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Analysis of marine container terminal gate congestion, truck waiting cost, and system optimization

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ABSTRACT

ANALYSIS OF MARINE CONTAINER TERMINAL GATE CONGESTION, TRUCK WAITING COST, AND SYSTEM OPTIMIZATION

by
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As world container volume continues to grow and the introduction of 12,000 TEUs plus containerships into major trade routes, the port industry is under pressure to deal with the ever increasing freight volume. Gate congestion at marine container terminal is considered a major issue facing truckers who come to the terminal for container pickup and delivery. Harbor truckers operate in a very competitive environment; they are paid by trip, not by the hours they drive. Gate congestion is not only detrimental to their economic well-being, but also causes environmental pollution.

This thesis applies a multi-server queuing model to analyze marine terminal gate congestion and quantify truck waiting cost. In addition, an optimization model is developed to minimize gate system cost. Extensive data collection includes field observations and online camera observation and terminal day-to-day operation records. Comprehensive data analysis provides a solid foundation to support the development of the optimization model. The queuing analysis indicates that there is a substantial truck waiting cost incurred during peak season. Three optimization alternatives are explored. The results prove that optimization by appointment is the most effective way to reduce gate congestion and improve system efficiency. Lastly, it is the recommendation to use the combination of optimization by appointment and productivity improvement to mitigate terminal gate congestion and accommodate the ever growing container volume.

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DEDICATION

To My Beloved Family:
my wife, Xinning Huang-Guan;
my mother, Jingyi Chang;
my dad, Boji Guan; and
my brother Changxin Guan,
for their love and support.

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CHAPTER 1

INTRODUCTION

Containerization has brought a revolution to maritime transportation by Malcolm McLean since 1956. The subsequent proliferation of containerization has resulted in the standardization of the cargo unit, handling process, and mode interchange. This has drastically improved the efficiency of cargo loading and discharging operations (Muller, 1999). Further, it greatly helped to accelerate the development of intermodalism that integrates ship, rail, and truck together into a very viable alternative for international container shipment. In this intermodal supply chain, the trucking industry plays an indispensable role that it serves the first and last linkage for all intermodal movement whether by ship or rail. Trucks perform the "door" moves, taking cargo from seaport or rail terminal to shippers' warehouses, or vice versa. Such truck service interfaces with other modes: ship and rail at the freight terminal's gate.

With globalization of the economy and trade liberalization, world trade, especially in container traffic, has grown rapidly. According to the annual report "Review of Maritime Transport," published by United Nations Conference on Trade and Development (UNCTAD), world-wide port container throughput volume grew from 135 million TEUs[1] in 1995 to 303 million TEUs in 2003. This represents an annual growth of 15.5% on average (UNCTAD, 1997 - 2005). In the U.S., port container traffic grew from 14.9 million TEUs in 1997 to 25.9 million loaded TEUs in 2004 (MARAD, 1997 - 2004), an average 10.6% growth annually. The future outlook also points out that

[1] TEU – Twenty foot equivalent unit, a standardized container unit.

the international trade volume will double by 2020, according to a freight study conducted by DRI-WEFA (currently known as Global Insight) for the Federal Highway Administration (FHWA) (FHWA, 2002).

The development in container trade and the container shipping industry has a direct impact on port development as well as on the regional transportation network, especially on highways and intermodal connectors. Freight infrastructure such as access channel, terminal facilities, cargo handling capacity, intermodal network and connectors are under increasing pressure to keep up with the ever growing container volume. On the other hand, the supply chain industry requires a high level of service from intermodal carriers in terms of service reliability and predictability. The general trend for retailers and manufacturers is to use more frequent shipment, substituting for costly and high level inventory and outsourcing production to overseas low cost countries. In a "just-in-time" logistics environment, manufacturers and retailers basically use their carriers as moving warehouses – warehousing in motion. For a manufacturer, parts from oversea may be delivered by a truck within hours or even minutes before they are used in an assembly line (Frittelli, 2003). During the last few years, the freight community has experienced significant delays due to inadequate intermodal transportation infrastructure, either in marine terminals, or highways, or railroads, or intermodal facilities (Rooney, 2006). Furthermore, the increasing container truck volume has led to serious congestions; truckers have to wait for a long time at port facilities. Congestion reduces travel time reliability for both commuters and truckers, which is a significant concern for large and small businesses. The delay caused by congestion could drastically increase the costs of freight movements. The extra time spent in congestion causes service providers to make fewer calls per day, resulting in higher prices for consumers. For trucking, congestion has two significant impacts: one is the increase travel time that will add direct costs; and two is the reduction in reliability that will decrease predictability, adding more costs, a problem for truckers who must meet "just-in-time" delivery schedules set by shippers (FHWA, 2004). Such congestion problems reduce the efficiency of freight flow, worsen environmental quality, and eventually increase the costs of doing business, a detriment to truckers' economic well-being and regional economic competitiveness. Although, freight flow is a private sector business activity, the public sector is becoming more and more aware of the impact of growing container traffic and delays at port facilities. This dissertation will analyze marine container terminal (MCT) operations, investigate truck congestion problem at the MCT gate, model the congestion problem and quantify truck congestion costs, and evaluate congestion mitigation alternatives.

1.1 Background

In a study by ICF Consulting for FHWA, it identifies that delay at port facilities is one of the pressing issues facing the motor carrier industry. Though this only affects the harbor trucker, it is a serious issue. The harbor trucking industry plays a vital role in the intermodal supply chain industry; it is an important stakeholder of a port community. It performs critical functions of pickup and delivery of containers to and from the MCTs for shippers. Port facility congestion threatens to erode the harbor trucking industry's productivity and compromise the high level of service to shippers (FHWA, 2003). Truckers working in the harbor drayage business are mostly owner – operators; they are paid by the trip, not by the hours they work. Any delay such as long waiting lines at the MCT gates costs truckers' time and money (Mongelluzo, 2002b). The MCT gate congestion is well-documented problem in the Journal of Commerce (JOC), a trade publication, specialized in freight transportation and logistics issues. According to Mongelluzo, various stakeholders in the port intermodal supply chain have bickered for years to solve one problem: the long queue of trucks idling outside MCTs. This illustrates the port system's inability to handle the fast growing volume of container freight. Drivers sometimes have to wait for hours to pick up or drop off a container (Mongelluzo, 2002a).

The MCT gate congestion problems and harbor trucker related issues in major container ports such as the Port of New York/New Jersey, Port of Savannah, and the Port of Long Beach/Los Angles were reported in a series of articles in the JOC. The truckers often complain that terminal management's practices worsen delays and penalty rules are written so that terminals are not responsible for truckers' waiting time outside terminal gates (Bledsoe, 2003). Severe congestions at MCT gates prompted several state legislators to propose fines for terminal operators whose operations regularly have truckers to wait in long line at the gate. In California, due to the chronic serious gate congestion at terminals in Los Angles and Long Beach, the state legislature passed the "Lowenthal Bill", which imposes a $250 fine per violation on terminal operators if trucks with appointments wait for more than 30 minutes at the terminal gates. The bill was implemented in July, 2003 (Mongelluzo, 2003). In Massachusetts and New Jersey, similar state bills are pending. In 2002, chronic congestion problems at container terminals in New Jersey led to a petition by the Bi-State Motor Carrier Association, who represents harbor truckers in New York and New Jersey, filed to the Federal Maritime

Commission (FMC) (Dupin, 2002). In the petition, it asked for compensation from terminal operators to pay for trucker's excessive waiting time at the terminal gates. However, the petition was denied based on the ground of insufficient evidence (Bonney, February, 2004) that the economic damage was not quantified. According to a study commissioned by National Chamber Foundation of U.S. Chamber of Commerce (2003), "… a typical congestion at port gates is worse than that experienced on freeways during rush hours in metropolitan areas." These examples of MCT gate congestions demonstrate there is economic harm caused by container terminal gate congestions.

As container volume growth has showed no sign of slowing down, port and intermodal infrastructures have been under the spotlight for many years. Since the port is an indispensable node in the global supply chain, port development and port operation issues have been the subject of research and studies. In particular, how to reduce port congestion is of great interest. Though port congestion is a well known problem and continues to be a serious challenge to both the private and public sectors, there are only a handful of studies to address MCT congestion issues.

In a study to identify truck congestion problem in California ports (Regan and Golob, 2000), a detailed survey was conducted among intermodal trucking companies. Out of 1,200 trucking companies surveyed, 450 served the ports in California. Questions were asked about the marine intermodal facilities regarding typical delays and predictability of time required for pickup and delivery at those facilities. In addition, operators were also asked to provide descriptions about the types of problems they encountered at those facilities. The result indicated that waiting time and variability of waiting at ports can be significant. Such delays occurred both outside the MCT gate as well as inside the MCT gate. More than 40% of maritime intermodal carriers reported that drivers typically spent more than an hour waiting outside the MCT gate to get in. Also more than 75% of them said drivers spent more than an hour inside the gate. More importantly, over 80% indicated the time spent at the port was not predictable to within 30 minutes. Among the carriers serving the ports in California, less than 15% reported never having problem; almost 44% said that their operations were often affected by the congestion at the ports. Lastly, congestion/waiting/delays present the worst problems facing the carriers.

To measure system performance of goods movement in California, a study was undertaken by the METRANS Transportation Center, University of Southern California and State University of California Long Beach. A set of indicators were developed (Barber and Grobar, 2002); they were mobility/accessibility, reliability, sustainability, environmental quality. To assess the truck waiting time that truck drivers face in the Ports of Los Angles and Long Beach, the databases of three trucking companies with large volume of business in the ports were used. Truck waiting time for each trip inside the ports were tabulated and analyzed. In addition, monthly and seasonal variations were calculated. The result of data analysis revealed significant waiting time problems. In addition, temporal distributions of truck arrivals and departures were identified. However, truck waiting time outside MCT gate was not measured, but nevertheless indicated that congestion problem of long waiting lines outside the gate existed.

Recently, another study by Professor K. Manaco and Professor Grobar at METRANS provided further indication that port delays at marine terminals are the most significant impediment to improving the pay of truck drivers, reported by the Journal of

Commerce (JOC) on October 20, 2005. It surveyed 175 drivers doing business at the Port of Long Beach in 2004. Though the details of the study is not yet available, it concluded that maximizing drivers' turn times at marine terminals is critical to their earning power since the drivers are paid by the trip, not by the miles. Reportedly, drivers spend as much as one-third of their working day in non-driving activities such as waiting in line at terminal gates or inside the terminals. On the other hand, the terminal operators and union employees at the terminals do not suffer such financial losses from the inefficiencies imposed on harbor truckers (Mongelluzzo, Oct 20, 2005). All these indicate that truck waiting is a serious problem that needs to be addressed.

1.2 Problem Statement

North America has a growing port capacity problem, leading to congestion that is detrimental to global supply chain efficiency. Such port congestion problem triggers a chain reaction. It increases ocean carriers' cost due to in-transit schedule adjustments, higher fuel and labor costs. Carriers in turn will pass these costs onto shippers. Port congestion also causes unpredictable shipment delays, leading to increaseed inventory levels. As a result, the supply chain productivity is reduced (Maloni and Jackson, 2005b). On the other hand, increasing vessel size will put additional pressure on port capacity; 8, 000 TEU Super Post Panamax ships are already serving the West Coast ports and 10, 000 TEU ships are already being built (Mongelluzo, 2005). Port capacity becomes a critical issue; some even argued that the nation's port industry is facing a capacity crisis and congestion could crush U.S. ports by 2010 (Mongelluzo, 2005a and 2006). In a port capacity study, actual port volume growth based on historical data is much greater than forecast; the gap is in the range of 7 million TEUs. This is a clear indication that ports are reaching their capacity limits a lot faster. Among the ten important factors that affect port capacity, MCT gate capacity is one of them (Maloni and Jackson, 2005b).

A marine container terminal (MCT) serves as a critical node in the global supply chain. It performs many functions: ship-shore container transfer, container storage, cargo receiving and delivery. In addition, it is a focal point where cargo information is exchanged, container equipment is interchanged, and liability transfer takes place. Therefore, for every container coming in or out of the MCT, a business transaction takes place that requires proper procedures to ensure transaction security, transfer of liability, and smooth monetary transfer. The harbor trucker is the party that provides services for local container pickup and delivery. When truckers come to the MCT to pick up and drop off containers, they have to wait in line in front of the gate complex for security clearance and cargo/equipment information processing. As container volume grows rapidly, waiting time outside the MCT becomes a serious issue. This problem arises for two significant reasons: one, is that container terminals in the US are open only five days a week (Monday through Friday) with ten to twelve operating hours per day; two, is the limited number of gate lanes at each terminal. Therefore, the gate processing capacity is critical to accommodate the growing container volume. As a result, as container volume continues to grow, long truck waiting lines are usually formed at the terminal gate complex.

The harbor trucking industry operates in a highly competitive market. The industry consists of many small firms and owner-operators competing to provide services to clients such as shippers, third party logistics providers, and ocean carriers. Harbor truckers are paid by the load; they are not paid to wait for loading and unloading. This business relationship requires frequent "turns" to make a living. Waiting time outside the MCT is time wasted. In addition, diesel burning while inching up a queue wastes fuel and pollutes the environment (Barton, 2001). Therefore, such delays have negative impacts on harbor truckers; congestion at the MCT gate imposes a financial penalty on these firms in lost revenue and profits. However, such economic costs imposed on truckers are not borne by the MCT operator because the MCT operator is paid by ocean carriers whose vessels call at the terminals on a regular basis, and the truckers are paid either by shippers, third party logistics providers, or ocean carriers for the pickup and drop off containers. There is no direct financial transaction or relationship between the two parties. Furthermore, harbor truckers get paid by the jobs they perform, not by the hours; that means the burden of MCT gate congestion is solely on the shoulders of the harbor truckers.

On the other hand, the MCT operator can impose long waiting times on the truckers with impunity (FHWA, 2003). The service provided by the MCT operator directly affects the financial well-being of the truckers. The congestion at the MCT gate causes truckers to wait in line without being compensated. In addition, congestion at the MCT gate causes environmental pollution in the vicinity. The severity of the MCT gate congestion is evident in the aforementioned FMC petition and the promulgation of the "Lowenthal Law" in California. However, few studies have been done to quantify the economic costs of MCT gate congestion imposed on harbor truckers. There are only a few studies that provide in-depth congestion modeling and congestion cost analysis.

However, in these studies there is little data actually focused on the trucking waiting cost at the MCT gate.

The passage and pending legislation regarding MCT gate congestion, and the FMC case underscore the seriousness of the MCT gate congestion issue. Further, they illustrate that there is an economic harm to harbor truckers due to MCT gate congestion. On the other hand, the lack of congestion data demonstrates the need to quantify the cost of congestion. In turn, the quantification of trucker waiting costs at terminal gates will demonstrate the magnitude of the congestion problem. In addition, this will help to formulate a public policy and provide a mechanism to mitigate the congestion and improve freight flow efficiency.

The economic analysis of the MCT gate congestion problem will fill the gap in quantifying the MCT gate congestion costs, help to gain better understanding of the MCT gate congestion issue, and investigate possible solutions for promoting economic efficiency and fairness. A number of techniques will be utilized to evaluate the magnitude of the MCT gate congestion costs, provide alternatives to mitigate gate congestion and maintain freight efficiency.

1.3. Research Objectives

The purpose of this thesis is to analyze the MCT gate system operation, develop a model to measure and quantify economic costs of gate congestion, provide alternatives to optimize gate operation, and investigate gate congestion mitigation alternatives in the Port of New York/New Jersey. The first objective is to analyze the MCT gate system operation. The MCT gate system serves many different functions; it is not just another checking point. Rather, it is an integral part of an overall container terminal logistics system. It involves many critical activities that affect the performance of the terminal. In addition, gate system performance has a direct bearing on many supply chain entities. This analysis will identify key elements of gate operation and operational processes, which will serve as an input for subsequent model development. Furthermore, the relationship between container volume and the number of truck trips generated is analyzed. This will provide critical information to port planners for land access and infrastructure planning purposes.

The second objective is to develop a model to analyze the MCT gate congestion and quantify congestion costs. The model has two major components: trucker's waiting cost and terminal operator's cost. The trucker's waiting costs are the congestion costs; the MCT gate operating costs include labor cost, fixed cost, and other costs of the gate system. The trucker's waiting costs are subject to truck traffic volume, arrival pattern, and gate system processing capability, besides labor cost, equipment cost, fuel cost, and other miscellaneous costs. Because of the stochastic nature of truck arrivals at the MCT, various techniques will be applied in quantifying the waiting costs.

The third objective is to analyze the gate capacity system utilization and compare it to the congestion level. Gate system utilization is closely related to the congestion problem. An analysis to the capacity utilization and corresponding congestion level can identify the relationship that helps to understand congestion behavior. This will help gate capacity planning and identify opportunities for system optimization.

The fourth objective is to provide alternatives to mitigate gate congestion. As container volume continues to grow, truck traffic will increase accordingly. The analysis will analyze gate congestion level and estimate congestion costs, based on several assumptions of gate processing productivity, gate capacity, and traffic volume. Based on the result of the analysis, alternatives will be provided to increase capacity and reduce congestion costs for the MCT operator and truckers.

1.4 Contribution of Research

As stated in the FHWA report regarding the challenges facing the motor carrier industry, MCT gate congestion is an important issue that has economic implications for stakeholders of the supply chain community. Furthermore, the implementation of the "Lowenthal Bill" in California and the pending state bills in Massachusetts and New Jersey demonstrate the urgency of the issues. As container volume keeps growing, MCT congestion issue will become more pronounced. During an interview with Mr. Dick Jones, the Executive Director of the Bi-State Association of Motor Carrier, he emphasized the following:

> "Harbor trucker plays an important role in the supply chain; they are the ones that provide services to link the beginning and the final segments of the supply chain. However, their work is underappreciated. Because of chronic terminal congestion, truckers suffer tremendously for waiting at the gate without compensation. The lack of quantitative data in this regard hampers their effort to gain support to address their economic loss. The association is quite frustrated by its inability to quantify the waiting cost in order to support its petition to FMC. The quantification of truck waiting cost will help harbor truckers argue for their case more effectively to get better service. In the end, the increased public awareness of MCT congestion problem will lead to better public policy; and reduction in gate congestion will ultimately benefit shippers and consumers."

The development of the gate congestion model will help to better understand the intricacies of the MCT gate operation and root causes of gate congestion. The development of a congestion model will help to quantify the MCT gate congestion cost, an important issue in freight congestion. It will demonstrate the magnitude of the congestion costs and increase public awareness. In addition, the model can serve as a planning tool to forecast truck traffic volume, potential congestion in the future, and sustainable port development. Alternatives of freight distribution can be developed to mitigate congestion.

As freight volume increases, port capacity shortages and freight related congestion issues will become more pronounced in major container ports where metropolitan areas are located, compounding traffic congestion problem. This thesis provides an in-depth analysis in direct economic cost of MCT gate congestion, extending the knowledge of freight congestion. More significantly, the study will increase the public awareness of congestion problems at the MCT gate, and its economic consequence; this will help port development planning to formulate future public policy, minimizing or mitigating such chronic congestion for sustainable development. The FHWA's motor carrier industry study clearly states: "Research on the cost of port gate delays for draymen, shippers, and the economy could serve to highlight the magnitude of the problem, and help advocates push for solutions (FHWA, 2003)."

1.5 Research Scope

This thesis addresses a wide range of research issues in MCT gate operation, MCT gate system modeling, truck waiting time modeling, gate operation optimization, and public policy analysis. The scope of this research is focused on the development of a model to evaluate MCT gate congestion and quantify the trucker's waiting cost at the MCT gate within the context of freight congestion. Such analysis can be extended to port planning and public policy applications. However, to ensure a thorough and in-depth analysis of the issue, this thesis will focus on the model development to analyze MCT gate congestion and truck waiting time cost.

Since this study is focused on MCT gate congestion, various techniques will be used to analyze critical elements of the congestion problem such as arrival patterns, service times, queue lengths, waiting times, etc. Data will be obtained through on-site observations, from terminal operators and trucking companies as well as from publicly available data. Optimization modeling will provide alternatives for policy analysis to mitigate congestion problems at the MCT. Computer simulation will be used to test different scenarios of various levels of MCT congestion and alternatives for optimization.

This research provides five distinctive products regarding MCT gate congestion. The first one is the compilation of existing literature regarding MCT operation and gate congestion issues. The review of the literature gives an assessment of the current state of practice. The second one is the behavioral patterns of container activities at the MCT gate that will help to gain in-depth knowledge of freight movement of the port. The third one is a conceptual framework to model MCT congestion problems. It serves to identify elements that affect MCT gate operations, efficiency, and level of congestion, and evaluate costs of gate congestion. The fourth one is the congestion modeling that analyzes truck waiting time and waiting costs. The last one is the optimization of MCT gate operations to reduce congestion and improve service.

As container volume continues to grow rapidly, intermodal terminals are under stress to deal with such volume increases. U.S. MCT operators in particular are facing the daunting challenging of how to accommodate the ever increasing freight volume and maintain freight flow efficiency, given various capacity constraints. The various reported congestion problems and actions taken by truckers and legislators become the primary motivation of this research. The MCT gate congestion, though a private sector operational problem, have captured the attention of the general public. As the majority of container ports in the US operate in the form of public-private partnership, MCT gate congestion and the trucker's waiting cost have become a public policy issue that needs to be addressed. To come up with a solution that is equitable to all parties concerned, this research provides in-depth analysis on the issue and alternatives to solve the problem.

