terminals.

2.2.4.2 Tactical Level. Given the stack layout and type of transfer cranes, the tactical decision is to determine the number of transfer cranes needed to ensure a satisfactory level of efficiency in storing and retrieving containers**.**

Kim, K.H., Kim, H.B. (1998). The optimal determination of the space requirement and the number of transfer cranes for import containers.

Kim, K.H. and Kim H.B. (2002). The optimal sizing of the storage space and handling facilities for import containers.

2.2.4.3 Operational Level. The operational decision involving transfer cranes to store and retrieve containers is the route that they should take. Depending of the type of transfer crane used (some can traverse the yard more easily than others) the optimal routing can be very different.

Kim, K.H., Kim, K.Y. (1999a). An optimal routing algorithm for a transfer crane in port container terminals.

Kim, K.H., Kim, K.Y. (1999b). Routing straddle carriers for the loading operation of containers using a beam search algorithm.

Kim, K.Y., Kim, K.H. (1997). A routing algorithm for a single transfer crane to load export containers onto a containership.

Kim, K.Y., Kim, K.H. (1999). A routing algorithm for a single straddle carrier to load export containers onto a containership.

Other operational decisions include 1) which crane(s) serve the vessel trucks (seaside) and which crane(s) serve the road trucks (landside), 2) where to store export containers, and 3) the order in which vessel and road trucks are served.

Kim, K.H. (1997). Evaluation of the number of rehandles in container yards.

Kim, K.H., Bae, J.W. (1998). Re-marshaling export containers in port container terminals.

Kozan, E., Preston, P. (1999). Genetic algorithms to schedule container transfers at multimodal terminals.

2.2.5 Complete Container Terminals

Unlike the studies listed above which deal with just one aspect of container terminal operations, the studies given below encompass a broader scope of work on container terminals.

Gambardella, L.M., Rizzoli, A.E., Zaffalon, M. (1998). Simulation and planning of an intermodal container terminal.

Jone, E. G. (1996). Managing Containers in Marine Terminals: An Application of Intelligent Transportation Systems Technology to Intermodal Freight Transportation.

Kozan, E. (1997). Comparison of analytical and simulation planning models of seaport container terminals.

Kozan, E. (2000). Optimising container transfers at multimodal terminals.

Merkuryev, Y., Tolujew, J., Blümer, E., Novitsky, L., Ginters, E., Vitorova, E., Merkuryeva, G., Pronins, J. (1998). A modelling and simulation methodology for managing the Riga Harbour container terminal.

Ramani, K.V. (1996). An interactive simulation model for the logistics planning of container operations in seaports.

Van Hee, K.M., Huitink, B., Leegwater, D.K. (1988). Portplan, decision support system for port terminals.

Van Hee, K.M., Wijbrands, R.J. (1988). Decision support system for container terminal planning.

Yun, W.Y., Choi, Y.S. (1999). A simulation model for container-terminal operation analysis using an object-oriented approach.

2.2.6 Landside Receiving System

The land-side receiving system, though an integral part of terminal operations, has received very little attention. This is partly because in the past truck traffic was not significant. This is no longer the case. A number of studies have dealt specifically with the landside receiving system. There are two areas that researchers have addressed: 1) impact of truck traffic on surrounding infrastructure, and 2) impact of truck traffic at the terminal gate.

Easley (1994). Gate operations at Barbours Cut container terminal: a case analysis.

Johansen, R. S. (1999). Gate solutions.

Klodzinski, J. and Al-Deek H. M. (2002). Using seaport freight data to distribute heavy truck trips on adjacent highways.

Palmer, J. G, McLeod, M., and Leue, M. C. (1996). Simulation modeling of traffic access for port planning.

Tathagata, G. and Walton, M. C. (1994). Traffic impact of container port operations in the southwest region: a case study.

2.2.7 Remaining Literature

The following lists other studies found in the area of port operations and logistics, but did not fall into any of the above classifications.

Bortfeldt, A., Gehring, H. (2001). A hybrid genetic algorithm for the container loading problem.

Chen, C.S., Lee, M.S., Shen, Q.S. (1995). An analytical model for the container loading problem.

Cheung, R.K., Chen, C.Y. (1998). A two-stage stochastic network model and solution methods for the dynamic empty container allocation problem.

Crainic, T.G., Gendreau, M., Dejax, P. (1993). Dynamic and stochastic models for the allocation of empty containers.

Davies, A.P., Bischoff, E.E. (1999). Weight distribution considerations in container loading.

Kiesling, M. K. (1991). Analysis of loading-unloading operations and vehicle queueing processes at container port wharf cranes.

Leeper, J.H. (1988). Integrated automated terminal operations.

Scheithauer, G. (1999). LP-based bounds for the container and multi-container loading problem.

Shen, W.S., Khoong, C.M. (1995). A DSS for empty container distribution planning.

Wan, T.B., Wah, E.L.C., Meng, L.C. (1992). The use of information technology by the port of Singapore authority.

2.2.8 Review of Relevant Studies

The idea of employing an appointment system at a marine container terminal is fairly new. Recall that the Lowenthal Bill has only been passed recently (Lowenthal, 2002). Because of this, little to no research is available on the appointment system. The lone study found is a demonstration conducted by Marine Terminals Corporation (Longbotham, 2004) to show that by using the appointment system to spread out the demand throughout the day, a significant number of truck-hours can be saved. The concept of an appointment system and how it is applied in a marine container terminal will be described in a later section.

The other area in which this report addresses, determining the number of yard cranes needed by a terminal to effectively serve the road trucks, is scarcely documented. Only two studies were found and they are summarized below. One reason why there are so few studies is because they may have been performed by private contractors and proprietary issues may have kept them from getting published. A second reason why such studies are rarely performed is because until recently trade volumes have not been large, so the impact of trucks on the road and environment has been minimal. Lastly, for the longest time, reducing ship turn time is the single most important criterion for a terminal.

In the study conducted by Regan and Golob (2000), a survey was performed of 1200 private and for-hire carriers operating in California to examine the efficiency of maritime intermodal transfer facilities in California, from the point of view of the trucking companies that use these facilities. Their study reported that over 75% of the respondents typically spent more than 60 minutes in a terminal. About 19% said that congestion or other problems at the ports impacted their operations always or very often, and an additional 25% said that congestion at the ports often impacted their operations. These findings highlight the significance of terminal inefficiencies. Their survey also asked respondents to react to twelve hypothetical congestion-relief solutions. It is reported that responses of operators serving ports were more positive than operators not serving ports in four areas (1) completing installation of electronic clearance stations, (2) having longer hours at ports and distribution centers, (3) having truck-only streets for access to ports, rail, terminals, and airports, and (4) installing electronic clearance stations at international border crossings. None of the solutions asked about adding more yard cranes or installing an appointment system.

The other study was done by Kim and Kim (1998, 2002), which addresses nearly the same problem as this research. In their study, they proposed a method to determine the optimal amount of storage space and the optimal number of yard cranes for handling import containers. They developed a cost model, consists of space cost, cranes cost, and operating costs of cranes and trucks. They sought solutions (i.e. storage space and number of cranes) for two cases 1) minimize terminal costs only, and 2) minimize both terminal costs and trucking costs. The solution procedures are illustrated using numerical examples. Their method of obtaining truck turn time entails estimating the time analytically for each portion of the trip and then summing them up. Lastly, in their paper, they discussed some of the over simplifying assumptions used. These assumptions are 1) the number of import containers handled in a terminal is fixed, 2) import containers would be picked up randomly, 3) traffic is uniformly distributed over the entire yard for import containers, and 4) containers unloaded from different vessels are not mixed with each other in the same bay. The authors acknowledged that actual operations can deviate from these assumptions.

2.2.9 Review of Relevant Topics

While there are only a few studies directly related to the topics of this research, there are several bodies of work that are intimately related to this research. The primary body of work is simulation. A detailed review of simulation studies on container terminals is presented below. The review also includes a brief overview of Arena, the simulation software employed in this research.

2.2.9.1 Simulation. Traditionally, the maritime sector has been a successful area for simulation, especially for training equipment and ship design support. Due to the costs and the complexity of both harbors and vessels, the use of simulation techniques has been justified in this area for many years (Bruzzone, 1998a). Also, as argued by Ramani (1996), analytical models, in particular queuing models, cannot be employed to analyze terminal operations in the estimation of port performance indicators because queuing models are valid only if the probability distribution of the arrival time of the ships and their service times belong to the Erlang family of distribution functions. It is noted here that while analytical models by themselves cannot be used exclusively to model terminal operations, they can be used to model certain aspects of terminal operations. In fact, a number of researchers have used analytical models effectively for their purposes. For example, Kim K. H. (1997) proposed a methodology to estimate the expected number of rehandles to pick up an arbitrary container and the total number of rehandles to pick up all the containers in a bay for a given stacking configuration. He and Kim K. Y. (1999a) also formulated a mixed integer program to minimize the total container handling time of a transfer crane. To a greater extent, Van Hee, K. M. (1988a, 1988b) developed a decision support system for terminals using analytical models such as queuing, Markov, and optimization. However, analytical models cannot capture minute details of terminal operations. A well-designed simulation tool on the other hand can capture a vast amount of details to meaningfully mirror the complexities of a real system. It can effectively incorporate qualitative variables such as human behavior in the model. Furthermore, simulation offers the ultimate flexibility in analyzing changes to the system as a result of some perturbation.

Today, simulation is prevalent because of growing interest in developing new support systems for the management and control of maritime transportation. Recent developments in hardware and software technologies have made it possible to use simulation as a viable decision support tool in this field. These advances, together with the improvements in graphical interfaces and software techniques, have made simulation an attractive tool. Indeed, there are a growing number of studies that use simulation as a means to accomplish their objectives. The following review summarizes the different problems tackled and simulation models developed by various researchers.

One of the most comprehensive simulation software, at the time, for analysis of port operations was developed by Hayuth et al. (1994). It dealt with coordination between terminals in more than one port. It was developed as a result of the Israel Ministry of Transportation wanting to know the timing and investments needed based on the costs incurred by idled ships waiting for port facilities. In their paper, a significant portion was devoted to explaining what choice of software and hardware would be best. For their purpose, the simulation model was written entirely in C, aided by an external simulation library. Their simulation model was event-driven, with the ship being the main entity. They implemented the model based on the following sets of events.

Event ARRIVAL:

Redirect this ship for a less busy port if necessary;
If a berth is available or this ship can preempt one then schedule START after towing;
Else this ship waits outside;

Event NEXT:

If a ship is waiting next to a berth and a suitable gang exists then schedule end after finishing this load;

Else if a ship is waiting outside port and a berth is available then schedule START after towing;

Event START:

If a gang is available then schedule END after finishing this load;

Else ship waits alongside berth;

Event END:

Free gangs;

If there is no more cargo then {free berth and ship, schedule NEXT immediately ;}

Else if this berth cannot deal with this cargo then {free berth; if a berth is available or this ship can preempt one then schedule START after towing; else this ship waits outside;}

Else if a gang is available then schedule END after finishing this load;

Else {waits next to berth; schedule NEXT immediately ;}

Event SHIFT:

Stop working on ships;

Update work force according to date and shift;

Allocate ordinary work force;

Allocate overtime workers;

Schedule SHIFT after this shift;

Event OVERTIME-END:

Ship waits alongside to berth;

Another comprehensive port simulation model is PORTSIM, developed by Nevins et al. (1998). It is a discrete-event, time-stepped simulation that facilitates the analysis of movements of military equipment through worldwide seaports and allows for detailed infrastructure analysis. It simulates in detail both the embarkation and debarkation processes of the following cargo types 1) vehicles, 2) containers, and 3) palletized cargo. It also simulates in detail ship operations including 1) docking at the berth, 2) calling forward appropriate cargo items, and 3) loading and unloading cargo items. PORTSIM was developed to assist planners in comparing and selecting ports and to help determine port throughput capability and utilization of critical resources. The developers' approach was to model all cargo items, ships, and port infrastructure resources as individual objects. They implemented the simulation model using object-oriented programming techniques, which allowed for data abstraction, data encapsulation, code reusability, and inheritance. The software they used to implement PORTSIM is MODSIM II. Since its initial development, PORTSIM has been extended to be a general-purpose port simulator. Also, the developers have added animation and visualization capabilities to the model (Nevins et al., 1998).

Merkuryeva et al. (2002) built a simulation model of the Baltic Container Terminal, within the Riga Commercial Port, to support these tasks 1) to regulate transportation routes within the terminal by segregating different traffic flows, 2) to improve layout utilization, and 3) to analyze the impact of weather conditions on terminal operations. They used Arena and SLX to build their model. Their methodology involved formalizing all logistical processes (e.g. arrival of ships, their discharging and loading processes) in the form of flow charts. The detailed flow charts were then directly translated into a computer simulation program within the Arena modeling environment using SIMAN language block-diagrams. In another study led by the same author, a simulation model was built for the Riga Harbor Container Terminal, also part of Riga Commercial Port (Merkuryeva et. al, 1998). The goal of that simulation study was to improve the logistical processes at the Riga Harbor Terminal, in particular, decreasing the amount of time trucks remained at the terminal, bring containers to the terminal, and/or taking them away. Simulation allowed them the possibility of evaluating the efficiency of different decisions regarding the use of the new data processing system and updated technological resources. They used GPSS/H and Proof Animation simulation and animation tools to build their model. The methodology they employed was a queuing network model that served as a basis for elaborating the container terminal processes. Within the model, they had two levels of details. Level 1 is a "micro" level, where separate technological operations are simulated in order to investigate their durations, and level 2 is a "macro" level, where results of micro-modeling are used within the overall model of the container terminal.

Bontempi et. al (1997) built a simulation model as part of a decision support system (DSS) they developed for La Spezia container terminal. Their DSS comprised a forecasting model, a planner, and a simulation module. The forecasting module was used to estimate container traffic. The planning module was used to generate efficient policies for storage, resource allocation, and scheduling. Lastly, the simulation module was used to assess the performance of management policies. The DSS was developed using genetic algorithms, tabu search, and dynamic programming techniques. In regard to the simulation module, they developed it based on object-oriented analysis and design techniques. The design has two hierarchies of classes: terminal components and management policies. Terminal components are objects such as transport vehicles, cranes, and yard areas. Management policies are classified into resource allocation, container storage in the yard, and ship loading/unloading scheduling. They implemented the simulation module using Modsim III, a discrete event simulation language which supports both process-oriented paradigm and object-oriented paradigm.

Similarly, Gambardella et al. (1998) developed a decision support system for the management of La Spezia container terminal. The problems they sought to address were spatial allocation of containers in the terminal yard, the allocation of resources, and the scheduling of operations to maximize a performance function based on economic indicators. They used techniques such as job-shop scheduling, genetic algorithms, and mixed-integer linear programming. Central to their optimization scheme is a simulation model of the terminal. The design of the simulation model was grounded in object-oriented analysis and design paradigm. They modeled simulation agents and components as objects which store and exchange information on terminal inputs, states, and outputs. These objects performed actions according to their local behaviors with no supervising agents. The simulation model in its entirety would replicate the terminal activities based on the principle that external events are acted upon by agents, which in turn operate on components. The responses of agents are determined according to the policies generated by the optimization modules. It was not stated in their paper which programming or simulation language was used to implement the simulation model.

Bruzzone and Signorile (1998) integrated simulation with genetic algorithms (GAs) to support terminal operators in making strategic decisions about resource allocation and terminal organization. They developed a simulation tool that uses two genetic algorithms, one for ship scheduling and one for creating clusters in the yard. The simulation model feeds results to the GAs, which in turn generates new input to the simulation. In their paper, a significant portion was devoted to explaining the genetic algorithms they employed. Very little information was conveyed about the simulation model, other than that they modeled small trucks that move the containers in the yard, the wharf cranes at the dock, and the movement of the containers. They also mentioned that they used a high-level approach for these resources. Their original model was developed in C, however, it was recently ported to Arena.

To address the problem of whether the existing container terminal in Pusan, Korea is efficient enough to handle a high number of container flow or whether the system is more effective by using transfer cranes and gantry cranes, Yun and Choi (1999) built a simulation model for the study. Their model considered three main subsystems: terminal gate, container yard, and berth. They develop the simulation model using an object-oriented approach. Thus, each component of equipment was created as an object (e.g. transporter object). To control the system, they created control methods. At each level, the control methods manage the interaction of objects and check the work situation. At the highest level, the control methods manage the container generation, system initialization, and system reset. Their simulation model was not actually applied to a full-size terminal (Pusan East container terminal), but rather a reduced one. The software they used is SIMPLE++.

Ramani (1996) took simulation of container terminal operations one step further. He developed an interactive simulation model for the logistics planning of Indian port. The model provided estimates on port performance indicators such as berth occupancy, ship output, and ship turn time for various operating strategies. The built-in menu consisted of 1) a data input menu, 2) a run simulation menu, 3) an output statistics menu, and 4) an exit menu. The logic of the model was based on the "next event scheduling approach." The sequence of events modeled is given below. It was not conveyed in the paper which programming or simulation language was used to implement the simulation model.

Ship arrival (in the harbor)

Ship berthing

Ship operations start:

Unloading operations:

Engage crane: quay crane ready to lift an import container from the ship's bay for unloading it onto a prime mover.

Arrival PM: empty prime mover (PM) arrives on the quay side

Engage PM: PM ready to receive the import container

Disengage crane: quay crane disengaged after it places import container on PM

Departure PM: PM departs with the import container

Loading operations:

Arrival PM: arrival of a PM to quay side with export container

Engage crane: quay crane ready to lift the export container from the PM for placing it in the ship's bay

Disengage PM: PM disengaged after the quay crane lifts the export container

Departure PM: PM departs empty to the storage yard

Disengage crane: quay crane disengaged after it places the export container on the ship's bay as per she stowage plan

Ship operations complete

Ship departure, berth release

Holguin-Veras (1996) for his dissertation developed a simulation model of a terminal to analyze the performance of different priority systems. His simulation system, which he named PRIOR, simulated terminal operations at a microscopic level. That is, it estimated the service time of different service processes as a function of corresponding equipment micro-movements, in particular, tasks' attributes such as distance traveled by the yard crane. His general approach was to model the terminal using arrays to represent the storage location on ship and in the yard and the network of links representing travel times for the different servers. The truck network was represented by a directed network. The yard crane and gantry crane networks, on the other hand, were represented by non-directed networks. PRIOR operated based on a set of principles the author specified for each aspect of terminal operations (e.g. creation of containers, lot assignment, gantry crane operations, and yard truck operations). It was implemented using FORTRAN.

Similarly, Jones (1996) for her dissertation developed a simulation model of a terminal to assess applications of intelligent transportation systems (ITS) technologies to the management of containers in a marine container terminal. Her model consisted of three systems: landside receiving, container handling and storage, and seaside receiving. The approach she adopted was discrete-event. Her simulation program comprised components that are typical of discrete-event simulation models. The components include system states, simulation clock, event list, statistical counters, initialization routine, event routines, library routines, report generator, and main program. By far the most involved aspect of her model is the system states, which are described in detail in her dissertation. Examples of the defined system states are ship flow, container arrival and departure patterns, import container flow, export container flow, road truck flow, yard truck flow, and yard crane flow. Jones implemented her simulation program using PASCAL.

The above review summarizes simulation studies that are intimately related to this research. Additional container terminal simulation studies which address other areas can be found in the literature review sections of Holguin-Veras' (1996) and Jones' dissertations (1996). In addition, a review of older port simulation models is provided in Hayuth et al. (1994) and Ramani (1996). As seen in the review, the technique in which researchers have used to develop their simulation models varies. Some built their models from scratch using a programming language like FORTRAN, Pascal, and C/C++. Others built their models using simulation languages like SLAM II, GPSS, and SIMAN. Coding the model from scratch is highly customizable and this approach offers the ultimate flexibility. There is also much flexibility with simulation languages. The advantage of using simulation languages is that it provides a better framework for simulation and can help reduce development time. On the other end of the spectrum, there are high-level simulators with available modeling constructs which can be used to build simulation models in a relatively short time. For this research, Arena is used because it offers all three functionalities. A brief description of Arena is provided in the following section.

2.2.9.2 Arena. First released in 1993, Arena was designed to provide a general purpose collection of modeling features for all types of applications. Increasingly, it is being applied to transportation systems. Arena can be used to model dynamic systems either as discrete, continuous, or mixed. It provides templates of graphical simulation modeling-and-analysis modules that one can combine to build a simulation model. Different templates provide different sets of simulation modeling constructs and capabilities. Arena is flexible in that it allows the user to mix the use of modules and SIMAN (simulation language) constructs. For specialized needs, like complex decision algorithms or accessing data from an external application, Arena allows the user to write codes in procedural language like Visual Basic, FORTRAN, or C/C++. Arena also provides dynamic animation. Figure 2.1 below shows the hierarchical structure of Arena. Researchers interested in learning Arena should consult the textbook written by Kelton et al. (2002).

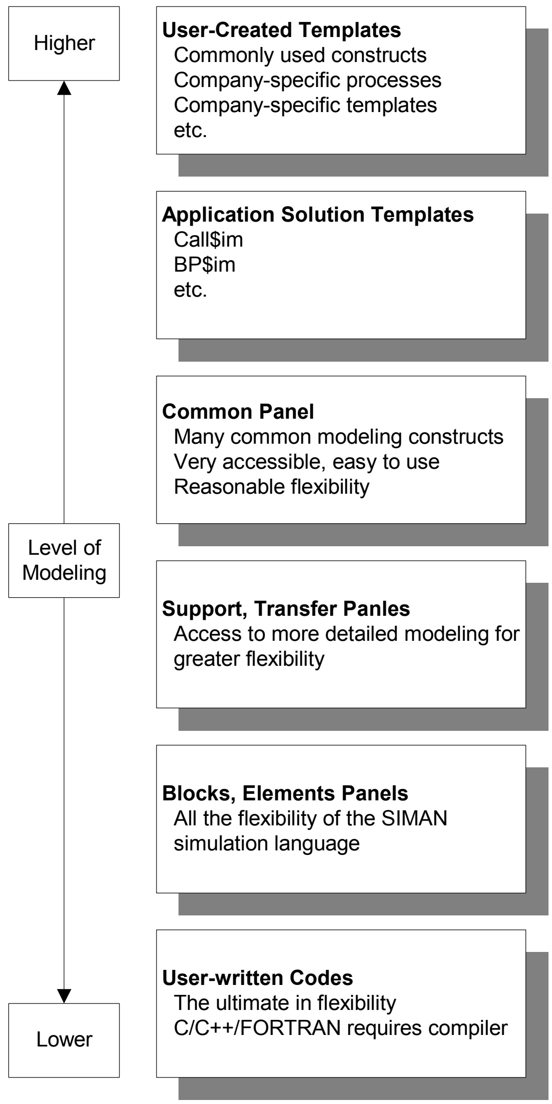


Figure 2.1: Arena's Hierarchical Structure (source Kelton et al., 2002)

2.3 OVERVIEW OF MARINE CONTAINER TERMINAL OPERATIONS

In this section, a brief overview of marine container terminal operations is presented. The discussion will only cover those areas that are needed to understand the remainder of this report. It omits many areas of terminal operations and management. For a comprehensive discussion of modern marine terminal operations and management, see Muller (1999).

2.3.1 Preliminaries

Containers are large boxes used to transport goods from one destination to another. They are designed to facilitate the movement of goods without intermediate reloading. Compared to conventional bulk, they require less packaging, are less likely to be damaged, and result in higher productivity. They are fitted with devices permitting their ready handling by terminal equipment and transportation systems (ships over sea and trucks or trains over land). Their dimensions are standardized by the International Standards Organization (ISO). The ISO recommended lengths are 10, 20, 30 and 40 feet, but most containers are 20 and 40 feet. Some steamship lines use 45-foot containers. Figure 2.2 shows pictures of a 40-foot container on the left and a 20-foot container on the right. The width of a container is eight feet and their heights are 8.5 feet or 9.5 feet; the 9.5 feet tall containers are called high-cubes. There is a movement underway in Europe for a new container width – 8.5 feet (2.61 meters). This change would allow European shippers to place two standard European pallets side-by-side in a container; existing containers based on North American pallet dimensions. The term TEU (twenty foot equivalent unit) is used to refer to one container with a length of twenty feet. Thus, a 40-foot container is two TEUs.

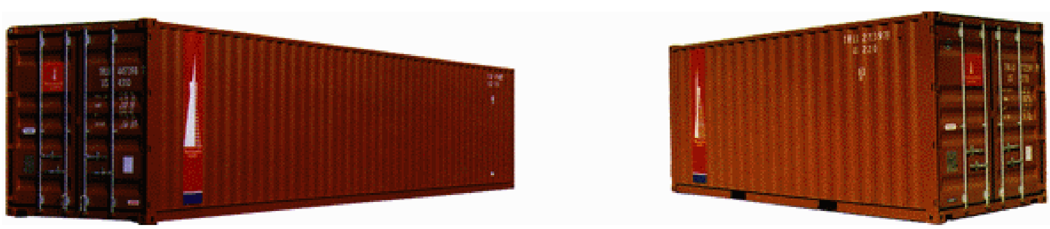


Figure 2.2: 40-foot and 20-foot Containers

2.3.2 Terminal Functions

A marine container terminal has four basic functions: 1) receiving, 2) storing, 3) staging, and 4) loading. These four functions are performed for all containers, whether they are imports, exports, or transshipments. Transshipments are containers that are discharged from a vessel, stored temporarily in an intermediate terminal, and stowed onto another vessel prior to reaching their ultimate destinations. Figure 2.3 outlines the flow of export containers (i.e. containers that enter the terminal by land and leave by ship). The receiving function involves providing entry for import containers or export containers, recording their arrivals, and capturing relevant information about the containers. The storing function involves placing the container on the terminal at a certain location where it can be retrieved when needed. The staging function involves getting a container prepared to leave the terminal. An export container may be staged at the time of initial storage, or at a later time. Lastly, the loading function involves placing the correct container on the ship, truck, or train.

There are other activities that take place at a terminal in addition to the mentioned 4 functions. An activity that is always performed is the surveying of containers and chassis. Such activity entails inspecting for things like damages on containers, operability of chassis, and whether or not the proper container and/or chassis is being taken in or out. Inspections by U.S. Customs and USDA are often performed, though not for every container. There is also the activity of packing and unpacking containers at the terminal's warehouse. This is performed whenever containerized cargo has "less than container load" in size. These small shipments must first be consolidated into a single container.

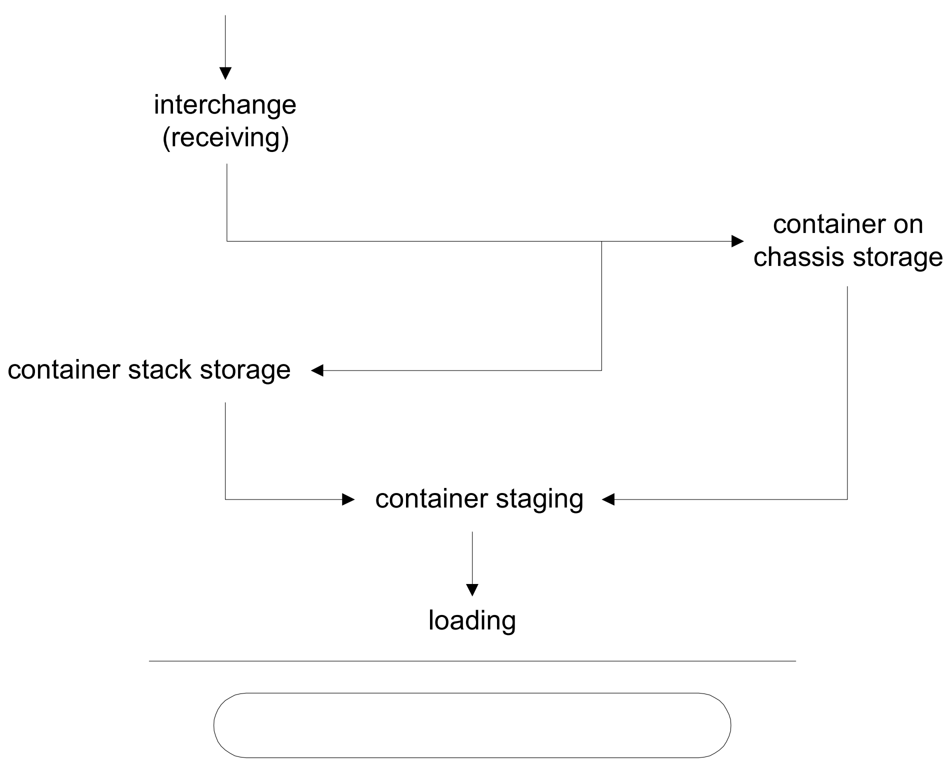


Figure 2.3: Flow of Exports in a Container Terminal (source Chadwin et al., 1990)

2.3.3 Participants

There are 6 principal participants at a terminal: 1) the shipper who loads the container and sends it to the terminal, 2) the inland carrier who transports the container to and from the terminal, 3) the terminal operator who oversees the terminal operations, 4) the stevedore who loads and unloads the containerized vessels, 5) the steamship line, and 6) the consignee or recipient of import cargo. The shipper could be the owner of the cargo, freight forwarder, or broker. The inland carrier could be a truck or rail company. The terminal operator might be a public port authority that operates a facility open to any vessel that makes arrangement to call there, or a steamship line operating the terminal as a dedicated facility, serving only its own vessels and customers. The stevedore could be the terminal operator itself or an independent contractor hired by the steamship line. The steamship line is the one who owns the vessel and is a key player in the process. It interacts with the shipper, terminal operator, consignees, and government officials. Lastly, the consignee could be a retailer who bought the cargo or a subsidiary of the shipper.

2.3.4 Terminal Equipment and Organization

Every terminal has one or more wharf (ship-to-shore) gantry cranes (see Figure 2.4). They are positioned on the shore and can slide back and forth along a track as it works a vessel. They can lift anywhere from 40 to 100 tons and load or discharge between 25 to 50 containers per hour. By 2005, the newest and most sophisticated wharf crane costs about seven million US dollars. These wharf cranes can process two containers at once and could reach across 22 rows of containers on board a ship; that is, they have an outreach of 60 meters or more (Robinson, 2005).

Most terminals employ a mixture of storage organization. The main different types of storage organization are chassis storage, stack-with-transtainer storage, and stack-with-straddle carrier storage. In chassis storage, the container is stored with the chassis in the yard as a married unit. Transtainer storage involves moving a container in and out of the stack by a transtainer (also known as yard cranes, see Figure 2.5). The yard cranes can also move a container in and out of a truck's chassis. Lastly, a container can be stacked using a straddle carrier (see Figure 2.6). There are trade offs between these three storage methods. Chassis storage requires the most land, but makes it fast for trucks to drop off and pick up containers.

Straddle carriers tend to be more flexible and mobile than yard cranes but require more land; a straddle carrier can stack at most 1 container wide and 2 containers high whereas a yard crane can stack up to 7 containers wide and 5 containers high. Typically, it takes longer for a truck to pick up a container at a terminal if the container is stacked because it takes time for the yard crane or straddle carrier to dig out the container.

Figure 2.4: Wharf Crane at the Port of Rotterdam, the Netherlands

Figure 2.5: Yard Crane at the Port of Salerno, Italy

Figure 2.6: Straddle Carrier at the Port of Rotterdam, the Netherlands

2.3.5 Processes at a Container Terminal

The association between terminal functions and terminal equipment/organization can be understood by examining the flow of containers. As seen in Figure 2.7, when a ship arrives at the terminal, import containers are unloaded. This is done by wharf cranes, which remove the containers from the ship's hold or deck and place it onto yard trucks (a.k.a. vessel trucks). After receiving the container, the yard truck moves to the stack. The yard cranes then take the container off the yard trucks and store it in the stack. After a certain period the containers are retrieved from the stack by the yard cranes and placed onto road trucks or trains for delivery to the recipient. The process is reversed for an export container. There are two important aspects in these processes. First, unlike road trucks (see Figure 2.8) which can travel over the road, yard trucks can only operate within the terminal. Their primary purpose is to take import containers from wharf cranes at the dock and transport those containers to the stack area for yard cranes to store. The process is reversed for export containers. Second, terminal managers may assign a set of yard cranes to serve yard trucks (vessel operations) and another set to serve road trucks (road operations). There are instances when a yard crane may serve both yard trucks and road trucks.