CHAPTER 2

LITERATURE REVIEW

The growth of the container volume and the increasing size of containership have presented numerous challenges to the port industry. In the past decade, stakeholders in the supply chain are sensitive to the issue of congestion in the intermodal transportation network. Congestion developed at one place of the network will have a snowball effect on the entire network. As the majority of international trade is carried by water transport, seaports are indispensable nodes in the global supply chain. They provide the crucial interface between water transport and land transport. In addition, they perform many vital functions to facilitate freight movement. In general, port efficiency is an important indicator of regional economic competitiveness (Yahalom et al. 2001). Therefore, port authorities and terminal operators are under pressure to improve efficiency and performance (Tongzon, 1995). Ultimately, port capacity and efficiency usually determine the economic and growth potential of the region it serves (Frankel, 1987).

Containerization revolution was a phenomenon in international shipping that brought profound changes the way the entire shipping industry operated. Ships have become more specialized that are divided into different categories: crude oil tanker, product tanker, bulk carrier, Ro-Ro carrier, container ship, and breakbulk ship. To meet the change in industry structure, port authorities and terminal operators responded by specializing their facilities and services. Container terminals were built to accommodate the increasing number of containerships. At the same time, port operational efficiency became critical in maintaining regional economic competitiveness; port congestion was recognized as the main problem, causing delays and resulting in financial loss for ship owners and shippers.

Port operation, especially MCT operation has been a research subject for many years. Researchers study issues of the MCT operation from different perspectives and use many different techniques to improve efficiency and performance. The literature review is concentrated on capacity and congestion problems that are closely related to the dissertation topic. In general, the MCT system is divided into four main areas: ship-shore operation, yard operation, receipt/delivery operation, and overall terminal operations.

2.1 Quay Side Operation – Berth Planning and Capacity

Efficient utilization of resources efficiently is the goal of management in many container ports, in order to reduce costs. Resources to provide service to ships include human resources, berths, container yards, ship-shore cranes, and various container handling equipment. Since ships are the primary customer for ports, berths are considered the most important resource among them. Inadequate berth, crane, storage, handling, and labor all mean delay, causing high value of waiting time for ship owner and cargo interests. Daley (time) is a critical variable in structuring operational relationships in port operation and elapse time had financial consequences for all stakeholders in port business (Robinson, 1976). In quay side operation, there are three elements: one is berth allocation and the others are vessel loading and discharging. In general, the entire quay area of a container terminal is divided into several berths. The allocation of incoming vessels to the proper quay location is based on the berth. A good berth scheduling (allocation) is essential to improve customer satisfaction as well as to increase cargo throughput, resulting in higher revenues of ports (Kim, K. H. and Moon, K. C., 2003). Also, construction of berthing facilities requires large amount of capital that high return on asset is desirable for either public or private investment in ports. Vessel loading and discharging issues deal with how efficient the crane operation can be carried out after vessel berthing. The third issue is berth planning and capacity. Since the focus of this thesis is on capacity issue, therefore, berth allocation and cargo loading and discharging will not be discussed. They are beyond the scope of this thesis. The literature review will be concentrated on how to address the berth planning and capacity issues.

To study port operation and the relationships among different factors in the port operation system, queuing theory has been widely used to identify operational bottleneck and optimization solutions. Hansen, (1972), Wanhill (1974), Robinson (1976), Edmond E. and Maggs, R. (1978), Noritake and Kimura (1983), Noritake (1985), Schonfeld and Sharafeldien (1985), Sheikh, et al. (1987), Ramini (1996), Gambardella et al. (1998), Thomo, et al., (1998), Bruzzone et al. (1998, 1999), Shabayek, and Yeung (2001), Chu and Huang (2002), and (Yamada et al., 2003) have applied queuing theory and computer simulation to study berth planning problems and capacity issues with the objectives of optimal use of resources. Their researches represent a more practical approach to address the port operation and planning issues.

Hansen (1972) points out that port capacity issues actually involve three areas: cargo loading and discharging (vessel operation), storage, and transfer cargo in and out of the port area. He analyzes a number of parameters that influence the economic optimum size of a seaport such as quay length, the number of cranes, and vessel traffic patterns. Statistical distributions of the various parameters, costs of ship waiting, costs of crane and berth serve as input to build simulation models. Ship arrival rate is found to be a Poisson distribution and ship service time uses three different types of distributions. The simulation output includes mean service time for ships and its statistical distribution, the mean delay for ships, mean waiting time for ships and its statistics distribution, the probability of delay in queue, the optimum number of berths,, and length of quay, and the number cranes. In addition, sensitivity analysis is performed.

To measure the port system performance, a systematic approach is essential. Robinson (1976) argues that the traditional approach failed to develop quantitative and predictive models capable of revealing the basic dimensions of spatial structure and functions of a port. Robinson proposes a framework to rectify such shortcomings. The first step was to conceptualize the port as an operational system. Such conceptualization made it possible to develop a modeling framework that functional linkage between sub-systems can be quantified, spatial structure defined, and capacity and efficiency determined. As a result, progressively, the port system can be modeled at varying levels of complexity and a hierarchy of models is formulated to deal with more complex relationships progressively --- starting from arrival and service time to queuing, simulation, and optimization models. Three basic dimensions are identified: elapse time (time for ship stay in port), inter-berth shipping linkages, and system capacity and efficiency; each of them is amenable to statistical analysis. They form the foundation for modeling the port as an operational system.

Robinson's application of queuing theory with three parameters of ship arrival, ship servicing time, and queuing times are particularly appropriate in modeling the time-capacity relationship in port. Two types of statistical distributions: Poission and Erlang distributions are used in constructing his queuing models: Poisson distribution to model and Erlang distribution to model service time (k = 2, or 3). Lastly, Robinson suggests that since queuing models are restricted by assumptions and system behaviors may not conform to such assumptions, simulation is necessary. Simulation can be used in problem solving, optimization, and long term planning.

Edmond E. and Maggs, R. (1978) investigate the operational characteristics of U.K. container terminals and shipping services. Some traditional queuing models such as M/M/S and D/M/S are applied to evaluate investment decisions in berth construction and cargo handling equipment. The evaluation concluded that common queuing models provided a reasonable approximation to some aspects of container terminal operations, but the interpretation of the result should take factors that are not quantifiable into consideration. Queuing models, with arrival rates and working rates dependent on the state of the terminal and the service level, prove to be useful. In addition, results are very sensitive to the cost function for ship's port time --- waiting time cost function. Simulation models may be the only way to represent all the relevant port operations to give satisfactory results.

Wanhill (1974), Noritake and Kimura (1983), Thomo, et al. (1998), and Yamada, et al. (2003) use a total cost approach to identify the optimal number of berths and minimize cost. In the total model, there are two components: cost of berth and ship cost (including cost of ship at berth and cost of ship waiting). Wanhill (1974) and Thomo, et al. (1998) apply M/M/S model to calculate ship's waiting time and incorporate ship's loading and discharging rates into the model. Wanhill (1974) uses simulation and iterative procedures to obtain an optimal solution. Thomo et al. (1998) model ship arrival and port service in the Port of Thessaloniki, Greece, based on operational data collected. In addition, ship waiting cost and cost of berth are incorporated in the analysis. The result revealed that the number of berths in the port was sufficient to accommodate current vessel traffic. Therefore, port expansion was not necessary. Instead, the port should focus on improving port service, mainly in productivity.

Noritake and Kimura (1983) and Yamada, et al. (2003) apply several multi-server queuing models to calculate the optimum number of berths by minimizing total costs of both the cost of berth and the cost of ship cost, in which trade-off is involved for these two components. In calculation of ship's waiting time and the number of ships in waiting, Noritake and Kimura (1983) use two models: M/M/S and $M/E_k/S$. To deal with the complexity of ship service time in Erlang distribution, Lee and Longton (1959), and Cosmetatos (1976) approximation are applied and tested, based on operational data. It is found that Cosmetatos' approximation is more practical and accurate. Sensitivity analysis is conducted to test different values of various parameters such as total tonnage of cargo to be handled, average rate of cargo handling, cost of berth, cost of ship, and the number of Erlang phases of service time distribution k. The results are applied to some ports in Japan.

Due to high cost of container terminal development and vessel waiting time, there is a need to establish an efficiency container handling system that can optimize container handling to minimize the total costs of terminal development and vessel waiting time cost. Though Yamada et al. (2003) uses the similar approach, the authors go further. Not only queuing theory is used, but also simulation to model container vessel arrivals and loading/discharging operations at berth in the Port of Osaka, Japan. In the optimization model, multi-server queue models are applied; container vessels are the customers and container berths are the servers. The most critical task in the analysis was to calculate vessel waiting time under various conditions. Multi-server queue models were used to calculate the average number of vessels in the system. In particular, $M/E_k/n$ (Poisson distribution of vessel arrivals and Erlang distribution for vessel service time) and $E_k/E_l/S$ (Erlang distribution for both vessel arrivals and vessel service time) models with Cosmetatos and Kimura approximation methods are utilized to obtain a more accurate vessel waiting time calculation for a public and a private terminal, respectively. In addition, a simulation model based on queuing theory is also developed. Simulation procedures are based on the logical sequence of vessel arrival, berth availability, container loading and discharging rates, and vessel departure. The results from the mathematical models and simulation are compared. Based on the results, the authors provided recommendation to improve capacity utilization and productivity enhancement towards the objective of lowering total costs.

When a ship arrives at a port, a berth is needed to accommodate cargo loading and discharging operation. If a berth is vacant, the ship can go in and undertake loading and discharging operations right away. If there is no berth available, the ship has to wait until a berth is available. A ship sitting idle does not generate revenue, instead there are operating costs incurred such as crew wage, insurance, fuel, port charges, etc. Therefore, it constitutes a waiting line and waiting cost problems. Queuing theory can be applied to analyze such seaport berth congestion problem. The ship arrival pattern can be treated as a stochastic process with an arrival rate (vessels/day), the length of a ship stay at berth for cargo operation can be treated as processing time (days/vessel). Since a port has several berths in general and each berth can be treated as a service station, several multiple server queuing models, M/M/S (∞) and M/E_k/S (∞) are applied to analyze the berth congestion problem (Noritake, 1985). In this analysis, the author identifies cost composition and estimates congestion costs using various scenarios with different parameters, such as ship arrival rate, time at berth, and the number of berth. The degree of congestion is measured by the average waiting time of ships, and such time losses are transformed into economic losses. It concludes that congestion in a port is caused by the mutual relation between ship demand for port services and the supply services provided by the port in terms of berths. The total cost for a port system has two components: total berth cost and total ship cost. The port congestion cost is regarded as one of the external diseconomies; it is defined as the difference between the marginal total cost for the port system and the average ship cost. However, determining the marginal cost for a port is a major difficulty. When the number of berths is small, the marginal cost can be calculated theoretically. But when the number of berths is large, there are no appropriate methods that can be applied; therefore, approximation is used. Finally, the paper also provides a theory on how to use marginal cost pricing as a mechanism to achieve a better distribution among several seaports to reduce total ship waiting time.

Schonfeld and Sharafeldien (1985) develop a model to optimize container port design and operation. In addition, the model also resolves the trade-offs among various elements of a container terminal. The model has six variables: berth cost, cost of container cranes, cost of storage yard, labor cost for ship's gang, cost of ship in port, and cost of containers and their cargo. Rather than using an average cost figure, capital recovery factor is applied in calculating the costs of berth, ship, crane, and container. The model developed is a comprehensive one in order to obtain realistic results. The M/M/S is also applied to calculate the ship's waiting time and service time. Sensitivity analysis is conducted by varying the six cost components of the model. The authors also emphasize the importance of institution factors and their impacts on optimality in terms of the number of berths, the number of cranes, and total system costs.

By nature, one reason for fluctuation in trade volume is the seasonal factors such as Thanksgiving, Christmas, and the New Year. To evaluate the impact of the seasonal factors on container terminal performance, Shabayek, and Yeung (2001) apply the queuing theory to Hong Kong's Kwai Chung Container Terminal to model vessel arrivals and terminal service time of container vessels. In their paper, container vessels are viewed as customers and the terminal operators' berths are treated as servers. Using data collected from terminal operators at Kwai Chung Terminal, vessel inter-arrival time and vessel service time are analyzed. To calculate vessel average waiting time, the M/G/n (Poisson arrival and deterministic service time) model with Costmetatos (1976), approximation is used. The results of theoretical queuing model and the results from observed data are compared to evaluate the accuracy of the model applied. Incorporating the developed seasonal indices, the forecasted vessel waiting time and system time can be used to improve customer service, productivity improvement, berth planning, and future port development.

Sheikh et al. (1987) uses a micro-computer based simulation to calculate the number of berths required according to service level desired (the length of ship waiting time). A queuing model is built according to observed data in terms of ship arrival, service time, types of cargo, types of berths, cargo handling rate, and ship departure. In addition, berth allocation rules are applied in the simulation model. The distributions of ship arrival and service times are found to be Erlang. Different scenarios of traffic forecast and cargo operation are simulated to estimate the number of berths required based on a set of indices such as the level of ship waiting time and berth occupancy rate. The model enables port planners to estimate port development needs for various levels of service and demand at the port corresponding to different cargo handling rates.

Due to the relatively small container yard and high level of container traffic at the Port of La Spezia, Italy, how to properly allocate quay cranes and yard cranes to service ships and truck traffic becomes critical. Gambardella, et al. (1998), develops a resource allocation model using mixed-integer linear programming with the objective of maximizing profit for the terminal operator. At the same time, a simulation model is also developed to simulate quay and container yard operations. In the vessel operation module, the simulation provides solutions to allocate quay cranes and yard cranes in order to optimize equipment usage.

Mosca et al. (1996), uses an object – oriented simulation model (in C language) to replicate behavior of a container terminal with the objective to better manage quay and yard operations. The data input is based on stochastic events of ship arrival, and statistical distribution is validated. The model provides a useful tool to estimate quay and yard capacity. Ramani (1996) develops a simulation model (in C language) to estimate port performance in terms of berth occupancy, ship outputs (number of containers handled), and ship turnaround time. He argues that port operation is quite complicated and analytical models lack the capability to estimate port performance indicators. Simulation methodology is more appropriate. Data input uses observed operational data and statistical distributions for ship arrival times, ship waiting timed, ship turnaround times, and yard truck turnaround times are validated. Furthermore, operational rules such as FIFO are incorporated into the model. Alternatives of handling strategies are presented to shorten ship turnaround time.

To address berth planning and resource optimization problems at a container terminal, Legato and Mazza (2001) apply a queuing network based model to simulate ship arrivals and berth planning under different scenarios, using Visual SLAM software. The authors argue that due to non-standard service stations (berths), time-dependent priority mechanisms such as service priority for certain vessels, and complex resource allocation policies, analytical models are not suitable. A process – driven discrete event simulation is utilized. Observed data from the Port of Giao Tauro, Italy is used as input to simulate the operation process. Statistical distribution of vessel arrivals, quay crane allocation, and vessel departures are validated. Erlang distribution for vessel arrival and probability of waiting is analyzed. Simulation results allow terminal management to evaluate "what if scenarios" to optimize berth planning problems.

To address port capacity constraint issue, Kia and Ghob (2002) use computer simulation to evaluate an alternative of using on-dock rail for container distribution to ease up terminal congestion as compared to the current system that up to 85% of the containers are distributed by trucks. The focus is on berth occupancy and berth utilization. Operational data of the Port of Melbourne, Australia is used as input for the simulation model. Ship inter-arrival times and ship service times are found to be Poisson distribution and Erlang distribution, respectively, using Chi squared test at 95% confidence level. The simulation results show that the proposed on-dock rail container distribution improves efficiency, berth utilization, energy efficiency, as well as cost savings for ship operations, infrastructure development, and shipper's inventory carrying.

To demonstrate that analytical models can actually achieve the same results as simulation model in vessel operations, Kozan (1997a) develops to two analytical models based on queuing theory of batch-arrival multi-server queuing models. These models are compared with a simulation model. Containers are considered to arrive in a batch with the same ship per arrival. Container service time is actually the load and discharging time for a container. Statistical distributions for ship arrival and service times are Poisson and Erlang distributions, respectively. The simulation model incorporates all relevant properties of a MCT such as ship arrivals, coefficient of ship's carrying capacity, distribution of different types of containers, ratio of import and export containers, service time, the number and capacity of quay cranes, working rules, working hours, container handling equipment, dwell time of containers, queuing discipline, etc. The comparison shows that despite the capability of the simulation model in dealing with complicated situations, the analytical model is still a very useful tool to analyze complicated MCT operation and provide an optimal solution of service improvement.

In summary, there are plenty of studies addressing the quay side operation problems of a terminal. Research techniques range from analytical models in operations research to computer simulations. Among analytical models, multi-server queuing models are widely used in addressing waiting time and capacity problems. Mixed- integer programming and heuristics algorithms are used in berth allocation problems. Simulation models are used frequently to solve problems that are deemed too complex.

2.2 Yard Operation

Yard operation plays a vital role in the overall MCT operations; it serves as a buffer to support both the quay side operation and container receipt and delivery operation. It provides the critical interface function between water transport and land/ intermodal transport. The yard operation involves the following (Yahalom et al., 2001):

- Space allocation for import, export, empty containers, and chassis
- Segregation of containers according to their size, weight, port of discharge, ownership, vessel/voyage, special cargo such as reefer or hazardous, etc.
- Sorting out containers
- Stacking and unstacking of containers
- Delivering and receiving of containers
- Traffic control

The objectives of the yard operation are two-fold: minimizing truck turnaround time and providing adequate support for vessel operation (high productivity). On the other hand, it needs to minimize operating costs to maintain profitability. There are different types of yard handling systems that have different operating characteristics. The selection of yard handling system is primarily subject to dynamics of traffic volume, land space availability, cost of land, labor cost, and equipment cost. These factors are interdependent of each other. Mainly there are five types of yard handling systems: chassis system, front lift truck/reach stacker system (FLT), straddle carrier system (SC), rubber tire gantry system (RTG), and rail mounted gantry system (RMG). A number of studies have been done to address various yard operation issues using operations research techniques and computer simulation.

How to allocate yard handling equipment is of main interest for terminal management. Lai and Lam (1994), Gambardella et al. (1998), Kim K.H. and Kim, K.Y. (1999), Chung et al. (2002), Zhang et al. (2002) use various simulation and analytical models on this issue.

To improve day-to-day yard operation at a Hong Kong container terminal, Lai and Lam (1994) develop a computer simulation model formulated on a queuing system. The model is programmed in Pascal using observed operational data such as truck inter-arrival time distributions of import and export containers, service time distributions for container handling, and tractor travel time distribution. Performance measures include productivity of container handling (containers handled per hour), yard equipment and truck waiting time, and handling equipment utilization. Queuing discipline is FCFS.

How to allocate yard space to container storage is one of the primary concerns for terminal management. Kim, K. H. and Kim, H. B. (1998, 1999, 2002), and Zhang et al. (2003) use analytical models to address this issue from various perspective. Kim, K. H. and Kim, H. B. (1998) provide a cost model to determine the optimal amount of storage space and the optimal number of transfer cranes for import containers. The model includes cost of land, fixed cost of the transfer cranes (investment cost), operating cost, and waiting cost of outside trucks inside the terminal. Using observed operational data, a solution procedure is provided. Kim, K. H. and Kim, H. B. (2002) go further to consider two scenarios: minimizing the terminal operator's cost and minimizing the total cost of the terminal operator and outside truckers inside the terminal. Using M/G/1 queuing model to calculate truck waiting time, a total cost model is derived. Kim, K. H. and Kim, H. B. (1999) develop an analytical model to address the space allocation problem while minimizing the number of rehandling for import containers. Using Lagrangian relaxation technique, an algorithm is provided to obtain optimal solution. Zhang et al., (2003) address the issue of allocating space for import containers to balance the workloads for RTGs in the yard. The authors use a mixed integer program with Lagrangian relaxation to generate an optimal solution. The authors also argue that the model provides a fast solution in executing a dynamic deployment in the container storage. But the focus is on import containers and little attention is paid to the export containers arrival at the gate.

Yard operation productivity is critical to support both the receipt/delivery and vessel operation. For terminal operators to increase land utilization, one way to achieve this goal is to increase the stack height of container storage block. This might lead to higher number of "unproductive moves" – the number of shuffling in the yard operation. To study the impact of such policy, Chen (1999) examines several major factors that affect the productivity of the yard operation, and identifies possible solutions to reduce such negative impact on yard operation productivity.

To address the issues of yard transfer crane productivity to support vessel loading operation for export containers, Kim K.H., and Kim, K.Y. (1999) present an integer programming model with an objective to minimize the total operational set up time for container handling in yard blocks, and travel time between container blocks for yard cranes. An algorithm for optimal routing for the yard cranes is provided. Nishimura et al. (2005) address the issue of yard trailer routing in order to support vessel operations.

To deal with yard handling problem for incoming containers by trucks on a day-to-day basis, Sgouridis et al. (2003) use Extend, Version 3.2.2 to simulate an all-straddle-carrier container yard operation for short and medium term planning with the objectives of quantifying efficiency such as truck turnaround time, optimizing the number of straddle carriers, space utilization, service level, port expansion, and quantifying benefits for a semi-automated yard system. The simulation of yard operations to accommodate inbound trucks is a discrete-event problem. Data input includes the number and dimension of container stacks and trucks receiving grids, distance between trucks receiving grids and container stacks, truck arrival distribution, container shift patterns, yard space utilization, average speed of straddle carriers, and work roles in the port organization. Using observed data, model verification and validation are based on comparing the simulation model with observed data. The simulation results show various ways to optimize yard operations in shortening truck queues, improving space utilization, and increasing service level.

There are different types of container yard handling systems. The selection of which system to use depends on a variety of factors. Huang and Chu (2004) analyze the characteristics of SC, RTG, and RMG systems and provide a cost function model to estimate the total system cost under various scenarios and parameters such as land area, cost of land, cost of development, equipment purchasing costs, operating costs, maintenance costs, required financial return, equipment productivity, cargo volume, interest rate, service life of equipment, and equipment depreciation. Sensitivity analysis is conducted to evaluate different alternatives for port planning purpose.

In summary, the studies addressing yard operation problems come from different perspectives. Resource allocation issues are solved by both analytical and simulation models. At a tactical level regarding daily operation, operations research techniques, such as integer programming and heuristic algorithms, are popular. On the other hand, at the strategic level such as handling system selection, analytical models are used. The overall objective is to optimize resource allocation and minimize operating cost. On the other hand, studies addressing cost issues tend to be rare.

2.3 Receipt and Delivery Operation

The receipt/delivery operation performs the interface function between sea and land transport. The land transport is divided into two modes: rail and truck. Rail loading and unloading operations are similar to the quayside vessel operations. Intra-terminal vehicles are move alongside rail tracks. Top loaders/reach stackers, or RTG, or RMG will undertake load and unload operation. On the other hand, receipt/delivery operation for trucks is different. Trucks arriving at the gate have to undertake documentation processing and equipment inspection. Therefore, inbound trucks in most cases form a queue at the gate complex entrance waiting to be processed. Then instructions are given to pickup or deliver containers in the yard. Using information processed that the gate complex, the yard operations take place to serve those truckers. Truck arrivals are random events; the pickup and delivery of containers at MCT are subject to a wide variety of factors, such as shippers' own logistics requirements, the availability of truckers, vessel schedules, and warehouse operations.

Literature addressing MCT receipt/delivery operations, especially truck processing at the gate, is rare; there are only a few studies. Ballis and Abacoumkin (1996), and Kim et al. (2003) investigate the receipt/delivery operations in the yard. The former develop a computer program with animation capabilities to simulate container yard operations that service outside trucks. The simulation model is based on a straddle carrier operation at the container terminal, the Port of Piraeus, Greece. Yard layout with container storage blocks is built, equipment service characteristics are described, and truck arrivals process is configured. Unlike other simulations that service discipline is mostly FCFS; the service discipline is based on five heuristics including FCFS. The program not only simulates yard receiving and delivering operations, but also provides performance evaluation. Kim et al. (2003) recognize that truck turnaround time is one of the important indicators of customer service level for a container terminal. Applying a reinforcement learning technique, such technique addresses the question how a learner to chooses an optimal actions in an environment that is highly uncertain. A dynamic programming model is developed to solve the sequencing problem for trucks that their arrivals are known. For trucks arrivals unknown arrivals, the authors present a learning based method to derive decision on serving those trucks. Heuristics algorithms are suggested to come up with different sequencing rules such as FCFS, UT (uni-directional travel), NT (nearest truck first served), and SPT (shortest processing time). Simulations are performed to evaluate the different sequencing rules developed.

To deal with the problem of truck queue at the MCT gate complex, Wantanabe (2003) investigates the environmental impact of truck waiting at the port entrance gate. In his research, the author points out that no literature exists that the study can apply. Experiments are carried out to measure the amount of noxious emissions of trucks in the Port of Yokohama. There is no international regulations in place to govern such air pollution problem and suggests further study is necessary to tackle this issue.

Rail/truck intermodal terminals are different from MCTs that they are not located on the water front, but somewhere inland. They are tightly interconnected to rail and highway networks. Despite such difference, there are some similar features in terms of receipt/delivery operations and terminal layout (Rizzoli, et al. 2002). In this study, they investigate the operation of an intermodal terminal, using simulation. The terminal is modeled based on a set of rail platforms that are served by gantry cranes and top loaders. Train arrivals and truck arrivals are modeled as a deterministic input. Using a discrete-event simulation model and observed data, rail corridor and rail network, truck arrivals at the gate, and terminal process are simulated to evaluate operational performance. In particular, the relationship between gate processing time and truck waiting time is revealed.

To alleviate congestion traffic congestion problem, environment, energy, and labor costs issues, Taniguchi et al. (1999) propose a concept of public logistics terminals. The objective is to establish a more efficient logistics system and a cooperative freight system with public ownership, but operated jointly by private companies. To determine the optimal location and size of such public logistics terminals, a mathematical model is developed using both queuing theory and nonlinear programming. The goal is to obtain the best trade-off between the transportation cost and facility cost, ultimately the minimum total costs of the two. A multi-server queuing ($M/E_k/S$) with Cosmetatos approximation is used to model truck arrivals and waiting time issues; genetic algorithms are applied as a solution to the large scale nonlinear programming problem. This study deals with a problem that is not related to MCT receipt/delivery operation, however, it provides an excellent example of how queuing theory can be applied to address truck arrival and waiting time issues at a freight terminal.

In summary, there are only a few studies dealing with the MCT receipt/delivery operation. Actually, none of them directly addresses the gate congestion issues. On the other hand, one clear indication is that multi-server queue models and simulation are appropriate tools to solve waiting time problems at freight terminals.

2.4 Overall Terminal Operations

Rather than focusing on an individual component of a MCT system, many researches are concentrated on the overall port and terminal performance. The issues can be analyzed from different perspectives. Mainly, the literature is divided into the following categories:

- Port economic performance
- Terminal operations analysis using simulation
- Terminal operation optimization using analytical models

2.4.1 Port Economic Performance

As mentioned earlier, the port serves as an important node in the global supply chain. Containerization has helped to improve port operation performance tremendously, resulting in great improvement of port efficiency. At the same time, port competition is also heating up to attract cargo to support the regional economy. To measure the port's economic production performance, there are a few studies in this area.

Kim and Sachish (1986) study the impact of containerization on a port in terms of structure of production, technical change, and total factor productivity. The paper is focused on the case of the Port of Ashdod, Israel and its structure change since its adoption of containerization. Cost models and total productivity factors are examined; statistical testing of parameters and empirical results are evaluated.

Roll and Hayuth (1993), Martinez-Budria et al. (1999), Tongzon (2001), and Cullinane et al. (2004) use data envelopment analysis (DEA) to study port performance. According to Cullinane (2004), "DEA is roughly defined as a non-parametric method of measuring the efficiency of a decision making unit (DMU) with multiple inputs and/or multiple outputs." Roll and Hayuth (1993) presents an initial attempt to address port performance issue using DEA analysis. By using actual data, the paper demonstrates how useful DEA can be in analyzing port efficiency. Martinez-Budria et al. (1999) put 26 ports into three categories: high complexity, medium complexity, and low complexity. Using DEA models to analyze the efficiency of those ports based on a set of inputs, it is found that high complexity ports are closely associated with high degree of efficiency as compared with lower efficiency in medium and low complexity ports. Tongzon (2001) analyzes four Australian ports and twelve other international container ports for the year of 1996, using DEA. Due to the lack of data as well as small sample size, the study is only able to identify efficient ports, not the inefficient ones. The author suggests undertaking more observations and increasing sample size. Cullinane et al. (2004) examine the top 25 container ports of the world using DEA models with cross-section data analysis. Quay length, terminal area, number of ship-shore gantry cranes, number of yard gantry cranes, and the number of straddle carriers are used as input. The paper identifies ports that are efficient as well as the inefficient ones. The authors also suggest port competition may be the driver in terms of efficiency. Inefficiency might be the results of port ownership structure, local attributes, and the level of competition faced.

2.4.2 Terminal Operations

Because of the growing complexity of modern marine terminals, the changing dynamics of port and shipping technology, and the enormous amount of capital involved, port planning requires more sophisticated and flexible planning tools to evaluate performance, future needs, and the optimal investment strategy. Simulation methods have been used for analysis of throughput capacity, operational efficiency, terminal design, fleet composition, vessel arrival patterns, and equipment needs (Hayuth and Roll, 1994).

To apply the simulation tools effectively, Bruzzone et al. (1999) analyze the operative requirements for the new generation simulators in multimodal container terminals. Because of the extensive interaction with different entities or stakeholders in container terminal operations and the difficulties to satisfy the various operative constraints, interoperability and access to large dynamic database are necessary. In addition, integration is the key. Further, the VV&A (verification, validation, and accreditation) for an operational optimization is important.

Wadhwa (2000) presents a simulation model dealing with bulk cargo terminal with the objective to optimize ship loader's deployment. The model comprises different parameters of bulk cargo loading costs such as ship waiting time cost, maintenance cost of ship loader, revenue earned due to shorter ship time in port, and service levels. It simulated several scenarios to obtain a set of trade-offs. The least cost alternative with acceptable service level is recommended. It addresses only terminal resource allocation in bulk cargo terminals.

Park and Noh (1987) present a comprehensive port simulation model as a planning and analysis tool for bulk cargo operations. The simulation model is based on

SLAM (Simulation Language for Alternative Modeling) to model port operations; it includes six major modules using a discrete-event approach. Input data include vessel traffic, berth assignment, cargo handling, truck traffic, operating costs, construction costs, and port revenue. Data from the Port of Mobile, US is used to test the model and run simulation for port expansion under different scenarios. The simulation model provides important information regarding operational planning, vessel turnaround time, service level, queuing length, port expansion alternatives, physical impact, and economic impact. However, it only deals with bulk cargo.

To deal with the rapid rising container volume at the Port of Singapore, Koh et al (1994a and 1994b) propose a computer simulation model for port operation encompassing all aspects of the MCT operations. The simulation model uses actual operational data as input to develop a decision support system – The Computer Integrated Terminal Operations System (CITOS); it divides the overall MCT operation into five modules: berth operations, ship operations, yard operations, gate operations, and equipment scheduling. This simulation model allows planning to see the proposed operational plan, improve efficiency, and analyze problems. The authors only present an overall description of the overall simulation model development process, no statistical distribution and detailed operational scenarios are provided.

Hayuth and Roll (1994) describe the development of simulation software for port operations. The authors address the multifaceted functions of port functions, different ship arrival patterns, fleet composition, labor management, and operational productivity issues. In addition, the authors analyzed the applications of existing software at that time. However, the authors do not address any port congestion problem.

Villefranche et al. (1994), Gambardella et al. (1996, 1998, and 2001), Gambardella and Rizzoli, (2001), Merkuryev et al. (1998), Zaffalon et al. (1998), Yun and Choi (1999), Razzoli et al (2000), Rida et al. (2003) analyze the simulation of a container terminal from different perspectives and address the various aspects of container terminal operations. Villfranche et al. (1994) describe the service process of MCT operations and emphasize on process modeling. The authors divide the simulation into different segment of the overall process based on operational procedure and policy with respect to vessel loading and discharging and container yard handling. Equipment is treated as server; vessels and trucks are treated as customers. Waiting line issues are also discussed. Gambardella et al. (1996 and 1998) present a methodology to integrate simulation, forecasting and planning for a MCT. To solve the problem of resource allocation and scheduling in terms of labor, equipment, and other MCT resources, three modules are terminal simulation, forecasting, and planning. The forecasting module utilizes multivariate statistical models, time series, and neural network models to predict economic activities such cargo flow, equipment and manpower staffing, and vessel traffic. The simulation module provides different operational scenarios to estimate cost functions and measure performance for decision support. In addition, it verifies the validity of operational policy. The planning and operation module provides tools for operational planning and optimization, including waiting line issues in the storage yard.

Zaffalon et al. (1998) and Rizzoli et al. (2000) investigate terminal resource allocation and scheduling of operations at the La Spezia Container Terminal, Italy. To solve problems in loading and unloading of containers as well as allocation of resources, Zaffalon et al. (1998) develop a network model to simulate container flow from/to ships, train, and trucks. Optimization algorithms are discussed to validate effectiveness of operational policies. The authors believe that the combination of simulation and optimization can be the main components of a MCT decision support system. On the other hand, Rizzoli et al. (2000) put the emphasis on the evaluation of the impact of new operational policies in the real operating environment. Simulations are run on two modules: ship planner and yard planner to evaluate performance under various scenarios with the objective of optimized resource allocation.

Gambardella et al. (2001b) address several key issues in MCT management. Management tasks, the role of EDP (electronic data processing) and EDI (electronic data interchange), trends in optimization, simulation in container terminals, integration of ship and yard operation, and the importance of simulation are discussed. Rida et al. (2003) present a container terminal simulation model, using an object-oriented and Java-based distributed simulator. The model encompasses ship and yard operations to evaluate the effectiveness of the operational policy in a dynamic environment. However, the model is not exhaustive; other models should be integrated into the analysis.

Nevins et al. (1998a and 1998b) develop a simulation model to solve problems of military mobility at ports, based on the discrete-event approach using PORTSIM and MODSIM, simulation software. The model is designed to accommodate container cargo, Ro/Ro cargo, and breakbulk cargo. It simulates cargo arrival, staging, and loading/unloading processes in the port. It provides a planning tool to analyzing operational processes and optimizing cargo operations. In addition, animation and visualization capabilities of PORTSIM and MODSIM allow decision-makers to fully grasp the impacts of various operational scenarios. However, due to its emphasis on the military aspect of port operation, its application is quite limited.

Merkuryev et al. (1998) develop a simulation to evaluate the operational performance of Riga Harbour Container Terminal, Latvia, through the discrete-event approach with ARENA, a simulation software package. The modeling methodology is focused on container handling processes in three different areas of the MCT: quay crane operation, yard operation, receipt/delivery operation (including rail intermodal operation). Each step in the handling process is analyzed and distribution of handling time is calculated. Attention is on queuing dynamics, such as waiting time for quay crane, yard crane, and truck. Using operational data from the terminal, several experiments are conducted. Alternatives for improvement are proposed. In this study, no statistical distribution is presented, nor is there any analytical model.

Using similar approach as Merkuryev et al. (1998), Yun and Choi (1999) present a simulation model, using SIMPLE ++ (an object-oriented simulation software package) to provide a set of performance indicators for the overall terminal, container handling, equipment utilization. The simulation of the terminal is divided into three main operational areas: quay crane, yard handling, and receipt/delivery. Statistical distribution for container handling process is calculated from historical data. The simulation results provide some insights into the parameters or variables that affect the terminal performance, which can be used for port planning. However, the study does not provide any analytical model, nor is there any sensitivity analysis.

Kia et al. (2000) investigate the importance of the various types of information technologies in data transmission such as microwave technology, tagging technology, radio frequency microcircuit system, and voice recognition technology in container terminal management. In addition, the author presents a simulation of the application of these information technologies to improve terminal operations with improvement in operational efficiency and cost savings, using Taylor II for Windows. In the simulation, statistical distributions for crane service time, straddle carrier movement, and stacking area occupancy are derived from operational data. The simulation results demonstrate the benefits of applying the various types of information technologies.

Simulation is also used in evaluating different alternatives for feasibility study in port expansion and cost-benefit analysis. Turner (2000) investigates the link between the port authority leasing policy for container terminals and terminal throughput productivity. The author compares the performance of common user container terminals and dedicated container terminals in the Port of Seattle, USA, using historical data. The author uses simulation to investigate the impact of container terminal leasing policy and terminal performance. Key performance measurements are compared. The simulation results reveal that the pooling of demand in a common user terminal can reduce total vessel port time by 17.1% without sacrificing throughput capacity. Nam et al. (2002) investigate the cost-benefits of the various container handling systems in the Port of Pusan, South Korea. Using simulation (AweSim), the authors develop a set of simulation logic and process based on operational data; cost input such as equipment, labor, operating, and infrastructure costs and key performance measurements are compared. Various trade-offs scenarios are presented. The simulation results seem to support the argument of sharing resources in terms of crane and berths among terminal operators.

Recently, due to a dramatic increase in cargo volume, consideration is given to increase the use of rail for container distribution. Therefore, on-dock rail has become an important factor of port competition. Several studies have been conducted to evaluate the impacts of dock rail on terminal performance as well as port expansion planning. Kia et al. (2002) study the terminal capacity issue through computer simulation, the focus of the paper is on the relationship between the container handling system and its impact on terminal capacity. It compares the performances of two different handling systems (current one and proposed). The proposed new system involves an on-dock rail paralleled to the quay line with the objective to shift more containers to rail from truck for inland distribution. Statistical distributions for ship arrival, and service time are derived, Poisson distribution and Erlang distribution, respectively. The simulation results demonstrate the costs and benefits of the two systems. However, the paper does not address the issue of who will pay for the costs and who will benefit from the proposed system. Parola and Sciomachen (2005) use simulation as a strategic decision-making tool to evaluate port expansion alternatives of integrating rail network with the Ports of Genoa and La Spezia, Italy. In particular, it studies the impact of growth of maritime container traffic on land infrastructure, the degree of saturation of the railway lines serving these two ports, and the level of congestion of the truck gates. Several investment scenarios based on traffic growth and modal split between truck and rail are investigated. The simulation results demonstrated the need to invest in new rail infrastructures in order to maintain port competitiveness. In this study, no economic impact is presented.

Another approach to study terminal operation performance is to use both the analytical model and simulation at the same time. Gambardella et al. (2001b) propose a methodology that models the entire MCT operation at different levels of detail with the objective of optimal allocation of resources. At the highest level, the paper uses a network design approach to treat the loading and discharging of container terminal operations as a flow problem inside the terminal. The problem is solved by mixed-integer programming. At the lowest level of yard handling, it is modeled as a scheduling problem and solved using a new neighborhood function and a new self tabulated search. In addition, a simulation model is developed to evaluate the overall policies of optimization. Lastly, the computer simulation model is applied to La Spezia Container Terminal, Italy; it shows sizable improvement in terminal performance – the same amount of work can be done with only 67% of the resources originally planned.

In summary, various approaches were used to address the MCT operations as a whole, including operations research methods and computer simulation. In addition, application of information was analyzed in improving operational performance.

2.4.3 Terminal Optimization Using Analytical Models

To optimize overall terminal operations, analytical models have been used to identify bottlenecks, constraints, trade-offs, and the least cost option or the most beneficial alternative. Kozan (2000) uses a network model to solve an overall investment problem regarding the purchase of different types of handling equipment. It divides the container handling process from ship-to-yard-to truck or ship-to-yard-to-train and vice versa into different stages; the objective function is to minimize the total throughput time for containers in different stages with associated constraints and given resources. Different alternatives are analyzed; traded-off and sensitivity analysis is undertaken. Such analytical models can serve as decision making tools in evaluation of port investment and expansion. However, the model does not provide any cost-benefit analysis, nor is there any assessment on terminal operational performance, which is critical to the port's competitiveness. Alessandri et al. (2005) investigate the overall optimization problem of container terminal operations. The focus is on container transfer operation. The authors treat the problem as a series of queue at different stages of the transfer formed inside the terminal. Using discrete-time equations to describe the dynamic evolution of those queues in which state variables represent the queue lengths, the problem is solved by minimizing the total transfer delays of containers in the terminal, using Mathlab and Lindo software. However, the paper does not address the stochastic nature of container flow, which contributes much of the waiting time and delays. The use of average figure without statistical distribution oversimplifies the problem.

In summary, economic models are used to evaluate macro level port performance issues. They look at several overall performance indicators and measurements. Due to the complexity of the MCT operation process, it is quite obvious that to analyze the overall terminal operational performance, computer simulation is the preferred method. Furthermore, simulation models are mostly developed from certain software platforms; such simulation models are used to evaluate performance, optimize resource allocation issues, and address port development/planning alternatives.

In summary, among all the studies on container terminals, the amount of literature addressing the various aspects of the MCT is quite large. But the literature on receipt/delivery operations is the least. Actually, none of them addresses the waiting time problem of gate congestion, nor is there model to calculate the waiting costd. There is little research in measuring MCT gate congestion cost and providing viable alternatives to optimize the MCT gate system. On the other hand, congestion problem and waiting cost issues are solved either by multi-server queuing models or simulation. In some cases, both are used to solve the same problem.

CHAPTER 3

MCT SYSTEM MODEL AND CONCEPTUAL FRAMEWORK

A MCT is an intermodal transfer, storage, and distribution center within the global supply chain; its objective is to optimize cargo flow efficiency. It is an indispensable node that provides the most crucial interface between water transport and surface transport in container trade. It serves as a distribution center for both import and export commodities that generates significant amount of economic activities of the region. Its performance directly affects a port's competitiveness and becomes one of the important variables that influences shippers' and shipping lines' cargo routing decisions. MCT's efficiency has become critical to the region's economic competitiveness.

The first part of this chapter describes an overall system description of a MCT. The second part presents a qualitative model to show the function of the MCT gate system, system process, and the MCT gate congestion problem. The third part describes several cost functions of the MCT gate operation and harbor trucking operation. Lastly, it provides a conceptual framework to optimize the MCT gate operation.

3.1 Operation System of MCT and its Sub-systems

To facilitate container flow, a MCT performs multiple functions. It has three sub-systems: sea-shore transfer (vessel operation), yard storage and handling (yard operation), and receipt and delivery (gate operation) (see Figure 3.1). For vessel operation at the quay side, the objective is to minimize vessel port time. The constraints are the number of ship-shore cranes, crane productivity, crane capability, and the number of berths. For yard operations, the objectives are to minimize truck turnaround time, utilize existing storage space, and utilize container handling equipment. For gate operations, the objective is to accommodate inbound and outbound trucks for container receipt and delivery. The constraints are the number of gates, gate operating hours, and gate processing technology (Yahalom et al. 2001).