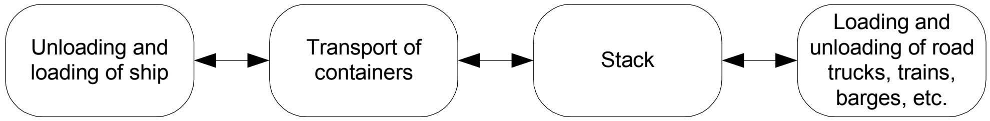


Figure 2.7: Processes at a Container Terminal

Figure 2.8: Transport of Containers by Truck, Nevada, USA

2.4 SUMMARY

The body of literature on modeling container terminals is vast; an attempt is made in this chapter to document the research that has been performed in different areas. The literature review described in this chapter sought to serve two purposes. The first is to show the different subjects in which this research is built on. The second is to highlight the uniqueness and contribution of this research.

CHAPTER 3. IDENTIFICATION OF EQUIPMENT NEEDS

3.1 INTRODUCTION

A marine container terminal's efficiency is often measured in terms of its throughput and ship turnaround time. However, due to environmental concerns, terminals are increasingly looking to reduce their truck turn time (Mongelluzzo, 2003). Terminals are also looking to reduce truck turn time in order to lower the inland transportation cost of shipping a container. As shown on Figure 3.1, the trucking cost represents a significant portion of the cost of shipping a container via the Port of Houston; the trucking cost is an estimate for moving a non-hazardous, non-overweight container within the Houston area. By lowering the trucking cost, terminals gain competitiveness against nearby terminals and possibly allow terminals to boost profit through increased rates.

High truck turn time is the result of demand exceeding supply. For terminals that stack their containers, demand is mainly the number of trucks coming to the terminal to pick up or drop off containers. Supply is the number of yard cranes available to serve these road trucks. Supply is typically low on high volume ship days because the majority of the yard cranes are assigned to work the ship. In such a scenario, truckers must wait for a longer period of time before a yard crane is available to perform the load or unload move. This waiting process can take a considerable amount of time. Indeed, in a survey of six trucking companies in the greater Houston area, the responses indicate that the yard loading/unloading process of grounded containers takes up the most time of the entire process. The survey responses can be found in Appendix A.

The solution, of adding more cranes to reduce truck turn time, may seem obvious for terminals that stack their containers. However, the high cost of these cranes often prohibits terminals from freely buying more. Another reason terminals are reluctant to add more yard cranes is because there is no clear understanding of how yard cranes impact truck turn time. That is, it is not clear how much reduction in truck turn time can be attained with an additional yard crane.

To date, no study has adequately examined the effect of crane availability on truck turn time. The challenging issues inherent in this problem, coupled with the limitation of existing research, motivate this study. This chapter presents the statistical results obtained for the study of cranes availability versus terminal efficiency (research objective #1). The goal of the analysis is to develop a regression model to determine the number of yard cranes needed to achieve a desired level of efficiency. The regression models are developed based on data gathered from the Port of Houston Authority Barbours Cut Terminal (BCT).

The remainder of this chapter is organized as follows. In the next section, an overview of BCT's processes and operations is presented, followed by some statistical information about the terminal. Then the estimation of a truck turn time model and the identification of the number of road cranes needed at BCT are discussed. Concluding remarks are made in the last and final section of this chapter.

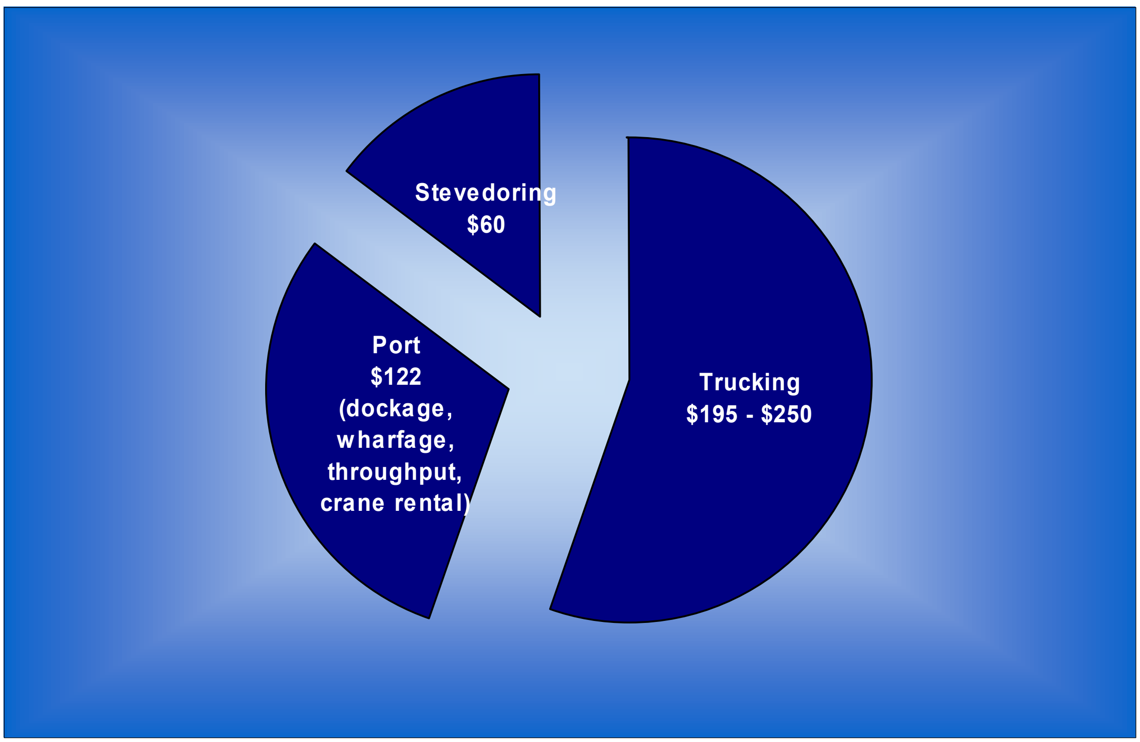


Figure 3.1: Cost of Shipping a Container Locally in Houston via BCT

3.2 BARBOURS CUT TERMINAL'S PROCESSES AND OPERATIONS

This section provides an overview of the procedures and operations followed at BCT. A diagram of BCT is shown in Figure 3.2. The Port of Houston operates terminal 1 through 5. Terminal 6 is operated by a private operator Maersk. From here onward, any reference made to

BCT will refer only to the portion that is operated by the Port of Houston. In 2003, BCT handled a little more than 500,000 vessel moves. This volume is generated by 30 steamship lines with 16 weekly services. The cargo mix is 60% exports and 40% imports. About 85% of the containers in the yard are stacked. The other 15% stay on chassis, most of these are hazardous, refrigerated, or out-of-gauge cargo.

BCT has 30 blocks for stacking containers for a total capacity of approximately 23,000 TEUs. Each block has about 80 20-foot sections (length), each section has 6 stacks (width), and each stack has 4 tiers (height); refer to Figure 3.3 for a visual depiction. A block (commonly referred to as pad at BCT) is used for storing import containers, export containers, or both. Import containers are typically stored in the available blocks designated for imports and where it is most convenient for stevedores to work the ship. As import containers are discharged from a ship, they are stacked in the allocated space without any segregation. Export containers, on the other hand, are methodically stored by 1) service; 2) container type; 3) port of discharge; and 4) weight classification. This is done so that when export containers are loaded onto the ship, no digging is required.

BCT primarily uses rubber-tired gantry (RTG) cranes, referred to here as yard cranes, to load and unload containers in the blocks. Figure 3.4 shows a schematic diagram of a block from the front view and illustrates how a yard crane is positioned in a block. BCT has a total of 24 yard cranes (18 that can stack 4 high stacking and 6 that can stack 3 high). On any given day, the yard cranes are assigned to either support the ship operation or support the road operation. Ship operation has higher priority, so the number of yard cranes available to support road operation is the total number of yard cranes available minus the number of yard cranes assigned to ship operation. Road operation refers to the process of truckers dropping off export containers and/or picking up import containers. Ship operation refers to the process of unloading import containers off a vessel and stowing export containers to a vessel.

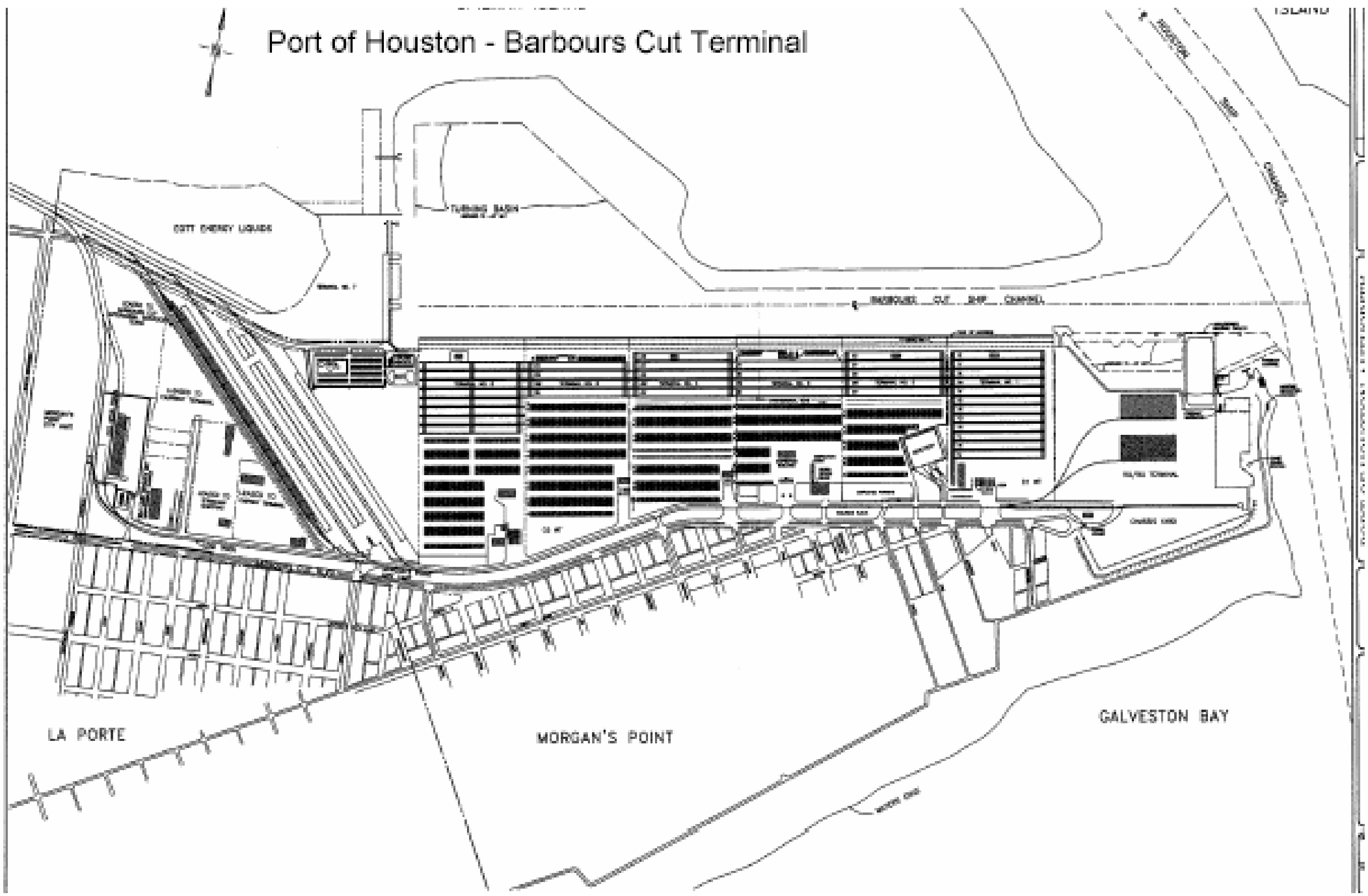


Figure 3.2: Diagram of Barbours Cut Terminal

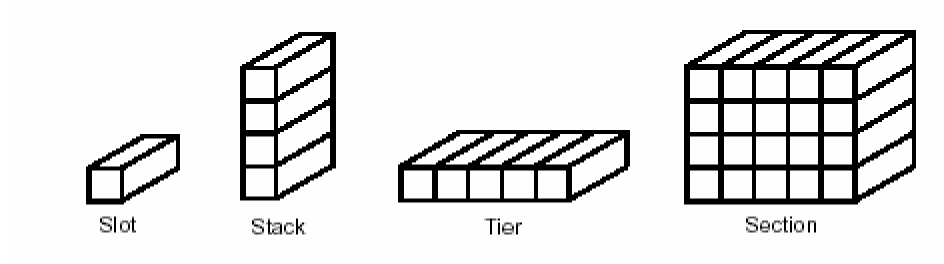


Figure 3.3: Elements of a Container Yard Storage Block

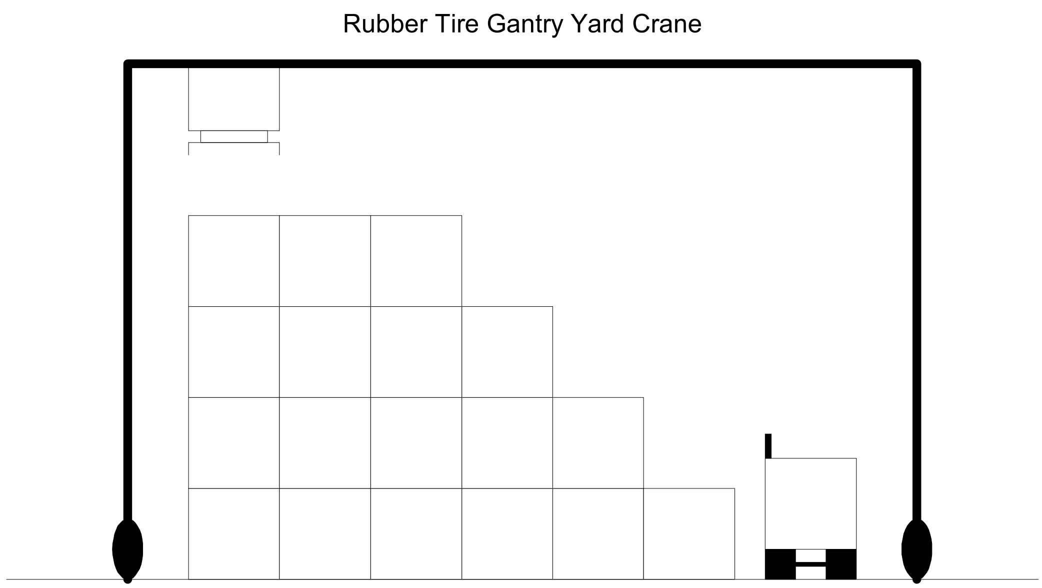


Figure 3.4: Front View of a Stack

3.2.1 Export Moves

When a truck arrives at the terminal with an export load, the driver is presented with a gate pass from a security guard. The truck then proceeds to the inbound lane and onto the scale. The truck is then surveyed by a clerk; the clerk checks to make sure the cargo weight is not over the container safe weight, the seal on the container is intact, the container is not damaged, the chassis is functional, etc. After the clerk finishes checking the truck and chassis, the survey form and the transaction request which the driver filled out ahead of time are submitted to a logistic associate for processing. If there is a problem with the paper work (e.g. booking number not on file), the truck is sent to customer service to get the problem resolved. If the paper work is valid, then an interchange is printed and the truck is clear to proceed into the terminal. The interchange includes the location where the export container is to be placed. Directions to the park location are provided, if needed.

Upon arriving at the specified park location, the truck waits for RTG cranes for service (i.e. taking the container off the truck). The trucks are served based on where they are in the block relative to the RTG. The closer a truck is to an RTG, the higher the likelihood it will get service first. After the container is taken off, the truck exits through a lane designed for quick exit, since no surveying of the container is necessary. The check out process involves a clerk checking the interchange to ensure that the proper move has been made. In particular, the clerk verifies that the chassis taken out is the same one that was taken in. If everything is valid, the truck may exit.

The diagram below (Figure 3.5) shows the entire process flow for an export container and the people involved in each step of the process.

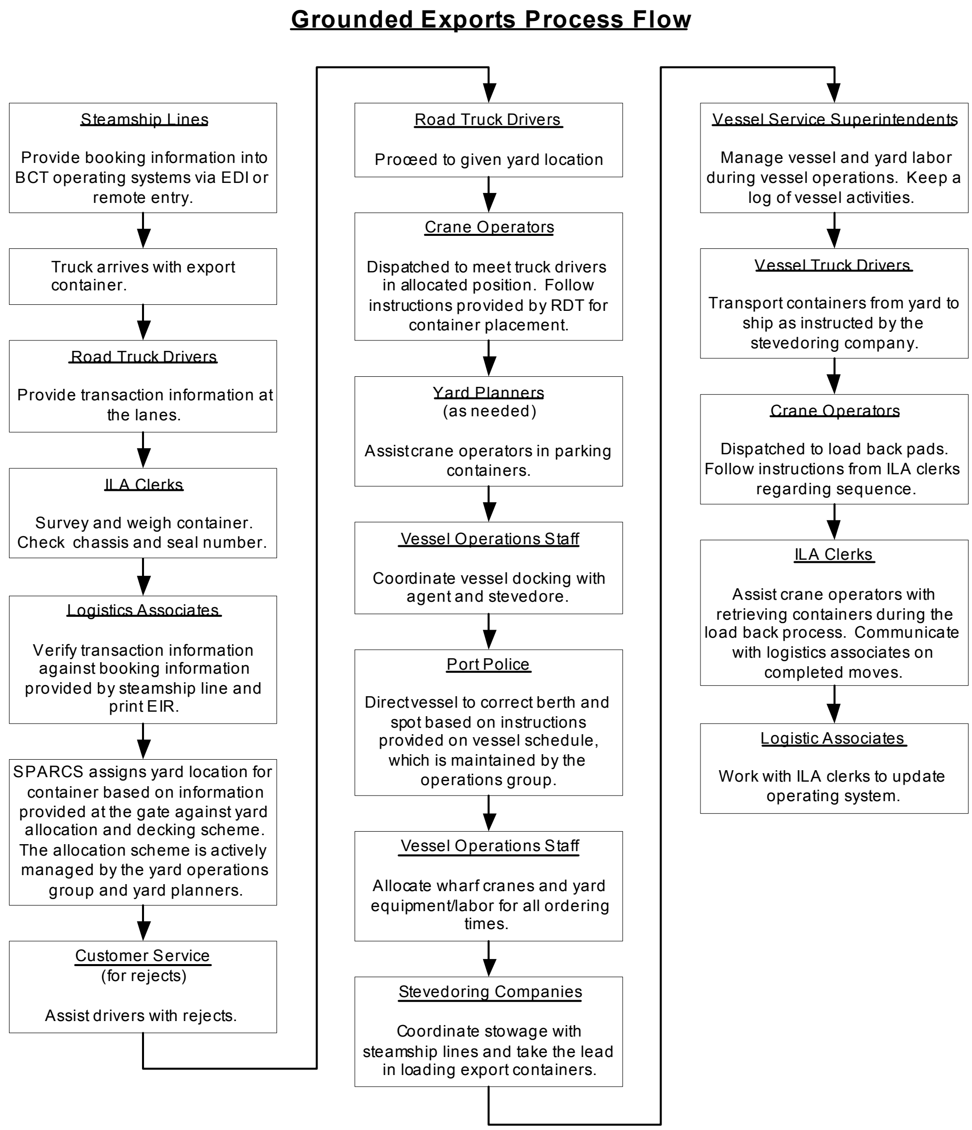


Figure 3.5: Process Flow of Grounded Export Containers

3.2.2 Import Moves

When a truck arrives at the terminal for an import load, the driver is presented with a gate pass from a security guard. The truck then proceeds to the lane. Then the driver submits the transaction request which he filled out ahead of time to a logistic associate for processing. The logistic associate verifies that the container has been released by the steamship line and that no other holds exist on the container (e.g. USDA inspection, Customs exam). If there is a problem with the paper work (e.g. wrong container number), the truck is sent to customer service to get the problem resolved. If everything is valid, an interchange is printed and the truck is clear to proceed into the terminal. The interchange includes the location where the import container resides in the yard. The truck can then proceed to the park location. Directions to the park location are provided, if needed.

Upon arriving at the specified park location, the truck waits for RTG cranes for service (i.e. have the requested container put on the truck). These trucks are served based on where they are in the block relative to the RTG. The closer a truck is to an RTG, the higher the likelihood it will get service first. After the container is placed onto the truck, the truck proceeds to the outbound lane. Upon exit, the container and chassis are surveyed. If everything is valid, the driver is given a copy of the interchange and the truck may exit.

The diagram below (Figure 3.6) shows the entire process flow for an import container and the people involved in each step of the process.

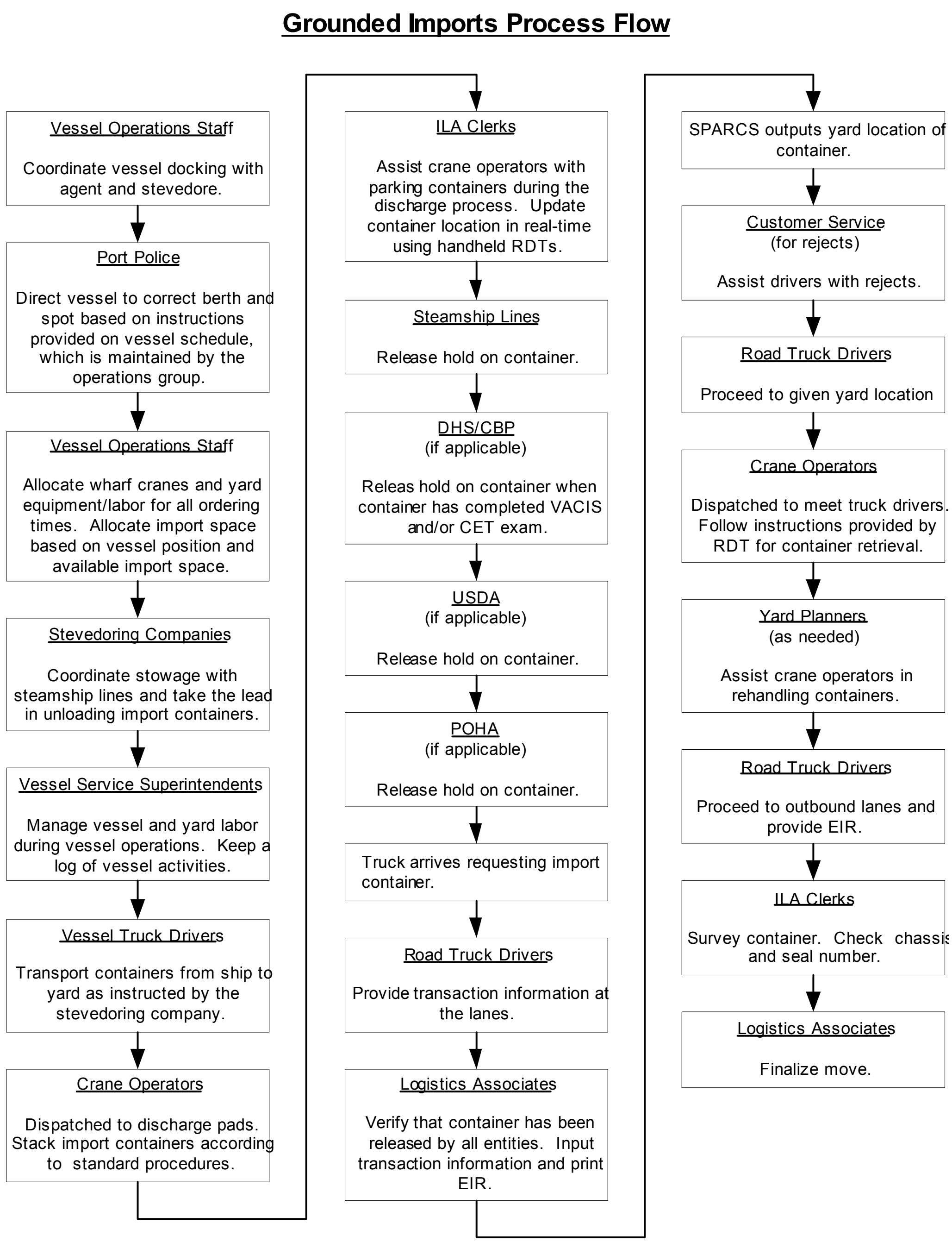


Figure 3.6: Process Flow of Grounded Import Containers

3.2.3 Gate Setup

Truckers enter and leave BCT through five gates, three are for entry only and two are for both entry and exit (Figure 3.7). The gate in which a truck enters the terminal depends on which steamship line it is serving. Generally, truckers choose the gate that is most convenient in terms of distance to where they need to go and where it is easier to find chassis (if necessary). Similarly, they choose nearest exit gate when exiting.

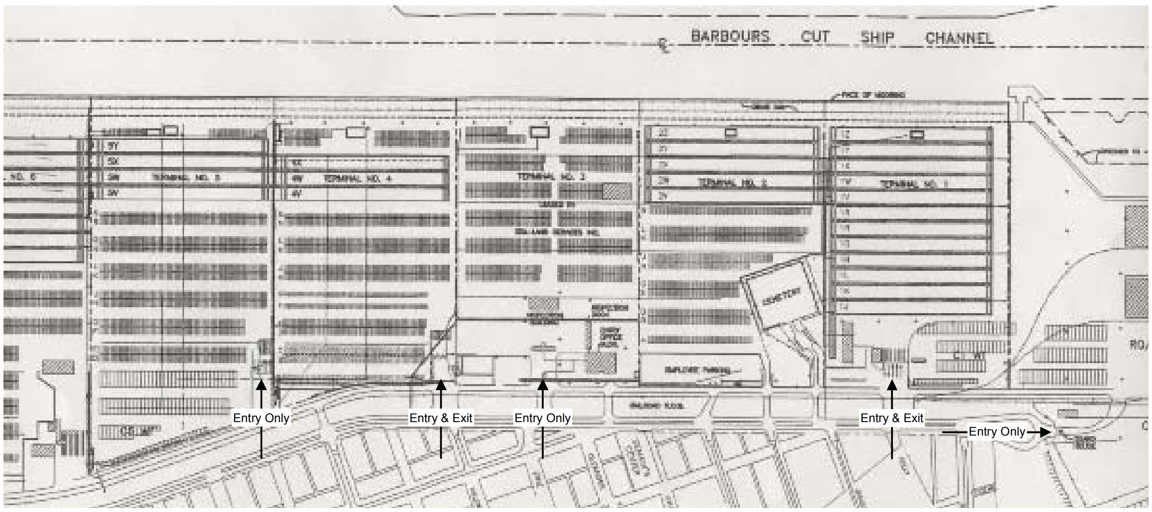


Figure 3.7: Diagram of BCT Gates

3.3 STATISTICAL INFORMATION ABOUT BCT

In the following, information regarding BCT's work loads, resources, and levels of service are presented, for the period from July 30, 2002 to September 30, 2002.

3.3.1 BCT's Work Loads

During the observed two months span, the frequency in which BCT had 0, 1, 2, 3, 4, 5, and 6 ships during the working days, Monday through Friday, from 7AM to 6PM are shown in Table 3.1. Also shown in Table 3.1 is the average number of vessel moves generated corresponding to the number of ships berthed. Note that these vessel moves are averages from a collection of ships that vary greatly in sizes.

The distribution of ships berthed at BCT over the course of a week is shown in Figure 3.8. Data shows that on average, more ships berth at BCT on Mondays and Tuesdays than any other day of the week.

In addition to performing vessel moves, yard cranes are also responsible for performing road moves, and other-yard moves. Figure 3.9 below shows the number of various moves performed by yard cranes over the two months span.

Table 3.1: Ships Generated Activities from M-F and 7AM–6PM

No. of ships	Frequency	Vessel Moves
0	4	0
1	7	203
2	15	741
3	10	945
4	4	1499
5	3	1389
6	1	1488

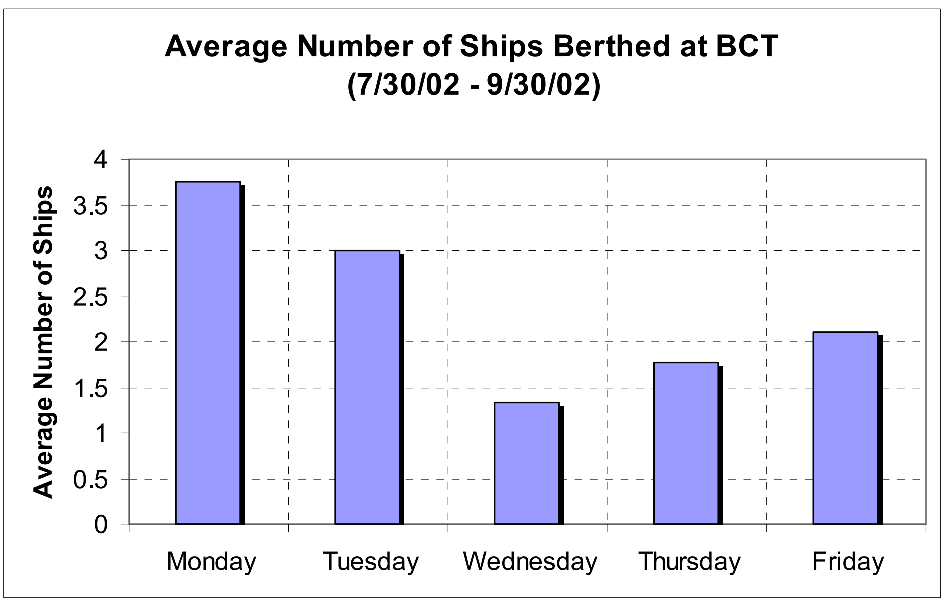


Figure 3.8: Ships Berthed at BCT by Day

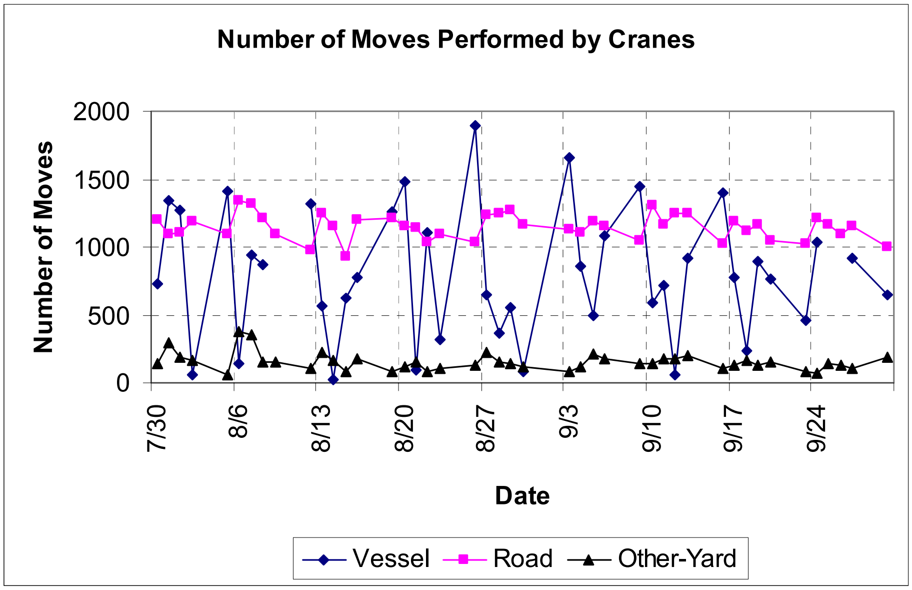


Figure 3.9: Moves Performed by Yard Cranes

3.3.2 BCT's Resources

BCT's primary resource that affects truck turn time is yard cranes. It currently owns 26, including 2 that are operated by Maersk. Data shows that one ship can take up as few as 1 crane and as many as 5 cranes. With just 2 ships working, it is possible that 8 to 10 cranes are assigned to work the ships, leaving just 14 to 16 cranes to work the road trucks. Figure 3.10 shows the total number of yard cranes available for service each day and the number available to work the road trucks that day. Recall that vessels get priority over road trucks for yard cranes; hence, the number of yard cranes assigned to work the road trucks fluctuate daily. Note that even though BCT has 24 yard cranes, not all of them are available for service each day because of scheduled maintenance and mechanical failures.

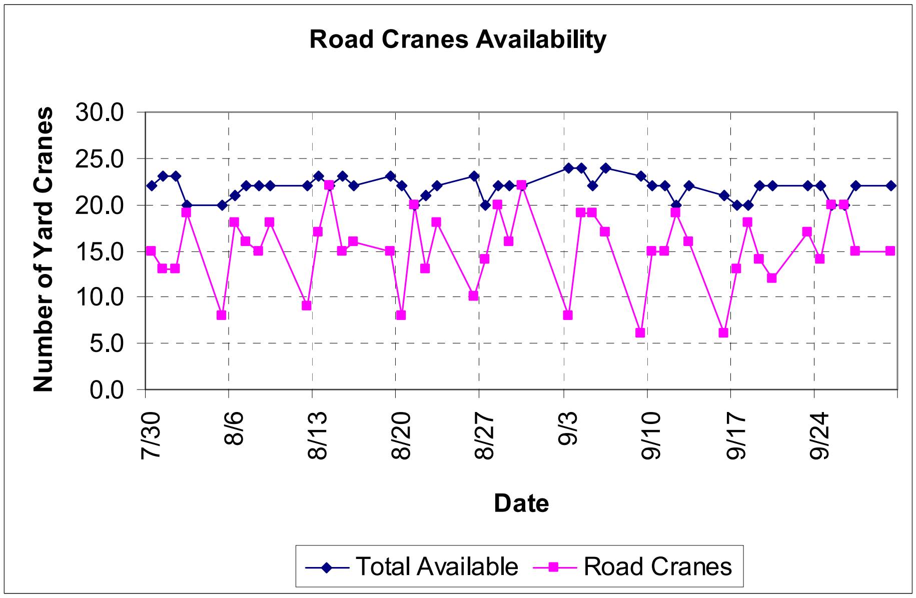


Figure 3.10: Cranes Availability

3.3.3 BCT's Service Levels

BCT's truck turn time during the analysis period with the given work loads and resources is shown in Figure 3.11. Note that the turn time shown in Figure 3.11 and subsequent figures include gate processing times. It can be seen that the turn time decreases slightly over the two months period. This finding may seem odd at first glance because the number of road moves performed during the observed two months span is nearly constant (see Figure 3.9). The reason for this is because additional stacks were made available with the completion of the terminal 3 retrofit. When there are more stacks available, containers are more spread out. That is, containers are not stacked as high and thus fewer diggings (referred to as rehandles) are required. This fact can be observed in Figure 3.12. Note the similarity in peaks and valleys between turn time and the number of rehandles.

Turn time is affected by several factors, such as the number of road cranes available and the number of road moves to be performed. Figure 3.13 and Figure 3.14 depict these relationships, respectively. Note that in Figure 3.14 rehandles are included with road moves. As expected, the result in Figure 3.13 indicates that the more road cranes there are the lower the turn time. The result in Figure 3.14 does not clearly indicate the relationship between road moves and turn time.

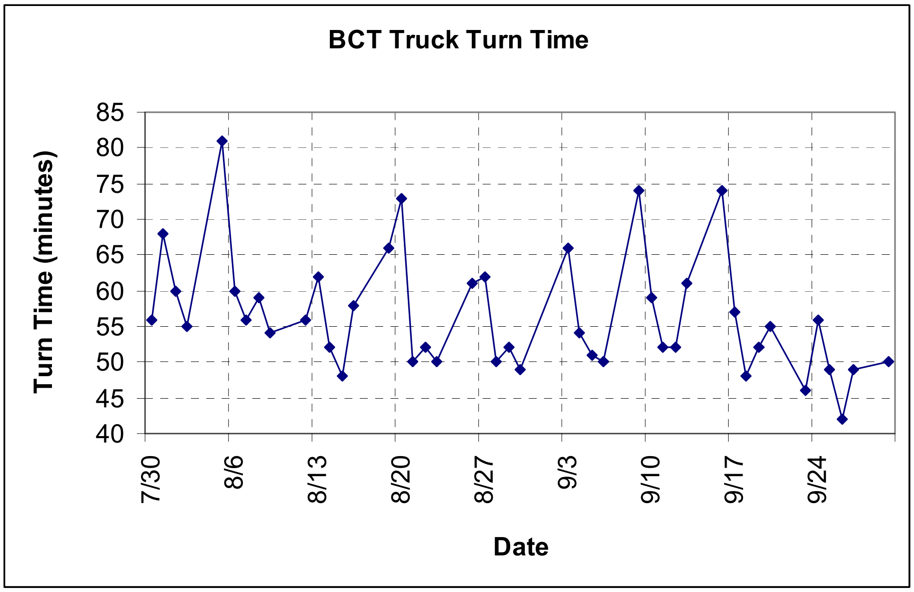


Figure 3.11: BCT's Truck Turn Time

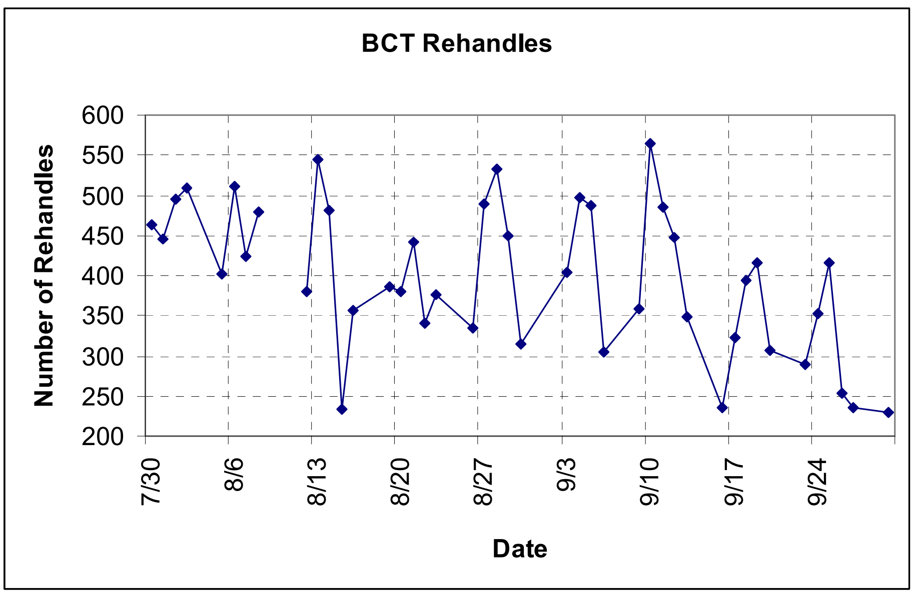


Figure 3.12: BCT's Rehandles

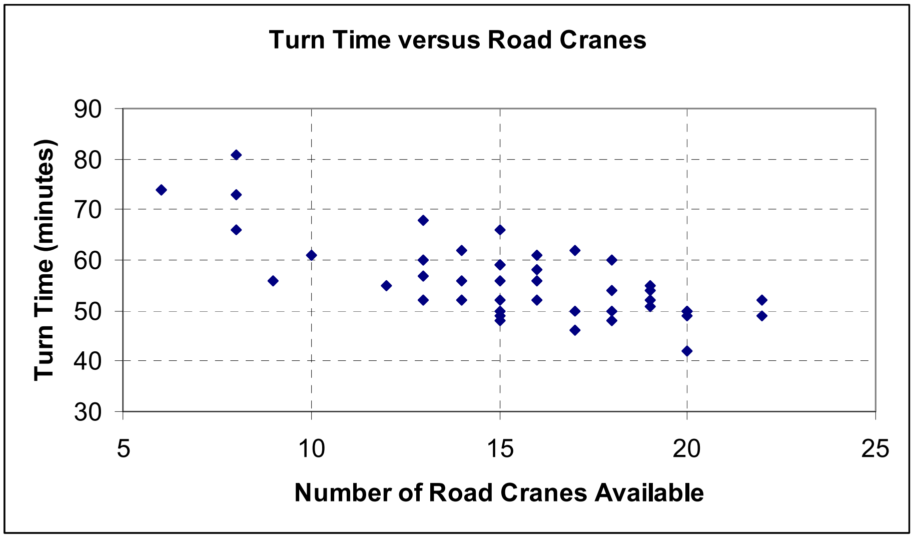


Figure 3.13: Truck Turn Time Versus Road Cranes

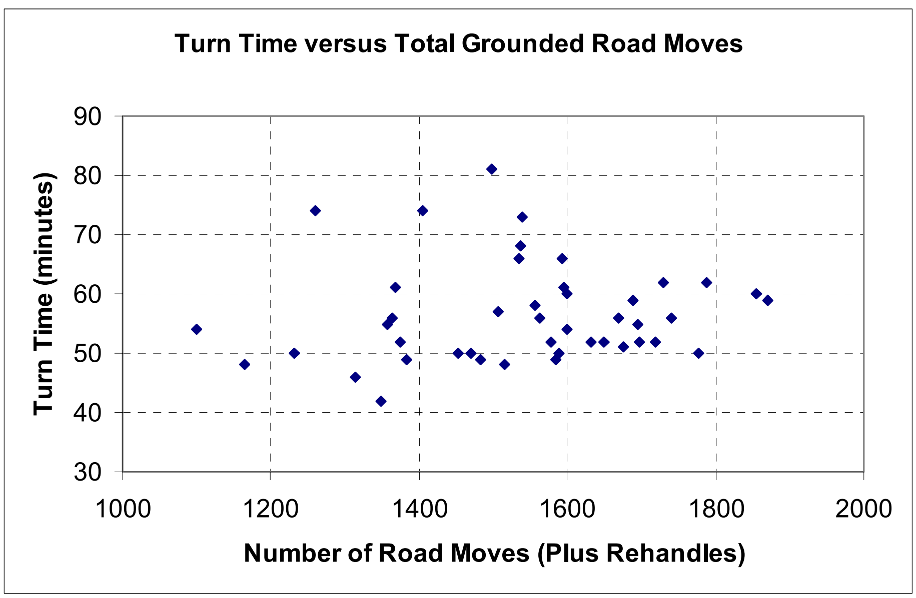


Figure 3.14: Truck Turn Time Versus Total Grounded Road Moves

3.4 ESTIMATION OF TURN TIME

As shown in the previous section, variables such as number of road cranes and number of road moves seem to be associated with turn time. It is not immediately clear from inspection of the graphs which variables have stronger or weaker relationships with turn time. Therefore, modeling techniques are needed to untangle all of this. The regression technique employed entails identifying a model that relates a set of explanatory variables to turn time. The explanatory variables explored are number of road cranes, vessel moves, road moves, other-yard moves, and rehandles. The goal is to develop a model that best fits the data. Estimation results from several models are discussed.

3.4.1 Multiple Regression

The dependent variable, turn time, is regressed against road cranes and those sources competing for crane service. The explanatory variables explored are number of cranes, vessel moves, road moves, other-yard moves, and rehandles. The estimation results are summarized in Table 3.2. The results of model 1 indicate that vessel moves and other-yard moves are statistically insignificant. It makes sense that the vessel moves attribute is not significant because road cranes are assigned to work road moves only. Interestingly, the results indicate that other-yard moves do not have an effect on turn time. An explanation for this is that oftentimes other-yard moves are performed after hours; hence they did not compete for cranes service during the day. When these two variables are removed, the resulting model (model 2) is improved as indicated by the adjusted R-squared, from 0.6728 to 0.6839. Since rehandles are basically moves performed on top, or rather as part, of road moves, they are combined in the next model (model 3). Again, the modification resulted in a better model; the adjusted R-squared goes from 0.6839 to 0.6917. Therefore, it can be concluded that truck turn time is dependent on two key factors: the number of road cranes available and the number of road moves to be performed (plus rehandles). It can also be concluded that as the number of cranes increases, the turn time will decrease and that as the number of road moves increases, the turn time will increase. These findings correspond to expectation.

Lastly, in model 4, turn time is regressed against road moves (plus rehandles) per road crane. This relationship can be seen graphically in Figure 3.15. It can be seen from the graph that, for the most part, the turn time increases as the number of road moves per road crane increases. This is expected because the more road moves there are relative to the number of road cranes available, the greater the turn time. The resulting multiple regression model is an improvement over the previous one (model 3); the adjusted R-squared goes from 0.6917 to 0.7254. All variables are statistically significant. The positive sign of the coefficient suggests

Table 3.2: Truck Turn Time Multiple Regression Models

	Model 1		**Model 2**		**Model 3**		**Model 4**	
Variable	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat	Estimate	t-stat
Intercept	50.618	4.14	53.044	5.58	52.559	7.83	35.874	17.35
Cranes	-1.656	-4.44	-1.84	-9.54	-1.842	-9.77		
Vessel Moves	0.002	0.61						
Road Moves	0.018	1.58	0.20	1.92				
Other-yard Moves	0.007	0.56						
Rehandles	0.02	1.95	0.021	2.09				
Total Road Moves					0.021	4.45		
Total Road Moves/Crane							0.185	10.85
Adjusted R^2	0.6728		0.6839		0.6917		0.7254	

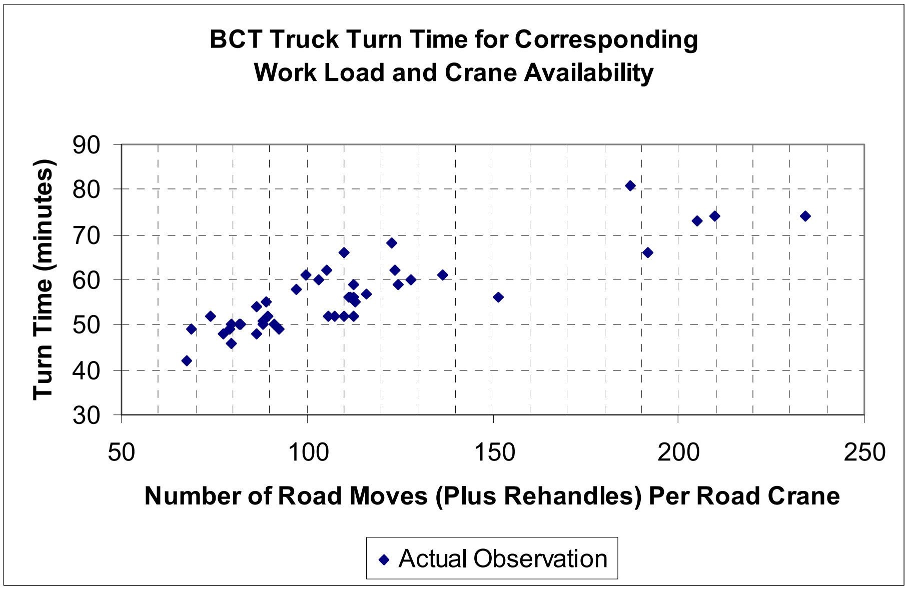


Figure 3.15: Truck Turn Time with Respect to Work Load and Crane Availability

that as the ratio increases, the turn time increases. This result agrees with the graphical evidence.

3.4.2 Polynomial Regression

A limitation of models 1 through 4 is that they assume a linear relationship between turn time (independent variable) and its dependent variables. This assumption implies that as the number of road moves per crane increases, the turn time increases proportionally in a linear fashion. However, the latter trend in the data in Figure 3.15 suggests otherwise. On the higher end (road moves/crane > 200), turn time appears to taper off with increasing road moves (plus rehandles) per crane. Therefore, other functional forms are needed to better estimate the functional relationship between turn time and road moves per crane. The result from model 4 serves as a benchmark for all other models to be developed.

Since the data in Figure 3.15 resemble a polynomial function, polynomial regression is employed. Several polynomial functions are investigated, 2nd order, 3rd order, etc. The best model found is the quadratic function (2nd order); it is of the form $y = \beta_0 + \beta_1 x + \beta_2 x^2$, where y is turn time and x is the ratio of road moves (plus rehandles) per crane. The estimation results of this model, shown in Table 3.3, indicate that it provides a better fit than model 4; the adjusted

R-squared goes from 0.7254 to 0.7381. With polynomial coefficients, it is tricky in regard to the interpretation of the coefficients because the concept of marginality does not hold. For example, the coefficient associated with x^2 would assume that all other variables would be held fixed, but if one changes x by any amount, x^2 also changes. In general, β_0 represents the overall position of the curve up and down the y-axis. The value of β_1 represents the amount of overall upward downward linear trend in the values of y as one move along the x-axis; in other words, if one draws a straight line to fit all the points well, β_1 is the slope of the line. Lastly, the value of β_2 represents the amount of curvature in the data. In this case, the negative sign in the coefficient "total road moves per crane squared" suggests that it is an upside down parabola, which corresponds to graphical evidence.

Table 3.3: Truck Turn Time Polynomial Regression Model

Truck Turn Time Polynomial Model		
Variable	Parameter Estimate	t-Value
Intercept	24.587	3.59
Total Road Moves per Crane	0.366	3.45
Total Road Moves per Crane Squared	-0.001	-1.72
Adjusted R^2	0.7381	

3.4.3 Non-Linear in Parameter Regression

The curve in the data shown in Figure 3.15 suggests a non-linear in parameter specification should also be investigated. Two versions are explored. The first version has the form.

$$y = \beta_0 x^{\beta_1}$$

where y is the turn time and x is the ratio of road moves (plus rehandles) and road cranes. To estimate equation, the natural logarithm transformation is performed to convert it to the following model, which can then be estimated like any regression model.

$$\ln y = \beta_0 + \beta_1 \ln x + \varepsilon$$

where ε is an error term ~ N(0,1) and β_0 and β_1 are the coefficients to be estimated. The estimation results of this model are shown in Table 3.4. All variables are statistically significant. The adjusted R-squared is 0.7423, which is an improvement over the polynomial regression model with an adjusted R-squared of 0.7381.

Table 3.4: Truck Turn Time Non-linear in Parameter Model 1

Truck Turn Time Non-Linear in Parameter Model 1		
Variable	Parameter Estimate	t-Value
Intercept	2.125	12.32
LOG(Total Road Moves per Crane)	0.407	11.05
Adjusted R^2	0.7423	

The second version estimated has the following form.

$$y = \beta_0 c^{(\gamma_1 + \gamma_2 m)}$$

where y is the turn time, c is the number of available road cranes, and m is the number of road moves (plus rehandles). The coefficients to be estimated are β_0, γ_1, and γ_2. The resulting model after performing the natural logarithmic transformation is:

$$\ln y = \beta_0 + \gamma_1 \ln c + \gamma_2 m \ln c + \varepsilon$$

The estimation results of this model are shown in Table 3.5. They indicate that all variables are statistically significant and that model 2 provides a better fit than model 1 (0.7597 compared to 0.7423).

Table 3.5: Truck Turn Time Non-linear in Parameter Model 2

Truck Turn Time Non-Linear in Parameter Model 2		
Variable	Parameter Estimate	t-Value
Intercept	5.081	54.35
LOG(Cranes)	-0.625	-10.40
Total Road Moves*LOG(Cranes)	0.000148	5.86
Adjusted R^2	0.7597	

To estimate truck turn time at BCT as a function of resources and work loads, several models are examined. They include multiple regression models, polynomial regression models, and non-linear in parameter regression models. The best model found is of the form*:

$$y = 8.37x^{0.41} \qquad \text{eq. 3.1}$$

where y is the turn time and x is the number of road moves (plus rehandles) per road crane.

Figure 3.16 shows the estimated model (equation 3.1) that captures the relationship between y and x in relation with actual observations. Given such a model (equation 3.1), turn time can be estimated from knowing the number of road cranes and the number of road moves (plus rehandles). The use of this model is explained in the next section.

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* The best model chosen here is actually not the best fit model. It has an R^2 value of 0.7423, compared to 0.7597 of the best model. However, it is chosen because of its parsimonious specification and easy to understand relationship.

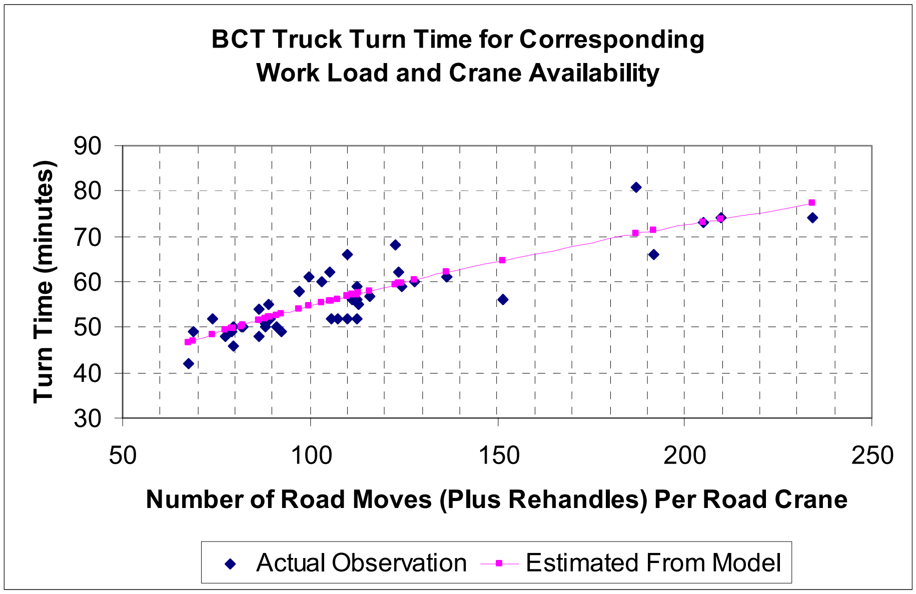

Figure 3.16: Actual and Estimated Relationship between y and x

3.5 IDENTIFICATION OF ROAD CRANES NEEDED FOR DESIRED LEVEL OF SERVICE

Suppose the target truck turn time for BCT is 50 minutes. By this standard of efficiency, BCT is efficient only 27% of the time. Hence, it is evident that additional road cranes are needed. When BCT fails to have a turn time of 50 minutes or lower, it has on average 14 road cranes and about 112 road moves (including rehandles) per road crane. To achieve the desired turn time of 50 minutes, there needs to be 1 road crane for every 80 road moves (including rehandles); this value is derived from equation 3.1. Therefore, the average number of additional road cranes needed to achieve a consistent turn time of 50 minutes is 6. By repeating the above procedure for different desired turn times, the following ratio of road moves (plus rehandles) per road crane and number of additional cranes needed for each scenario are obtained (Table 3.6).

Table 3.6: Road Moves per Crane and Additional Cranes Needed

Desired Turn Time (minutes)	Maximum Road moves (plus rehandles) Per Crane	Additional Cranes Needed
45	62	10
50	80	6
55	101	4
60	125	2

3.6 SUMMARY AND CONCLUSION

Through the estimating procedure, it is identified that truck turn time is primarily affected by the ratio of road moves to be performed and the number of road cranes available. Using the best model obtained (see equation 1), it is found that by investing in 6 additional yard cranes to bring the total road cranes available on average to 20, BCT will be able to turn trucks around in 50 minutes or less on a consistent basis.

It is important to note that the models developed are based on the terminal's density at the time of analysis. As a terminal gets denser, there may be other types of moves that will result (e.g. transfers to create space). These additional moves as a result of the terminal getting denser have not been accounted for in the model. Also, it is important to note that the models developed do not account for scheduled maintenance and mechanical failures. If these factors are considered then the number of additional yard cranes needed may be higher; data on cranes' maintenance and mechanical failures were not available.

CHAPTER 4. SIMULATION MODEL OF CONTAINER TERMINAL

4.1 INTRODUCTION

The regression models discussed in chapter 3 are useful tools to terminal operators who wish to determine the number of yard cranes needed to achieve a certain truck turn time or conversely the truck turn time given a certain number of yard cranes. While such models are useful, they are limited in terms of answering what-if questions. A question that is raised and discussed in the next chapter is what impact an appointment system will have on a terminal. To answer such questions, a simulation model is needed. This chapter discusses the development of a simulation model of a container terminal and its application to analyzing truck turn time with respect to crane availability and deployment.

The remainder of this paper is organized as follows. First, the framework of the simulation model is presented, followed by a discussion on verification and validation. Then the model application and results are discussed.

4.2 DEVELOPMENT OF SIMULATION MODEL

In determining whether to build a generic model or a terminal-specific model, it is reasoned that since container terminals differ from one another in layout, capacity, and equipment, a terminal-specific model is more desirable. The Barbours Cut Terminal (BCT) of the Port of Houston Authority is selected for the study. Even though BCT is unique in itself, the general processes and characteristics are similar to other container terminals (see Figure 4.1); hence, the model building approach discussed here can be applied to other container terminals.

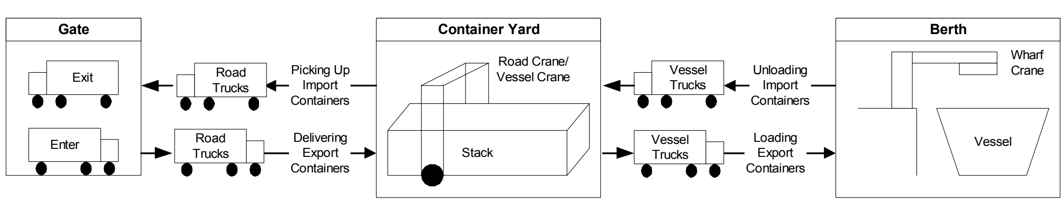

Figure 4.1: Processes and Characteristics of BCT

4.2.1 Scope

In this research, the key measure of performance is truck turn time at the terminal. Note that the term truck turn time used here is different from the commonly understood term by the trucking industry. It excludes the truck queuing time outside the yard. In particular, only the lanes-to-exit turn time is of interest; that is, the time when a truck enters the yard (from the inner gate) until the time it exits the yard. High truck turn time at BCT is typically due to the long waiting time in the yard for service by the road cranes or at times by the ship cranes. Hence, the scope of the simulation model is limited to the container yard, with special emphasis on the movement of the cranes as they go about serving the road trucks. The entities modeled are road trucks, road cranes, and ship cranes. Road cranes are rubber tire gantry (RTG) cranes designated to serve road trucks. Ship cranes are RTG cranes designated to serve vessel trucks; however, they serve road trucks when they are free.

Figure 4.1 shows the three main components of a container terminal and the flow of trucks through them. The components and entities not modeled explicitly are gate, berth, and vessel trucks. The gates are modeled only as the points of entry into the yard. The queuing at the gates is not modeled because only the lane-to-exit time is desired. The lane-to-exit time excludes the queuing at the inner gate; it begins when the trucks are cleared to proceed into the yard. Lastly, vessel trucks are modeled indirectly. Even though they are not shown in the model, they are accounted for in how the simulation model determines when a ship crane is available to serve a road truck. Thus, the operations at the berth are accounted for implicitly through this mechanism.

4.2.2 Data Description

The development of the simulation model is heavily tailored to the available data. The primary reason for this is to have actual operations data to calibrate the model and subsequently, to validate the model outputs. Also, by developing the model hand-in-hand with the available data, there is no need to extract unobserved data, which may add unnecessary complexity to the model and more importantly, increase the error sources in the model. However, no operational aspects are omitted from the model because of the lack of data. In such instances, practical and/or theoretical assumptions are used. A brief summary of the data available to this study is given below. A detailed description of the data source and how they are extracted are provided in Appendix B.

- Truck data –information about a truck include park location, whether or not it is a reject (i.e. truck with invalid paperwork), whether or not it is picking up or dropping off a chassis only, whether or not it is picking up both container and chassis, whether or not it is dropping off both container and chassis, the gate it enters, the time it enters the yard, and the time it exits the yard.
- Crane data – information about cranes include how many road cranes are designated to work the road trucks and how many ship cranes are designated to work the vessel on a particular day.
- Move-out exit time – before exiting the yard, trucks performing a move-out (for an import container) must go through the inspection process (i.e. surveying of container). The move-out exit time is the wait time for these out-going trucks.
- Container loading/unloading time – the time a crane takes to load or unload containers.
- Rehandles – the number of extra moves performed by a crane to retrieve the desired container.
- Road moves performed by ship cranes – percent of moves that ships cranes performed on road trucks while on vessel operation.

4.2.3 Assumptions

Some assumptions are made to simplify the model to some extent. These assumptions are deemed appropriate because the details not modeled do not in any way compromise the realism of the model. Also, it is unlikely the inclusion of those extra details will make the model any more accurate. These assumptions are:

- All containers have the same length.
- All stacks have the same length.
- No collision among trucks and between trucks and cranes.
- No double moves. A double move is when a truck comes into the terminal to drop off an export container and then pick up an import container before leaving the terminal.

- Only one crane operates in a block.

4.2.4 RTG Cranes and Road Trucks Network Definition

To model the movement of trucks and cranes, a travel network is needed for the respective vehicles. Because of the few overlapping areas where both trucks and cranes travel, two separate networks are created; one for the road trucks and one for the RTG cranes. To create these networks, the terminal layout is examined to identify nodes and links for the networks. Basically, links are those physical segments used for travel and nodes are where segments intersect. It is important at this stage to incorporate terminal-specific movements. For example, at BCT, trucks are only allowed to go from east to west in between stacks and RTG cranes are only allowed to traverse east-west or west-east on terminals 1 through 5 for row V, W, and X, but not Y. The created networks for RTG cranes and road trucks are shown in Figure 4.2 and Figure 4.3 , respectively. The crane network is made up of 60 nodes and 94 links. The truck network is made up of 134 nodes and 198 links.