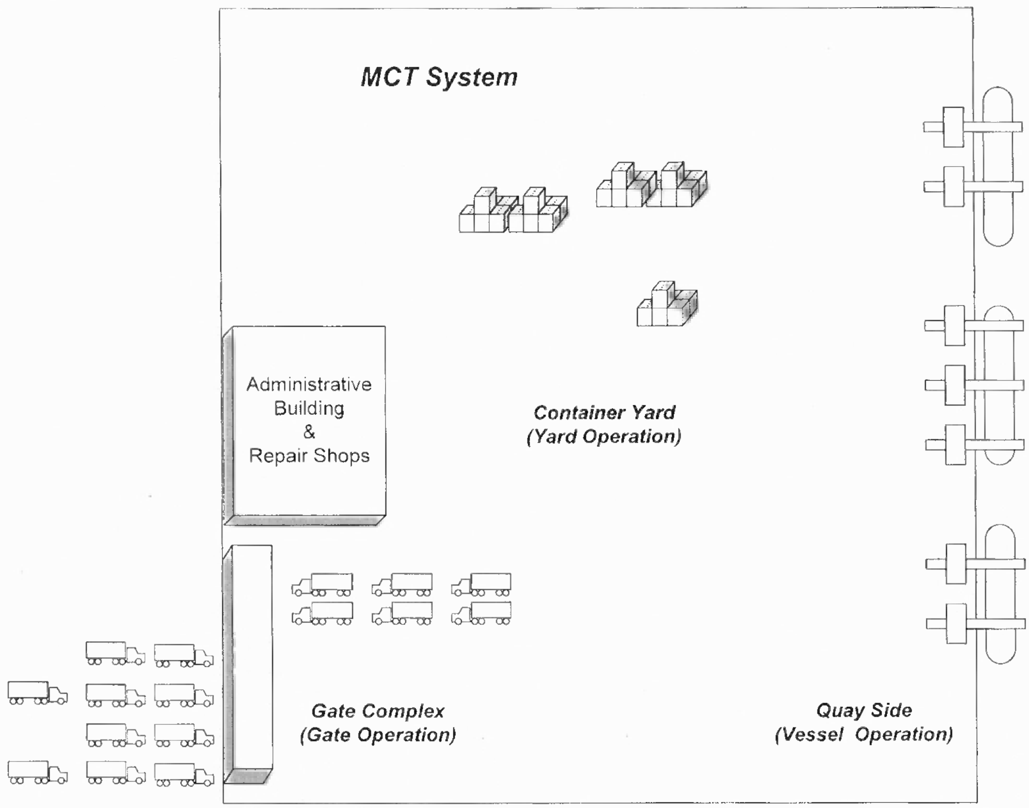


Figure 3.1 MCT and its sub-systems.
Source: Author

The process of import and export container movements involves a series of steps and mechanisms with different participants. Before ship arrival, export cargo bookings are made with shipping lines to reserve empty containers. In turn, shipping lines transmit such booking information to the MCT. Upon confirmation of bookings, truckers are dispatched to pick up empty containers from the MCT. With specific booking numbers, truckers come to the MCT for information processing. Upon the validation of bookings, instructions are given to truckers as to where to pick up their respective empty containers in the yard. After being served and picking up the empty containers, truckers have to go through the MCT gate again to "check out". At the MCT gate, the container number is verified against the specific booking and appropriate information is input into the MCT's computer system.

Truckers take the empty containers to the exporter's warehouse where export cargo is loaded into the containers. Truckers then deliver the loaded containers back to the MCT. At the MCT gate, gate clerks verify the container numbers against the record to ensure the information is matched. In addition, the physical condition of the container is checked to ensure its integrity, and paperwork is collected. Any damage will be properly noted. Instructions then are given to truckers as to where to drop the export containers off. Upon dropping off the export container, the truckers leave the MCT. All export containers are properly organized into different stacks according to their respective vessel/voyage, port of discharge, size, weight, and any other special requirement such as hazardous cargo, refrigerated cargo, etc. Upon vessel arrival, they are loaded onboard.

Upon vessel arrival, import containers are discharged from the vessel into the container yard and relevant information such as container number, size, and yard location is input into the MCT's information system. Upon clearance of customs and payment of freight charges by importers, truckers are dispatched to the MCT to pickup import containers. At the MCT gate, the truckers' IDs are checked and container information is verified. Upon completion of gate processing, truckers are given instructions as to where to pickup import containers. After picking up their respective import containers, truckers go through the gate-out process, in which container numbers and physical conditions of the containers are checked. Truckers then take the import containers to warehouses where import cargo is taken out for distribution. Lastly, truckers take the empty containers back to the MCT; they go through the gate information processing again and drop their empty containers in the yard.

Cargo flow through the MCT is divided into import flow and export flow. The system process can be summarized in the following:

Import Process:

1) Inbound cargo manifest and discharge plan for a particular vessel are provided by the shipping line to the terminal operator
2) Containers are discharged from the vessel and stored in the container yard in the pre-determined area, waiting to be delivered to shippers
3) Truckers are dispatched to the MCT to pickup import containers
4) Truckers pickup import containers from the MCT and deliver to the shipper's warehouses where cargo is taken out
5) Empty containers are returned to the MCT

Export Cargo Process:

1) Export cargo bookings are made with shipping lines
2) Upon confirmation of cargo booking, relevant information such as commodity, port of loading and port of discharge, type of container, vessel, voyage, etc. is provided to the MCT

3) Truckers are dispatched to the MCT to pick up empty containers
4) Truckers pickup empty containers to the MCT and take them to the shipper's warehouses where export cargo is stuffed into the containers
5) Truckers deliver the export containers to the MCT and the containers are stored in the pre-determined locations
6) Booking information is compiled, export containers are staged, and the vessel loading plan is made
7) Export containers are loaded onto the vessel

As the size and capacity of the MCT are relative fixed in a short term, how to utilize such asset is critical to ensure profitability of the terminal business. Therefore, the main objective of the terminal operator is to achieve maximum velocity of container movements; that is to move containers in and out of the terminal as much as possible in a given period of time. This can be achieved by effectively controlling and integrating the three sub-systems and turn them into an efficient operating entity. Some of the important functions performed by the MCT are:

- Ship-shore cargo transfer (vessel loading and discharging),
- Container storage (providing a buffer),
- Cargo and equipment information exchange,
- Interface with surface transport, and
- Cargo and equipment liability transfer.

3.2 MCT Gate System

From the above description, both the import and export processes involve a series of tasks to complete the container movement, in which information is exchanged and the physical assets (containers) are transferred from one party to another. These all require necessary information processing and the inspection of the physical condition of those containers for liability purpose (see Figure 3.2). The MCT gate system performs various vital functions to facilitate freight movement. The gate is the point where legal responsibilities and liabilities are transferred from one party to another. As a result, important information processing takes place at the gate. Shipping information including container number, size, ownership, type of cargo, weight, vessel, and voyage, and destination is also processed at the same time. Furthermore, for liability reasons, the physical condition of the container is checked as well. All this information is supplied to the terminal's computer system. To facilitate the gate transaction, there are several documents issued at the gate:

- Gate security pass --- check in and check out
- Equipment Interchange Receipt (EIR) --- evidence of equipment hand-over from one party to another
- Terminal Inspection Report (TIR) --- report on equipment's physical condition to determine liability in case of damage, if needed
- Spot ticket or routing slip --- instruction to trucker where to pickup/drop off equipment in the yard

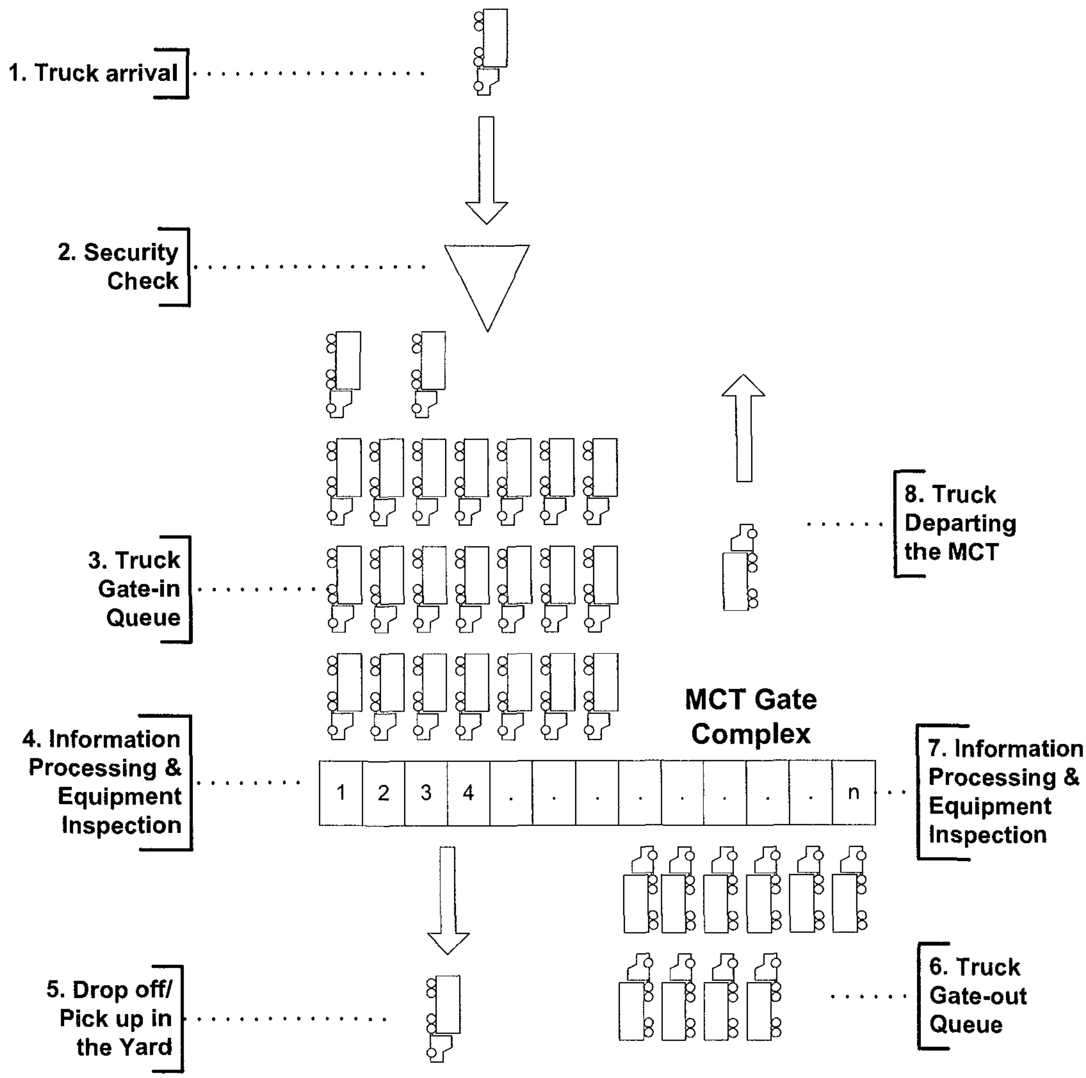


Figure 3.2 MCT gate system and process.

In addition, the information gathered at the gate also serves to facilitate vital management functions of the terminal with respect to the following:

- Container inbound and outbound moves
- Inventory change in the yard for various types of containers and shipping lines
- Equipment interchange
- Roadability information

- Gate operating hours
- Container dwell time
- Truckers' credit standing
- Gate productivity
- Shipping lines' billing

In Figure 3.2, it clearly demonstrates the formation of a queuing problem at the terminal gate complex. In this queuing problem, the main two entities are truckers and the MCT operator; both are engaged in commercial activities in which the prime motive is profitability with the underlining objective of minimization of costs. For harbor truckers who perform the local container pickup and delivery (drayage), their income is based on the number of jobs (the number of container pickups and deliveries), not based on the distance they drive. Therefore, minimization of waiting time at the MCT gate complex is essential for them to maintain their earning power in the business. On the other hand, the primary objective of the MCT operator, though it has to service truckers for container pickup and delivery activities, is to minimize the costs in serving the gate complex. However, there is no direct business relationship between these two entities that their revenues are independent of each other. But the service provided by the MCT operator at the gate complex has a direct impact on the truckers' economic well-being. Since both parties incur operating costs at the MCT gate, one way to solve the problem is to identify key elements of the gate system and its operation and to find ways to mitigate gate congestion and improve efficiency at the same time.

3.3 Truck Flows at the MCT and Types of Inbound and Outbound Trucks

There are different types of inbound trucks at the MCT gate. For inbound trucks, there are four types: bobtail/flatbed, trucks with chassis, trucks with empty containers, and truck with loaded containers. The patterns of pickup and delivery and the types of container moves are subject to a number of factors such as the balance of trade, how well truck dispatchers coordinate with truckers for pickup and delivery, and shippers' requirements. The number of trucks generated is dependent on the number of import and export containers (including loads and empties).

There are different scenarios for truck pick-ups and deliveries (see Figure 3.3). A trucker can be dispatched to the MCT to either pick up or drop off containers and/or chassis. Under this scenario, he will go to the MCT gate as a bobtail either to pick up a chassis or an empty container for export booking or a loaded container for import delivery. Sometimes the trucker might bring his own equipment, such as flatbed. At the MCT gate, after proper information processing is done, he will be directed to a specific location in the container yard to pickup that specific container or chassis. On the way out, he has to go through the gate-out processing to verify the transaction is finished appropriately. When a trucker is dispatched for drop off only, then the trucker will come to the MCT with either a chassis or an empty container, or a loaded container for export. After the gate-in processing, he will be given instruction to drop off the container or chassis in the yard. On the way out, since he is not picking up any container or chassis, he will directly go to the security gate, get processed, and leave the MCT. For pickup and drop off activity only, it is called a single move.

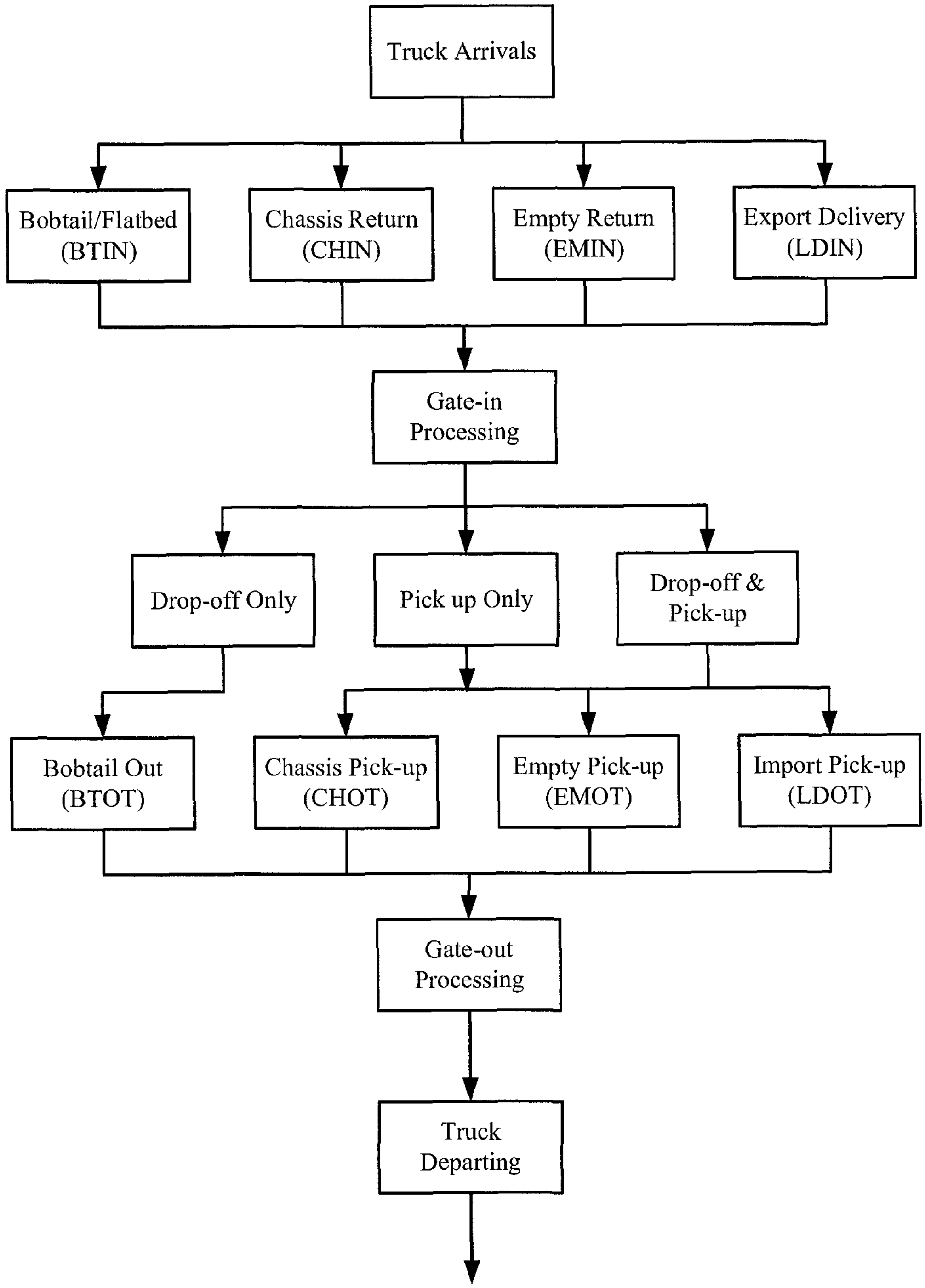


Figure 3.3 Flows of inbound and outbound trucks.

Also a trucker can be dispatched to drop off and pick up containers or chassis on the same trip. In this situation, the trucker will come to the MCT with a container or chassis and leave the MCT with a container or chassis. This is called a double move. Apparently, a double move is more productive and efficient for truckers. In terms of gate processing, due to the different types of inbound trucks, the requirements for processing time are different. The amount of time it takes for gate processing is critical and will have a direct impact on gate processing capacity; this issue will be discussed later in this thesis.

3.4 MCT Gate Congestion and Conceptual Model

In the MCT gate congestion context, there are two cost components in the system, 1) service provider's cost, and 2) user cost, truckers' waiting cost. Waiting time (congestion) and waiting cost at the MCT gate occur when there are more truckers arriving at the gate than the gate system can handle. The gate system's capacity is determined by the number of gate lanes, the number of operating hours, and the gate processing productivity. The truckers' waiting cost is a function of the truckers' operating cost and waiting time. Waiting time is a function of truck arrival rate, the MCT gate processing productivity, the gate operating hours, the number of gate lanes, and the number of employees used. Truck arrivals are driven by ship schedule and shippers' distribution/delivery requirements; their arrivals are also subject to traffic conditions on highways. Therefore, their arrivals at the terminal cannot be determined beforehand. In short, the degree of congestion is dependent upon three main factors; the first one is the average truck arrival rate λ, the second one is the average gate processing productivity (service rate) μ, and the third one is the number of gate lanes (S). Among these three factors, S and μ are constant in a short run; therefore, the higher the λ, the longer the waiting time.

The system dynamics is dependent upon a number of factors. From the service provider's perspective, it desires high system utilization, using the minimum number of gates and personnel to process large number of trucks. On the other hand, from the service user's perspective, it desires high level of service, meaning high information processing productivity, longer gate operating hours, and more gate lanes. Under this circumstance, the truckers' queue time and waiting cost are reduced.

Gate operating cost: To calculate the gate operating cost, it is a quite straight forward case. The gate operating cost components include labor, equipment, building, land, office, and utility. The cost of equipment, building, office, and land can be amortized over a long period of time and the utility cost is also relatively small. The largest cost component is labor cost. Thus, the gate operating cost is mainly the labor cost; the hourly gate operating cost can be expressed in the following:

$$C_g = L_c S \tag{3.1}$$

where,

C_g: Hourly gate operating cost (\$/hour)

L_c: Labor cost per gate lane per hour (\$/hour)

S: Number of gate lanes

As stated earlier, to achieve high asset utilization, the more trucks it can process in a given time period, the lower the cost per truck processed from the terminal operators perspective. On the other hand, the hourly gate operating cost C_g is independent of truck arrivals. To calculate the average hourly gate operating cost, it can be expressed in the following:

$$AC_g = \frac{C_g}{\lambda} = \frac{L_c S}{\lambda} \tag{3.2}$$

where,

AC_g: average operating cost per truck processed ($/hour/truck)

λ: average hourly truck arrival rate (trucks/hour)

From formula (3.2), the relationship between AC_g *and* λ is an inverse one; the higher the λ, the lower the AC_g, and vice versa. The curves of average hourly gate operating costs with the number of gate lanes are shown in Figure 3.4; the AC_g are represented as a set of hyperbolic curves.

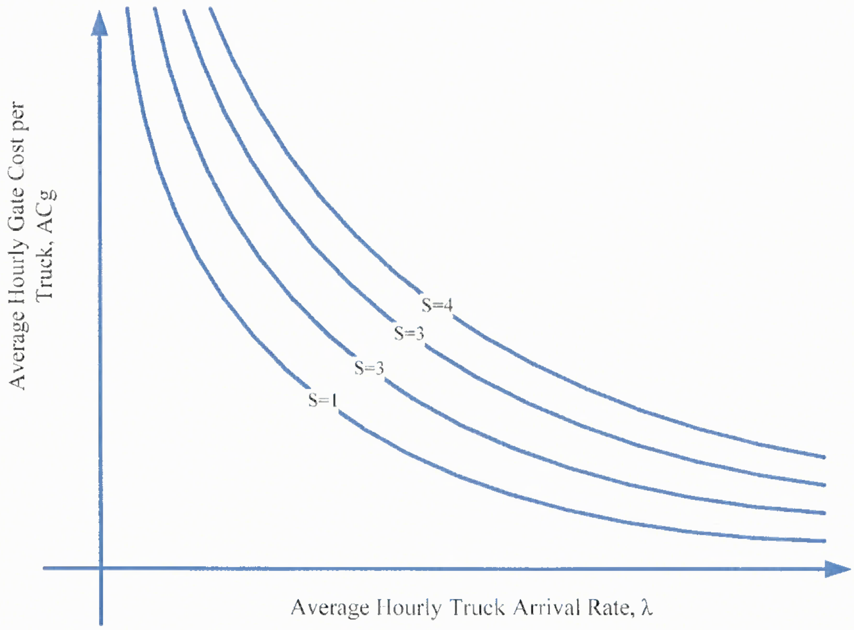


Figure 3.4 Average hourly gate cost curves.

Truck Waiting Time and Waiting Cost: Truck waiting cost ocurr when the number of truck arrivals is more than the gate system can handle. Trucks have to wait at the gate. How long a truck stayed in the gate system has two components; one is the waiting time and the other is the gate processing time at the service booth. Truck waiting cost is a function of truck arrival rate, the gate processing productivity, and the number of gate lanes. In a short run, however, the gate processing productivity and the number of gate lanes are fixed; thus the average hourly truck time in the system is a function of truck arrival rate λ (see Figure 3.5).

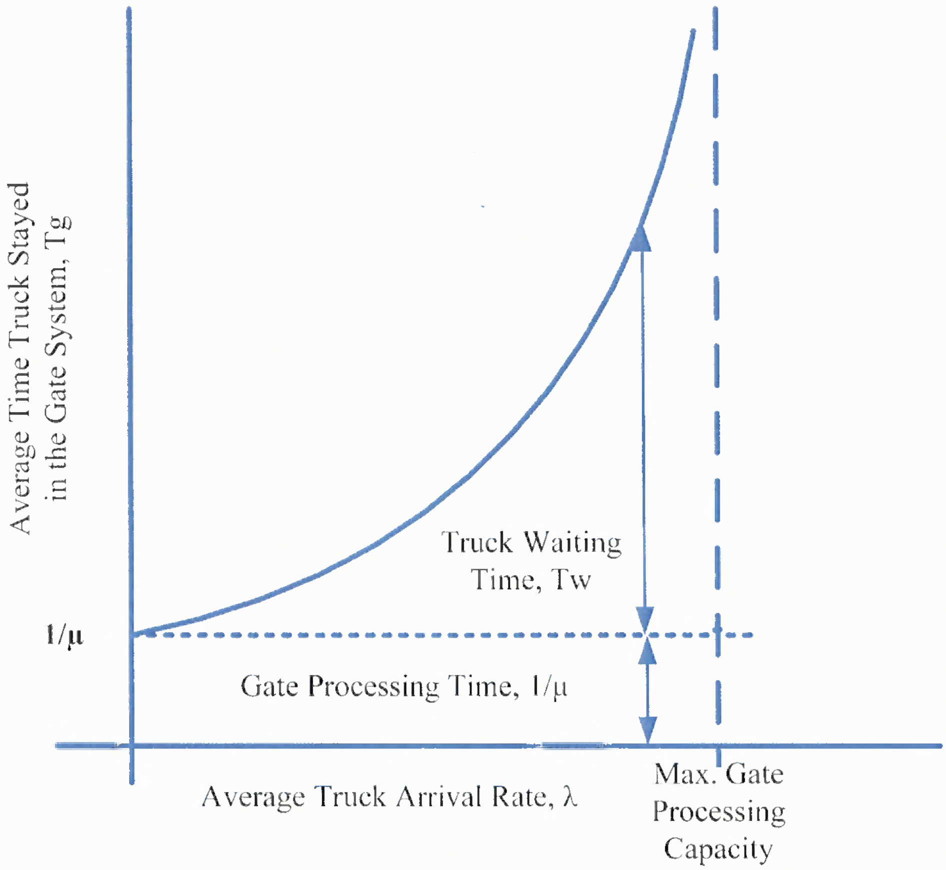


Figure 3.5 Average time truck stayed in the gate system.

The average time for trucks stayed in the gate system can be expressed in the following formula:

$$T_t = T_p + T_w \tag{3.3}$$

where,

T_t: Average time for a truck staying in the gate system

T_p: Average gate service time (i.e. hour/truck)

T_w: Average truck waiting time

If the average gate service time is μ (number of trucks/hour), then T_p is 1/μ; and for average truck waiting time, $T_w = f(\lambda)$. Since μ is more or less fixed in the short run, it

To measure the marginal cost of trucks spent at the gate (MC_t), which is caused by one additional truck arriving at the gate with S gate booths, it is equal to the first derivative of the first order of C_t with λ. Based on equation (3.7),

$$MC_t = \frac{dC_t}{d\lambda} = \frac{d(\lambda AC_t)}{d\lambda} = AC_t + \lambda(\frac{dAC_t}{d\lambda}) = C_hT_t + \lambda C_h(\frac{dT_t}{d\lambda}) \quad (3.8)$$

In Equation (3.8), the first term of the right-hand side is the average truck cost, AC_t; the second term of the right-hand side provides a measurement of the diseconomy of trucks in the gate system that suffer from the marginal truck's entry into the gate system. This is an external diseconomy is termed congestion cost. Based on Equation (3.7) and (3.8), it is clear that when λ is close to zero, the AC_t and MC_t are minimal. When λ increases, both AC_t and MC_t grow, however, MC_t grows at a faster rate than that of AC_t.

Further, let C_{TS} = total hourly cost for the gate system with S service booths; it is the sum of the gate hourly operating cost (C_g) and truck hourly waiting cost (C_t). From Equation (3.1) and (3.4),

$$C_{TS} = C_g + C_t = L_cS + C_h\lambda T_t \quad (3.9)$$

Set AC_{TS} = average total cost per truck for the gate system with S service booths, from Equation (3.9), the following equation is obtained.

$$AC_{TS} = \frac{C_{THC}}{\lambda} = AC_g + AC_t = \frac{C_gS}{\lambda} + C_hT_t \quad (3.10)$$

is obvious that the higher the λ, the longer the average waiting time T_w. As truck waiting cost is directly related to truck waiting time; the longer the waiting time, the higher the waiting cost. The total hourly truck cost can be expressed with the following:

$$C_t = C_h N_t \tag{3.4}$$

where,

C_t: Total hourly truck cost at the gate ($)

C_h: Truck operating cost per hour per truck ($/hour)

N_t: Average number of trucks in the gate system

To calculate the total truck cost in the gate system, queuing theory is an appropriate methodology. Based on Little's formula,

$$N_t = \lambda\, T_t \tag{3.5}$$

Substitute Equation (3.5) into (3.4),

$$C_t = C_h\, \lambda\, T_t \tag{3.6}$$

Set AC_t = average truck waiting cost spent at the gate with N_t ($/truck), then from Equation (3.6),

$$AC_t = \frac{C_t}{\lambda} = C_h T_t \tag{3.7}$$

Let MC_{TS} = marginal cost of the gate system with S service booths, from Equation (3.9),

$$MC_{TS} = \frac{dC_{THC}}{d\lambda} = \frac{d(L_cS)}{d\lambda} + \frac{d(C_tT_l)}{\lambda} \quad (3.11)$$

Since L_cS is more or less, it is treated as a constant, therefore,

$$MC_{TS} = C_hT_l + \lambda C_h(\frac{dT_l}{d\lambda}) \quad (3.12)$$

It is obvious, the $MC_{TS} = MC_t$. In economic terms, the concepts of the AC_{TS} and MC_{TS} are average hourly social cost and marginal hourly social cost, respectively. In Figure 3.6, the AC_{TS}, MC_{TS}(or MC_t), AC_t, and AC_g are plotted together.

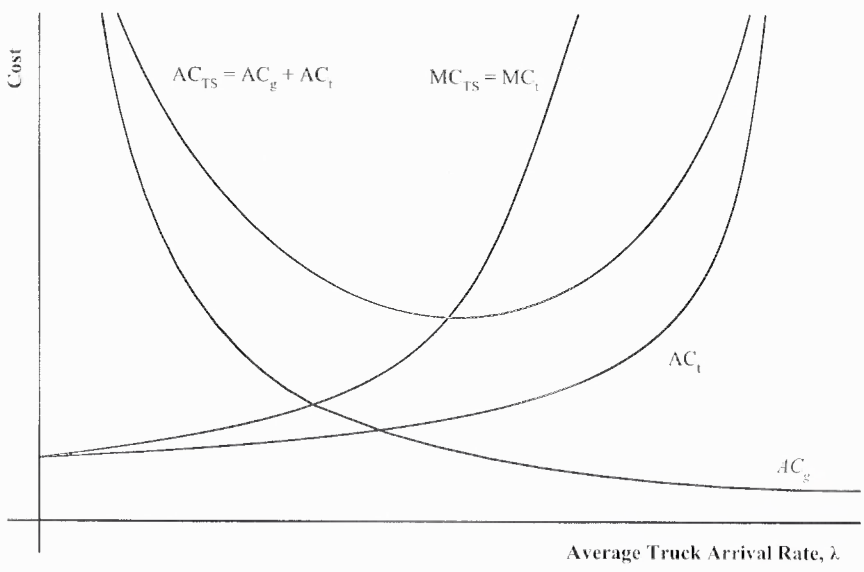


Figure 3.6 Cost components of a gate system.

In Figure 3.6, AC_t and AC_g have an inverse relationship with respect to average truck arrival rate λ. When λ is close zero or very low, AC_t, the average truck cost, is quite small since there is very little congestion or waiting time incurred; on the other hand, AC_g, the average gate operating cost is very high since the number of truckd is very small. As λ increases, AC_t grows accordingly depending on the congestion level; at the same time, AC_g is becoming smaller. Based on Equations (3.7) and (3.8), MC_t (which is equal to MT_{TS}) is rising faster than AC_t. Also, the AC_{TS} is equal to the sum of AC_g and AC_t. Lastly, based on Equations (3.8) and (3.12), the congestion cost is defined as the vertical distance between MC_{TS} (or MC_t) and AC_t curves. The optimal point is at where AC_{TS} and MC_{TS} (or MC_t) intercept, where the average total per truck is minimized.

However, the above optimization is predicated upon a given set of parameters of S, μ, and λ. In Figure 3.6, the S and μ are fixed, the objective is to identify the value of λ. Given the nature of truck arrivals at the MCt gate, λ is not fixed. Another way to optimize the gate system is to identify the number of gates that should be operating so as to minimize the average total cost. Therefore, based on (3.9), S will be determined under a different value of λ. Finally, the overall optimization should be the minimization of total system costs that is based on dynamic analysis given on different value of S, μ, and λ. The conceptual optimization model for the minimization of total costs is the following:

$$\text{Minimize } C_{TS} = C_g + C_t \tag{3.13}$$

Subject to:

$$C_g = f\,(Lc, S, H) \tag{3.14}$$

$$C_t = f\,(C_L, \lambda, \mu, S, H) \tag{3.15}$$

In (3.14), Lc, S, and H are operating cost per gate hour, number of gates, number of gate operating hours, respectively. In Equation (3.15), C_h, λ, μ, S, and H are truck operating cost per hour, truck arrival rate (number of trucks per hour), gate processing time, the number of gates, and gate operating hours, respectively. The dynamic analysis of the total gate system cost will provide a mechanism of system optimization; detailed methodology will be described in the next chapter.

3.5 Summary

In this chapter, firstly, it describes the MCT system and its major components. There are three major operational areas: the vessel operation, yard operation, and the gate operation. Secondly, it also describes the import and export container pickup and delivery process; the import and export activity is the primary driver of truck trips to and from the MCT. Thirdly, it analyzes the different types of inbound and outbound trucks that pass through the gate, and the different scenarios of container pickup and delivery activities at the MCT. Fourthly, it identifies different cost components of the MCT gate operation as well as truck pickup and delivery operation. Lastly, it provides several conceptual approaches to analyze the gate congestion problem and gate system optimization.

There are different ways to optimize the system; the optimization is subject several parameters, mainly the number of gates, the service rate, and the truck arrival rate. In the conceptual model (Figure 3.6), there are two major cost components: the average hourly gate operating cost (AC_g) and average hourly truck waiting cost (AC_t). They are subject to average hourly truck arrival rate λ. They have an inverse relationship. Since ACg is more or less fixed, when λ increases, AC_g will decrease, and vice versa. On the other hand, AC_t is subject to λ as well. AC_t increases as λ becomes larger and larger. To calculate AC_t, a queuing model will be applied depending on the statistical distribution of μ and λ. The total hourly average costs (AC_{TS}) of the gate system are the sum of AC_g and AC_t. To measure the congestion cost, the marginal cost concept is introduced; the marginal cost of the average hourly trucking waiting cost (MC_t) is the same as the marginal cost of the total average hourly gate system cost (MC_{TS}). The vertical distance between MCt and AC_t is the congestion cost. MCt and AC_{TS} intercept at the point where AC_{TS} is at its minimum corresponding to a specific λ value, which is the optimal point of the system. The second approach is to identify the optimal number of gates given different rates of λ. The third one is to conduct a dynamic analysis that will consider a wide range of parameters.

The core of the gate system analysis is the application of queuing theory, in which two critical parameters have to be identified; one is the statistical distribution of μ, and the other is the statistical distribution of λ. From there, an appropriate queuing model can be used to calculate the average hourly trucking waiting cost (AC_t); optimization analysis can be undertaken.

CHAPTER 4

METHODOLOGY

Based on the conceptual model presented in the previous chapter, the methodology used to model the MCT gate congestion problem is a combination of economic analysis and operations research techniques. The operations research techniques provide the necessary means to calculate truck waiting time using the queuing model so as to optimize the level of the MCT gate system operations; economic analysis provides the tools to calculate relevant cost items and their relationships for both the truckers and the MCT operator, on the other. The combination of both gives the important tools to analyze the core issues of truck waiting cost, gate operation optimization, as well as congestion mitigation.

As indicated in the conceptual model, there are several critical components such as average gate operating cost, average truck waiting cost, marginal gate system cost, and congestion cost. The gate operating cost is based on the labor contract and the operating schedule of the MCT. The truckers' waiting cost is dependent upon the amount of waiting time and truckers' unit cost. By applying queuing theory, the amount of waiting time can be obtained; the trucker's unit cost can be obtained from government and trade publications as well as interviews with industry executives. To calculate the truckers' waiting cost, the key is to formulate an appropriate queuing model that can model the truckers' waiting problem at the MCT gate. In addition, optimization is subject to the statistical distribution of two critical parameters such as S and λ.

The organization of this chapter is the following. Part one describes the overall methodology framework. Part two discusses the process of the application of queuing model for the analysis of gate congestion; possible queuing models are evaluated. Part three presents the total cost function. A summary of the methodology is provided in the last part.

4.1 Framework of Research Methodology

To model gate congestion and related costs functions, it needs to address all relevant variables. Figure 4.1 provides a research methodology framework; it involves seven steps: 1) data analysis of MCT gate activity, 2) field observations, 3) development of the queuing model, 4) model validation and verification, 5) synthetic analysis, 6) sensitivity analysis, and 7) gate congestion mitigation alternatives. As mentioned before, the most critical component in modeling the gate congestion is the queuing model; the major focus is on how to develop the model through data analysis and field observation. The following provides detailed explanation of the methodology.

Step 1: In order to develop a queuing model that can be used to analyze gate congestion, several factors have to be taken into consideration. There are four critical variables that affect the MCT gate congestion: daily truck volume, truck arrival pattern, and pattern of gate processing time. First, daily truck volume is generated by import and export activities; it is derived from vessel loading and discharging activities. The number of container discharged from and loaded onto the vessels will determine the number of trucks and types of container moves that come to the MCT for pickup and delivery. Second, due to location, business needs, availability of truck service, and highway traffic conditions, truck arrivals at the MCT have certain distribution patterns. Third, gate processing time or gate processing productivity is a function of processing technology used, type of container, and skill of gate clerks.

Since gate congestion is not static, it is essential to identify behavioral patterns of the MCT gate activity. This data analysis is focused on four major areas: types and volume of container transaction, daily volume, truck trip generation, and seasonality.

There are different types of container transactions at the MCT gate as indicated in Chapter 3. The time it takes to process the various types of types of inbound containers is different. The distribution of the different types of containers provides a logical explanation for the gate processing time required. The variation in processing time is critical in identifying the statistical distribution of the service time. In turn, such distribution is an essential component of a queuing model.

Daily volume provides a more specific picture of truck volume on a daily basis. Through the analysis of daily truck volume, the result will be used as an input to the queuing model to evaluate congestion levels.

Truck trip generation is also an important factor. Since the driver for truck pickup and delivery activities is import and export activities, it is necessary to identify the relationship between container volume and the number of truck trips generated. As most of the forecast of freight movement is based on container volume, the relationship between freight volume and truck trips can be used to estimate truck volume at the MCT gate.

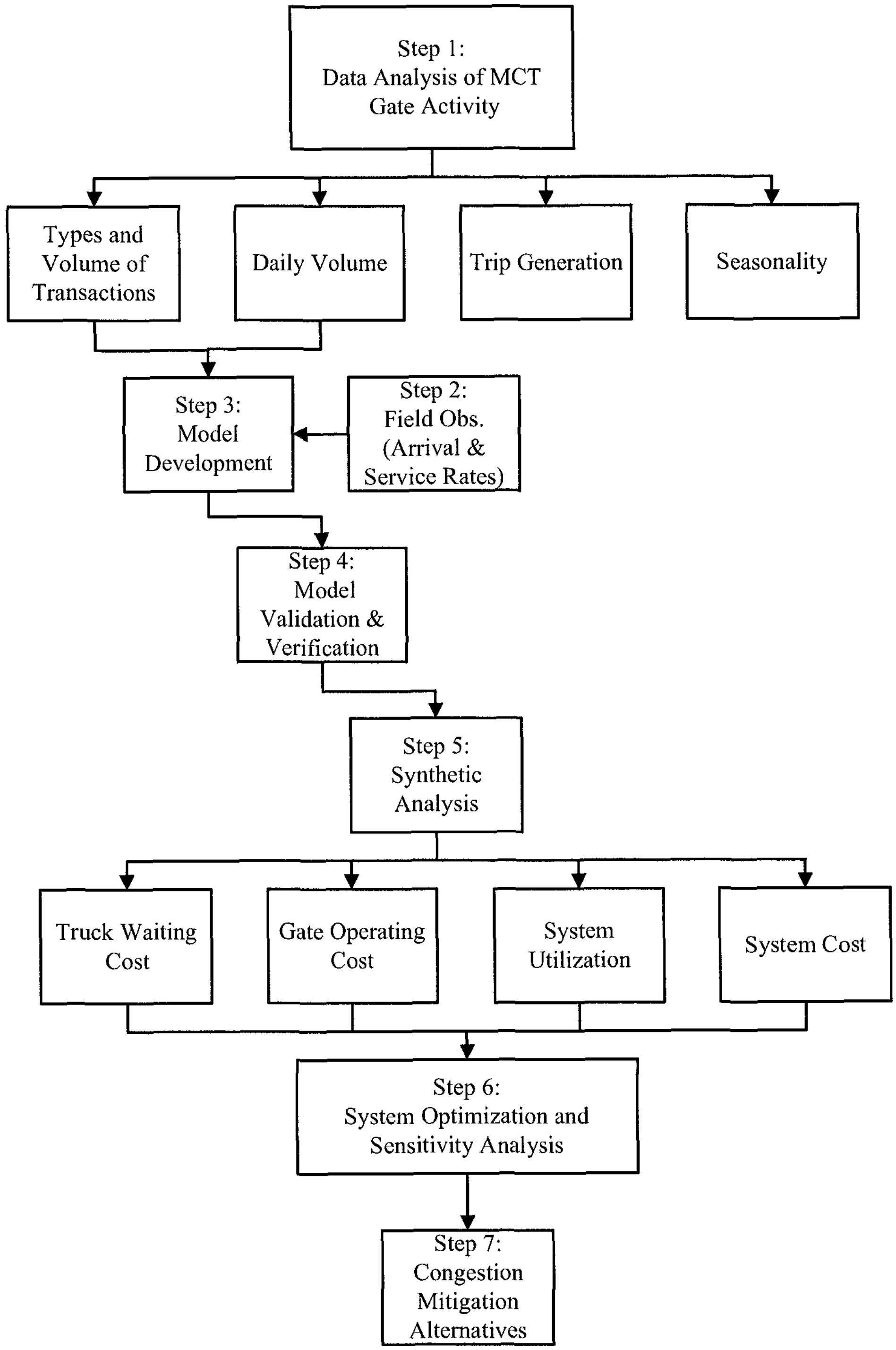


Figure 4.1 Overall framework of methodology.

Seasonal patterns help to understand the variation of freight movement in different time of the year. Therefore, this comprehensive data analysis will provide the necessary input in gate congestion evaluation. The actual operational data is obtained from a terminal operator in the Port of New York/New Jersey; the data set contains more than 200 days of detailed gate operational data. The identity of the terminal operator will not be revealed due to confidentiality requirement.

Step 2: The two most critical parameters for a queuing model are inter-arrival time and service distributions. The MCT does not provide this data; field observation is necessary. Through special arrangement, the MCT management will allow the observation to take place at the gate entrance. The focus is on truck arrivals and gate processing. The observed data will be processed and statistical testing will be used to identify the types of statistical distributions for both the inter-arrival time and gate processing time (service time). The results will determine which queuing model to use.