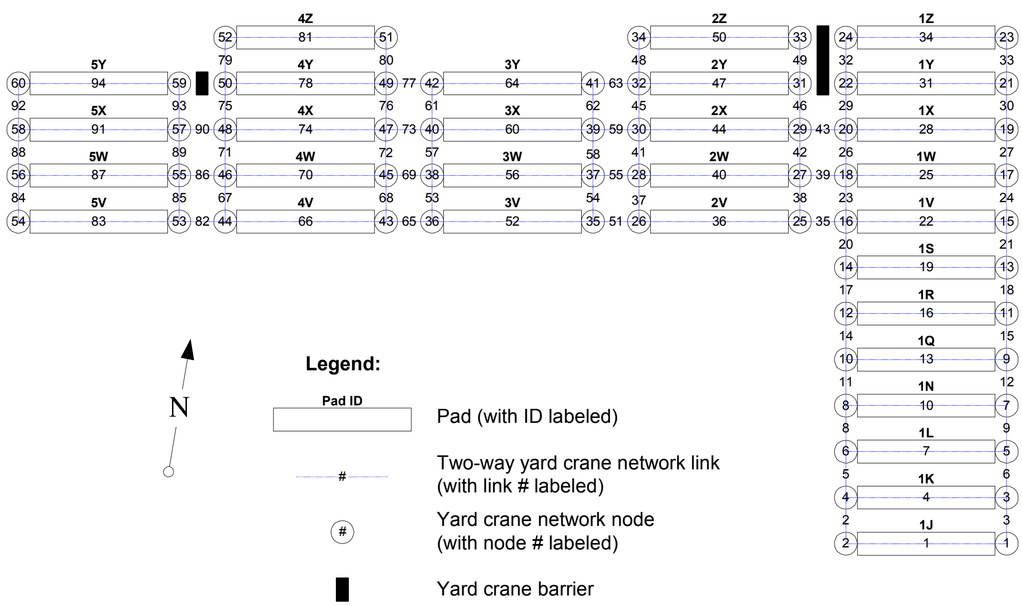

Figure 4.2: Crane Network

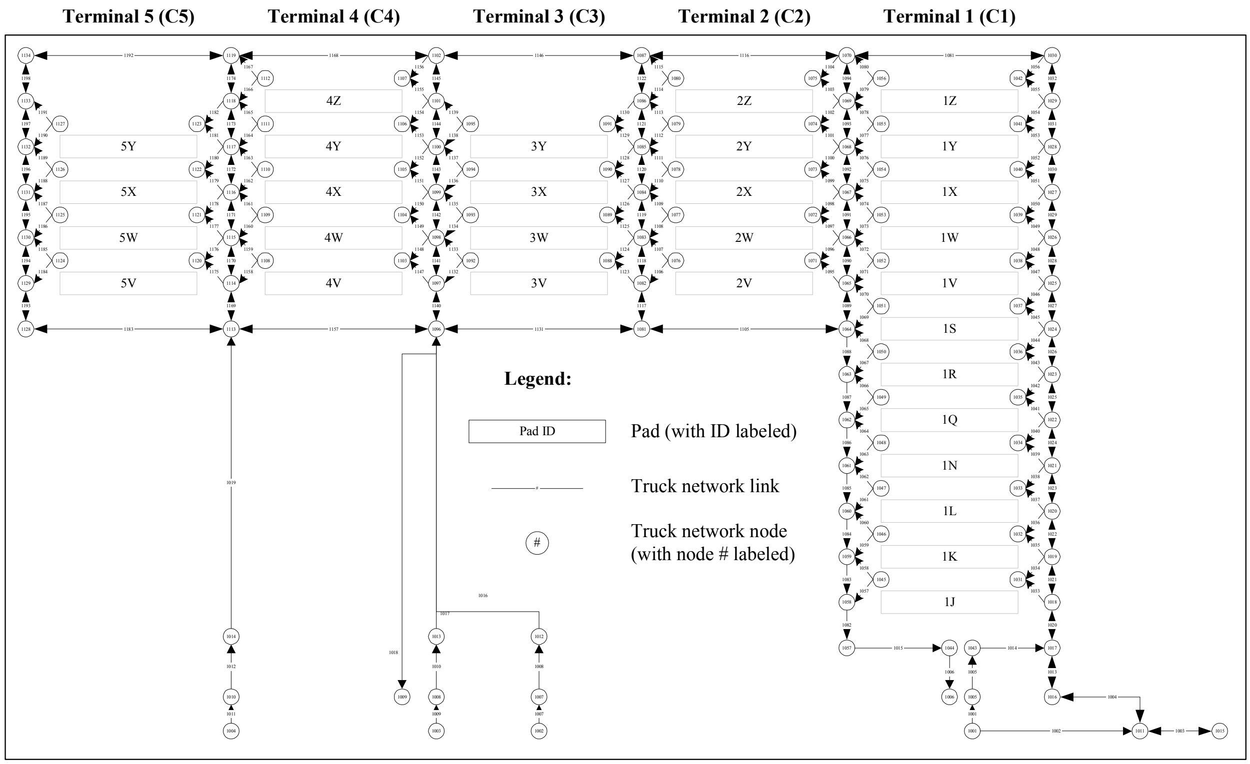

Figure 4.3: Truck Network

4.2.5 Road Crane Movement Control

The cranes go about serving the road trucks according to a few principles. First, they serve those trucks on the pad (i.e. stack) it is on. If there are multiple trucks waiting, they are served in the order of their park locations. As the crane moves toward the waiting trucks, it serves the first truck it comes in contact with, and the second, third, and so forth. Essentially, trucks are served in successive order. Second, crane operators know of a truck's arrival at the blocks as soon as the interchange is printed at the lane for the truck driver (at which time the truck has yet to depart the lane). If there are trucks coming to the pad the crane is on, the crane will stay on that pad. Third, when there are no trucks waiting or coming to the pad the crane is on, the crane operator will search for work closest to it. They do so by looking to serve trucks waiting in the east-west direction (of the inter-connected blocks) first; this is because they seek to perform moves that require minimal wheel turning. The inter-connected blocks are 1V through 5V, 1W through 5W, 1X through 5X, and 2Y through 4Y, as shown in Figure 4.2. Only when there are no trucks waiting in the east-west direction (of the inter-connected blocks) will they go north-south to serve trucks on other blocks. Lastly, cranes will serve any truck they encounter enroute to their destinations. Figure 4.4 illustrates the model logic for road cranes.

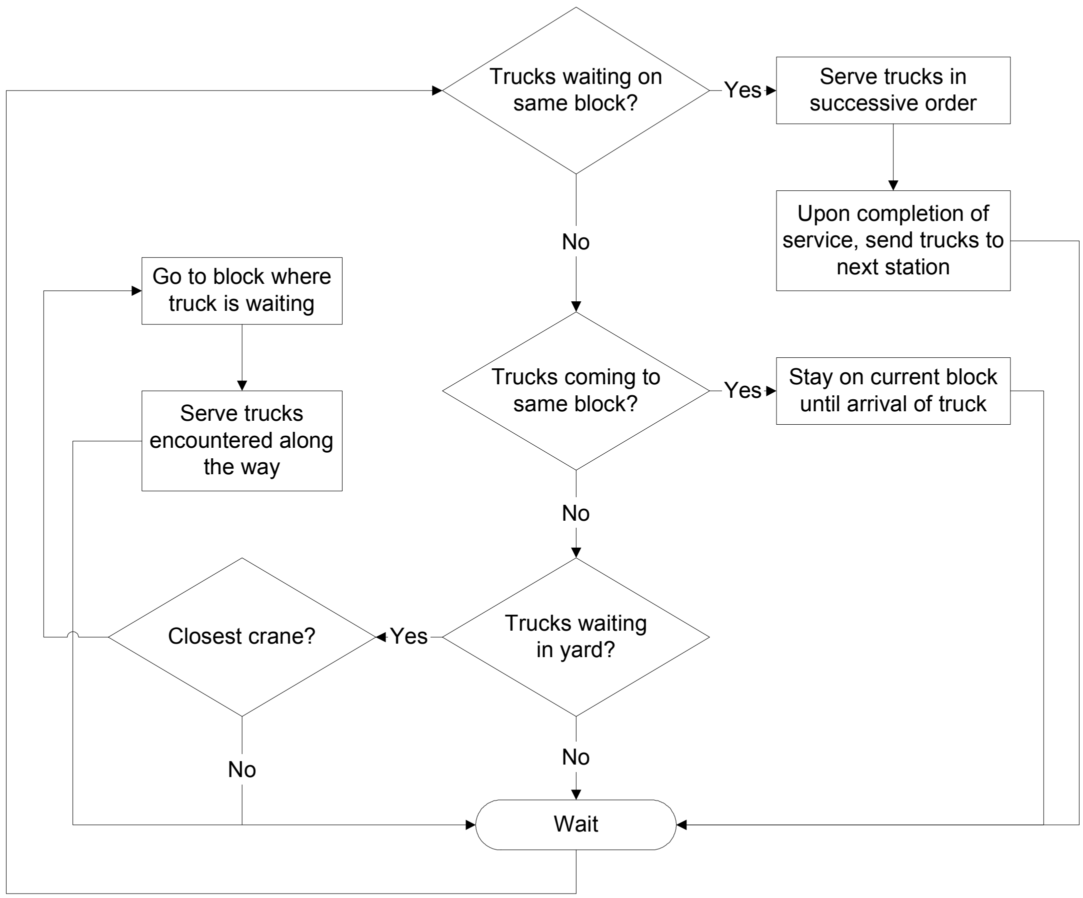

Figure 4.4: Model Logic for Road Cranes

4.2.6 Ship Crane Movement Control

The main difference between ship cranes and road cranes is that ship cranes are assigned to work the vessel trucks, whereas road cranes are assigned to work the road trucks. Another difference is that ship cranes operate on only a few blocks at a time; this is because in unloading and loading a ship, typically only a few export and import blocks are used. Ship cranes operate in the following manner. At the start of the day, they report to their assigned blocks and work the vessel trucks on those blocks. Even though their primary assignment is to work the vessel trucks, they will work the road trucks whenever no vessel trucks are waiting for service. When there is no more work on those blocks, they move on to other blocks to help out other ship cranes, if needed. At lunch time, they help out with road moves, at which time they operate just like road cranes. In the afternoon, ship cranes are again to report to their assigned blocks, which may or may not be the same blocks they were assigned to earlier in the day. They operate just as they did in the morning session. Figure 4.5 illustrates the model logic for ship cranes.

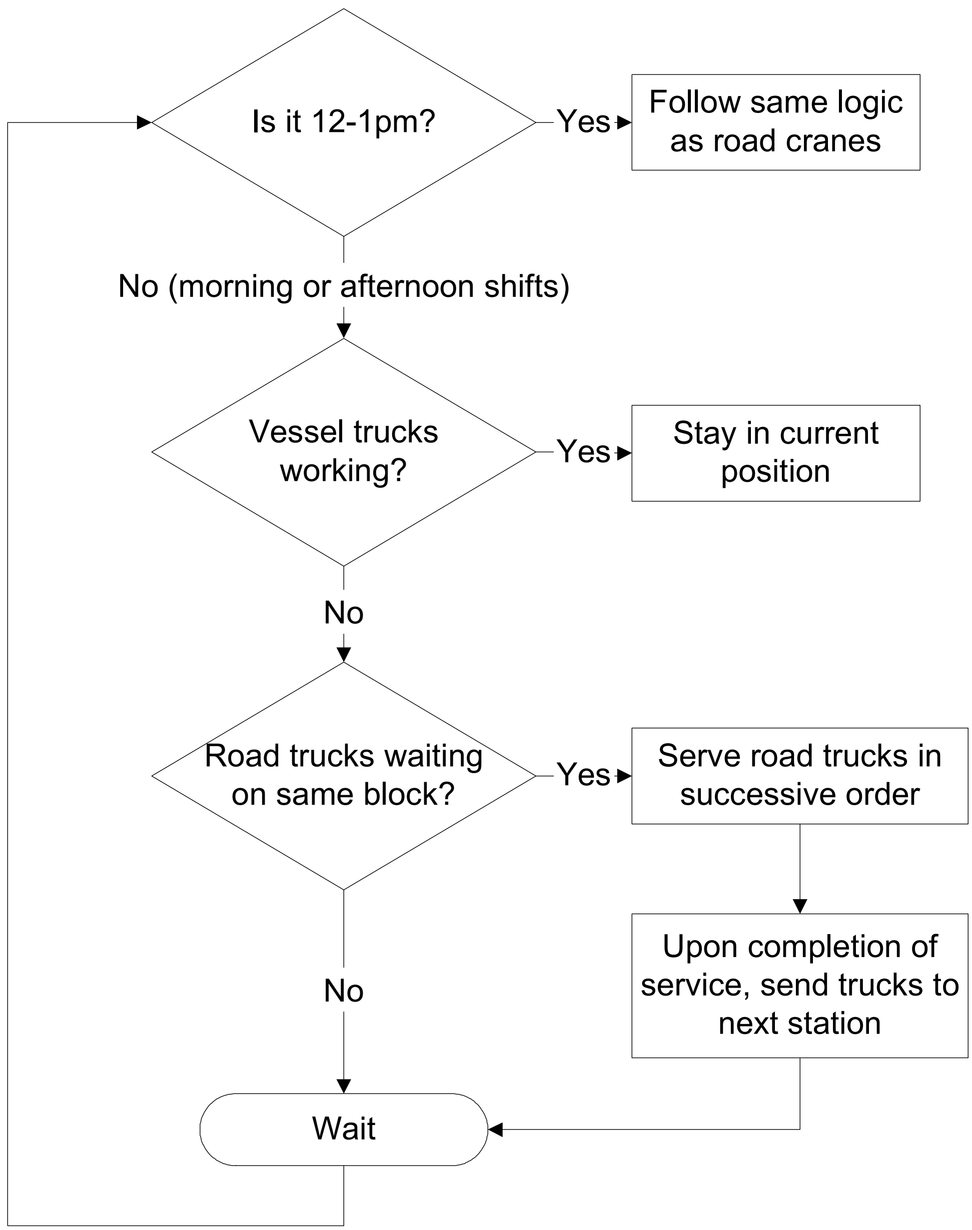

Figure 4.5: Model Logic for Ship Cranes

4.2.7 Processing of Trucks at Entry Lanes

The entry points of trucks in the model are at the gates. These gates correspond to the actual physical gates where trucks need to stop to receive their gate pass (with a time stamp). After receiving the gate pass, the truck will then pull up on the scale for the container to be weighed and inspected (if any) and the interchange to be processed. The processing of in-coming trucks depends on whether a truck is performing a move in (dropping off an export container) or performing a move out (picking up an import container). The main difference is that no inspection is needed upon entry for those trucks performing a move out; however, their container will be inspected when exiting. Trucks with invalid paper work are sent to the customer service station at each respective gate. Once the paper work is cleared and the inspection (if needed) is completed, the truck can proceed into the yard to load or unload the container. It is at this point in the entry process that the modeling of trucks begins. The reason this time is used as the start time is because it gives a more accurate measure of how truck turn time is dependent on crane availability and serviceability. Figure 4.6 illustrates the model logic for trucks at entry lanes.

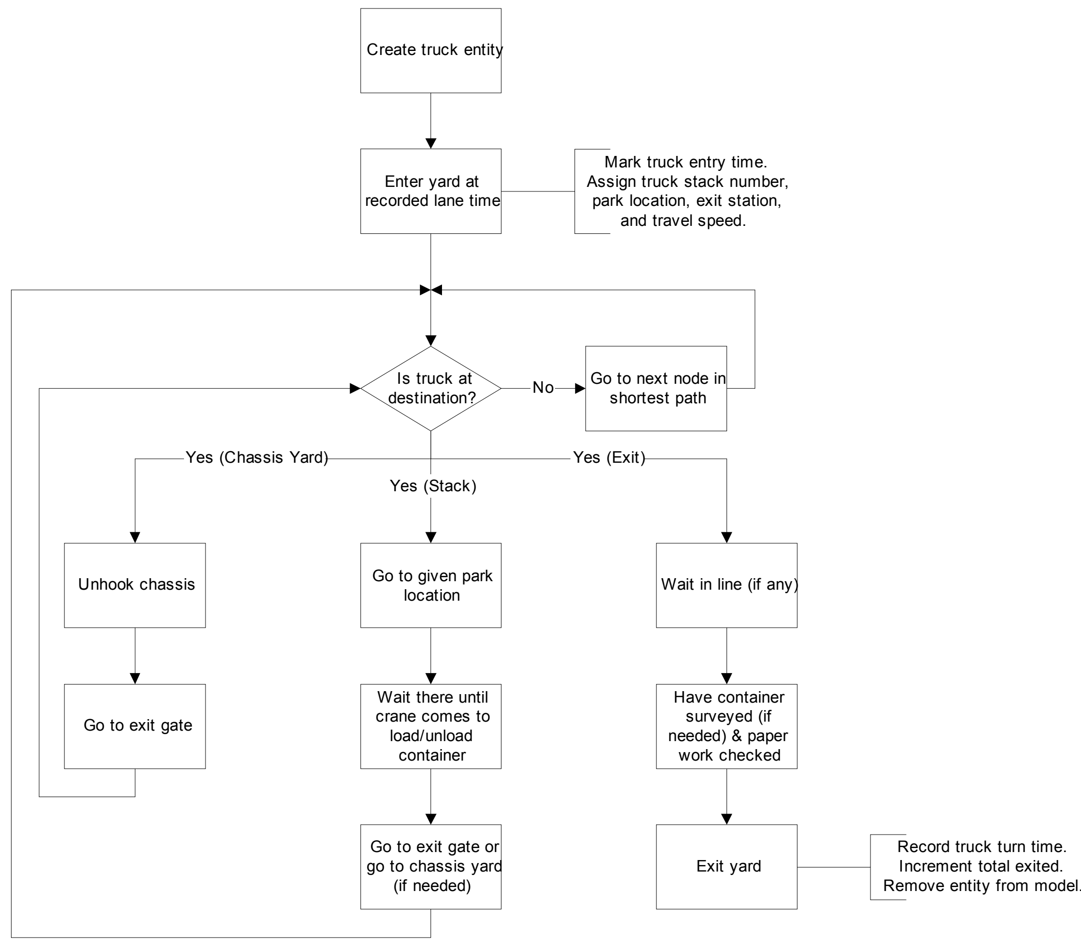

Figure 4.6: Model Logic for Trucks

4.2.8 Processing of Trucks in the Yard

After receiving clearance to proceed into the yard, the truck will go to its assigned pad and park location via the shortest path. Shortest path here means shortest distance path. If certain travel directions are prohibited in the yard, then this condition is met through the creation of the truck network. In other words, the truck network is created in a way that prohibits travel in certain directions. The logic in the yard processing submodel is to simply guide the trucks to their destinations: first to the blocks for loading/unloading of containers, then to intermediate destinations (if applicable), and finally to the exit stations. Figure 4.6 illustrates the model logic for processing trucks in the yard.

4.2.9 Processing of Trucks at the Stack

Upon arrival at their respective park locations, the trucks will wait until they get service; that is, have the container lifted off or have the container put on from the yard cranes. The time it takes the crane to perform such service is shorter when it is unloading. There are two reasons for this. First, only one move is needed in such a case, and second, trucks can take off as soon as the container is lifted off its chassis. This time is estimated from observed data. On the other hand, when loading containers onto trucks, cranes often need to dig out a specific container which might require reshuffling of containers (rehandles). Also, trucks need to wait until containers are secured before they can take off. This time is approximated as the time it takes to perform a single move times the number of rehandles. After receiving service, a truck will then make its way to the exit station, unless it is performing another move. If the truck needs to pick up a container, it will go to an import pad (i.e. the truck is making a double move). If the truck needs to drop off a chassis, it will go to the chassis yard.

4.2.10 Processing of Trucks at the Chassis Yard

Some trucks need to return their chassis before exiting. In that case, they will go to the chassis yard after dropping off the container. Returning the chassis is a simple process that drivers do on their own. They simply back up the chassis into the given location and unhook the chassis from the tractor. From there, they exit the yard. From the modeling perspective, this procedure is nothing more than a simple delay.

4.2.11 Processing of Trucks at Exit Lanes

When trucks complete their moves, they then make their way to the exit lanes. Trucks performing a move out exit through the C4 bobtail out gate, designed to serve those types of out going trucks. There is no inspection at this out gate, just final verification of paper work. Trucks performing other types of moves exit either through the C1 exit lane or C4 exit lane, where there is an inspection. Typically, trucks that entered through the C1 gate will exit through the C1 exit lane, and trucks that entered through the C3, C4, and C5 gates will exit through the C4 exit lane. The inspection process is modeled by delaying the truck for a period of time consistent with observed data. Upon removal of the truck from the simulation model, its statistics are recorded.

4.3 IMPLEMENTATION

The Arena simulation language is used to develop the simulation model. The logic component consists of several submodels, as shown in Figure 4.7. Note that the submodels are not interconnected. So, the submodels are used here simply to separate different parts of the model logic into manageable pieces. The design of the logic component is such that a submodel contains the definition of some elements or piece of the overall logic. As seen, there is a submodel to define the cranes network and another to define the trucks network. There is one submodel that defines all the elements, entity attributes, and global variables used in the model. The control logic of the road and ship cranes' movement are contained in two other separate submodels. To manage the flow of trucks in and out of the yard, the logic is divided into three separate parts: entry, yard, and departure. The details of those submodels which are most difficult to develop are elaborated in subsequent sections. The complexity of the model requires the use of hundreds of modules; therefore, it is not feasible to discuss the function of each module. The following attempts to provide a description of the primary steps that are needed to carry out the logic discussed in the model framework section.

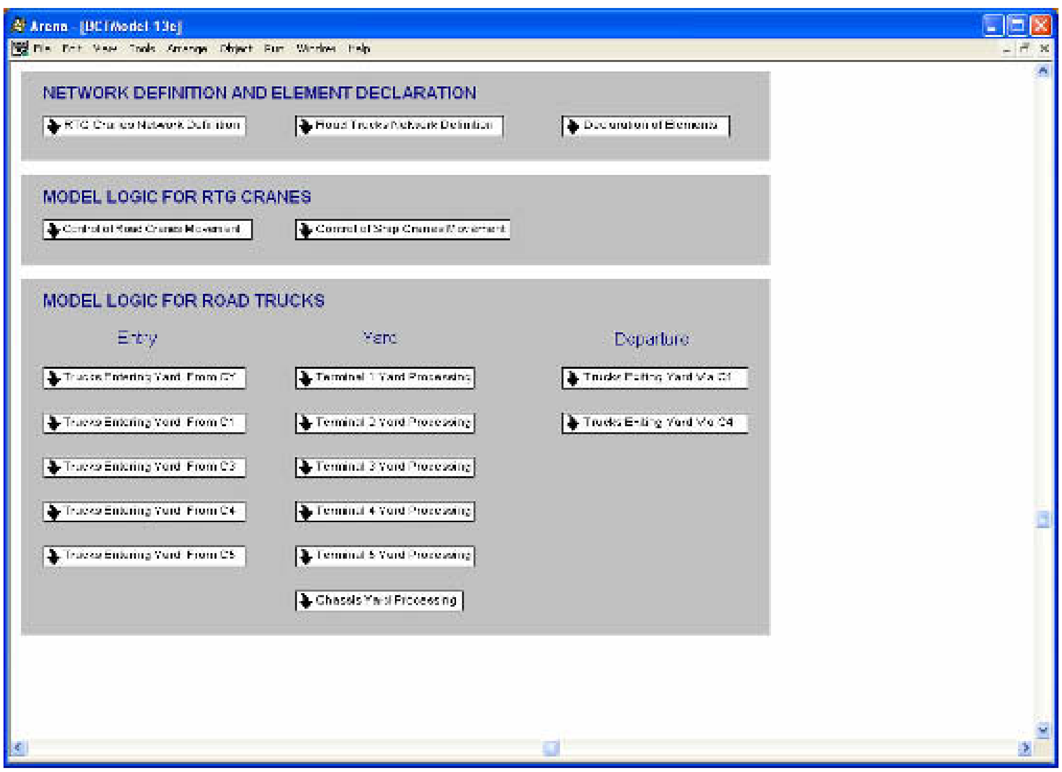

Figure 4.7: BCT Simulation Model Logic

4.3.1 RTG Cranes and Road Trucks Networks Definition

The "RTG Yard Cranes Network Definition" submodel defines the network in which cranes travel. To define the network, the *intersections*, *links*, and *networks* elements are used (see Figure 4.8). More specifically, nodes are entered in the *intersections* element, arcs are entered in the *links* element, and the network is defined by specifying the starting link and ending link in the *networks* element. Similarly, the "Road Trucks Network Definition" submodel defines the network in which road trucks travel. Note the numbering of the road trucks network starts at 1001. This is done to avoid numbering conflict with the cranes network. There are many useful network related functions available to the modeler, such as IDSNET (network distance), LNKNUM (connecting link), NEXTX (next travel intersection), NXB (beginning intersection), and NXE (ending intersection). These variables and others can be found in the help files under transporter guided network variables.

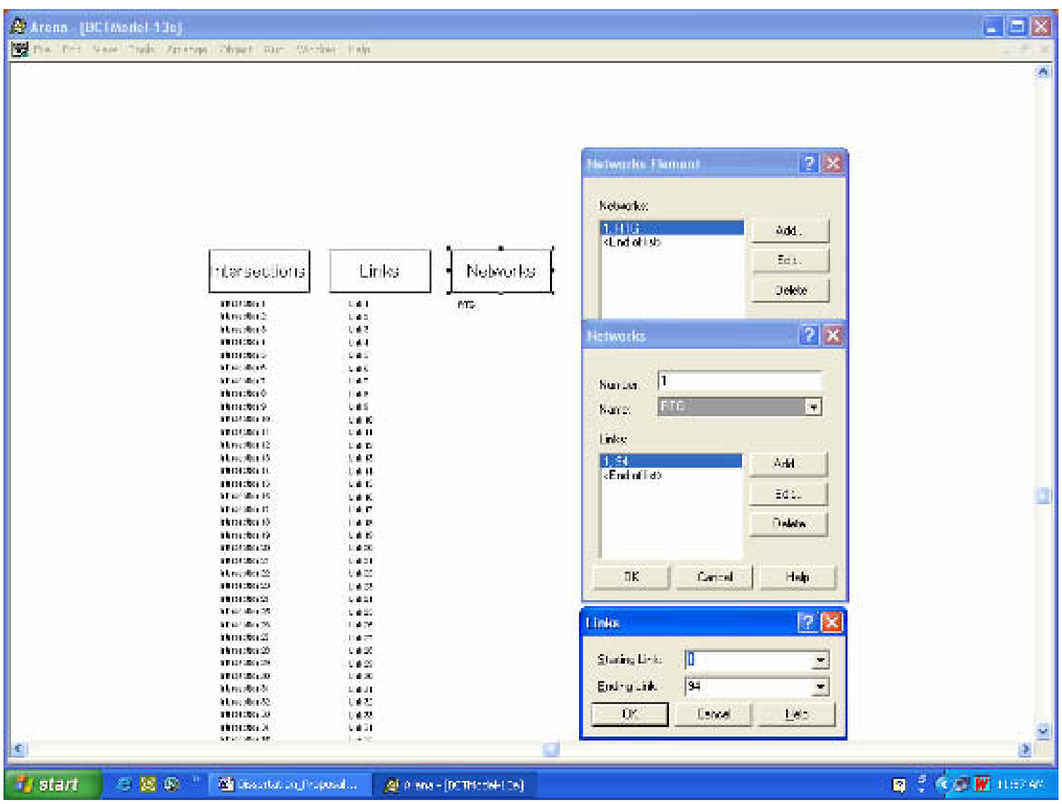

Figure 4.8: Creation of Cranes Network

4.3.2 Declaration of Elements

The "Declaration of Elements" submodel declares all those elements used in the model. As seen in Figure 4.9, these elements include *sets*, *storages*, *expressions*, *variables*, *attributes*, and *transporters*. The *sets* element stores the stacks' link numbers (i.e. the link number of the stack in the crane network). This information is needed by the cranes' movement control logic, to be discussed next. The *storages* element provides a way of showing trucks waiting for service throughout their stay at the terminal. The *expressions* element defines the input data to the model such as a truck's travel speed (often in the form of a distribution). The *variables* and *attributes* elements contain information used to control the movement of trucks and cranes and their statistics. Lastly, the *transporter* element specifies the number of cranes to be used, the network they travel on, and their starting positions (see Figure 4.10).

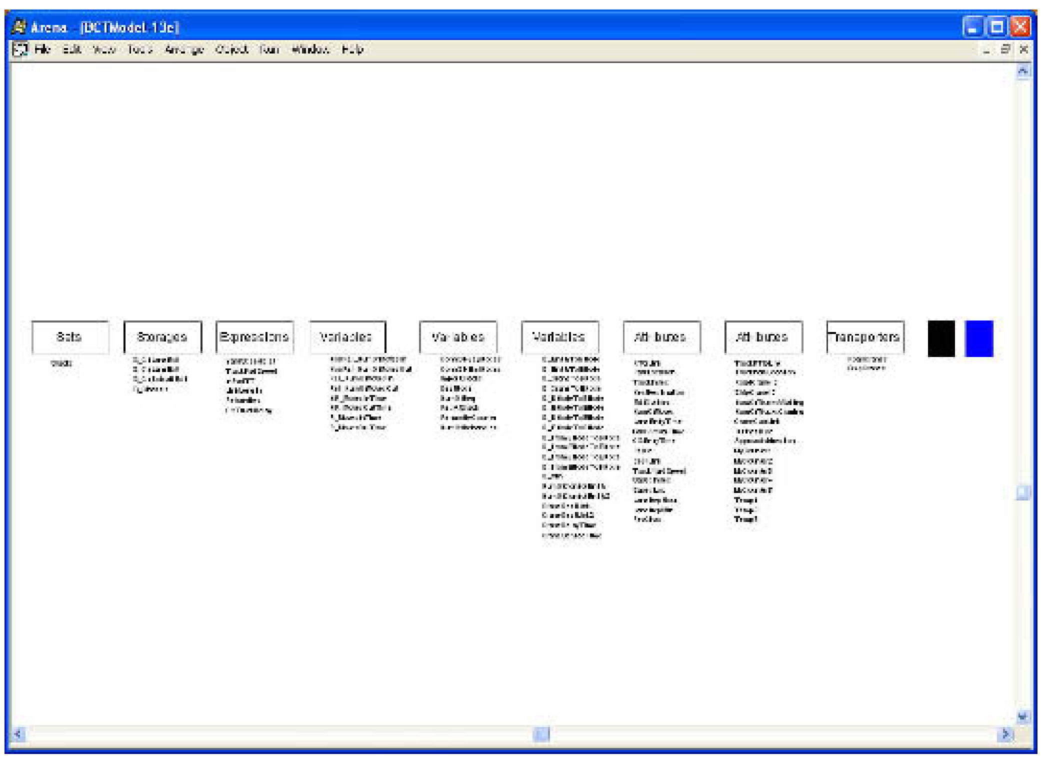

Figure 4.9: Declaration of Elements

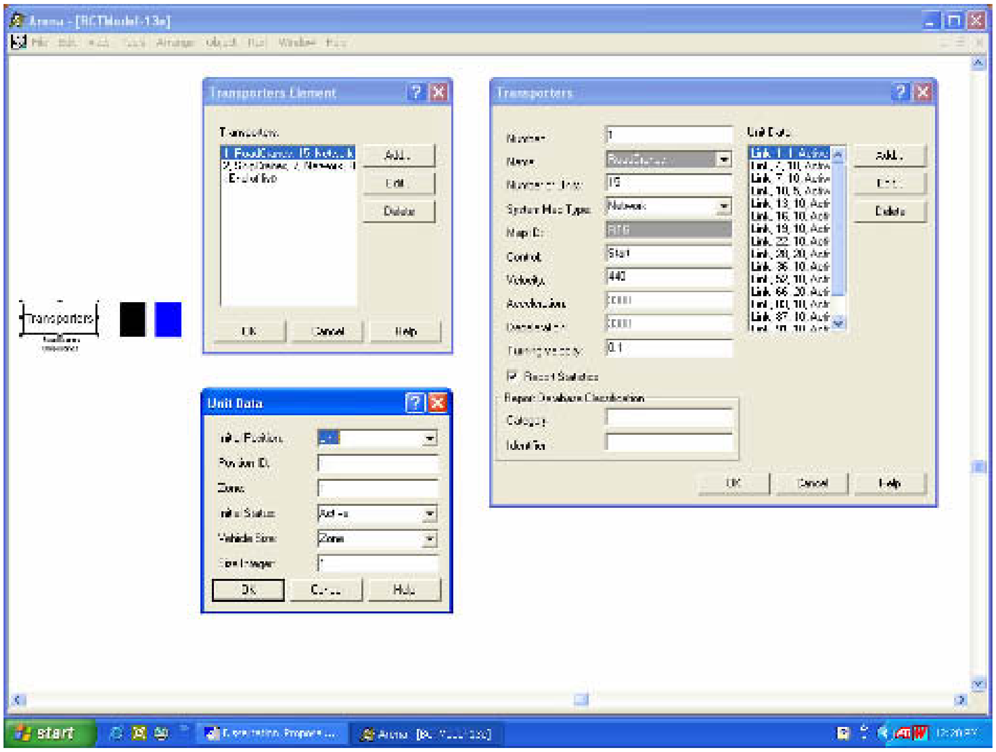

Figure 4.10: Specification of Transporters

4.3.3 Road Crane Movement Control

As the name implies, the "Control of Road Crane Movement" submodel contains the logic for controlling the movement of the road cranes. The first step in the logic (Figure 4.11) is to create entities and allocate cranes (transporters) to them. These entities do not correspond to any physical object. They are created for the sole purpose of controlling road cranes. The next step is to check to see if there are road trucks waiting for service at the stack which the cranes are on. The creation of entities is done on a continuing basis so that at any time each and every crane is assigned to an entity.

For clarity, the following discussion will focus on one particular road crane. Suppose this crane is currently positioned at stack 1J. If there are indeed trucks waiting at stack 1J, then the next step in the logic (Figure 4.12) is to determine if the truck waiting is on the left or right of the crane and then find the farthest waiting truck in that direction. Next, the logic (Figure 4.13) is to move the crane towards the farthest waiting truck found previously. As the crane makes its way there, it is to check along the way to see if there are trucks waiting for service and if there are any, provide service in the order encountered. Service time is dependent on the type of move, which is approximated from observed data. Upon completion of service, the trucks are freed to move on.