Step 3/4: Based on parameters obtained in Step 2, an appropriate queuing model will be developed. The validity of the model will be verified against the observed data.

Step 5: After the development of the queuing model and model validation and verification, a synthetic analysis will be provided. Using the queuing model, the analysis will provide four major results: truck waiting costs, gate service performance and standards, gate capacity utilization and gate operating costs.

Since daily truck volume varies from day to day, the calculation of truck waiting costs will be based on several assumptions and different scenarios. The hourly truck waiting cost figure will be obtained from executives of the harbor drayage trucking industry as well as government publications.

Since capacity shortage is one of the major causes of gate congestion, capacity utilization will be analyzed to identify potential problems. The seasonal pattern resulted from Step 1 will be also applied to calculate the capacity utilization during different seasons of the year.

Though the MCT is operated by a private entity, it actually leases the facility from the port authority, a public entity. Its performance has a direct bearing on the harbor trucking industry. In turn, gate congestion has broader impact beyond the terminal vicinity; eventually consumers will bear the costs of congestion. Therefore, there is a public interest in how efficient the terminal performs. Ultimately, the regional freight movement efficiency is at stake. Together with gate congestion level, truck waiting time, and capacity utilization, a service standard can be derived.

With regard to the MCT gate operating costs, it is important to recognize the uniqueness of the management structure of a MCT in major U.S. container ports. Except for managerial positions, the majority of employees working in container terminals belong to a dominant waterfront union: International Longshoreman Association (ILA) in the East Coast and International Longshoreman and Warehouse Union (ILWU). Most of the people working at the MCT gate complex are union members; their hourly cost can be obtained from labor contract information and interviews with industry executives. Thus, gate operating costs are relatively easy to obtain. Since the MCT gate is manned by union labor, the number of persons working at the gate is fixed. Thus its cost function is a linear one. Comparison will be made between the truck waiting cost and gate operating cost. Equilibrium point will be identified.

Step 6: Based on the results from step 5, analysis in marginal cost with respect to truck waiting cost and gate operating cost will provide the sensitivity of congestion level and capacity utilization. The result can be served as a guideline to identify different ways of congestion mitigation.

Step 7: Several alternatives of congestion mitigation will be discussed. The alternatives include physical expansion, productivity improvement, and pickup & delivery by appointment. These alternatives will be evaluated in terms of cost, service improvement, and effectiveness.

4.2 Queuing Theory Applications

There is plenty of literature on queuing theory and its applications in different commercial and industrial areas. The objective of this section is not to review the detailed mathematical approach of queuing theory; rather it discusses the fundamentals of queuing theory and the methodology, and whether it can be applied to model the MCT gate congestion problem. Based on the literature review from Chapter 2, this section provides two queuing models that are suitable to evaluate truck waiting function at the MCT gate.

4.2.1 Basic Elements of Queuing Systems

In order to specify a queuing system, the stochastic processes that describe the arrival pattern, the structure, and the discipline of the service facility should be identified. The first one is the arrival process; in general, it is described as the inter-arrival times in terms of the probability distribution. The assumption in most queuing problems is that the inter-arrival times are independent, identically distributed random variables (iid). The second one is service time; it is referred to as the length of time that a customer spends in the service facility. The third one is the number of service stations. The fourth one is the queuing discipline, the order in which customers are taken from the queue and served, such as first-come-first-served (FCFS), last-com-first-served (LCFS), or random order. The sixth one is the availability of the service facility; sometimes, it might not be available due to breakdown or needs from other tasks. The last one is the customer's behavior; it ranges from defection from the queue, jockeying among the many queues, balking before entering a queue, bribing for queue position, or cheating for queue position ((Kleinrock, L. 1975). Among all the elements of the queuing system, waiting time for a customer, the number of customer in the system, the length of an idle period, and the number of customers waiting are critical to this study.

There are different queuing systems. According to Winston (Winston, 1993), each queuing system is expressed through six characteristics. Kendall-Lee notation for queuing systems is the following:

1/2/3/4/5/6

1. the nature of the arrival process;
2. the nature of the service time;
3. the third is the number of parallel servers;
4. the queuing discipline;
5. the maximum allowable number of customers in the system; and
6. the size of the population in which customers are drawn.

The first three characteristics: distribution of inter-arrival times/distribution of service times/number of servers. The first characteristic can be expressed through the following:

M: exponential distribution

D: degenerate distribution (constant service time)

E_k: Erlang distribution

G: general distribution (any arbitrary distribution allowed)

The second characteristic specifies the nature of service times:

M: exponential distribution

D: degenerate distribution (constant service time)

E_k: Erlang distribution

G: general distribution (any arbitrary distribution allowed)

The third characteristic is the number of servers. The fourth characteristic represents the queue discipline:

FCFS: first come first served

LCFS: last come first served

SIRO: service in random order

GD: general queue discipline

The fifth characteristic specifies the maximum number of customers allowed in the system, including customers who are in the queue and customers who are being served. The sixth characteristic provides the size of the population from which customers are drawn.

Number 1 and 2 of these characteristics will be statistically estimated to produce a series of parameters (different distribution functions such as general distribution, Poisson, exponential, Erlang, etc.), using data collected from observations, surveys, and interviews with companies in the industry. The results of such estimation will determine the formation of probabilistic queuing functions, in turn; they will be used to estimate waiting time. Furthermore, the pattern of truck arrivals at the gate complex is also a dynamic one, subject to vessel schedules. Therefore, the queuing patterns differ time to time during the day and from day to day during the week. Number 3, 4, 5 and 6 will be obtained through field observations and interviews.

4.2.2 Modeling Truck Waiting Time Functions

In the terminal gate situation, truckers are viewed as customers and the MCT gate booths are treated as servers. They are integral parts of the queuing system (see Figure 3.2). First, due to the unpredictability of decisions regarding when truckers will be dispatched to the MCT for pickup and delivery, highway congestion, and weather delays, the arrival process can be viewed as a random process or stochastic process. Second, the system has unlimited capacity as the waiting area can be stretched from the gate holding pan to access roads. One of the concerns is whether the trucker waiting line is spilled over to major highway accesses. As a result, regular highway traffic or traffic on arterial roads will be affected. In the vicinity of the Port of New York and New Jersey, all marine terminals are located in industrial areas where sufficient road capacities are provided. In addition, little passenger vehicle traffic is present in these areas. Therefore, whether the truck waiting lines interfere with regular highway traffic is not an issue in this study.

Third, there is no priority for customers. Fourth, each gate booth can be treated as an independent and parallel server. In order to select an appropriate queuing model for the MCT gate system, the characteristics of the queuing theory must be determined.

Since there are no prioritized truckers in general, no limit on the number of truckers coming to the terminal to pickup or drop off containers, and the size of the trucker population is quite large, the impact of last three characteristics of the queuing system can be ignored. In general, the number of gate lanes opened is more than one under normal operating conditions; therefore, the system is a multi-server one. Regarding the type of distribution of truck arrivals, it generally falls into one of the following patterns: Poisson, exponential, or Erlang distribution. It will be statistically tested from the data collected in the field. For the distribution of service, it will be obtained through statistical tests from the data in field observation.

4.2.3 The Multi-Server Queuing Models

The MCT gate system in general consists of multiple inbound lanes and outbound lanes; each lane has a service station to attend inbound and outbound trucks. Each service station can be treated as a server. Based on this physical layout and characteristics of the MCT gate system and its operation, a multi-server queuing model is applicable. A multi-server queuing model with the following parameters:

λ = average truck arrival rate (trucks/hour);

μ = average service rate of truck, number of truck/booth/hour;

S = number of gate lanes;

When λ and μ have different statistical distributions, they lead to different queuing models. According to the characteristics of the MCT gate system and the findings of numerous studies (Kozon, 1997a, 1997b, and 2000; Noritake and Kimura, 1983; Noritake, 1985; Tariguchi, et al. 1999; Yamada, et al. 2003; and Dragovic et al. 2006), two multi-server models can be used based on two important assumptions. If truck inter-arrival time follows the Possion distribution and gate service time follow the exponential distribution pattern, the M/M/S model is applied. If truck inter-arrival time follows the Possion distribution and the gate service time follow the Erlang distribution, the M/E_k/S model will be applied. Therefore, $N_{tw}(\lambda,\mu,S)$, the average number of trucks waiting in the gate system including the number of trucks being served and waiting in queue Nt(λ,μ,S) in formula (3.9) and system utilization (ρ) are following:

$$T_t(\lambda,\mu,S)=\frac{1}{\mu}+\frac{a^s}{\mu(S-1)!(S-a)^2}\left[\sum_{n=0}^{S-1}\frac{a^n}{n!}+\frac{a^S}{(s-1)!(S-a)}\right]^{-1},\qquad a=\frac{\lambda}{\mu} \tag{4.1}$$

When λ follows a Possion distribution and μ follows an Erlang distribution, the M/E_k/S model is applied. Since there is no conventional mathematical M/E_k/S is available, approximation is necessary. There are two approximation formulas; one developed by Lee and Longton (1959) and the other developed by Cosmatatos (1976). These two M/E_k/S approximation formulas are the following:

$$T_t = \frac{1}{\mu} + \left[\frac{1+\frac{1}{k}}{2} \right] \left\{ \frac{a^n}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^S}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \tag{4.2}$$

and

$$T_t = \frac{1}{\mu} + \left\{ \frac{a^S}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \bullet$$

$$\left\{ \frac{1+v^2}{2} + \frac{(1-v^2)(1-\rho)(S-1)(\sqrt{(4+5S)}-2)}{32\rho S} \right\} \tag{4.3}$$

In (4.2) and (4.3), system utilization $\rho = \frac{\lambda}{\mu S} < 1$, traffic density $a = \frac{\lambda}{\mu}$, and $v = \frac{1}{\sqrt{k}}$, k is the degree of freedom or the number of Erlang phases of Erlang distribution for truck service time. Actually, k is the parameter of Erlang distribution; it should be positive integers; and it determines the shape of the Erlang distribution. For example, if k = 1, the Erlang distribution is an exponential distribution. As k increases, the Erlang distribution behaves more and more like a normal distribution (Winston, 1993). Substituting ρ and υ into (4.3), the following is obtained:

$$T_t = \frac{1}{\mu} + \left\{ \frac{a^S}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \bullet$$

$$\left\{ \frac{1+\frac{1}{k}}{2} + \frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)(\sqrt{(4+5S)}-2)}{32a} \right\} \tag{4.4}$$

In this study, truck waiting is defined as the amount of time trucks wait outside the gate, therefore, service time 1/μ can be excluded from the waiting time calculation. As a result, Equations (4.1) and (4.4) can be simplified into the following, respectively:

$$T_t = \left\{ \frac{a^S}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \tag{4.5}$$

$$T_t = \left\{ \frac{a^S}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \bullet$$

$$\left\{ \frac{1+\frac{1}{k}}{2} + \frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)(\sqrt{(4+5S)}-2)}{32a} \right\} \tag{4.6}$$

Among the two M/E_k/S models, one by Lee and Longton, the other by Cosmetatos, it is reported that Cosmetatos' approximation method has less than 2% error for most practical purpose (Cosmetatos, 1976, Noritake, 1983 and 1985, and Taniguichi et al. 1999). Therefore, Cosmetatos' approximation (4.6) will be used in this analysis.

4.3 Cost Functions of Truck Waiting Time

Using the multi-server parallel queuing models of (4.1), (4.2), and (4.3), the average truck cost function (3.6) has two alternatives. If the gate processing time (truck service time) follows an exponential distribution, the average hourly per truck waiting cost function is the following:

$$AC_t = C_hT_t = \quad C_h\left\{\frac{a^S}{\mu(S-1)!(S-a)^2}\left[\sum_{n=0}^{S-1}\frac{a^n}{n!}+\frac{a^S}{(S-1)!(S-a)}\right]^{-1}\right\} \tag{4.7}$$

If the gate processing time follows an Erlang distribution function, the Cosmetatos' approximation will be used.

$$AC_t = C_hT_t,$$

$$C_h\left\{\frac{a^S}{\mu(S-1)!(S-a)^2}\left[\sum_{n=0}^{S-1}\frac{a^n}{n!}+\frac{a^S}{(S-1)!(S-a)}\right]^{-1}\right\}\bullet$$

$$\left\{\frac{1+\frac{1}{k}}{2}+\frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)(\sqrt{(4+5S)}-2)}{32a}\right\} \tag{4.8}$$

4.4 Average System Cost

Average total system cost measures the cost of gate processing cost and truck waiting cost per truck. Based on Equation (3.10), the average total system cost has two components, average gate operating cost (ACg) and average truck waiting cost (AC_t). Substituting Equations (4.4), (4.5), and (4.6) into Equation (3.10), respectively, the following are obtained:

$$AC_{TS} = \frac{C_{THC}}{\lambda} = AC_g + AC_t = \frac{C_gS}{\lambda} + C_hT_t =$$

$$\frac{C_gS}{\lambda} + C_h\left\{\frac{a^S}{\mu(S-1)!(S-a)^2}\left[\sum_{n=0}^{S-1}\frac{a^S}{n!}+\frac{a^S}{(S-1)!(S-a)}\right]^{-1}\right\} \tag{4.9}$$

$$AC_{TS} = \frac{C_{THC}}{\lambda} = AC_g + AC_t = \frac{C_g S}{\lambda} + C_h T_t =$$

$$\frac{C_g S}{\lambda} + C_h \left\{ \left[\frac{1+\frac{1}{k}}{2} \right] \left\{ \frac{a^S}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \right\} \tag{4.10}$$

and

$$AC_{TS} = \frac{C_{THC}}{\lambda} = AC_g + AC_t = \frac{C_g S}{\lambda} + C_h T_t =$$

$$\frac{C_g S}{\lambda} + \mathrm{C_h}\, C_h \left\{ \frac{a^S}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \bullet$$

$$\left\{ \frac{1+\frac{1}{k}}{2} + \frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)(\sqrt{(4+5S)}-2)}{32a} \right\} \tag{4.11}$$

Equations (4.9), (4.10), and (4.11) present three different models to analyze average total system cost. At the lowest point of the cost curve; the gate system is at its optimum condition so that the cost to accommodate one truck is at its minimum.

4.5 Gate System Optimization

To optimize the gate operations, there are two issues that need to be analyzed. The first one is how to obtain the minimum hourly gate operating cost; that means the average total cost to handle a truck, including gate processing cost and truck waiting cost is at a minimum. The second one is more complicated; it has to deal with the variation in truck arrival rate based on different hours of the day and different days during a year. Equations (4.9), (4.10), and (4.11), show the average total cost per truck in the gate system; the trade-off will be analyzed by minimizing the sum of the relevant cost components related to the number of gate booths, average gate processing time, and average truck arrival rate. These three parameters are the key to analyze gate facility utilization, truck waiting costs, congestion costs, and congestion mitigation.

There are two ways to minimize the average total cost per truck in the gate system. The first one is to take the first derivative with respect to λ to obtain the marginal cost and set the marginal cost to zero or to use the numerical method that obtain a set of average cost value and identify the minimum value. The second one is to obtain the optimum number of gates to accommodate the various truck arrival rates.

Based on (3.12), $MC_{TS} = C_h T_t + \lambda C_h (\frac{dT_t}{d\lambda})$, the key is to obtain $(\frac{dT_t}{d\lambda})$. Since the queuing function is a discrete one, it is easier to use the numerical method to obtain the minimum value of AC_{TS}.

4.5.1 Determination of the Optimum Number of Booths

As mentioned earlier, there are two cost components in the gate system; the gate operating cost and truck waiting cost. Based on Equation (3.13), the objective function of the total hourly cost of the gate system is:

$$\text{Minimize } C_{TS} = C_g + C_t \tag{4.12}$$

Subject to

$$C_g = f(L_C, S) \tag{4.13}$$

$$C_t = f(C_h, N_t) \tag{4.14}$$

$$0 \leq S \leq S_{max}$$

$$N_t = f(\lambda, \mu, S) \tag{4.15}$$

L_C, C_h S, N_t, λ, and $\mu \geq 0$

where,

N_t: the average number of truck waiting

Simply, the hourly gate operating cost is equal to the hourly gate operating cost per gate booth multiplying the number of gate booths. Therefore, C_g can be expressed as follows:

$$C_g = f(Lc, S) = LcS \tag{4.16}$$

Also according to Little and Longton's formula on queuing theory, the average waiting cost is equals to the hourly trucking operating cost multiplying the average number of trucks waiting. C_t can be expressed as follows:

$$C_t = C_h N_t \tag{4.17}$$

Substituting (4.12) and (4.13) into (3.13), the following is obtained:

$$C_{TS} = C_g + C_t = LcS + C_h N_{t(S)} \tag{4.18}$$

Dividing both sides of (4.18) by C_h, (4.18) becomes the following:

$$R_{TC} = \frac{C_{TS}}{C_h} = \left(\frac{L_C}{C_h}\right)S + N_t = r_{gt}S + N_{t(S)} \tag{4.19}$$

R_{TC} is the total hourly cost with S number of booths to hourly truck operating cost ratio, and $r_{gt} = (L_C/C_h)$ is the gate – truck operating cost ratio. In (4.19), if the number of booths is at optimum; that means the relevant cost ratio of R_{TC} should hold the following relation:

$$R_{TC(S)} < R_{TC(S+1)}, \text{ and } R_{TC(S)} < R_{TC(S-1)} \quad (4.20)$$

Applying the above relation into (4.19), the following are obtained:

$r_{gt}S + N_{t(S)} < r_{gt}(S+1) + N_{t(S+1)}$, and $r_{gt}S + N_{t(S)} < r_{gt}(S-1) + N_{t(S-1)}$,

Consequently,

$$N_{t(S)} - N_{t(S+1)} < r_{gt} = (L_C/C_h) < N_{t(S-1)} - N_{t(S)} \quad (4.21)$$

Equation (4.21) serves a critical purpose in determining the optimum number of gate booths; it means that the number of gate booths should be increased as long as the marginal cost of one additional booth is less than the marginal benefit of one additional booth (which is equal to the reduction in cost of truck waiting at the gate). By the same token, the optimum number of booths is the one that the marginal cost exceeds the marginal benefit. Since L_C and C_h are known, the only critical variable in obtaining the optimum number of booths is N_t, in which queuing theory can be applied. According to Little's formula, $N_t = \lambda T_t$; applicable queuing models can be used to obtain the value of T_t. Using (4.5) and (4.6) for T_t and substituting into Little's formula, there are two applicable models for obtaining N_t as follows:

$$N_{t(M/M/S)} = \lambda T_{t(M/M/S)} = \frac{a^{S+1}}{\mu(S-1)!(S-a)^2}\left[\sum_{n=0}^{S-1}\frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)}\right]^{-1} \quad (4.22)$$

and

$$N_{t(M/Ek/S)} = \lambda T_{(M/Ek/S)} = \left\{ \frac{a^{S+1}}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \bullet$$

$$\left\{ \frac{1+\frac{1}{k}}{2} + \frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)(\sqrt{(4+5S)}-2)}{32a} \right\} \quad (4.23)$$

Substituting Equations (4.22) and (4.23) into Equation (4.19), the following are obtained for M/M/S and M/E_k/S queuing models, respectively:

$$R_{TC(M/MS)} = r_{gt}S + N_{t(S)} = r_{gt}S + \left[\frac{a^{S+1}}{\mu(S-1)!(S-a)^2} \right] \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \quad (4.24)$$

and

$$R_{TC(M/Ek/S)} = r_{gt}S + N_{t(S)} = r_{gt}S + \left\{ \frac{a^{S+1}}{\mu(S-1)!(S-a)^2} \left[\sum_{n=0}^{S-1} \frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)} \right]^{-1} \right\} \bullet$$

$$\left[\frac{1+\frac{k}{2}}{2} + \frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)\sqrt{(4+5S)}-2}{32a} \right]$$

(4.25)

In Equations (4.24) and (4.25), r_{gt} and S are known; and the number of Erlang phases can be obtained through field observation and statistical testing. Further, μ can be obtained through field observation. It is obvious that R_{TC} is a function of a, the traffic density, which is equal to λ/μ. Since μ is relatively fixed in a short term, the optimum number of booths is obtained through (4.19) and (4.20). In essence, the optimum of S is found when the total hourly gate system cost with S is the same as with S+1. That means:

$$R_{TC(S+1)} - R_{TC(S)} = [r_{gt}(S+1) + N_{t(S+1)}] - (r_{gt}S + N_{t(S)}) = r_{gt} + N_{t(S+1)} - N_{t(S)} = 0 \quad (4.26)$$

Equation (4.26) indicates that for the gate system is at optimum, the marginal cost of adding one gate booth must be equal to the marginal benefit of reduction of truck waiting cost, $C_h[N_{t(S)} - N_{t(S+1)}]$. Therefore, the gate system optimization can be obtained through the following:

$$f(a) = r_{gt} + N_{t(S)} - N_{t(S+1)} = 0 \tag{4.27}$$

In essence, there will be a series of R_{TC} curves based on different values of the various parameters. The optimum number of S can be found at where $R_{TC(S)}$ intercept with $R_{TC(S+1)}$ with corresponding a value of a. Therefore, the hourly gate system optimization can be summarized in the following:

$$\text{Minimize} \quad C_{TC} = L_C S + C_h N_{t(S)} \tag{4.28}$$

Subject to:

$$r_{gt} + N_{t(S)} - N_{t(S+1)} = 0, \tag{4.29}$$

$$N_{t(M/M/S)} = \left[\frac{a^{S+1}}{\mu(S-1)!(S-a)^2}\right]\left[\sum_{n=0}^{S-1}\frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)}\right]^{-1} \tag{4.30}$$

or

$$N_{t(M/Ek/S)} = \left[\frac{a^{S+1}}{\mu(S-1)!(S-a)^2}\right]\left[\sum_{n=0}^{S-1}\frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)}\right]^{-1} \bullet$$

$$\left[\frac{1+\frac{k}{2}}{2} + \frac{(1-\frac{1}{k})(1-\frac{a}{S})(S-1)\sqrt{(4+5S)}-2}{32a}\right] \tag{4.31}$$

$$r_{gt} = (L_C/C_h), \tag{4.32}$$

$$a = \lambda/\mu, \tag{4.33}$$

$(\lambda/\mu S) \leq 1.0$; S is integer, (4.34)

L_C, C_h, S, λ, μ, and $k \geq 0$.