After moving the crane to perform service, the next step in the logic (Figure 4.14) is to check to see if there are 1) trucks waiting at the stack the crane is on, and 2) trucks coming to the stack the crane is on. If there are trucks waiting, then the crane is freed from its controlling entity and subsequently the controlling entity is removed from the model. Else, if there are trucks coming, the crane is to wait there until the arrival of the truck(s). At that time, the crane is freed from its controlling entity and subsequently, the controlling entity is removed from the model. The idea behind this logic is that there will be another entity that will take control of the crane on 1J and thus, that crane will pick up where it left off.

If none of the above two conditions are met, then the next step in the logic (Figure 4.15) is to check to see if there are trucks waiting for service at the other stacks and mark those locations. The logic should also check to see if there are road cranes already on those stacks or road cranes heading toward those stacks. If this condition is not met, then the distance between the truck found at the stack and its current position (somewhere on stack 1J) is computed. This procedure is repeated for all trucks in the yard waiting for service. The result of the procedure is that the crane finds a truck waiting for service closest to it. Once the closest truck waiting for service has been identified, the logic checks to see if there is another crane closer to the truck. Furthermore, it checks to see if there is a ship crane already on the stack it found waiting trucks or if its path will be blocked by any of the cranes. If any of these conditions is met, it will remain where it is. If not, it will move to the stack where the waiting truck is.

To get the cranes to favor the east-west direction (as done in practice to minimize wheel turning), a simple modeling trick is employed. This trick involves making the traveling distance in the north-south direction large; north-south directional links are 2, 3, 5, 6, etc. in the cranes network. In doing so, when the cranes look for work closest to it, by comparing distances, the work in the east west direction is always picked first.

The last step in the logic (Figure 4.16) moves the crane to the edge of the stack where the truck is waiting. Before moving the crane, the logic first checks to make sure there is no other crane blocking it at the end of the pad. If there is, it holds the crane where it is. Otherwise, it moves the crane to one end of the stack (which ends depends on the shortest path). As the crane travels to the next stack, it constantly checks for conflict of space with other cranes. If another crane already occupies the space it is moving into, it incurs a delay. If the crane is moving east-west or west-east on row V, W, and X, it checks to see if there are trucks waiting in the intermediate stacks. If there are any, it will provide service to those trucks before continuing on.

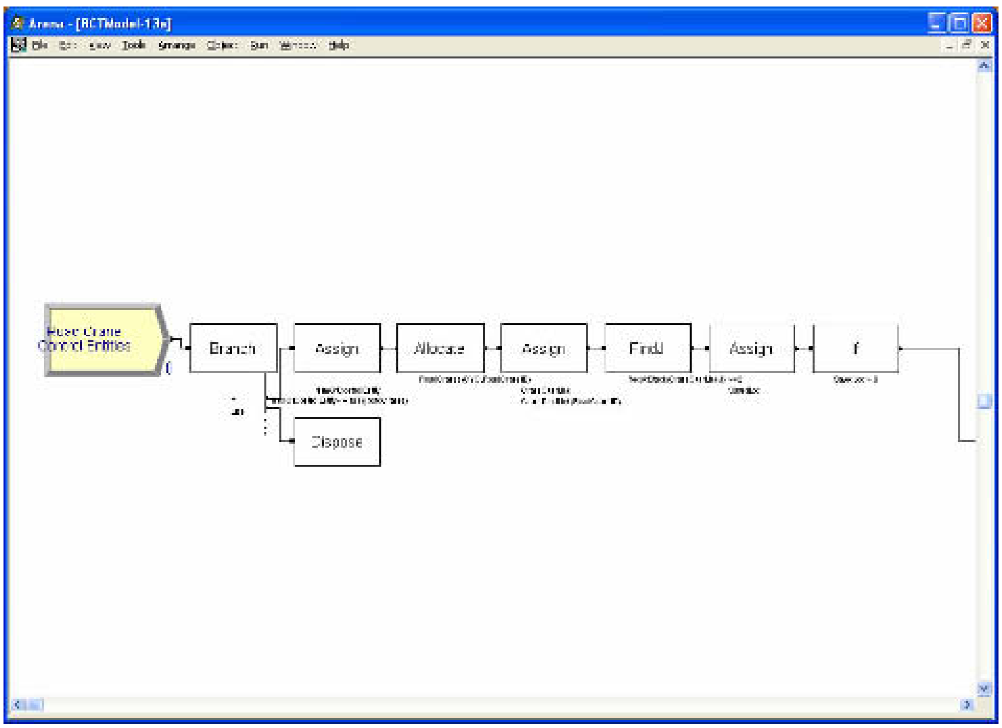

Figure 4.11: Group 1 of Road Cranes Control Logic

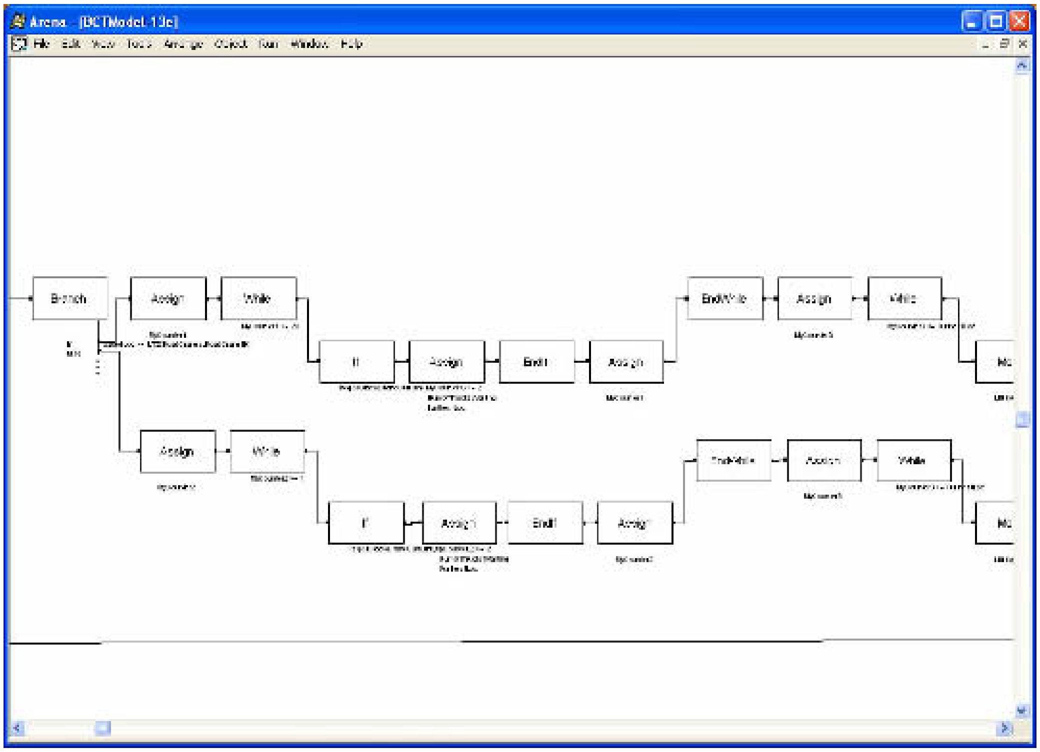

Figure 4.12: Group 2 of Road Cranes Control Logic

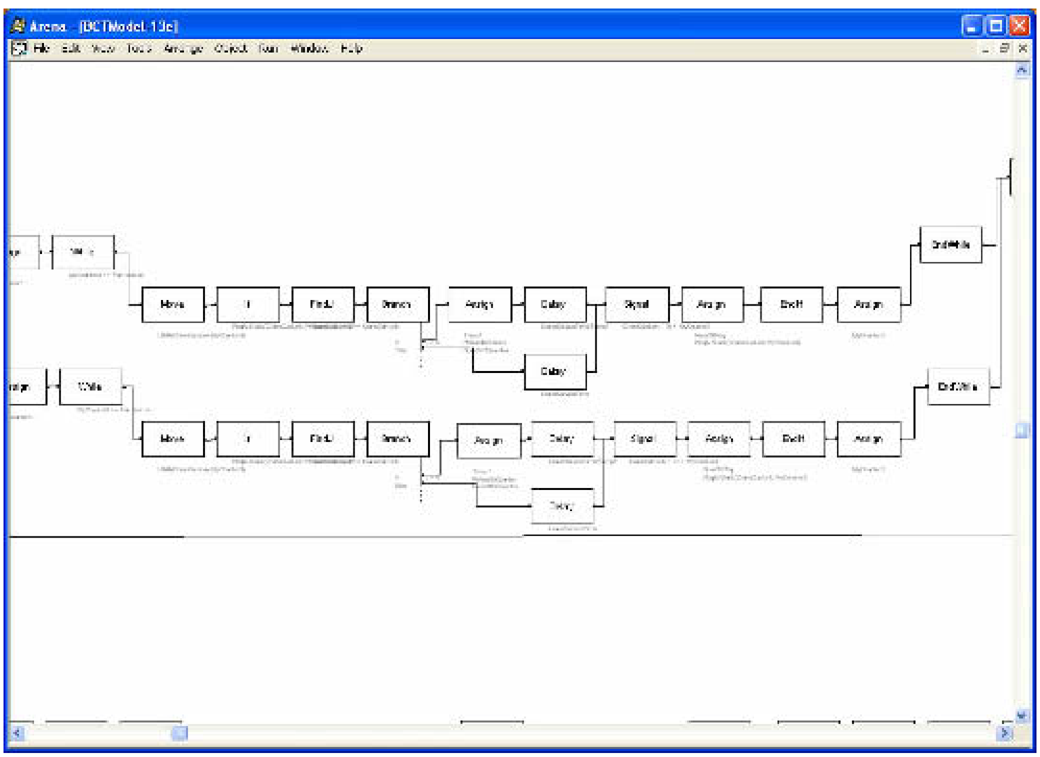

Figure 4.13: Group 3 of Road Cranes Control Logic

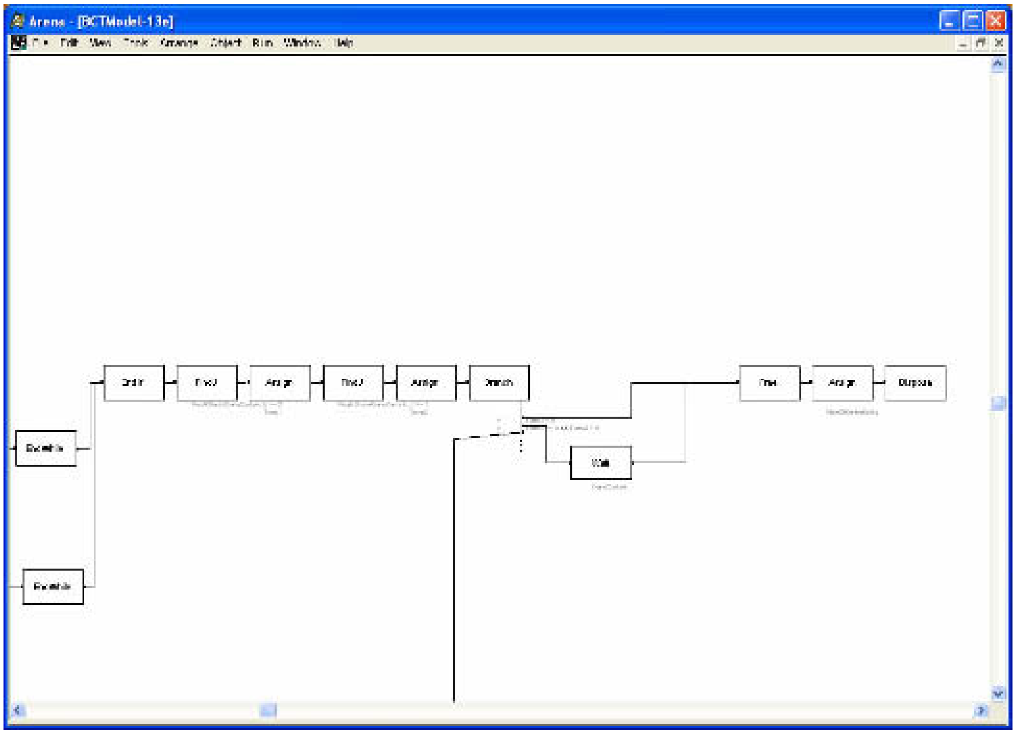

Figure 4.14: Group 4 of Road Cranes Control Logic

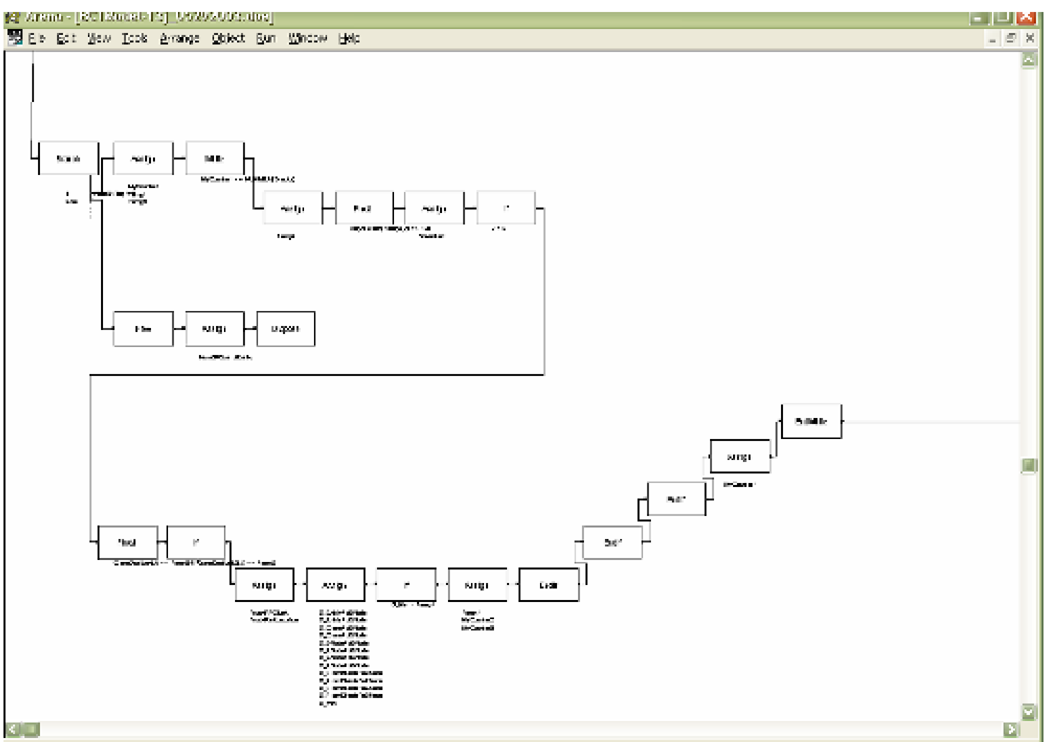

Figure 4.15: Group 5 of Road Cranes Control Logic

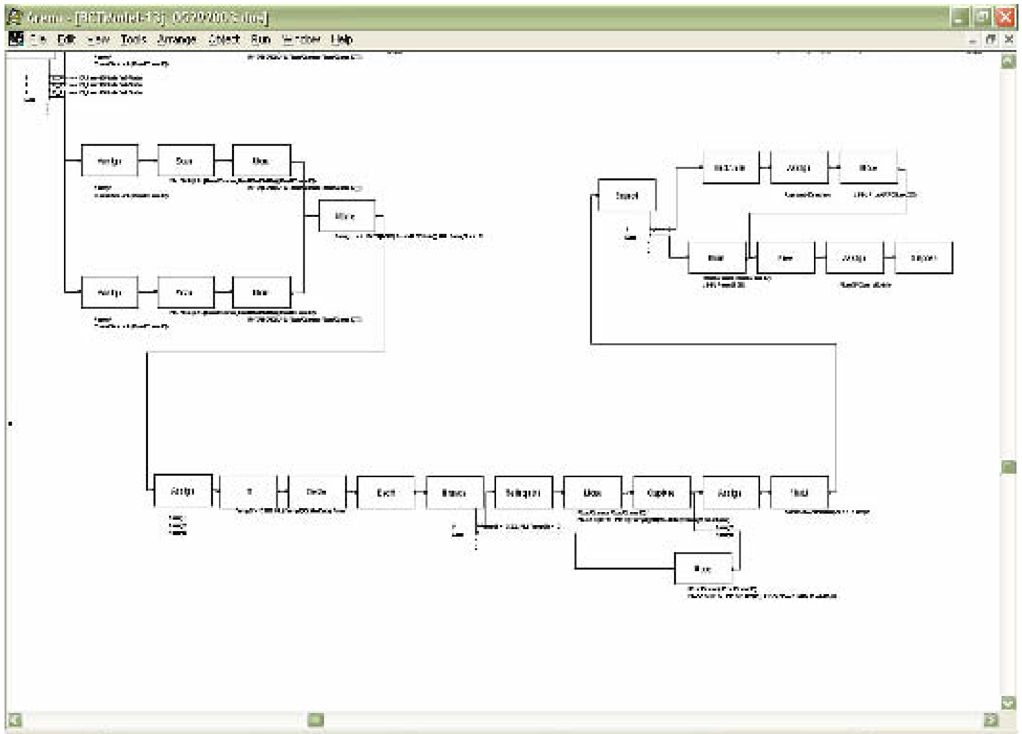

Figure 4.16: Group 6 of Road Cranes Control Logic

4.3.4 Ship Cranes Movement Control

The logic for ship cranes is almost identical to that of road cranes and will not be elaborated as done previously with road cranes. There are a few notable differences which are pointed out here. A time constraint is added to keep ship cranes operating on their assigned stacks for the morning and afternoon shifts. This constraint is relaxed during the lunch hour (noon – 1pm); this results in ship cranes going around the yard to work the road trucks just like road cranes. In the morning and afternoon shifts, ship cranes look first to serve vessel trucks before serving road trucks. This is accomplished by approximating from observed data the percentage of time a ship crane will work road trucks. The idle time of ship cranes (when there are road trucks waiting) can be interpreted as the time they spent working the vessel trucks. Hence, vessel trucks are modeled indirectly – they are not shown in the animation, but are accounted for in the model logic.

4.3.5 Processing of Trucks at Entry Lanes

The logic of all the submodels under "Entry" is almost identical. The main difference is that each station is at a different location in the yard and that each station has a different data file to process. Figure 4.17 shows the logic implemented for the C4 station. The idea is to read in data from a file which indicates when a truck entered the yard, the stack it went to, where it parked, if it was rejected, and if it returned a chassis. For each truck (line of data), the function of the logic is to create an entity to represent the truck, assigns it the truck attributes, and release it into the yard at the appropriate time.

The mechanics of processing a data file is the most challenging part of this logic. Fortunately, Arena provides some very useful examples one can learn from (look up SMART files). As shown in Figure 4.17, the *ReadWrite* module is used to read in a line of data and to process an entire data file, this module is included inside a *While-EndWhile* loop. Inside the loop, for each truck processed, the *Delay* block is used to hold the truck until its recorded entry time. Just before the truck enters the yard, it is assigned attributes known about that truck.

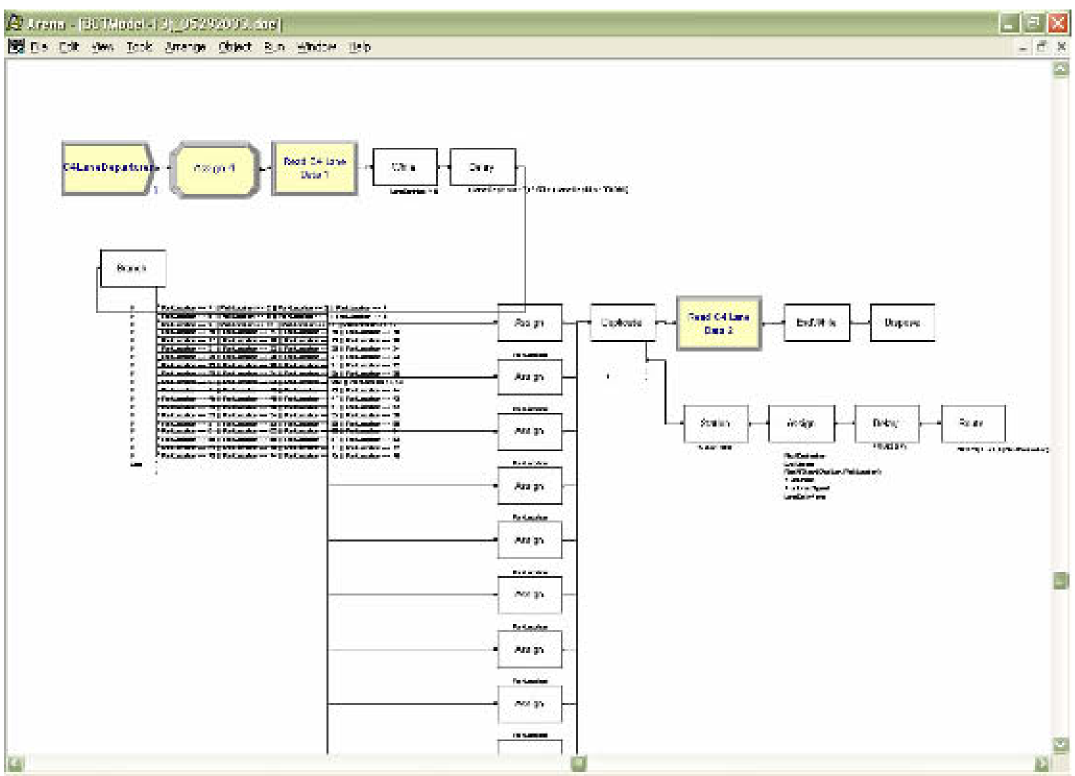

Figure 4.17: Logic for Processing the Entry of Trucks at C4 Lanes

4.3.6 Processing of Trucks in Yard

The submodels under "Yard" are responsible for carrying out the logic for moving trucks in their respective zones. For example, the "Terminal 4 Yard Processing" submodel contains the logic for those trucks that are moving or waiting for service in the terminal 4 area. It includes the processing of trucks at the C4 stacks (4V, 4W, 4X, 4Y, and 4Z). For this discussion, the logic implemented for terminal 4 is elaborated (Figure 4.18).

The logic that processes trucks in the yard works as follows. If a truck enters an intermediate station (i.e. it has not reached its destination node) such as stations 1013, 1096, 1097, and 1098, it is then sent to the next node in the shortest path. Note that there is no logic to determine the shortest path in the truck network. This is because when using the NEXTX command to send trucks to the next node, the underlying model engine computes the shortest path from the specified network and returns the appropriate next node.

If a truck reaches its destination node and that node is tied to a particular stack (e.g. node 1103 is tied to stack 4V), then it is sent to its park location. This is accomplished through the use of a self-created template labeled "Truck Service Lane" (Figure 4.19). The reason for making this part of the logic a template is because of the number of times it is used in the model. In all, there are 30 stacks. Experience proves this is a time-saving technique.

The idea of the self-created template is to guide trucks from one park location to the next until it reaches its designated park location. When that happens, it will broadcast to the crane that may be waiting on the stack that it is there; this is done with the use of the *Signal* block. When cranes know there are trucks coming to the stacks they are on, they will *Wait* there. Once it sends the signal, the truck will then *Wait* there until a crane comes to load/unload the container and then releases the truck with the *Signal* block. The use of the combination *Signal*-*Wait* is what enabled the interplay between cranes and trucks.

In addition to the five terminal areas, there is also the chassis yard where trucks go to drop off their chassis. The logic there (Figure 4.20) is simply to *Delay* the trucks for a period of time consistent with observed data. From there they are routed to the exit station (C4 bobtail exit).

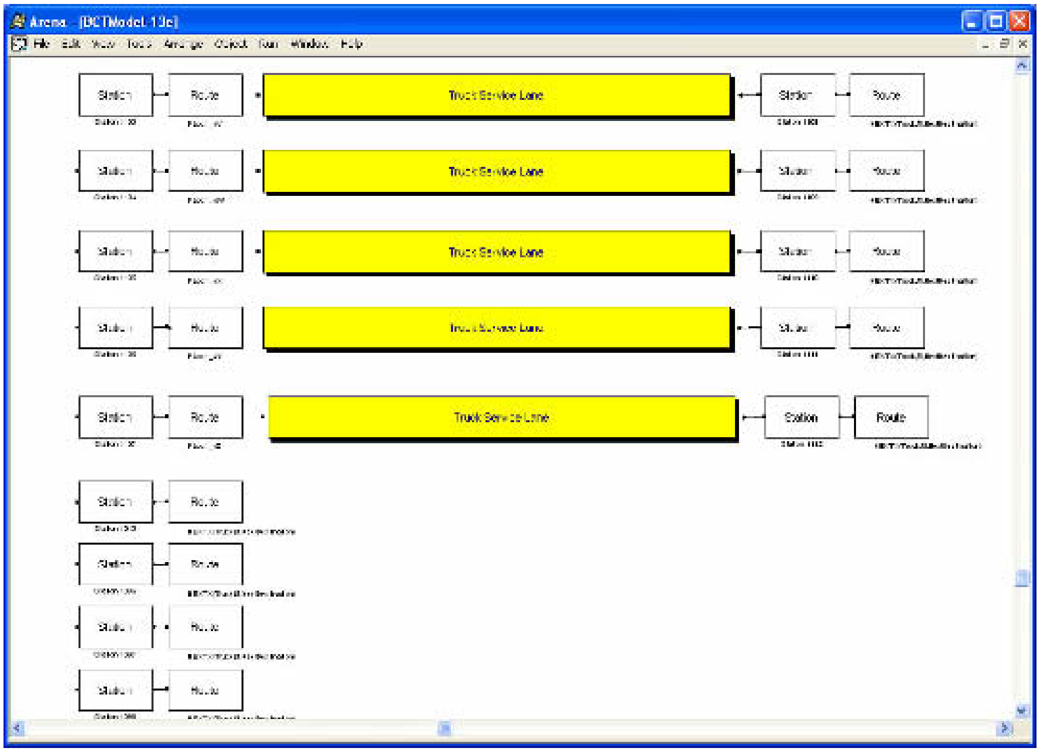

Figure 4.18: Logic for Processing Trucks in the Terminal 4 Area

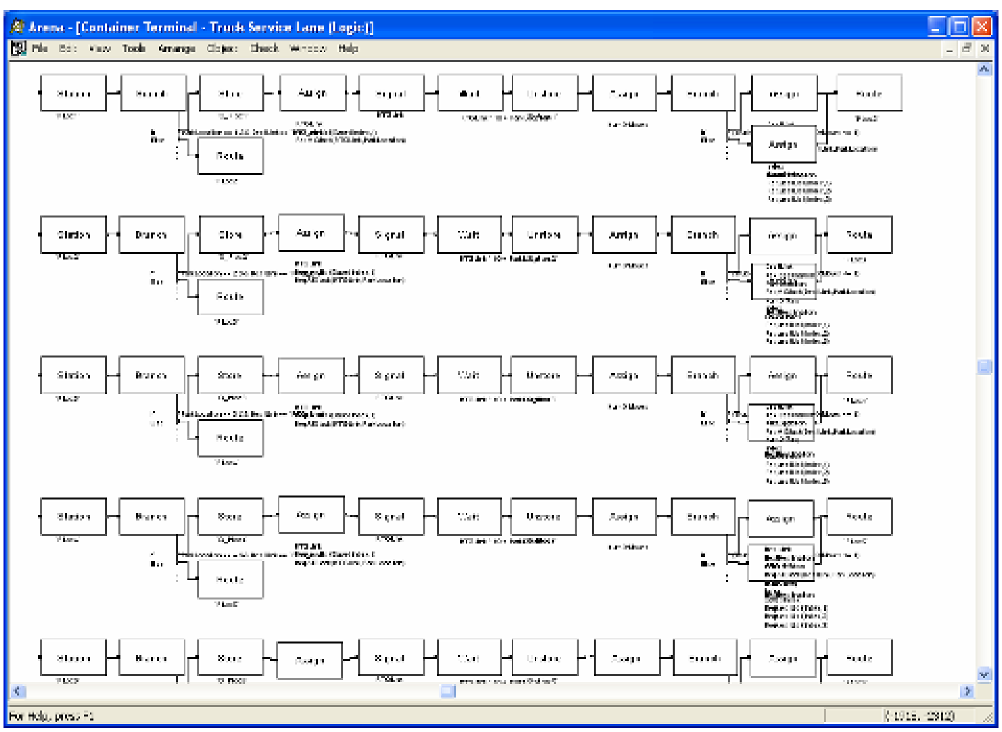

Figure 4.19: Logic of “Truck Service Lane” Template

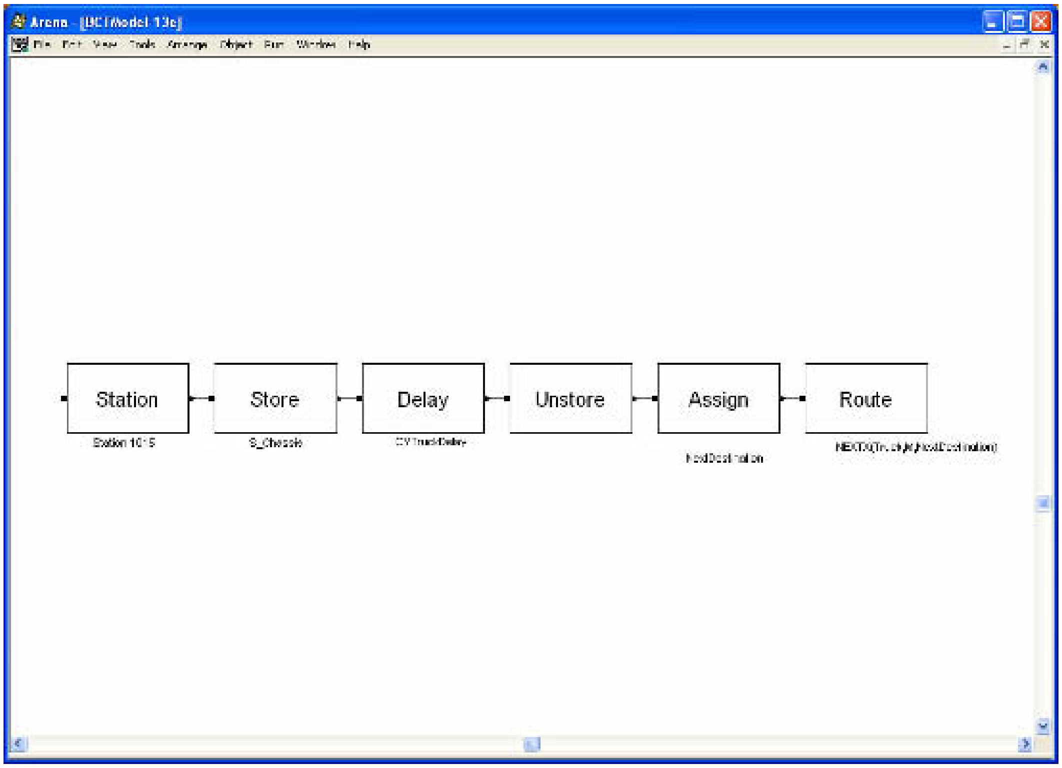

Figure 4.20: Logic for Processing Trucks at Chassis Yard

4.3.7 Processing of Trucks at Exit Lanes

To model trucks going through the checking process at the exit lanes, the combination of *Store-Delay-Unstore* is used, as done in other parts of the model logic. Essentially, the idea is to queue up those trucks waiting to exit and delay each truck for a period of time consistent with observed data. The delay time is dependent on whether or not a survey of the container is needed. It typically takes trucks longer to exit if they take out a container. The logic implemented for the C4 exit lanes is shown in Figure 4.21. Note that there are two types of exit lanes at C4, one for trucks with container and one for trucks without container. The delay time clearly shows how one process is faster than the other. The final step in the processing of trucks at exit lanes is to update statistics, namely, number of trucks that exited and turn time, for both rejects and non-rejects.