To illustrate the optimization process of the gate operation, the following is an example. Equations (4.22) through (4.32) are applied. Assuming that the truck arrivals and service times fit the M/M/S queuing model, the values for the relevant parameters are: $\mu = 0.41$, $\lambda = 0.10$ to 2.30, $L_C = \$46.3$, $C_h = \$35$, $S = 1$ to 6. $R_{TC\ (Si)}$ are calculated, using Lingo 10.0 software for queuing analysis. The corresponding values of $R_{TC(Si)}$ are plotted (see Figure 4.2).

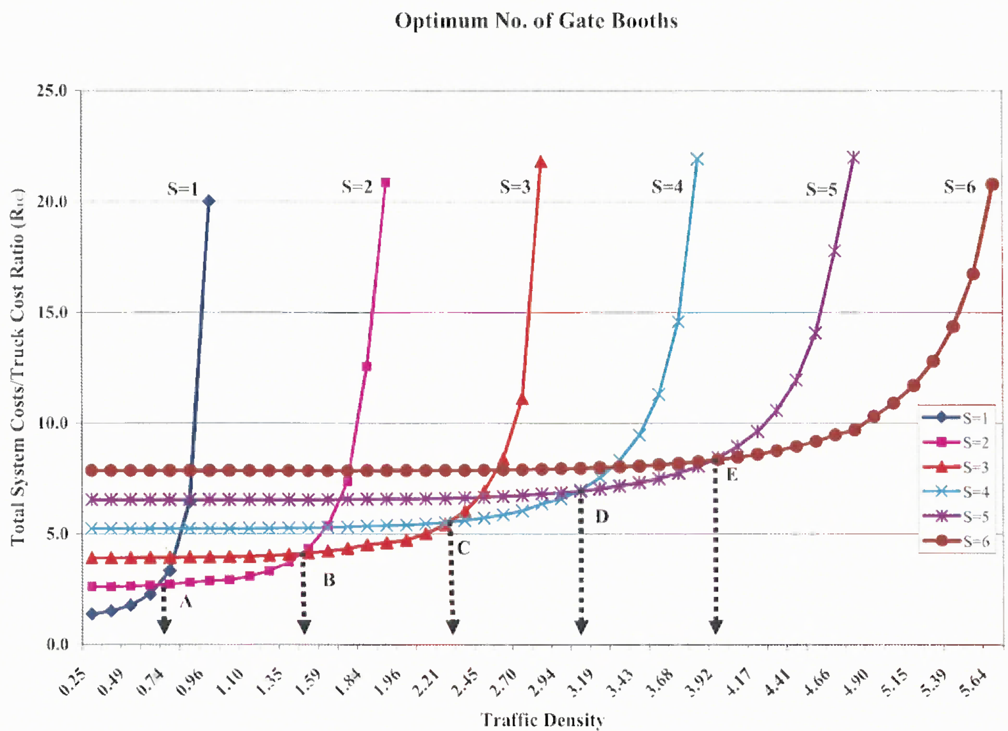


Figure 4.2 Optimum number of gate booths curves.

In Figure 4.2, it illustrates the boundaries where different values of $R_{TC(Si)}$ under various parameters of a and S. A, B, C, D, and E are points where $R_{TC(S)}$ and $R_{TC(S+1)}$ are equal. For example, A (a = 0.75) is where $R_{TC(S=1)}$ is equal to $R_{TC(S=2)}$. As traffic density (a) increases beyond 0.75, both $R_{TC\,(S=1)}$ and $R_{TC(S=2)}$ increases. But $R_{TC(S=2)}$ increases at a much lower rate. It means the number of gate booths should be two instead of one. Comparing with all other $R_{TC(Si)}$; $R_{TC(S=2)}$ is the lowest until it reaches B, where $R_{TC(S=2)} = R_{TC(S=3)}$. It means under different values of a (a = λ/μ), the optimum number of gate booths (S) is found by identifying the smallest value of $R_{TC(Si)}$ among all the the $R_{TC(S)}$ curves. As a result, A-B-C-D-E are the lower bound of all the $R_{TC(Si)}$ curves, which indicates the range of optimum number of gate booths corresponding to different values of a.

4.5.2 Optimization of Daily MCT Gate Operations

To optimize the MCT gate operations, the total daily costs (TDC) should be minimized. Since truck arrival rates vary from hour to hour, it is necessary that the optimization process needs to take this dynamic nature into consideration. In addition, there are several issues that need to be addressed. To optimize the gate system on a daily basis, it needs to include all the constraints based on actual terminal gate operations. The optimization of total daily costs (TDC) is formulated as:

$$\text{Minimize } TDC(C_g, C_t) = \sum_i C_{g_i} + \sum_i C_{t_i} = \sum_i L_{c_i} S_i + \sum_i C_h N_{t(S)_i} \tag{4.35}$$

Subject to

$$r_{gt} + N_{t(S)_i} - N_{t(S+1)_i} = 0 \tag{4.36}$$

$$N_{t(M/M/S)} = \left[\frac{a^{S+1}}{\mu(S-1)!(S-a)^2}\right]\left[\sum_{n=0}^{S-1}\frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)}\right]^{-1} \tag{4.37}$$

or

$$N_{t(M/E_k/S)} = \left[\frac{a^{S+1}}{\mu(S-1)!(S-a)^2}\right]\left[\sum_{n=0}^{S-1}\frac{a^n}{n!} + \frac{a^S}{(S-1)!(S-a)}\right]^{-1} \bullet$$

$$\left[\frac{1+\frac{k}{2}}{2} + \frac{(1-\frac{k}{1})(1-\frac{a}{S})(S-1)\sqrt{(4+5S)}-2}{32a}\right] \tag{4.38}$$

$r_{gt} = (L_C/C_h),$ (4.39)

$a = \lambda/\mu,$ (4.40)

$(\lambda/\mu S) \leq 1.0,$ (4.41)

L_C, C_h, S, λ, μ, and $k \geq 0$; all S are integers.

In Equations (4.30) and (4.31), it clearly indicates that it is a non-linear optimization problem with discrete variables representing the number of gate booths, gate operating cost, truck arrival rates, and truck operating cost. Therefore, approximation methods generic algorithms will be applied as provided in Equations (4.35), (4.36), (4.37), and (4.38). The procedure to obtain the optimum number of gate booths and minimize the total daily gate operating costs is the following:

1) Step one: obtain L_C and C_h and compute the volume of $r_{gt.}$
2) Step two: Observe λ and μ.
3) Conduct statistical testing to determine the types of statistical distribution for λ and μ, respectively.

4) Based on the results of statistical testing in step 3, determine which queuing model to use, either M/M/S, (4.37) or $M/E_k/S$, (4.38).
5) Calculate C_g and C_t.
6) Use (4.33) to obtain the optimum number of S under different circumstances.
7) Substitute observed and calculated values of L_C, C_h, λ, μ, and the optimum value of S into (4.35) to get the optimum TDC.
8) Conduct sensitivity analysis
9) Provide recommendations to reduce congestion and optimization.

Due to the complexity of the queuing model and the variability of truck arrival, it is necessary to calculate the truck waiting cost under wide range of truck arrival rates so the MCT gate congestion issue can be thoroughly analyzed. Using Lingo, a non-linear optimization program complemented with the approximation in Equation (4.38), the various values of μ, λ, L_C, and C_h are used as input; it generates different values of N_t. In turn, the values of N_t are substituted into Equation (4.36) to identify the optimum number of S. Therefore, based on the input values of μ, λ, L_C, and C_h, and applying other constraints to the gate system, the minimum TDC can be obtained. The main advantage of this program is that it can provide a range of solutions to different scenarios based on different values of μ, λ, L_C, and C_h. Therefore, sensitivity analysis can be conducted easily.

4.6 Summary

In this chapter, it represents the methodology to study the MCT gate operations. At the beginning, a general methodology framework is described. There are two queuing models that can be applied to analyze the MCT gate operations, mainly M/M/S and $M/E_k/S$ models. However, since there is no theoretical formulation for the $M/E_k/S$ model, Cosmetatos' approximation is adopted. Based on the gate system, a cost function is developed and an optimization model is presented. Through a series of derivation, the optimization model is simplified into a more manageable one for computation. Since the cost function is a non-linear and discrete one, approximation and generic algorithm are used. Lastly, a procedure for optimization is developed to analyze actual gate problem with various constraints and an optimization model is derived. The optimization model provides a solution tool to deal with various constraints and to obtain a range of solutions by changing the values of different input variables. Further, to simplify the optimization process, a computer program is developed to automatically search the optimum number of S. Ultimately, the minimum TDC can be obtained.

CHAPTER 5

DATA COLLECTION AND DATA ANALYSIS

The MCT gate operation is an integral part of the terminal system; its performance has a direct impact on regional freight efficiency as well as financial performance of the terminal operator. But there is a lack of data of gate processing and truck flow; detailed and systematic analysis of the gate operation and its behavioral pattern is seriously lacking. Part of the reasons is due to the lack of data; another is due to the complexity of the truck flow behavior. First of all, freight planners would like to know that given the current trade pattern, how many truck trips will be generated for infrastructure planning purpose. For a MCT operator, for a given number of vessel import/export container, the number of transactions they generate represent resources requirements for yard equipment and gate processing. For truckers, the number of import/export containers and the transaction volume represents business opportunities.

Lastly, MCT congestion level is of a serious concern for all parties. To address the gate congestion issue, it is essential to understand the overall characteristics of the gate operation and truck traffic behavior. A comprehensive data set was obtained from both a terminal operator and field observation. A general data analysis of the MCT gate operation and truck flow behavior is provided in this chapter. Due to confidentiality agreement, the identity of the MCT and its clients will not be revealed.

The comprehensive data set was obtained; it includes almost 50 weeks of terminal operational activities such as vessel loading and discharging volume, daily gate transaction volume, types of gate transactions, daily inbound and outbound truck volume, and hourly break-down of gate transactions. This chapter provides a comprehensive analysis of the MCT gate activities; it has six sections. Section one provides an overall description of vessel loading and discharging activities, and its patterns. Section two explains the various truck activities and gate transactions that take place on a day to day basis, resulted from vessel cargo activities. Section three analyzes the patterns of inbound truck activities. Section four analyzed the gate transaction patterns. Section five integrates the vessel, truck, and gate transaction activities, and identifies the relationship among them. Section six is a summary that highlights the major points of the data analysis and its implications.

5.1 Vessel Traffic

The primary driver for truck pickup and delivery activities is import and export containers. This directly translates into vessel loading and discharging volume. When an export cargo booking is made, trucks are dispatched to the MCT to pick up empty containers; after cargo is stuffed into containers trucks deliver those export loaded container back to the MCT before the intended vessel arrives. For import containers, trucks are dispatched to the MCT to pickup import containers and deliver to the importers' warehouses. After cargo is taken out of the container(s), truckers take those empty containers back to the MCT. Therefore, the volume of vessel loading and discharging containers provides a good indicator for the volume of MCT gate traffic.

Most of the container shipping lines nowadays use the weekly service, meaning the frequency of port calls is once a week for import and export cargo. Based on the information provided by the terminal personnel and author's own working experience at the terminal, almost all of the clients deploy their ships on weekly services; only one shipping line uses the 10 day service: one ship for every 10 days, a less frequent service. All the services cover major trade routes such as North America-Asia, North America-Europe, and North America-South America.

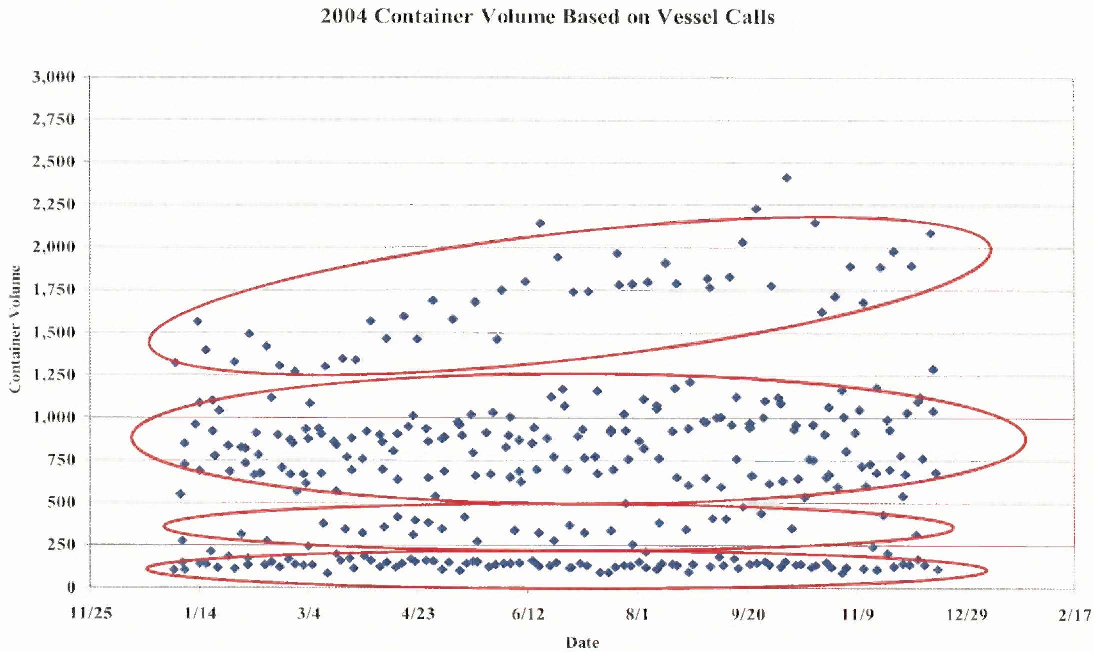


Figure 5.1 2004 Container volumes based on vessel calls.

The vessel load and discharge figures are compiled; there were 335 vessel calls with 241,513 containers from January 2 to December 16 in 2004 (see Appendix 1). With a ratio of 1.6 between the number of TEUs and the number of container, it translates into 386,421 TEUs. The load and discharge figure for each vessel is plotted in Figure 5.1. It shows a wide variation of cargo volume for different vessel calls. This reflects the fact that there are different shipping companies calling the terminal with various services deployed in different routes. In general, vessel sizes and the frequency of calls closely correspond to the trade volume in a particular route.

There are several clusters that can be identified from the chart. The first cluster is the vessel calls with cargo volume less than 250 container moves per call. The second cluster is the vessel calls with cargo volume between 250 and 750 moves per call. The third cluster is the vessel calls with cargo volume between 750 and 1,250 moves per call. The fourth cluster is the vessel calls with cargo volume between 1,250 and 2,500 moves. This cluster shows a very distinctive pattern; it starts around 1,300 moves per call at the beginning of the year and ends around 2,300 per call. The wide range differences are due to the differences in trade volume in different regions of the world, as well as the different sizes of vessels deployed in the various services.

Dividing the vessel calls based on different ranges of cargo volume per call, Figure 5.2 and Figure 5.3 shows the distribution of vessel calls. Clearly, vessel calls with cargo volume less than 250 containers per call represent the largest portion, 29.3%, but they only account for the second smallest percentage of total cargo volume, 5.8%. On the other hand, though vessel calls with cargo volume more than 1,250 containers per call represent only 14.9% of the total vessel calls, they account for the largest percentage of total cargo volume, 33.9%.

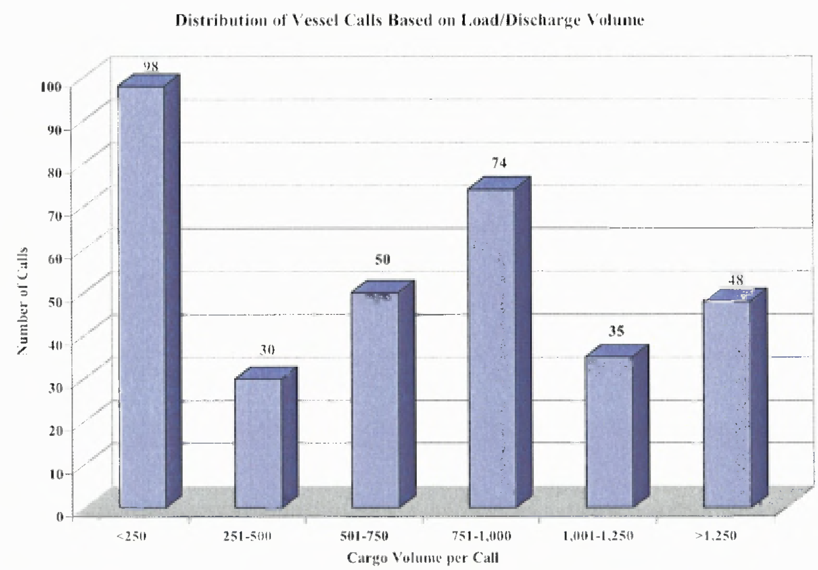


Figure 5.2 Distributions of vessel calls based on cargo volume per call.

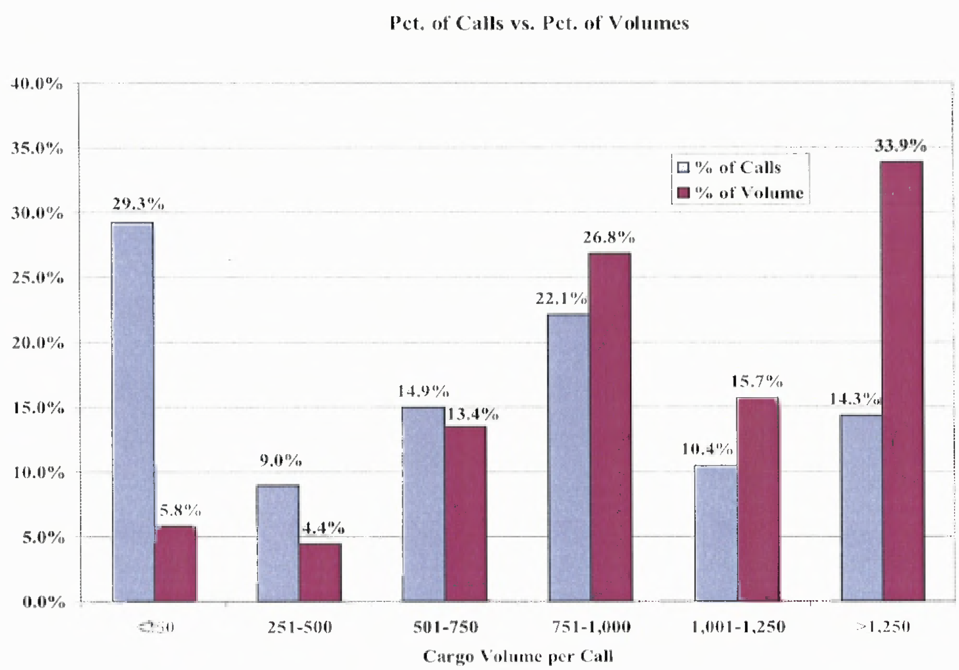


Figure 5.3 Percentages of vessel calls vs. percentage of cargo volume.

In order to analyze the impacts of vessel cargo volume on MCT truck traffic volume, it is necessary to show behavior of the vessel cargo volumes over time. Weekly vessel cargo volume is obtained by aggregating all vessel loading and discharging figures during the week. Since the first vessel that called the terminal was on Friday, January 2, 2004, the weekly vessel loading and discharging figures are aggregated from Friday to next Thursday. Figure 5.4 shows the weekly vessel cargo volumes; it illustrates several patterns. First, the weekly volume increased as time went by from the beginning to the end of the year. This corresponds to the general trend of increasing trade volume combined with seasonal factors in the Port of New York/New Jersey that cargo volume always increases during the peak holiday seasons started late July to the end of the year. The weekly cargo volumes are more or less within a certain range, except for a few irregularities as shown in the graph. The most plausible explanations for such irregularities are vessel schedule delays and holidays. For example, during winter, winter storms in the Atlantic and Pacific Ocean always cause vessel delays. Therefore, a vessel with large cargo volumes scheduled to arrive on Friday slipped to Saturday. The weekly cargo volume count would not count the cargo volume for this particular week, but add additional volume for the following week. The no-work week during the Chinese New Year in late January or early February will cause vessel call cancellations in certain ports in Asia, leading to sharp reductions in import cargo volume. The no-work July 4th Independence Day and Labor Day in early September will cause shipping lines to adjust their schedules, leading to variations in cargo volumes.