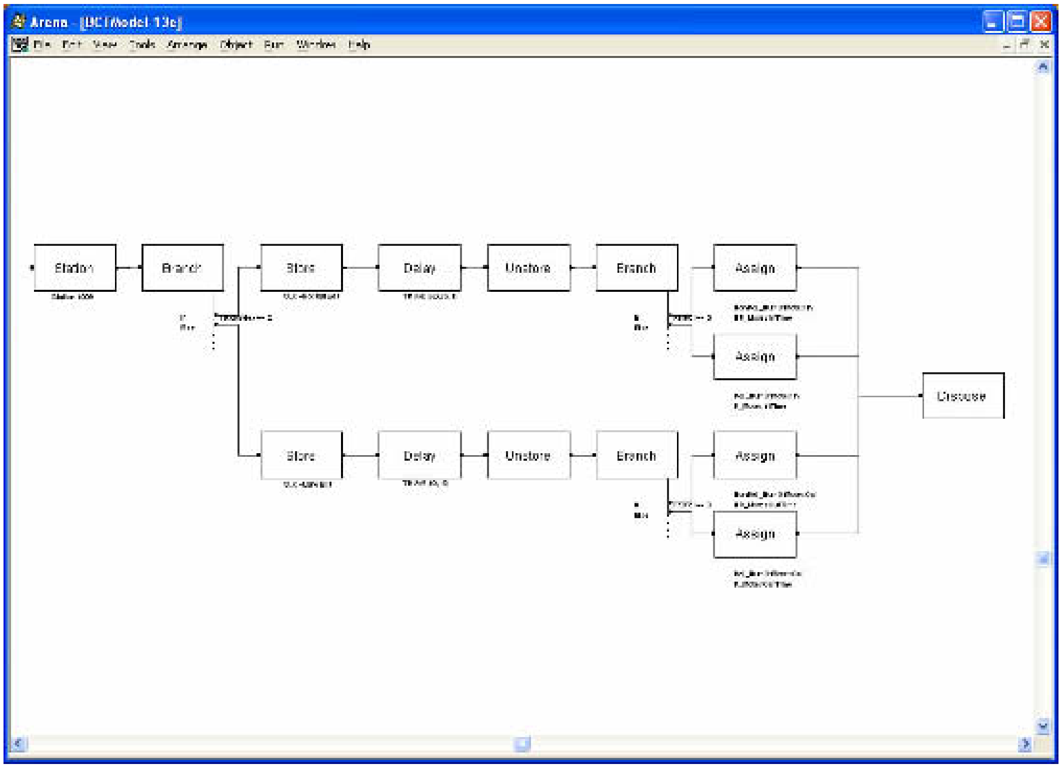

Figure 4.21: Processing of Trucks at C4 Exit Lanes

4.4 SIMULATION MODEL INPUT PARAMETERS

This section lists the parameters input into the model. The values of these parameters are either actual values recorded, values given by the BCT staff, or are estimated values from observed data using Arena's Input Analyzer. As shown in Table 4.1, these parameters belong to one of three main entities modeled: road trucks, road cranes, and ship cranes.

Table 4.1: Simulation Model Parameters

BCT Simulation Model Parameters	
Road Trucks' Parameters	**Values**
Yard travel speed (mph)	TRIA(10,20,35)
Stack travel speed (mph)	TRIA(5,10,15)
Time to drop off chassis (min)	TRIA(0.85,1,1.5)
Exit time with survey of container (min)	TRIA(4.5,6,28.5)
Exit time with no survey of container (min)	TRIA(0.02,0.099,0.3)
Road Cranes' Parameters	**Values**
Time to perform a single move (min)	0.26+LOGN(0.941,0.519)
Number of rehandles to retrieve import containers	CONT(0.000,1.220,0.016,1.414,0.359,1.608,0.906,1.802,0.969,1.996,1.0,2.190)
Delay time when there is a space conflict (min)	TRIA(2,4,6)
Speed (mph)	440
Acceleration/decleration (mph^2)	3300
Time to find next job (sec)	50
Ship Cranes' Parameters	**Values**
Time to perform a single move (min)	0.26+LOGN(0.941,0.519)
Number of rehandles to retrieve import containers	CONT(0.000,1.220,0.016,1.414,0.359,1.608,0.906,1.802,0.969,1.996,1.0,2.190)
Delay time when there is a space conflict (min)	TRIA(2,4,6)
Percentage of time it will serve road trucks	24.81
Speed (mph)	440
Acceleration/decleration (mph^2)	3300
Time to find next job (sec)	50

4.5 SIMULATION MODEL OUTPUTS

When running the simulation model for a period of 10 hours a day and for many days, the animation is typically turned off to speed up execution time. In doing so, the statistics shown in the animation output are not available at the end of the run. Thus, to be able to view results at the end of the run, similar statistics are generated in the end-of-run report; this is accomplished through the use of *Record* modules in the implementation of departure submodels. A sample of what is included in the report is shown below in Figure 4.22. As explained previously, the most relevant statistics are those pertaining to truck turn time.

A minor clarification is needed regarding the label "Half Width". They are half widths of confidence intervals (at the 95% level) on the expected value of the corresponding performance measure, provided that the simulation produces adequate data to form them. Because the results shown in Figure 4.22 are obtained after only a single iteration, no values are reported. However, if more than one replication were performed, Arena would take the summary results for an output performance measure from each replication, average them over the replications, compute the sample standard deviation from them, and finally compute the half width of a 95% confidence interval on the expected value of this performance measure. The formula to compute half widths is shown below (Kelton et al., 2002).

$$h = t_{n-1,1-\alpha/2} \frac{s}{\sqrt{n}}$$

where,

h = half width of the $(1-\alpha)$ confidence interval, $\alpha = 0.05$

s = sample standard deviation

n = number of replications

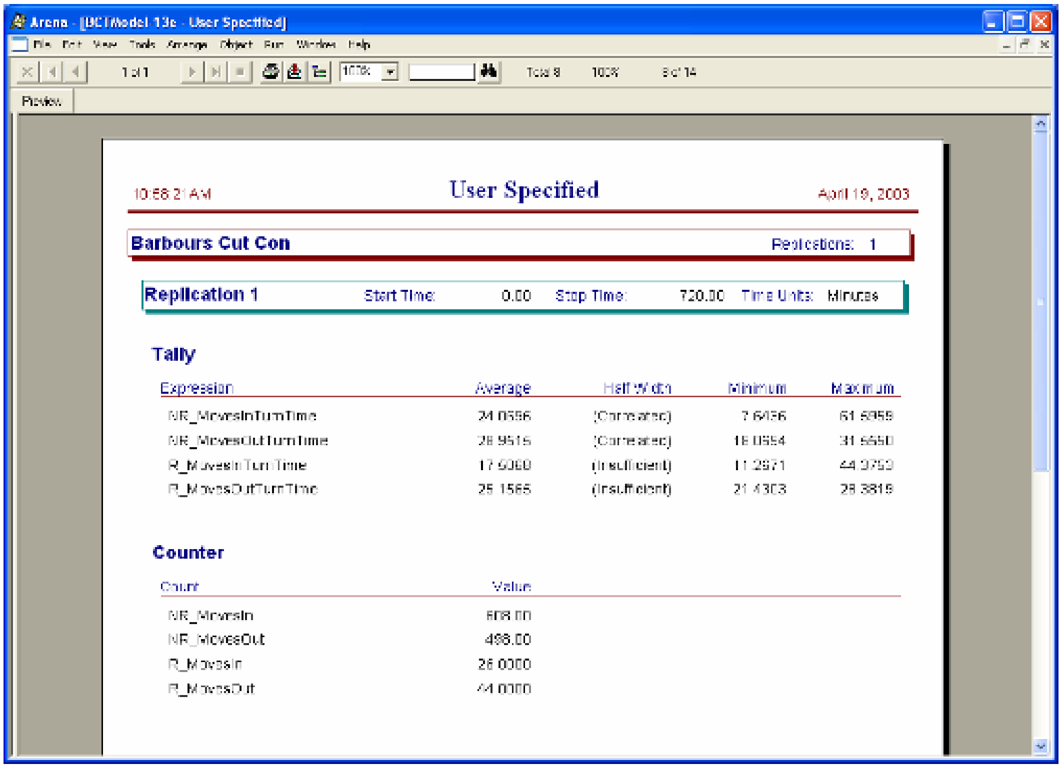

Figure 4.22: Simulation Model Outputs on Road Moves and Turn Times

Another performance measure often looked at is the cranes' utilization. Arena provides these statistics automatically when transporters are used in the model. Figure 4.23 shows a sample of what is included in the report.

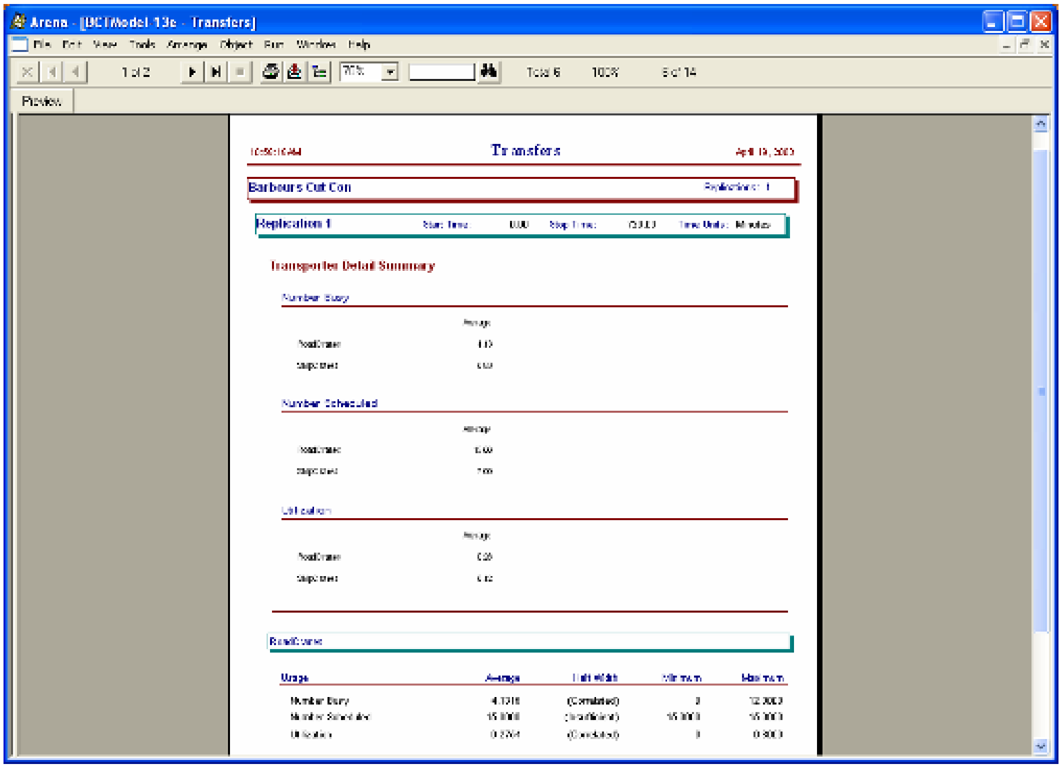

Figure 4.23: Simulation Model Outputs on Cranes' Performance

4.6 MODEL VERIFICATION AND VALIDATION

Model verification is defined as the task of ensuring that the model behaves as the modeler intended. In the early stages of model development, the focus is more on verifying that the model is performing correctly at the source level. To this end, a tool that is used extensively to debug the model is Arena's command-driven Run Controller. It allows the modeler to step through the program in increments (i.e. as an entity progresses from one module to the next) and view the resulting effect. This capability and that of being able to view SIMAN source codes generated from the model provided all the details needed to verify the model is functioning as intended. Other debugging functions used are Break on Module and Highlight Module.

In addition to using Arena's debugging tools, a great deal of effort is put into developing the animation to verify the logic implemented (see

Figure 4.24). The animation proved to be the biggest help in debugging the model at the output level. The ability to visually see how trucks and cranes move about the yard makes it easy to detect unintended and undesired movements. The animation allowed for the testing of many model logics that are easy to verify visually, but would have been laborious to do at the code level. Those logics tested range from checking to see if trucks indeed take the shortest path to checking to see if a truck is served by the nearest crane.

Model validation is defined as the task of ensuring that the model behaves in the same manner as the real system and yields results within an acceptable level of accuracy. To this end, model parameters are fine tuned with the goal of matching model outputs (average truck turn time) to actual values. Matching here means the two results are close in values (within 10 percent). The parameter found to be most sensitive, meaning it changes proportionally with truck turn time, is the crane wait time between the completion of a job and the start of the search for the next job. Figure 4.25 shows the relationship between crane wait time between jobs and truck turn time. This parameter is used extensively in calibrating the model. Three different data sets are used in the calibration: 7/30/02, 5/15/03, and 5/29/03. The average truck turn time yield by the simulation model versus actual truck turn time are as follows.

- 7/30/02: actual = 43.96 minutes; model = 46.37 minutes ± 3.16 ($\alpha = 0.05$)
- 5/15/03: actual = 32.55 minutes; model = 35.79 minutes ± 3.12 ($\alpha = 0.05$)
- 5/29/03: actual = 38.73 minutes; model = 38.12 minutes ± 2.9 ($\alpha = 0.05$)

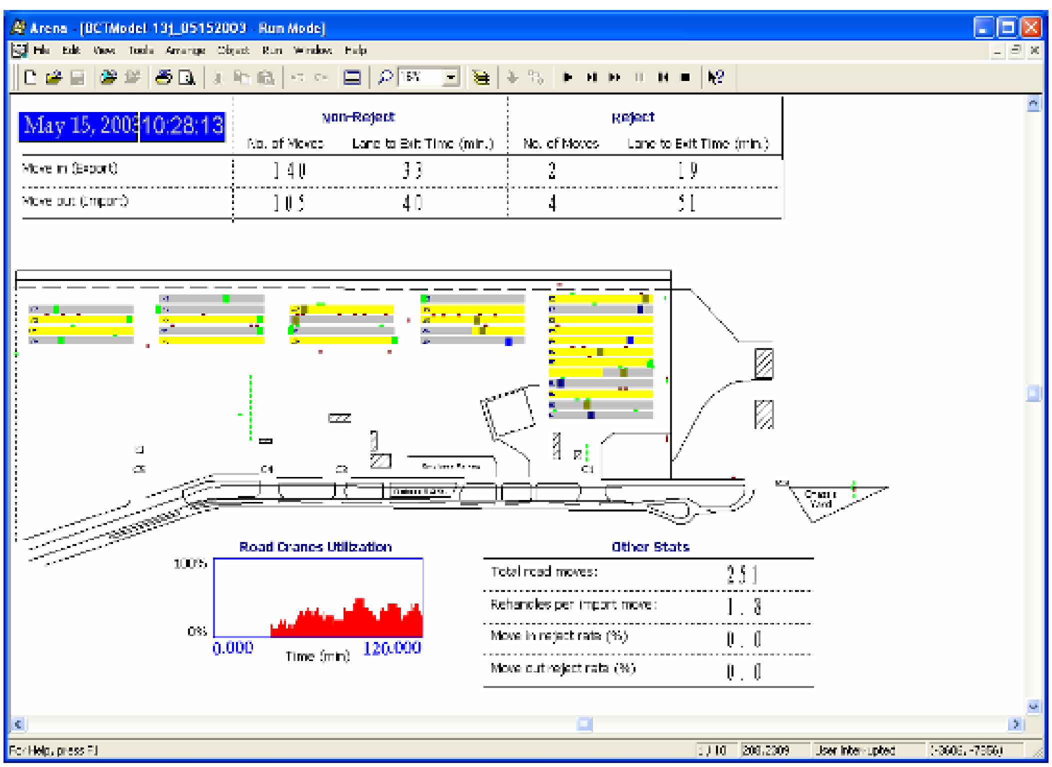

Figure 4.24: BCT Simulation Model Animation

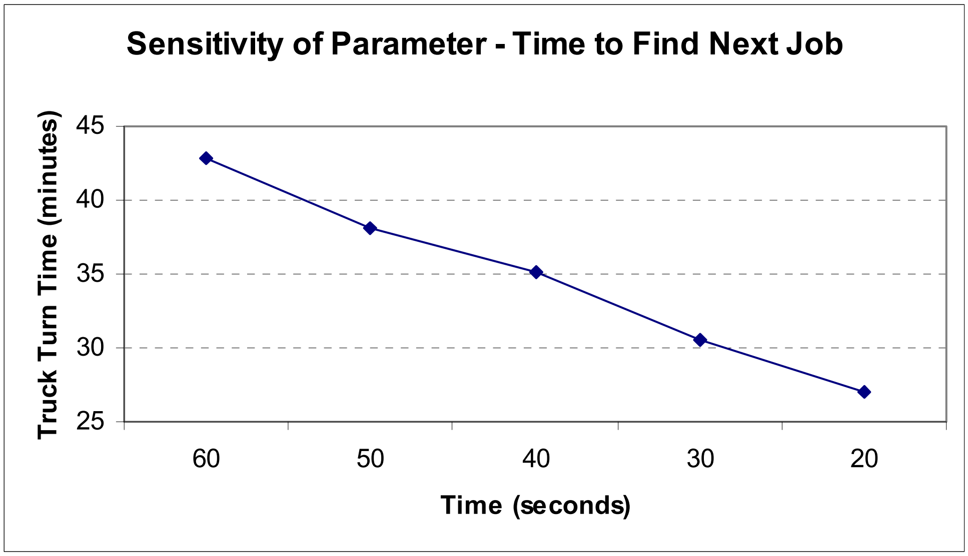

Figure 4.25: Sensitivity of Truck Turn Time to Crane Wait Time between Jobs

4.7 APPLICABILITY OF THE DEVELOPED SIMULATION MODEL

Since each container terminal is unique, applying the model to another terminal requires the analyst to follow nearly the same steps that were taken to build the model described herein. The essential steps are to design the truck and crane networks and to develop the logic in which yard cranes go about servicing trucks. Inevitably, some decisions will need to be made about which process can be simplified without sacrificing the model realism. For example, instead of developing three different sets of logic for handling containers of 20 feet, 40 feet, and 53 feet, a single logic can be used with the assumption that all three types of containers are handled in the same manner, except that longer containers require longer handling time. The handling time for each type of container will need to be estimated and subsequently feed into the model. The required data for the model are shown Table 4.1, plus truck data. Truck data are to include arrival time of each truck and where it went to drop off or pick up the container. Model validation requires the fine tuning of some or all of the parameters shown in Table 4.1. Validation is extremely tedious for a model of this size and complexity because a set of parameters may yield good results for one day, but not the next. Hence, a threshold must be set on what is considered “close enough”.

4.8 MODEL APPLICATION AND RESULTS

To determine the effect of road cranes on truck turn time, the developed simulation model is applied to two sets of data. The first set is data from May 15, 2003. On this day, there are 1028 trucks, 15 road cranes, and 5 ship cranes. The second set is data from May 29, 2003. On this day, there are 1318 trucks, 17 road cranes, and 5 ship cranes. The idea of the experiment is to examine the changes to truck turn time if there were additional road cranes available, all else constant. The experiment is run with 10 replications using the input parameters shown in Table 4.1. The results are shown in Figure 4.26.

The individual data points (and its confidence interval, $\alpha = 0.05$) in Figure 4.26 show that adding an additional road crane does not necessarily lower truck turn time. The reason for this is due to randomness in various processes. For example, it could be that ship cranes consistently (over 10 replications) serve fewer road trucks. So, even with an additional road crane, it is conceivable that the overall average truck turn time could be higher. Another reason why adding another road crane does not necessarily lower truck turn time is because of where it is placed in the yard. That is, it could be placed where it does not have the opportunity to perform more moves because work is closer to other cranes.

The model results are useful when viewed collectively as a whole. As can be seen, the trend is decreasing, which suggests that having more road cranes will lower truck turn time. Results from May 15, 2003 indicate that on average an additional road crane reduces truck turn time by 1.11 minutes (or 3.4 percent), while results from May 29, 2003 indicate that an additional road crane reduces truck turn time by 0.39 minutes (or 1 percent). These findings correspond to regression results discussed in chapter 3; it is found via regression that to reduce truck turn time from 45 minutes to 40 minutes, four additional road cranes are needed (i.e. one additional road crane reduces truck turn time by 1.25 minutes).

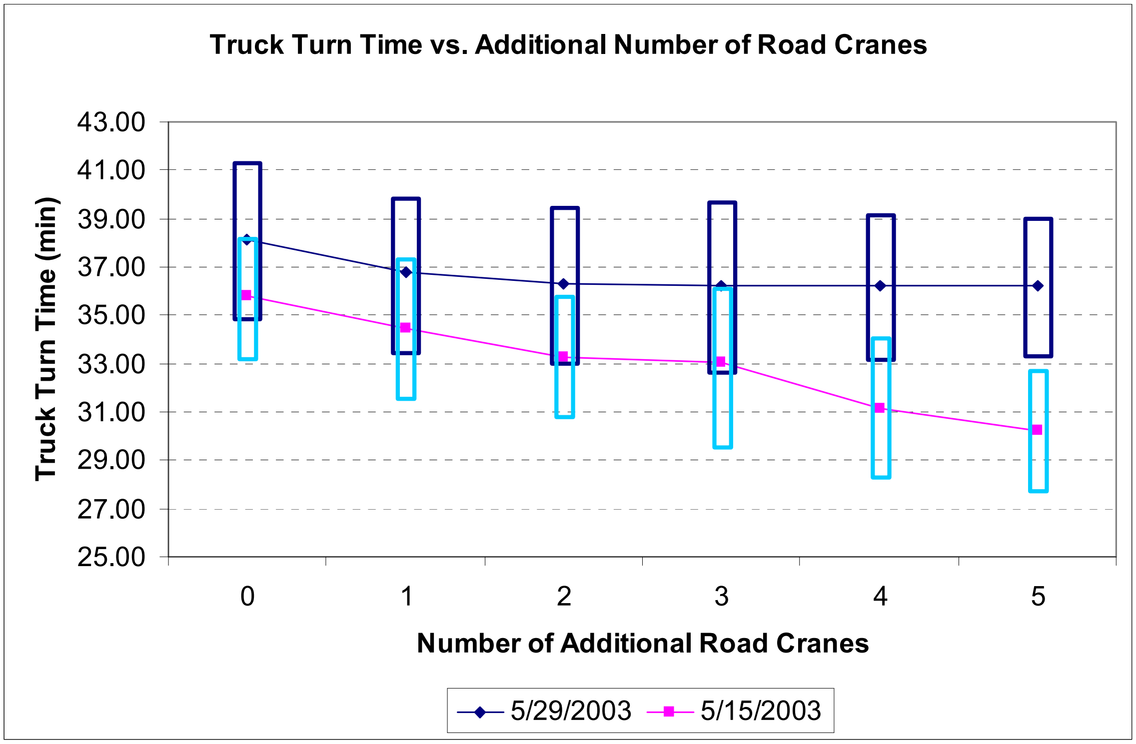

Figure 4.26: Effect of Having Additional Cranes

4.9 SUMMARY AND CONCLUSION

This chapter presents the development of a simulation model for the analysis of truck turn time with respect to crane availability and deployment. It is accomplished by modeling the precise movements of trucks and yard cranes. The model is built using the Arena simulation language. The developed model uses the Barbours Cut Container Terminal of the Port of Houston Authority as a test bed to demonstrate how it can be used to find the number of yard cranes needed to achieve a desired truck turn time. The results obtained from simulation are comparable to that of regression analysis and generally correspond to expectation – as the number of yard cranes increases the truck turn time decreases.

CHAPTER 5. ROBUST SCHEDULING OF TRUCK ARRIVALS AT MARINE CONTAINER TERMINALS

5.1 INTRODUCTION

A crucial element that often contributes to terminal congestion is the fluctuating arrival of trucks. This unpredictability in demand leads to situations where demand greatly exceeds supply or vice versa. When supply greatly exceeds demand, the terminal is wasting resources, and when demand greatly exceeds supply, truckers lose time and hence money. Neither extreme is good. Recognizing this, more and more marine container terminals (e.g. Evergreen L.A. Terminal, Total Terminals International's Pier T at Long Beach, and West Basin Container Terminal at L.A.) are employing the truck appointment system, not because of the Lowenthal Bill (*1*), but rather to regulate the truck arrivals into the terminals. The incentive for truckers to make appointments at these terminals is guaranteed entrance to the terminal. Without appointments the walk-in truckers have to wait until there are openings because these terminals put a cap on the number of appointments allowed in each zone in the yard for each hour.

The truck appointment system essentially allows a terminal to control the truck arrivals (i.e. spread out the work). A study conducted by Marine Terminals Corporation shows that by spreading out the work throughout the day, a considerable amount of truck-hours can be saved (Longbotham, 2004). To the best of our knowledge, this study is the first to show that the terminal and truckers are better off if truck arrivals are evenly distributed. It is expected that more terminals will use the appointment system to gain greater control of the trucks coming into their gates. However, before committing capital and resources, most terminals would want to know clearly the benefits and consequences of employing the truck appointment system. In addition, they would want to know how to properly implement a truck appointment system. This chapter addresses these two issues.

To study the benefits and consequences of employing the truck appointment system, this research now examines the effect of scheduling truck arrivals, in particular capping the truck arrivals, on the terminal overall truck turn time and yard crane utilization. Recognizing that there could be some benefits to capping truck arrivals and conversely consequences of over capping, the focus of this area of research is on finding the appropriate level of capping. With regard to how to implement a truck appointment system, this research proposes a methodology for determining the number of trucks a terminal should allow into a specific area of the yard per time window (referred to here as cap), for the appointment system to be effective. A common issue with appointments is tardiness and no-show. This problem is true to a greater extent in the maritime industry. As such, the proposed methodology is formulated to be robust; that is, insensitive to missed appointments. The motivation of this research is to develop a tool to assist terminal operators in the implementation of the truck appointment system.

The remainder of this chapter is organized as follows. The next section describes the formulation of the robust truck appointment system, followed by the discussion of the solution procedure used in this research to solve the formulation. Next, the design of the experiments is explained. Then the results are discussed. Finally, the conclusion is presented.

5.2 FORMULATION

In this research, the appointment system is viewed as a management tool for the terminal to use to spread out the work. As such, terminal operators have control over the number of zones and time windows to use. Once specified, these values serve as input to the model presented below. Other input values to the model include the maximum desired average truck turn time and the number of yard cranes available at each zone and each time window. The purpose of the model is to use these input values and in turn calculate the number of trucks that could enter into each zone during each time window without violating the constraints. The resulting numbers are caps that will be incorporated into the terminal's appointment system. The reason for setting these caps is that once the number of appointments made by truckers for a particular zone and time window exceeds the cap, no more appointments will be accepted by the terminal. The process of computing these caps is envisioned to be performed daily, or several times a day if the terminal chooses to accept same-day appointments.

For both the terminal and the trucking industry to benefit from the appointment system, the model needs to yield the maximum number of trucks the terminal can possibly handle with the given amount of resources. Hence, the objective function seeks to maximize the number of trucks to allow into zone z and time window w. To account for possible missed appointments, the model seeks a robust solution, meaning a solution that is close to the optimal solution with respect to any given scenario (e.g. 10% of trucks that scheduled appointments will be no-shows). This is achieved via the expected value function. Technically, the percentages of missed appointments are real numbers, but for all practical purposes, they are assumed here to be discrete. Thus, the expected value function uses the summation notation instead of the integral.

Sets and Indices

w = $1, \ldots, W$ number of time windows

z = $1, \ldots, Z$ number of zones

s = $1, \ldots, S$ number of scenarios

Decision Variables

x_{zws} = number of trucks to allow in zone z during time window w under scenario s

Parameters

D = number of appointments made

T = maximum allowed average truck turn time

y = average truck turn time

c_{wz} = number of yard cranes available during time window w at zone z

p_s = probability of scenario s occurring

Notation

y = f(x) denotes that y is some function of x.

Objective function

$$\max\ Z = \sum_{s=1}^{S} p_s \sum_{z=1}^{Z} \sum_{w=1}^{W} x_{zws} \qquad \text{eq. 5.1}$$

Resource constraints

$$y = f(x_{zws}, c_{wz}) \le T\ ; \forall z, w, s \qquad \text{eq. 5.2}$$

Demand constraints

$$\sum_{z=1}^{Z} \sum_{w=1}^{W} x_{zws} \le D\ ;\ \forall s \qquad \text{eq. 5.3}$$

Probability constraints

$$\sum_{s=1}^{S} p_s = 1 \qquad \text{eq. 5.4}$$

Non-negativity constraints

$x_{zws} \geq 0$; $\forall z, w, s$ eq. 5.5

The demand constraints state that the number of appointments to accept by the terminal should be less than or equal to the number of appointments made. Note that since this is a maximization problem, the sum of x_{zws} for all z and w will be equal to D in most cases. In the event that it is not, it is because the given resources cannot handle higher truck volume without violating the average truck turn time constraint ($y \leq T$). The probability constraints state that sum of all the probabilities for all scenarios is 1. Lastly, the usual non-negativity constraints state that the decision variables (x_{zws}) cannot be negative.

The resource constraints in the formulation states that the average truck turn time (i.e. total truck turn time divided by the number of trucks), which is a function of demand (x_{zws}) and supply (c_{wz}), must be less than or equal to the maximum average truck turn time specified by the terminal operator. So, given the number of yard cranes available for each zone and time window, the formulation seeks to find the maximum number of trucks the terminal could accept for each zone and time window, such that the average truck turn time for the entire day (7AM – 5PM) does not exceed the operator-input maximum average truck turn time. To obtain the average truck turn time (y), the developed discrete event simulation model is used (discussed in Chapter 4).

5.3 SOLUTION PROCEDURE

An ad-hoc heuristic is used in this research to solve the formulation presented previously. To illustrate the heuristic, the following example is used. On a particular day, the terminal operator will set up 1 zone (zone A) for truckers with appointments and will use 10 1-hour time windows. Two (2) cranes will be set up in zone A for the entire day. Truckers with appointments will miss their appointments (i.e. not show up at all) with the following scenarios and probabilities: 0% are no-shows ($p_1 = 0.05$), 10% are no-shows ($p_2 = 0.45$) and 20% are no-shows ($p_3 = 0.5$).

The search heuristic begins with the maximum allowable number of appointments. Assuming each yard crane can work 20 trucks an hour, the initial solution will be 40 trucks.

That is, the terminal can accept up to 40 trucks an hour in zone A. To evaluate this solution, the simulation model is run using a specified truck arrival pattern. For the first scenario (0% are no-shows), the model lets 40 trucks go into zone A, every hour, for 10 hours. At the end of the simulation, an average truck turn time is calculated. The simulation model is then run for however many more replications to obtain an overall average truck turn time. If the overall average truck turn time is greater the T, the operator-input maximum average truck turn time, then the results indicate that admitting 40 trucks into zone A every hour is not feasible; it violated the resource constraints (equation 5.2). To find the next trial solution, the heuristic simply reduces 40 by 1. So, the next trial solution will be 39 trucks for each hour in zone A. This cap value (39) applies to all 10 1-hour time windows. Furthermore, it applies to all zones. Note that the simplification used here to speed up the search is to have one cap value for all zones and time windows, as oppose to having different cap values across zones and time-windows (see Figure 5. illustration). Figure 5. depicts an appointment system with three zones and ten time windows. Applying our simplified approach to this example, our search procedure would only have to deal with one cap value instead of thirty.

The search continues until a trial solution is found to satisfy all constraints or the maximum number of iterations is reached. In the case of the former, the search procedure can stop here because this is a maximization problem, further reduction in the number of trucks allowed (x_{zw}) would only lower the objective function value. Then entire procedure is then repeated for the second and third scenario, 10% are no-shows and 20% are no-shows, respectively. Suppose the results of the search yield 30 trucks for the first scenario, 35 trucks for the second scenario and 40 trucks for the third scenario. Then, for zone A, the number of trucks to accept in all 10 time windows is $(30)(0.05)+(40)(0.45)+(45)(0.5)=37$ trucks. A step-by-step summary of the solution procedure is provided below. A graphical illustration is shown in Figure 5..

<u>Solution Procedure</u>

1. Initialization: $i = 1$; $s = 1$; $k = 1$.
2. Compute the maximum number of allowable trucks to accept for each zone and time window (x_{zw}), given number of cranes available in each zone and time window and

assuming each yard crane can work 20 trucks an hour. These values serve as the initial set of solution. Let $M = \max(x_{zw})$.

3. Specify a trial solution to evaluate. If i = 1, then trial solution is result from step 2. Otherwise, trial solution is $x_{zw} = x_{zw} - 1$ for all z and w.
4. Simulate scenario s with trial solution (x_{zw}). Increment k by 1. Repeat this step until k = K (desired number of replications). Compute an overall average truck turn time (OATT) for k runs.
5. If OATT ≤ T (operator-input maximum desired average truck turn time), go to step 6. Else, increment i by 1 and go to step 3. If i = M, exit the search procedure and issue error message, "No feasible solution found."
6. If s ≤ S (total number of scenarios), increment s by 1, reset i to 1, and go to step 3. Else, go to step 7.
7. Construct final solution: $x_{zw} = \sum_{s=1}^{S} p_s x_{zws}$; ∀z, w.

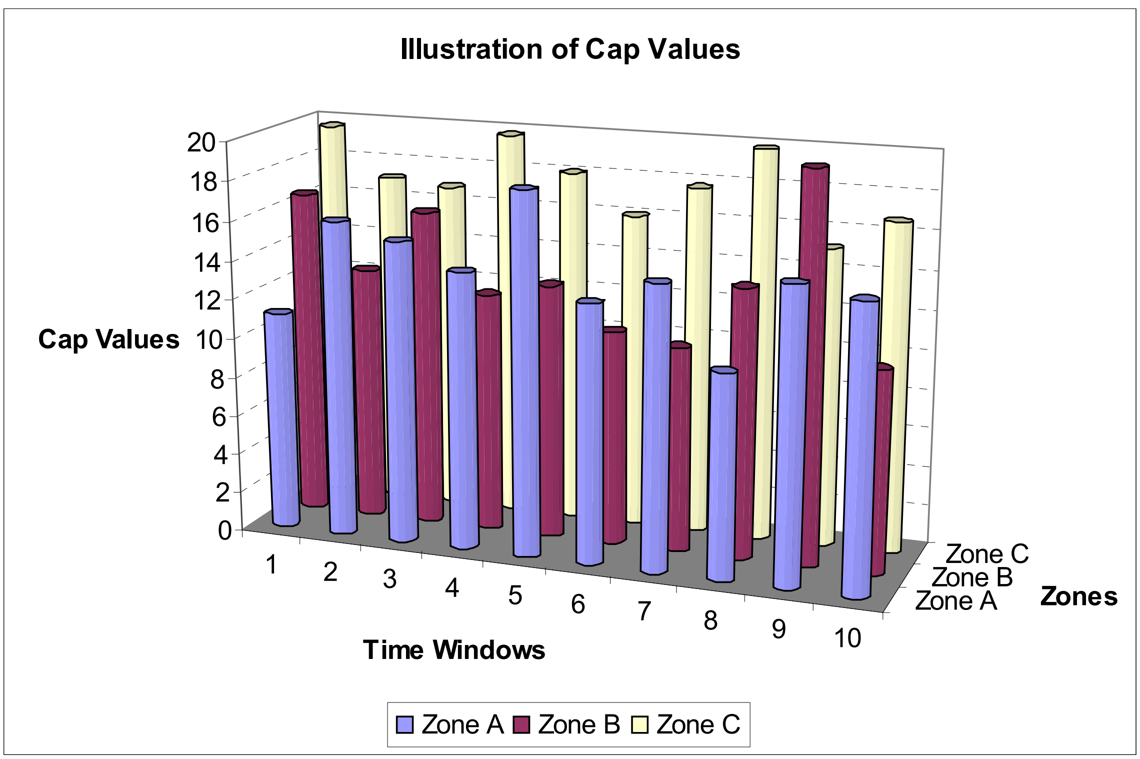

Figure 5.1: Illustration of Different Cap Values

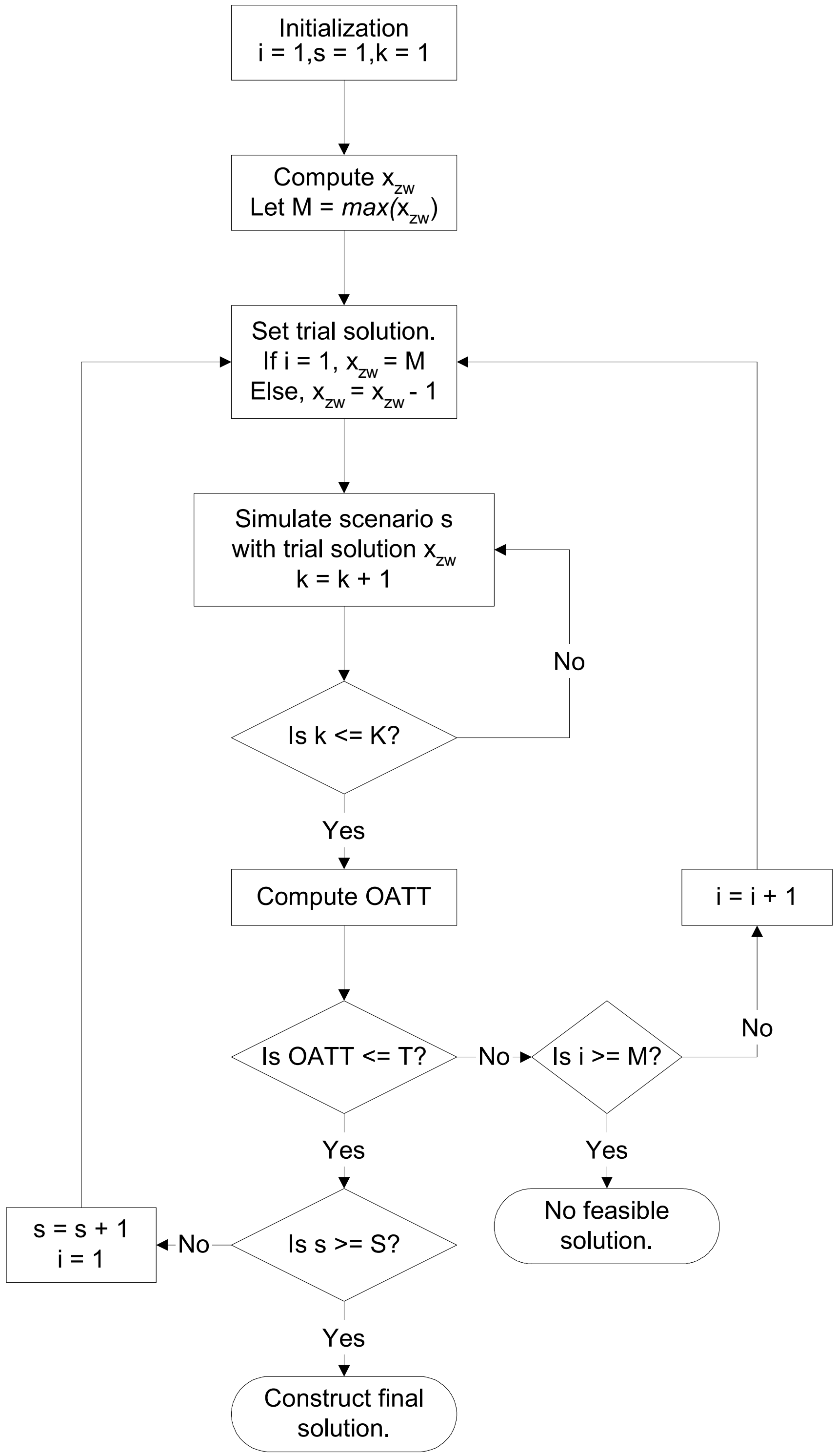

Figure 5.2: Graphical Illustration of Solution Procedure

5.4 EXPERIMENT SETUP

The experiments are carried out using the Port of Houston Barbours Cut Terminal (BCT). A map of BCT is shown in Figure 5.. The Port of Houston operates terminals 1 through 5. Terminal 6 is operated by a private operator Maersk. From here onward, any reference made to BCT will refer only to the portion that is operated by the Port of Houston. In 2003, BCT handled a little more than 500,000 vessel moves. This volume is generated by 30 steamship lines with 16 weekly services. The cargo mix is about 60% exports and 40% imports. About 85% of the containers in the yard are stacked. The other 15% stay on chassis, most of these are hazardous, refrigerated, or out-of-gauge cargo. BCT has 30 blocks for stacking containers (23,000 TEUs). Each block has about 80 20-foot sections (length), each section has 6 stacks (width), and each stack has 4 tiers (height). BCT primarily uses rubber-tired gantry (RTG) cranes, referred to here as yard cranes, to load and unload containers in the block. They have 28 yard cranes. On any given day, the yard cranes are assigned to either support the ship operation or support the road operation. Ship operation has higher priority, so the number of yard cranes available to support road operation is the total number of yard cranes minus the number of yard cranes needed for ship operation. Road operation refers to the process of truckers dropping off export containers and/or truckers picking up import containers. Truckers enter and leave BCT through five gates, three are entry only and two are entry and exit.

In this research, truck turn time is used as a performance measure. It is important to note that the truck turn time used here is different from the commonly understood term by the trucking industry. It excludes the queuing time outside the yard. In particular, only the lanes-to-exit turn time is of interest; that is, the time when a truck enters the yard (from the inner gate) until the time it exits the yard. The reason for measuring turn time in this manner is to get a more consistent reading on turn time as a result of the number of yard cranes available and the number of trucks they serve. The queuing time outside the inner gate is a result of delay in the processing of the interchange by the logistic associates. The yard cranes have no involvement in this process. Including the gate queuing time, which is random, in the truck turn time would make it harder to interpret the relationship between yard cranes and truck turn time.

Two experiments are conducted to study the benefits and consequences of employing the truck appointment system. The actual statistics from May 29, 2003 are used as the base data. These include the number of trucks and their yard entry times, as well as the number of yard cranes available. On that day, there were 1318 trucks, 52 had trouble transactions. There was one ship working that day, which required 5 cranes. There were 17 yard cranes assigned to support the road operation. The average truck turn time for that day was 38.25 minutes. The pattern of truck entry into the yard on that day is shown in Figure 5. for a number of selected blocks. The first experiment examines the effect of smoothing out demand on truck turn time. This involves putting a cap on each block in the yard. The number of trucks over the cap is moved to the next hour. For example, if the base case data has 16 trucks going into block 1J at hour 8 and if the experiment calls for putting a cap of 10, then the latter 6 trucks going into block 1J at hour 8 will now be entering block 1J at hour 9 instead. The same approach of smoothing is used in the second experiment, which examines the effect of smoothing out demand on crane utilization.

The third experiment is designed to evaluate the proposed simulation-optimization methodology. This experiment supposes import blocks 1J and 5V are set up to take appointments, and BCT wishes to know the maximum number of trucks it could allow into these two blocks with the overall terminal's average truck turn time not exceeding 45 minutes. Again the base case data are used. To test a range of demand in 1J and 5V, additional demand is created for these two blocks. The additional demand is created such that the time the trucks enter 1J and 5V are random. Likewise, the location where truckers go to pick up import containers is random. This experiment examines the effect of no-shows. Three scenarios of no-shows are considered: 5%, 15%, and 25%.

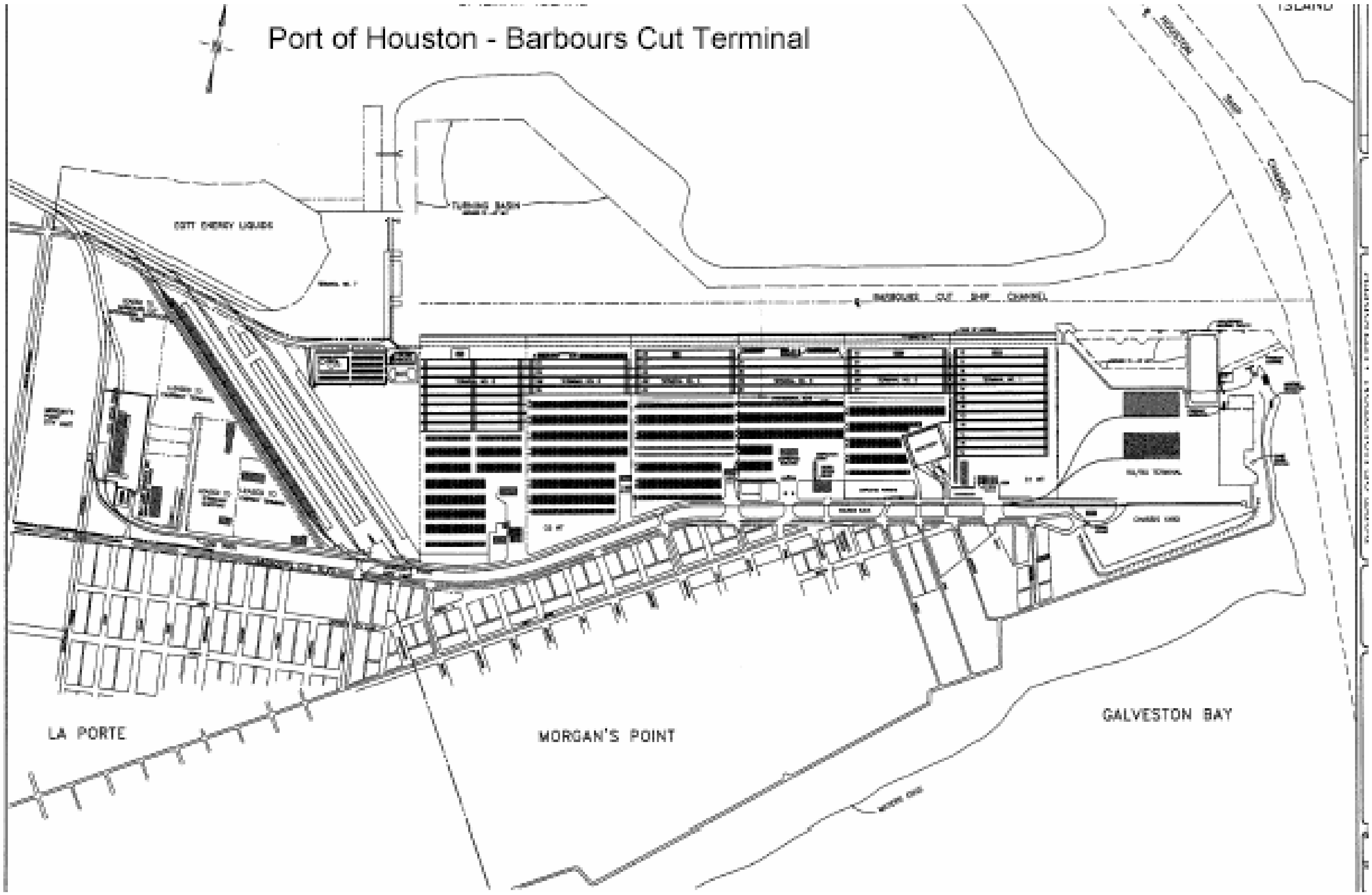

Figure 5.3: Barbours Cut Terminal.

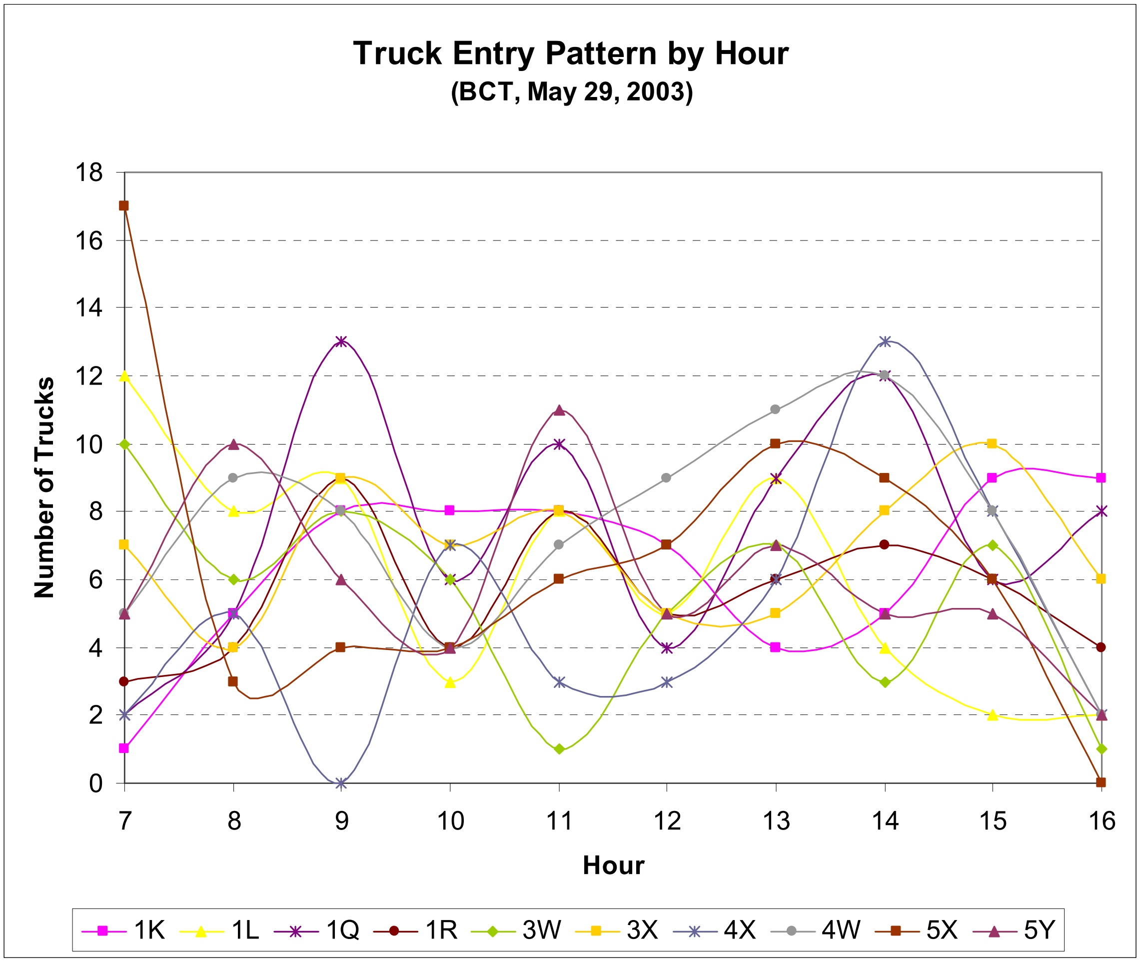

Figure 5.4: Number of Trucks Entering BCT Yard to Respective Blocks on 5/29/03

5.5 RESULTS

Figure 5. shows the result of experiment 1. The graph shows the relationship between average truck turn time and cap values. As seen on the graph, if BCT decided to put a cap of 14 trucks for each block per hour, then the average truck turn time under that scenario would be 38.05 minutes. Indeed, smoothing out demand can yield lower truck turn time. The reason for the small difference in truck turn time is because relatively few trucks are displaced. The trend depicted in Figure 5. points to an important phenomenon, setting the cap below a certain value (10 in this experiment) will increase the truck turn time. To understand how this can happen, consider the example of 16 trucks going to block 1J in hour 8 and none in hour 9. In this

example, the yard crane in 1J has the opportunity to work 16 trucks continuously. If a cap of 10 is employed, then the first 10 trucks will go to block 1J in hour 8 and the latter 6 will go to block 1J in hour 9. In this case, the yard crane in 1J has only 10 trucks to serve for hour 8. Upon completing the work in 1J, the crane may leave 1J to go to another block. The crane will then return to block 1J in hour 9 to serve the other 6 trucks. As illustrated, the 6 trucks arriving at hour 9 could end up waiting a lot longer for crane service.

Figure 5. shows the result of experiment 2. The graph shows the relationship between crane utilization and cap values. As seen on the graph, if BCT decided to put a cap of 8 trucks for each block per hour, then the average crane utilization under that scenario would be 0.34. Note that the utilization values shown in Figure 5. are calculated by dividing the number of hours yard cranes spend traversing the blocks divided by the total number of hours they are scheduled to work. It does not factor in the time the yard cranes spend loading and unloading containers. The trend depicted in Figure 5. shows little change in crane utilization going from no capping to capping at 10. Setting cap values at 8 and 6 results in a 3.12% and 4.74% reduction in crane utilization, respectively. This result suggests that the terminal could be wasting resources if it sets the caps too low.

The result from experiment 3 indicates that given the demands and resources similar to what BCT had on May 29, 2003, BCT can set the cap at 7 trucks per hour for blocks 1J and 5V in the scenario that 5% percent of those truckers with appointments will not show up, 10 in the scenario that 15% will not show up and 15 in the scenario that 25% will not show up. This set of results validates the intuition that some slack can be built into the solution for the scenario that a great majority of truckers with appointments will not show up. The final value to use depends on the probabilities assigned to each scenario. These probabilities can be estimated initially and as the appointment system evolves, the terminal could track the percentages of no-shows and update the probabilities accordingly. Table 5.2 shows some different possible cap values for a range of probabilities. Note that solution is the expected value of the different cap values obtained. Such solution is robust because the solution will yield close-to-optimal results for a wide range of scenarios.

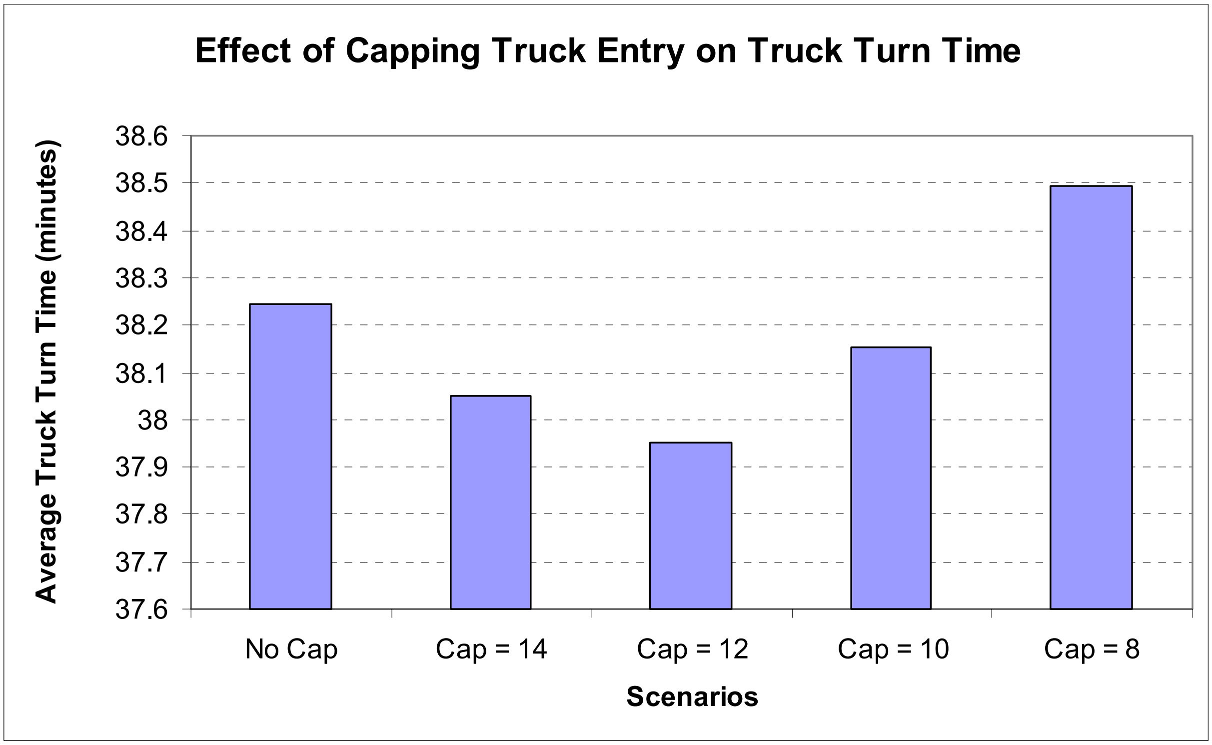

Figure 5.5: Effect of Capping Truck Entry on Truck Turn Time

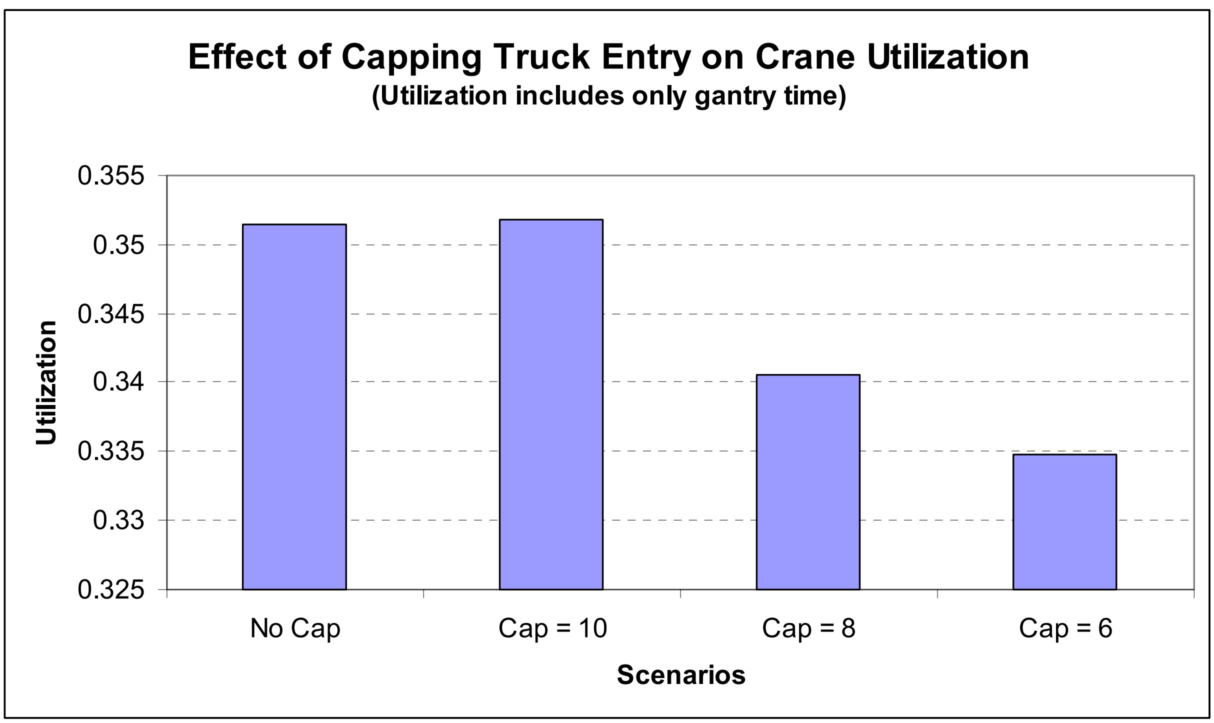

Figure 5.6: Effect of Capping Truck Entry on Crane Utilization

Table 5.2: Possible Cap Values for Blocks 1J and 5V

Prob. 5% no-show	Prob. 15% no-show	Prob. 25% no-show	Solution
0.75	0.15	0.10	8
0.15	0.75	0.10	10
0.10	0.15	0.75	13

5.6 SUMMARY AND CONCLUSION

This chapter discusses two issues related to the use of a truck appointment system at marine container terminals to smooth out demand. The first is the effect of limiting truck arrivals into the container yard on truck turn time and crane utilization. Experiments carried out using the Port of Houston Barbours Cut Terminal indicate that some smoothing of the truck arrivals to the terminal can be beneficial. Beyond a certain level, in particular, setting the caps too low can be counter productive to both the terminal (lower crane utilization) and truckers (higher truck turn time). The second issue this chapter discusses is finding the maximum number of trucks a terminal could allow into a specific area of the yard per time window without violating resource constraints and meeting the specified desired average truck turn time. To achieve this, this research develops a methodology that is based on robust optimization and simulation. The robust formulation is employed to account for truckers with appointments showing up late or not show up at all. An ad-hoc search heuristic is used in this study to solve the developed formulation. Results from the experiments corroborate intuition that some slack can be built into the solution for the scenario where a great majority of truckers with appointments will not show up.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF FINDINGS

This research examined two measures currently employed by terminal operators to reduce truck turn time at their terminals. The first measure is adding gantry yard cranes to facilitate the picking up and/or dropping off of containers. To assist terminal operators in deciding whether or not to purchase additional cranes and how many, this research developed two different methodologies to study the availability of cranes versus truck turn time. The first methodology employed statistical modeling, in particular, regression models, and the second methodology employed simulation.

The developed simulation model aimed to model the precise movements of trucks and yard cranes. Truck movements are modeled by identifying the processes each truck must follow for a particular transaction type and moving the truck through the process via a road network. Transaction types include trucks picking up import containers and/or chassis and trucks dropping off export containers and/or chassis. Double transactions are accounted for in the model; a double transaction refers to the situation when a trucker drops off an export container at the terminal and picks up an import container in a single trip. Also, trouble transactions are accounted for in the model; a trouble transaction refers to the situation where the trucker's paper work is invalid. A trouble transaction requires the additional assistance and typically takes longer to complete. Trucks are modeled to use the shortest paths to their destinations and are modeled to move at different speeds based on a specified distribution. Yard cranes are modeled by identifying the procedure in which they go about the yard providing service to the trucks and moving them accordingly on a crane network. Cranes are also modeled to use the shortest paths to get to their destinations, moving at a specified velocity, turning velocity and acceleration.

The second truck turn time reducing measure that was examined in this research is the utilization of a truck appointment system to regulate the number of trucks that enter the terminal. To assist terminal operators understand the benefits or consequences of a truck appointment system, this research used the developed simulation model to analyze its impact on truck turn time and crane utilization. In addition, this research developed a methodology for determining the optimal number of trucks terminal operators should allow into their terminals. The methodology is a combination of mathematical formulation and simulation. It seeks a solution that is beneficial for both the terminal operator and truckers. Moreover, it is formulated to yield robust solution to account for truckers with appointments showing up late or not show up at all.

6.1.1 Availability of Cranes vs. Truck Turn Time – Regression Model Results

To estimate truck turn time at BCT as a function of resources and work loads, several models were examined. They include multiple regression models, polynomial regression models, and non-linear in parameter regression models. The best model found is of the form:

$$y = 8.37x^{0.41} \qquad \text{eq (6.1)}$$

where y is the turn time and x is the number of road moves (plus rehandles) per road crane. Figure 6. shows the estimated model (equation 6.1) that captures the relationship between y and x in relation with actual observations. Given such a model (equation 6.1), truck turn time can be estimated from knowing the number of road cranes and the number of road moves (plus rehandles).

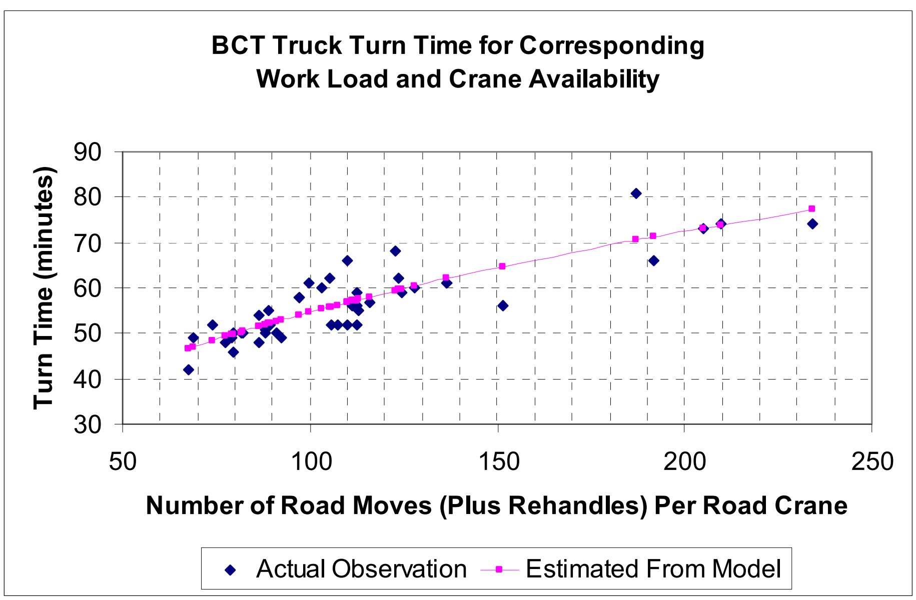

Figure 6.1: Actual and Estimated Relationship between y and x

6.1.2 Availability of Cranes vs. Truck Turn Time – Simulation Model Results

Results indicate that having more road cranes will in general lower truck turn time. Results from May 15, 2003 indicate that on average an additional road crane reduces truck turn time by 1.11 minutes (or 3.4 percent), while results from May 29, 2003 indicate that an additional road crane reduces truck turn time by 0.39 minutes (or 1 percent). These findings correspond to regression results; it is found via regression that to reduce truck turn time from 45 minutes to 40 minutes, four additional road cranes are needed (i.e. one additional road crane reduces truck turn time by 1.25 minutes). The simulation results also indicate that adding an additional road crane does not necessarily lower truck turn time. The reason for this is due to randomness in various processes. For example, it could be that ship cranes consistently serve fewer road trucks. So, even with an additional road crane, it is conceivable that the overall average truck turn time could be higher. Another reason why adding another road crane does not necessarily lower truck turn time is because of where the crane is placed in the yard. That is, it could be placed where it does not have the opportunity to perform more moves because work is closer to other cranes.

6.1.3 Effect of Truck Appointment System on Turn Time and Crane Utilization

Results indicate that regulating truck arrivals to smooth out demand can yield lower truck turn time. However, setting the cap value too low will result in an increase in truck turn time. Cranes' utilization are unaffected by cap values as long as the cap value is above a certain threshold. Once the cap value falls below the threshold, as the cap value decreases the cranes' utilization decreases. This result suggests that setting the cap value too low will lead to an inefficient use of resources (i.e. idle cranes).

6.1.4 Formulation of Truck Appointment System

A mathematical program was developed to determine the optimal scheduling.

<u>Sets and Indices</u>

w $= 1, \ldots, W$ number of time windows
z $= 1, \ldots, Z$ number of zones
s $= 1, \ldots, S$ number of scenarios

Decision Variables

x_{zws} = number of trucks to allow in zone z during time window w under scenario s

Parameters

D = number of appointments made

T = maximum allowed average truck turn time

y = average truck turn time

c_{wz} = number of yard cranes available during time window w at zone z

p_s = probability of scenario s occurring

Notation

y = f(x) denotes that y is some function of x.

Objective function

$$\max\ Z = \sum_{s=1}^{S} p_s \sum_{z=1}^{Z} \sum_{w=1}^{W} x_{zws} \qquad \text{eq. 1}$$

Resource constraints

$$y = f\left(x_{zws}, c_{wz}\right) \leq T\ ; \forall z, w, s \qquad \text{eq. 2}$$

Demand constraints

$$\sum_{z=1}^{Z} \sum_{w=1}^{W} x_{zws} \leq D\ ;\ \forall s \qquad \text{eq. 3}$$

Probability constraints

$$\sum_{s=1}^{S} p_s = 1 \qquad \text{eq. 4}$$

Non-negativity constraints

$$x_{zws} \geq 0\ ;\ \forall z, w, s \qquad \text{eq. 5}$$

6.1.5 Optimal Scheduling

The results from experimentation indicate that given the demands and resources similar to what BCT had on May 29, 2003, BCT can set the cap value at 7 trucks per hour for blocks 1J and 5V in the scenario that 5% percent of those truckers with appointments will not show up, 10 in the scenario that 15% will not show up and 15 in the scenario that 25% will not show up. This set of results validates the intuition that some slack can be built into the solution for the scenario that a great majority of truckers with appointments will not show up. The final cap value to use depends on the probabilities assigned to each scenario, as illustrated below in Table 6..

Table 6.1. Possible Cap Values for Block 1J and 5V

Prob. 5% no-show	Prob. 15% no-show	Prob. 25% no-show	Solution
0.75	0.15	0.10	8
0.15	0.75	0.10	10
0.10	0.15	0.75	13

6.2 CONTRIBUTIONS

The research performed in this research contributes to the area of container terminal modeling as follows:

1. Truck turn time is one of the prominent issues container terminal operators in the US are seeking to address, and this research is one of the first to shed light into this subject. It addressed real challenges terminal operators are facing. The methodologies developed are intended to be practical tools terminal operators could use to aid their daily decision making.
2. Development of a truck turn time regression model for container terminals. The model enables terminal operators to estimate truck turn time given the number of road moves (plus rehandles) and number of available RTG cranes. Conversely, it allows terminal operators to determine the number of RTG cranes needed given a desired average truck turn time. For example, the model could provide an estimate for terminal operators that 20 RTG cranes are needed to achieve a 40 minute average truck turn time. The model specification was derived using data from the Port of Houston Barbours Cut Terminal, and it is transferable to other container terminals with similar characteristics (e.g. uses RTG cranes to stack containers). The model parameters, however, would need to be re-estimated.

3. Development of a simulation model to obtain truck turn time given various inputs. Previous simulation models built by other researchers could be tweaked or modified to do what has been done in this research; however, none of these models currently possess the same type of capability in terms of modeling yard crane movements. This research is one of the first to document how a simulation model of a container terminal could be constructed using Arena. It also documented techniques to speed up the model construction. Since Arena is an off the shelf simulation software, the approach and implementation techniques documented could be applied to building simulation models of other container terminals.
4. Investigation of the effects of a truck appointment system on truck turn time and crane utilization at container terminals. This investigation is one of the first to examine the impact of a truck appointment system. Analysis and results showed that implementing a truck appointment system is not always a good thing. Furthermore, results suggest that to implement the truck appointment system effectively, its parameters such as the cap values cannot be haphazardly determined.
5. It is demonstrated in this research that implementing a truck appointment system requires putting proper cap values. To this end, this research developed a simulation-optimization methodology to help terminal operators determine the optimal number of trucks they should allow into the terminal. The developed methodology is one of the first attempts to formulate the truck appointment system mathematically. Combined with the proposed solution procedure, the developed methodology provides a framework in which terminal operators could use in a live environment to run the truck appointment system.

6.3 FUTURE RESEARCH

This research developed several methodologies to assist terminal operators address the truck turn time issue. One of the developed methodologies is the regression model. It is a simple and practical tool that terminal operators could use in deciding how many additional RTG cranes are needed to achieve their target truck turn time. The developed regression model was estimated and calibrated using data from the Port of Houston's Barbours Cut Terminal. It would be valuable to confirm the model specification's applicability to other terminals. It would also be valuable to identify the types of container terminals where the model could be applied.

The developed simulation model sought to replicate Barbours Cut Terminal's existing crane deployment procedure. It would be interesting to use the simulation model to test and compare different deployment procedures with one another. Results from this research suggest that limiting the movement of each crane to where it works in a confined area may lead to higher efficiency. Such investigation has not been performed, to the best of our knowledge. Through the evaluation of different procedures, an optimal RTG deployment procedure could be identified.

The simulation-optimization framework developed in this research recognized the problem of "no-shows" with appointments, but did not address what impact it might have. The "no-shows" phenomenon could potentially negate any effort made in regulating the truck arrivals. Currently, there are no published data to show its severity. Research is needed in this area to evaluate its impact and develop strategies to deal with them, such as fining the trucking company for every missed appointment not cancelled well in advance.

This research focused on two prevailing measures terminal operators are taking to reduce truck turn time at their terminals. There are other measures terminal operators are looking into. Some examples are extending gate hours and pre-advising the arrival of containers. The methodologies developed in this research could be extended to investigate these measures.

There are several emerging issues in the marine container industry. After 9/11, the Department of Homeland Security has stepped up their effort to screen import cargo. Their effort has had an impact on the yard operations and the availability of the import containers for pick up. Terminal operators are searching for ways to gain capacity and a popular approach is to reduce the dwell time of cargo in the yard. To achieve this, many have raised the demurrage rate and/or refuse advanced delivery of cargo. Lastly, shippers are increasingly looking at alternatives to trucking to transport cargo. Shortsea shipping is gaining a great deal of interest. With more ships, the dynamics of berth scheduling is certainly going to change. While these issues were beyond the scope of this research, they are natural extensions of the work completed.

APPENDIX A. SURVEY RESPONSES

A.1 INTRODUCTION

To better understand how delay at terminals affect the trucking companies' operations and what causes the delay, this research surveyed six trucking companies in the Houston metropolitan area that have business at Barbours Cut Terminal (BCT). The survey questions are grouped into three parts. Questions in part I pertain to the trucking company's business. Questions in part II pertain to the trucking company's operations. Lastly, questions in part III pertain to trucking company's perception towards BCT. The responses that are relevant to this research are summarized below.

A.2 EFFECT OF DELAY AT TERMINALS ON TRUCKING COMPANIES

A common theme from the responses is that delay at BCT reduces production; it inhibits a driver from hauling additional loads. Most companies interviewed say that a driver needs to make at least two runs in and out of BCT a day to make a "decent" living. When they fail to do so, they lose money in the process. Because drivers lose money whenever they are held up, many quit the business, further depleting an already low supply of qualified intermodal drivers. Another consequence of waiting at BCT is that it uses up a driver's hours of service. By law, a driver has only 15 hours of service a day, 10 of which are for driving and 5 for being on duty.

From the companies' perspective, delay at BCT makes it difficult for them to serve their customers effectively. Four of the companies interviewed said that they do not promise delivery on busy days at BCT and that at times avoid making trips to BCT all together (when cut off time permitted)[*]. In avoiding busy days at BCT, these trucking companies have to send their drivers out on other runs and as a result, it sets them back from covering their loads. It also makes it hard for the trucking companies to schedule their trucks. To compensate for delays at BCT, trucking companies often hire more than the necessary number of drivers. Lastly, trucking companies have to keep their staff working overtime whenever their drivers are held up.

[*] Data collected during the analysis period do not show a decrease in truck traffic at BCT on busy days.

A.3 PERCEPTION TOWARDS BCT CURRENT OPERATIONS

The majority of the companies interviewed rates the truck turn time at BCT (terminals C1 through C5) as above average or average on non-busy days and poor on busy days. Busy days were noted as Mondays and Tuesdays, or days which BCT has three or more ships. The responses indicate that the yard loading/unloading process is the main bottleneck in a truck's turn time for grounded containers. The main limiting factor as pointed out is the lack of yard cranes to serve the road trucks on high volume ship days.

APPENDIX B. DATA SOURCE, EXTRACTION, AND ANALYSIS

B.1 INTRODUCTION

The development of the simulation model was heavily tailored to the available data. The primary reason for this is to have actual operations data to calibrate the model and subsequently, to validate the model outputs. Also, by developing the model hand-in-hand with the available data, there is no need to extract unobserved data, which may add unnecessary complexity to the model and more importantly, increase the error sources in the model. However, no critical operational aspects were omitted due to the lack of data. The following describes the data sources that were made available to this research, the method in which they were extracted from the original source (if applicable), and the analysis that were performed to obtain the random distribution.

B.2 TABLE - ROAD

There are two main tables used to extract all the data needed. The more extensive one is called “Road”. It contains information about every container processed at the terminal. Note that BCT tracks primarily containers and not trucks. The fields in Road table are shown in Figure B.1. That is, for each container, there is a list of fields (attributes) associated with it. The fields relevant to this research are ParkLoc, Reject, GateYear, GateMonth, GateDay, GateHour, GateMin, EIRYear, EIRMonth, EIRDay, EIRHour, EIRMin, StopYear, StopMonth, StopDay, StopHour, StopMin, ChasOnly, RcvChas, and EntryStation. ParkLoc refers to the parking location where the container is stored (or will be stored); truckers are given this information when they come to pick up or drop off containers. The Reject field indicates if the truck that came to pick up or drop off the container had invalid paper work. The Gate fields indicate when the truck arrived at the gate. The EIR fields indicate when the truck leaves the lane to enter the yard. The Stop fields indicate when the truck dropped off the container (for exports) or when the truck leaves the terminal with the container (for imports). A ‘Y’ in the field ChasOnly indicates the truck is picking up or dropping off a chassis only. A ‘Y’ in the field RcvChas indicates the truck is dropping off both the container and chassis, whereas a ‘N’ indicates the truck is dropping off the container and keeping the chassis. Lastly, EntryStation refers to the gate (CY, C1, C3, C4, C5) in which the truck used to enter the terminal. This table provides the truck arrival data used in the model. Other relevant information that can be extracted from this table include number of moves in (exports), number of moves out (imports), time from gate and lane, and time from lane to exit. To illustrate the steps used in extracting and cleaning up the data for use, the truck arrival data at the C1 gate on 7/30/02 is used. Note that the data cleaning process is almost always necessary because very often real world data are not usable form. In this study, Microsoft Access is used to process the data. A query is developed using the built-in interface. The resulting SQL command is as follows:

```
SELECT Road.EIRHour, Road.EIRMin, Road.RcvChas, Road.Reject, Road.ParkLoc
FROM Road
WHERE (((Road.ChasOnly)="N") AND ((Road.EIRMonth)=7) AND ((Road.EIRDay)=30)
AND ((Road.[ENTRY STATION])="c1"));
```

Once the data are extracted, they are then sorted in increasing order of arrival time. This is accomplished by using the pull-down menu option Sort. The data are then copied to a text editor named UltaEdit. The reason for using UltraEdit is because it allows for editing of text column wise. This feature is needed to increase and decrease spaces between columns of text. With such a feature, the data cleaning process can be done with relative ease. When first copied the data to UltaEdit, the data will look like the following.

```
7	10	N	N	1N70B1
7	12	Y	N	3V45F1
7	14	Y	N	2X30E2
```

After running a macro written to facilitate the conversion of data and some manual manipulation, the data input to the simulation model is as follows.

```
7  10 0 0 10 70
7  12 1 0 52 45
7  14 1 0 44 30
```

Note that tabs have been replaced with spaces, ‘N’ is replaced with a 0, and ‘Y’ is replaced with a 1. This is done because Arena cannot process tabs and characters. Before the conversion, the last column indicates the position of the container. Subsequently, it is converted to link numbers corresponding to the truck network and slot number where the truck will travel to.

A portion of the macro is shown below.

```
InsertMode
ColumnModeOff
HexOff
Find "1J"
Replace All "1"
Find "1K"
Replace All "4"
Find "1L"
Replace All "7"
```

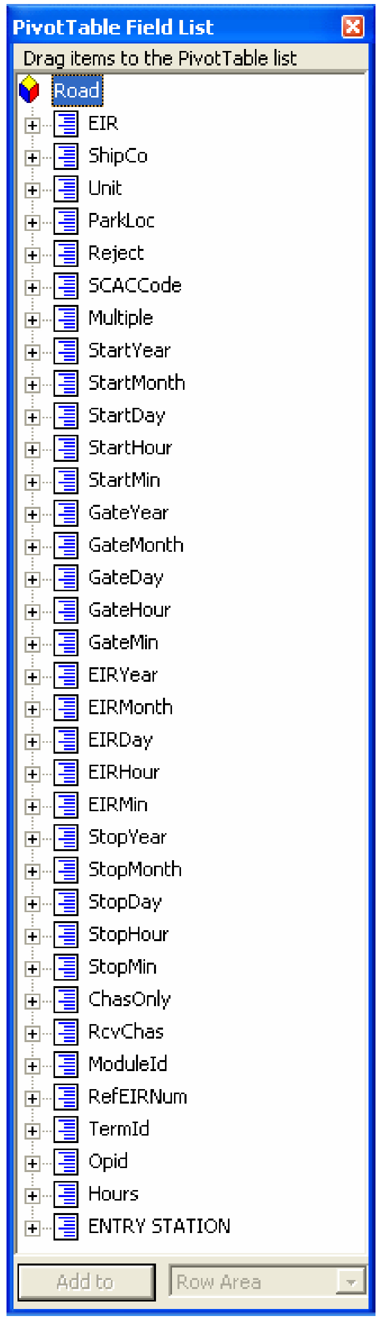

Figure B.1: Fields in Road Table

B.3 TABLE - CALENDAR

The other table used to extract data needed is called “Calendar”. It contains information about RTG cranes. The fields in Road table are shown in Figure B.2. The fields relevant to this research are Road Cranes AM, Road Cranes PM, and Ship Cranes. Ship Cranes AM indicates how many RTG cranes work the trucks in the morning (7AM – noon) and Ship Crane PM indicates how many RTG cranes work the trucks in the afternoon (1 - 5PM). Lastly, Ship Cranes indicates how many RTG cranes work the ship on a particular day.

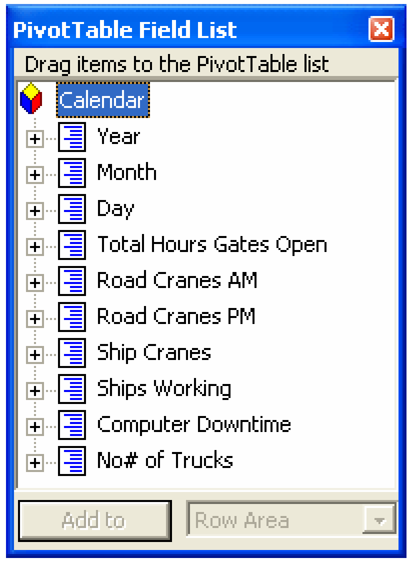

Figure B.2: Fields in Calendar Table

B.4 EXIT TIME WITH SURVEY OF CONTAINER

The exit time for trucks performing a move-out (import) is when the truck leaves the terminal. Because theses trucks take containers out, they must first pass the inspection (i.e. surveying of container). To incorporate the wait times for these out-going trucks, actual data are input into the model, in the form of a distribution.

The actual data were collected and processed by the BCT staff. They randomly selected two days to compute the wait times for out-going trucks with containers. The selected two days are 9/30/02 with a high volume and 10/8/02 with an average volume. For each day, they selected 25 import pick-up containers and recorded the time when the yard crane delivered the container to the truck and the time when the truck exited the terminal. This time frame includes 1) time the truck drives out to the gate, 2) time waiting in queue, 3) time for clerk to survey container and forward the interchange to the logistic associate, and 4) time for logistic associate to finalize the transaction. One 9/30/02, the average wait time was 16 minutes while on 10/8/02, the average wait time was 21 minutes. The data for 9/30/02, as provided by the BCT staff, is shown in Figure B.3.

The data from 9/30/02 and 10/8/02 are then merged and imported into Arena Input Analyzer to estimate the best fit distribution; four extreme values or outliners were first removed from the merged sample. The selected theoretical distribution is the triangular distribution. As shown in Figure B.4, the triangular distribution provides a good representation of the data with a p-value for the Chi Square test of 0.46; high p-values (0.1 or greater) suggest a fair degree of confidence in the theoretical distribution being a good representation (Kelton et al. 2002). The resulting expression for the distribution is: TRIA(4.56, 6, 28.5). The first parameter denotes the minimum, second parameter denotes the mode, and the third parameter denotes the maximum.

UNIT	PARK	MONTH	DAY	CRANE/ TRUCK	OUT GATE	PADS/EXIT
ACXU2029993	1K22C1	9	30	14:56	16:20	1:24
BONU9242389	5Y41C1	9	30	11:49	11:59	0:10
BONU9243343	4Y55B1	9	30	11:29	13:31	2:02
CBHU1219206	5Y26E1	9	30	15:28	15:39	0:11
CRXU2930447	4W29D1	9	30	11:03	11:16	0:13
CSVU4058765	2Z06D2	9	30	09:19	09:25	0:06
GATU4123933	3W58D1	9	30	14:44	14:53	0:09
HLCU4267028	1Y52C1	9	30	16:40	16:46	0:06
ICSU1736616	4W06C1	9	30	13:50	14:00	0:10
IVLU9536978	2Z25C1	9	30	14:47	14:58	0:11
KNLU3386027	1N59A1	9	30	09:28	10:45	1:17
MSCU8039068	4Y34D1	9	30	12:16	12:33	0:17
OCLU1313960	2V50E1	9	30	14:50	15:01	0:11
POCU0322631	1N53E1	9	30	15:28	15:40	0:12
PONU1419086	3Y44F1	9	30	16:21	16:36	0:15
PONU1582724	5Y06D1	9	30	14:30	14:44	0:14
PONU7542570	1N40D2	9	30	15:21	15:32	0:11
SUDU3031160	1L73E1	9	30	14:51	15:06	0:15
TIFU3252294	2Z09D1	9	30	14:36	14:51	0:15
TMMU4216577	3Y78A1	9	30	12:03	12:17	0:14
TPHU8118058	2Z09F1	9	30	12:42	12:49	0:07
TRIU5829682	3Y58C1	9	30	13:47	13:55	0:08
TRLU6263526	1Y26D1	9	30	11:08	11:14	0:06
TTNU5235109	4Y78E2	9	30	11:07	11:21	0:14
ZIMU4623651	1Y69E3	9	30	16:20	16:30	0:10

Figure B.3: Provided Data on Outbound Trucks' Wait Time

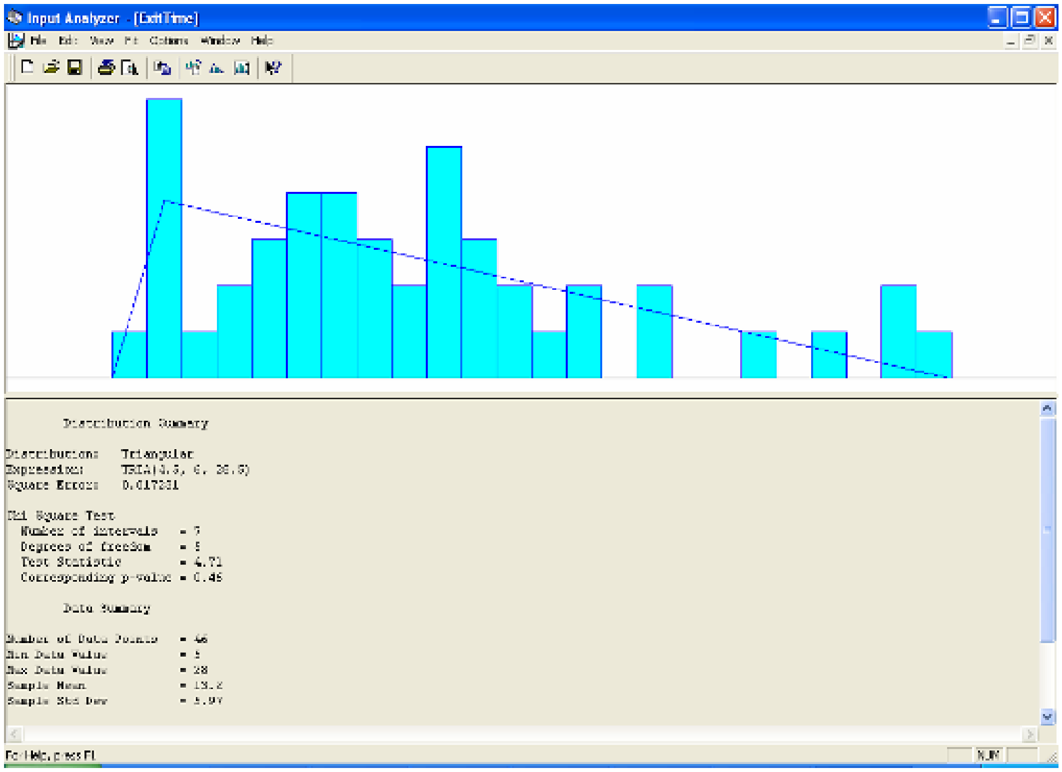

Figure B.4: Fitting of Triangular Distribution on Import Exit Time

B.5 EXIT TIME WITH NO SURVEY OF CONTAINER

For trucks performing a move-in (export), their exit time is relatively quick since they do not require container survey. Their exit process entails only a simple checking of paper work, in the order of seconds. To have a better estimate of the wait times for these out-going trucks, data were collected at the C4 bobtail exit gate on 4/10/03. In all, 30 readings were collected. The selected theoretical distribution is the triangular distribution. As shown in Figure B.5, the triangular distribution provides a good representation of the data with a p-value greater than 0.75 for the Chi Square test and 0.15 for the Kolmogorov-Smirnov Test. The resulting expression for the distribution is: TRIA(0.02, 0.099, 0.3).

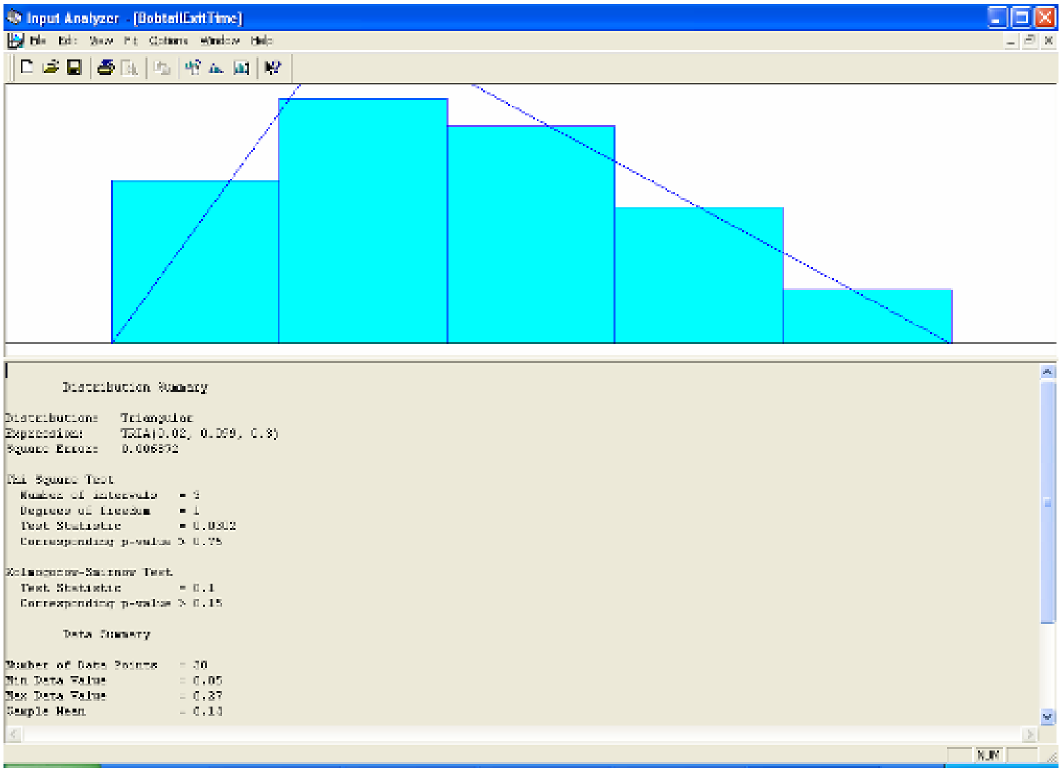

Figure B.5: Fitting of Triangular Distribution on Export Exit Time

B.6 CONTAINER LOADING TIME

To approximate the time it takes cranes to load containers, data were collected on a few randomly selected cranes on 4/10/03. In all, 30 readings were collected. The same procedure of fitting a theoretical distribution to the data was applied. The best fit theoretical distribution is the log-normal distribution; it is used despite the low p-value from the Chi Square test. This parameter will be revisited in the model calibration process. As shown in Figure B.6, the distribution parameters is 0.26 + LOGN(0.941, 0.519). Note that the parameters of a log-normal distribution is LogMean and LogStd, where $LogMean = \mu_l = e^{\mu+\sigma/2}$ and $LogStd = \sigma_l^2 = e^{2\mu+\sigma^2}(e^{\sigma^2} - 1)$.

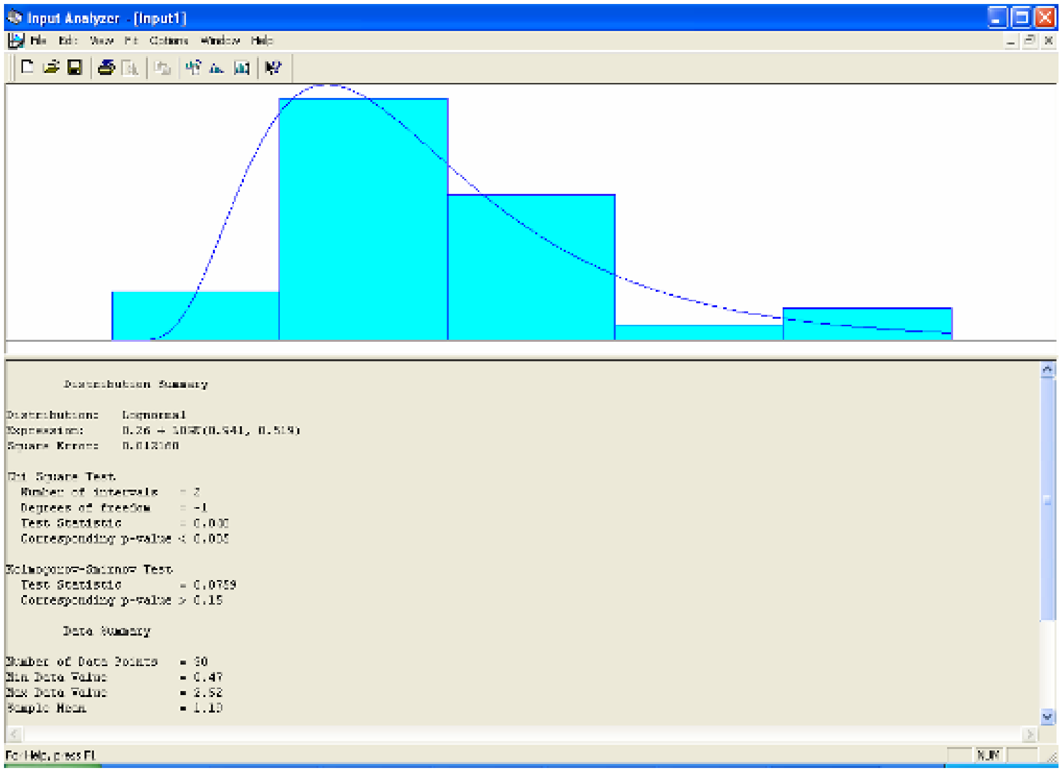

Figure B.6: Fitting of Triangular Distribution on Exit Time with No Survey Data

B.7 ROAD MOVES PERFORMED BY SHIP CRANES

Some road trucks are served by ship cranes. Recall that ship cranes are assigned to serve vessel trucks that are transferring containers between the yard and dock area. Therefore it is important to get an estimate of how many road trucks are served by ship cranes. If the number is high, then it needs to be taken into account in the model. In particular, ship cranes will need to be modeled, in addition to road cranes. Otherwise, the modeling of ship cranes serving road trucks can be omitted.

A 10-day study was conducted by the BCT staff. For each day, they tracked the total number of road moves performed by all the ship cranes. This information, along with others, is shown in Figure B.7. Note the last column in Figure B.7, which indicates the fraction of road moves performed by ship cranes in relation to the total number of moves performed by road cranes. Since this percentage is relatively high, the modeling of ship cranes cannot be omitted.

Date	Total Ship Cranes	Road Moves by Ship Cranes	Vessel Moves by Ship Cranes	Total Moves by Ship Cranes	Road/Total Moves (%)
10/10/02	7	275	918	1193	23.05
10/11/02	5	107	322	429	24.94
10/15/02	5	119	178	297	40.07
10/16/02	2	14	96	110	12.73
10/17/02	9	120	715	835	14.37
10/18/02	5	102	518	620	16.45
10/21/02	10	232	1176	1408	16.48
10/22/02	8	321	587	908	35.35
10/23/02	5	178	311	489	36.40
10/24/02	4	127	323	450	28.22

Figure B.7: Provided Data on Road Moves Performed by Ship Cranes

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