In summary, cargo volumes per vessel call can be divided into categories; they exhibit different behaviors. Though, there was a large number of vessel calls with low cargo volumes, they only account for a small percentage of the total cargo volume. On the other hand, there was a small number of vessel calls with large cargo volumes; this group accounts for the largest portion of the total cargo volume. Weekly cargo volumes show an upward trend from the beginning to the end of the year, indicating the general trend of the container trade of the port. Lastly, the weekly cargo volumes are more or less confined to a certain range except a few abnormal points, possibly due to no-work holidays domestic and abroad, as well as vessel schedule delays. Intuitively, the weekly cargo volume should be the driver for the gate traffic volume, which will be demonstrated in the next section.

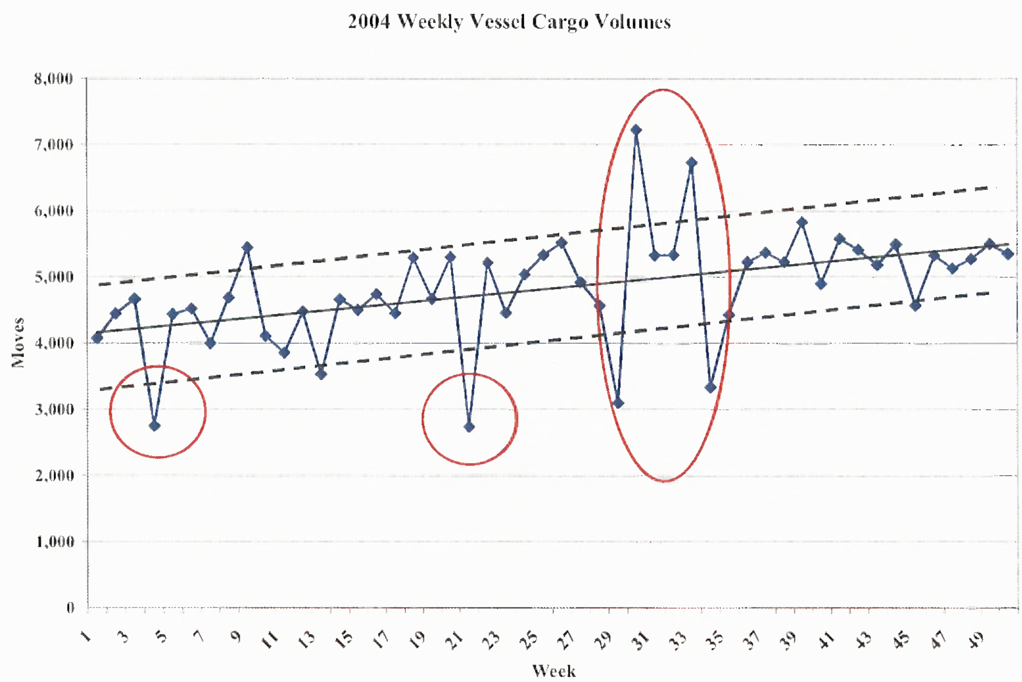


Figure 5.4 Vessel weekly cargo volumes.

5.2 Truck Traffic and Gate Transactions

Because of vessel loading and discharging activities, the MCT gate processes inbound and outboard container movements. As mentioned earlier in Chapter 3, there are different types of truck traffic passing through the gate complex. Since the gate is the point where equipment and cargo liabilities are exchanged, the gate complex processes and keeps track of what is coming in and what is going out. Any equipment both containers and chassis passing through the gate complex is of the interest of the MCT management, shipping lines, truckers, and shippers as well as government agencies. For example, a shipper may want to know when its export container is received by the terminal in order to meet the vessel schedule; or the shipper wants to know when the import container leaves the terminal in order to have the warehouse ready to receive the cargo for distribution. Shipping lines also want to know how many of the export containers have been received at the terminal against the total export bookings for a particular vessel. The MCT itself also wants to keep track of the number of containers and equipment in and out of the terminal for business purposed. When a piece of cargo equipment, either a container or a chassis, or both, passes through the MCT gate, it is considered a transaction. Therefore, the MCT gate transactions are important records.

In general, there is inbound and outbound traffic at the MCT. The inbound traffic includes returning empty containers (EMIN), export loaded containers (LDIN), returning chassis (CHIN), and bobtail (BTIN). The outbound traffic includes empty containers for export bookings (EMOT), import container deliveries (LDOT), outgoing chassis for equipment reposition purpose (CHOT), and bobtail (BTOT). BTIN and BTOT traffic are not considered a transaction since it does not involve any equipment passing through the gate, only the truck-tractors that owned by drivers or trucking companies. A trucker can come into the terminal to pickup or deliver a container or chassis only; this is called a single move. On the other hand, a trucker can also bring in a container or chassis to the MCT and pickup a container or chassis on his way out. This is called a double move. Apparently, double moves are more productive for both the trucker and the MCT operator.

In general, MCTs in the U.S. are open for container pickups and deliveries during regular weekdays between 6:00 a.m. and 6:00 p.m., to avoid high costs of overtime and warehouse work schedules during evenings and weekends. Also, they do not open during major public holidays such as New Year's Day, Independence Day, Thanksgiving Day, Christmas, etc. Therefore, out of 365 days, there are approximately 250 working days for the MCTs. But for vessel loading and discharging, the MCTs work 24 hours a day except for major public holidays mentioned above. Out of the approximately 250 working days for the particular MCT, 217 days of gate activities were obtained (see Appendix B). They provide a very detailed picture about the MCT gate activities.

5.3 Inbound and Outbound Truck Traffic Patterns

One critical issue facing MCT gate operations is the volume of inbound truck. As mentioned earlier, there four types of inbound truck traffic. Figures 5.5 and 5.6 show the pattern and distribution of the daily truck activities; the daily inbound traffic volume exhibits an increasing trend, but rate of increase is not as steep as the vessel traffic volume. It includes all four types of truck traffic (BTIN, EMIN, CHIN, and LDIN). Though the daily truck volume shows relatively high degree of variation; the variation is largely caused by terminal closure due to public holidays, irregularity of vessel schedule, and weather elements. From the figure, it can be easily identified that the spikes and valleys are mostly happened during holidays such Martin Luther King Day, July 4th, Labor Day, Thanksgiving Day, etc.

The frequency distribution of the daily inbound truck activities shows an asymmetric pattern (see Figure 5.6); it skews to the right. On average, there were 970 inbound trucks per day. Daily inbound truck volumes from 900 to 1,099 account for close to 70% of the total daily inbound trucks.

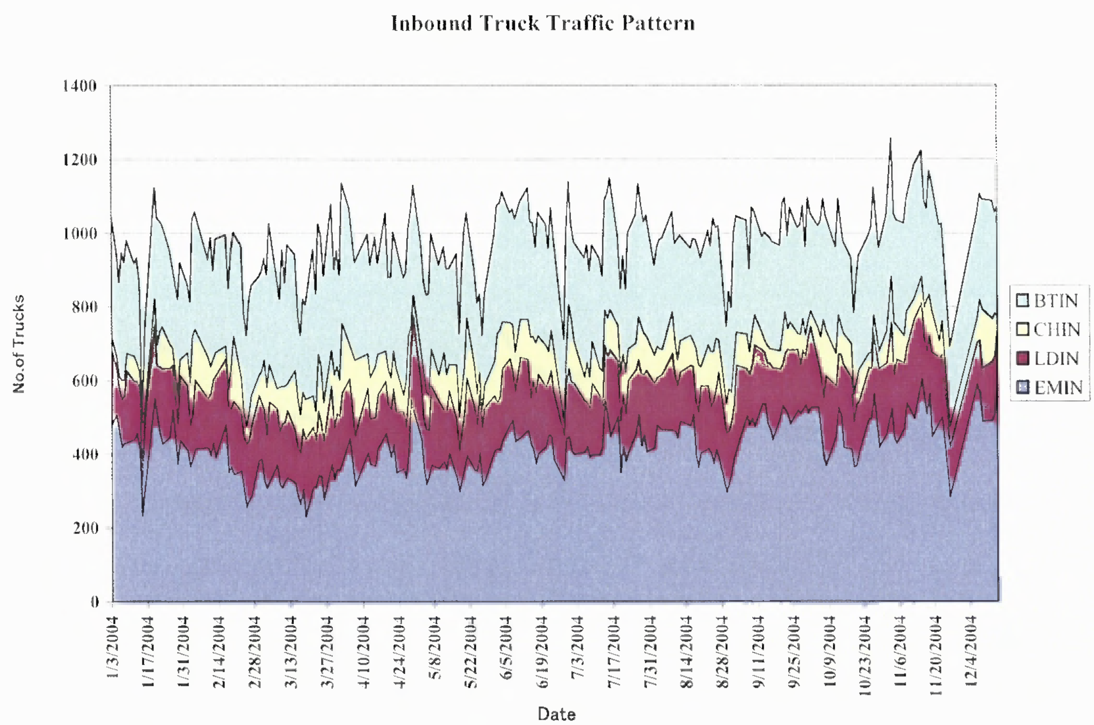


Figure 5.5 Daily inbound truck traffic pattern.

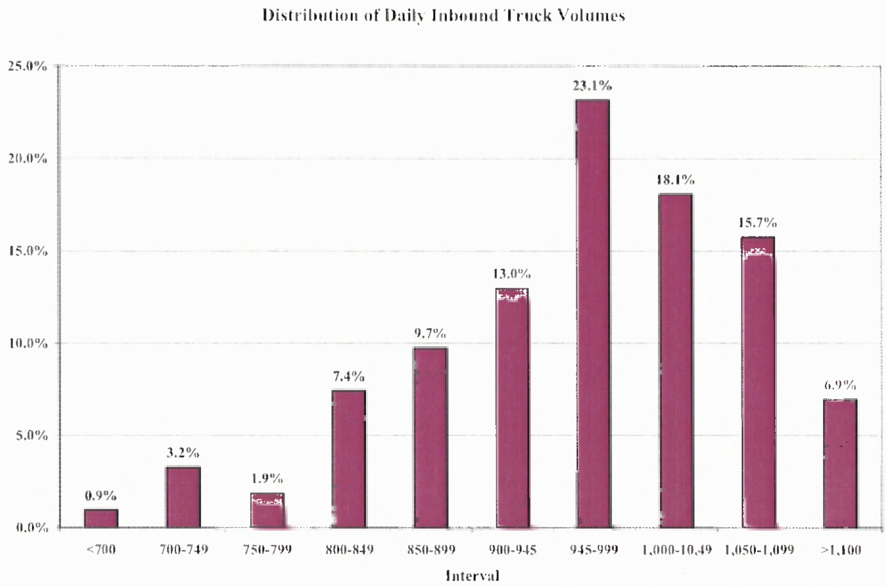


Figure 5.6 Distribution of daily inbound truck volumes.

Regarding the percentage breakdown of the different types of inbound truck traffic, EMIN (empty in) accounts for 43.0% (the highest); BTIN, 30.4%; LDIN, 16.7%, and CHIN, 9.7% (the lowest), respectively. In general, EMIN is the returned trip of an import delivery and LDIN the returned trip of an export booking with cargo. In addition, the composition of inbound traffic provides an indication for the pattern of gate processing. BTIN requires the least amount of processing time since there is no equipment transaction involved on the way-in. On the other hand, LDIN results in the longest processing time since large amount of information needs to be processed at the gate. Therefore, it is expected the service time will not be equally distributed. Its distribution is critical in determining which queuing model will be applied for the analysis.

For outbound truck traffic, the number of trucks is the same as the inbound truck traffic. But the percentage of breakdown of the outbound truck traffic is quite different;

on average 12.3% are for EMOT (empty out), 55.9% for LDOT (load out), 2.6% for CHOT (chassis out), and 29.1% for BTOT (bobtail out).

5.4 Gate Transactions and Patterns

The inbound and outbound truck traffic patterns reflect the truck activities; the gate transactions reflect the container movement in and out of the terminal (BTIN and BTOT are not included since there is no equipment transaction involved). Figure 5.7 shows the volume of total daily transactions (inbound and outbound) over time; the daily gate transaction volumes grow from the beginning of the year to the end of the year; this corresponds with the growing trend of vessel cargo volume. The lowest number of daily transactions is 705 and the highest one is 1,859. The graph also shows wide variation of the daily transactions, several spikes and valleys. The causes can be the closure of terminal for public holidays and vessel schedules. For example, due to Independence Day, the terminal will be closed for three days; shippers and truckers are taking a break before the holiday. Right after the holiday, the truck traffic will be usually high. Or due to vessel schedule delay, vessel arrivals that are usually spread overall several days might arrive within a 36 hour period, causing container pickup and delivery activities to be more concentrated within one or two days.

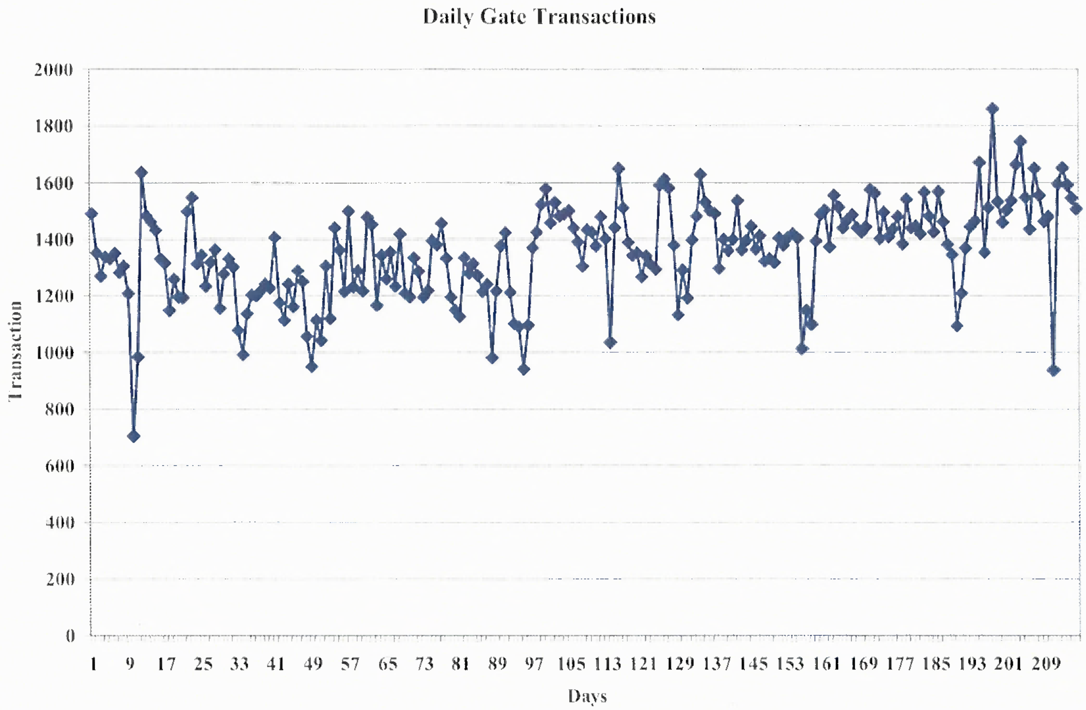


Figure 5.7 Daily gate transactions.

Figure 5.8 shows the distribution of the daily gate transactions; transaction volumes ranged from 1,300 from 1,499 account for 49.3% of the total daily transaction, the largest proportion. Daily transaction volumes range from 1,200 to 1,600 account for 78.8% of the total daily transaction activities. The distribution of daily gate transactions is not symmetric; it skews to the right.

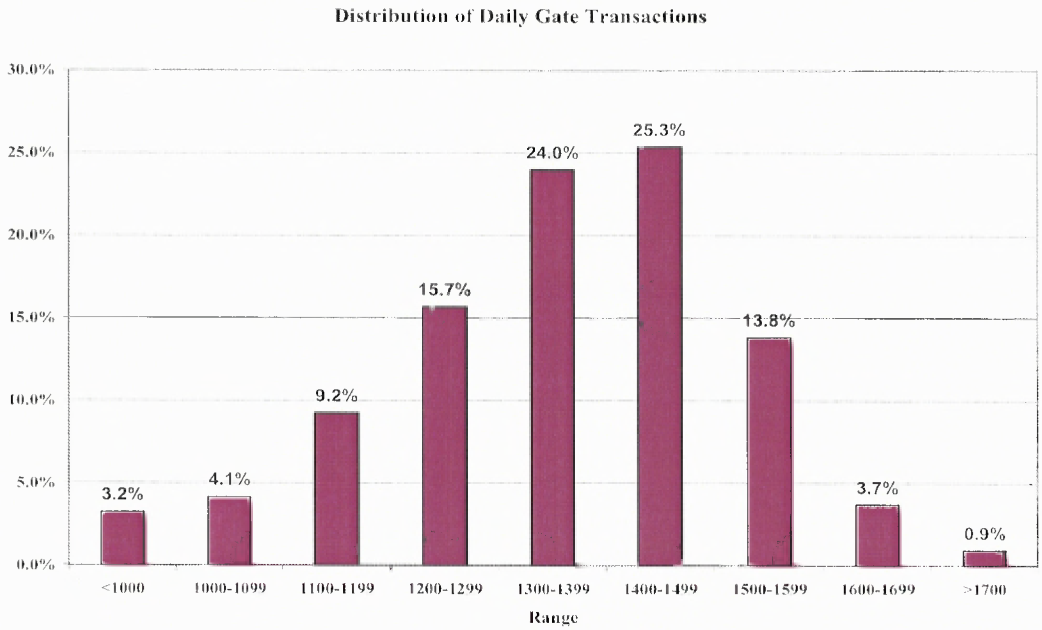


Figure 5.8 Distribution of daily transactions.

All inbound traffic has to go through gate processing; the types of traffic and the volume of inbound traffic will determine the gate processing requirements and affect waiting time at the gate, congestion level. Figures 5.9 and 5.10 show the behavior of daily gate transactions over time and the distribution of gate transactions, based on the data obtained. In general, the daily composition of daily gate transactions maintains a fairly consistent behavior over time, meaning the makeup of it remains more or less the same. On average, LDOT (import container deliveries) accounts for 39.4% of the total daily transactions, the largest proportion; on the contrary, LDIN (export container receiving) accounts only for 12.1%. By the same token, EMIN, the returned trips resulting from the LDOT activities, presents the largest proportion of the inbound transactions, 30.8% of the total daily transactions. The ratio between the LDOT and LDIN is more than 3, meaning the import container volume is more than two times of the export container volume. The huge difference between LDOT and LDIN reflects the fact that the regional economy is mainly a service economy that does not have many manufacturing activities. A large portion of the empty containers after delivering import cargo to customers and returning to the terminal will not go out of the MCT for export bookings and will be directly loaded back to the ships.

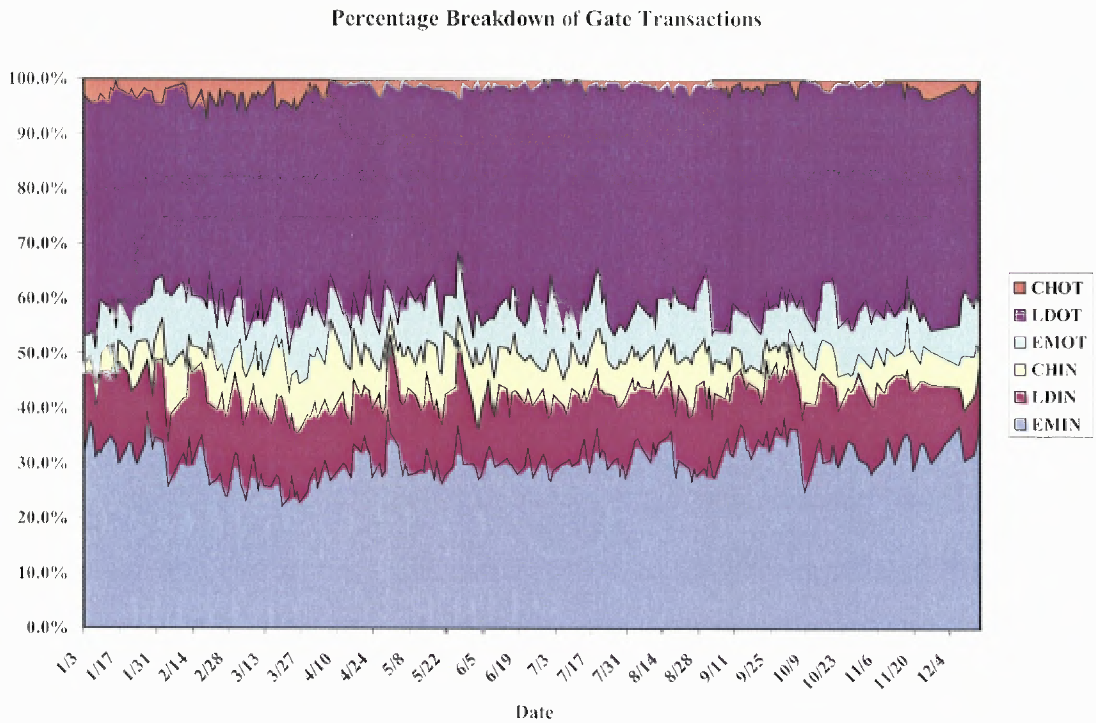


Figure 5.9 Patterns of daily gate transactions.

Supposedly, the proportion of LDOT should match the proportion of EMIN; a possible explanation is that not all of the import containers are for local consumption. Some of them are destined for inland locations such as Chicago, St. Louis, Toronto, Cleveland, etc. These containers come back with export cargo. This coincides with the fact that the LDIN has a larger proportion of the daily transactions than EMOT, 12.1% to 8.8%. Since this MCT does not have a on-dock rail facility for intermodal rail transfer, inference can be made that a large portion of the daily transactions is CHIN that import containers are taken to intermodal rail transfer facilities. From there containers are loaded onto stack trains for inland destination and chassis are returned to the MCT.

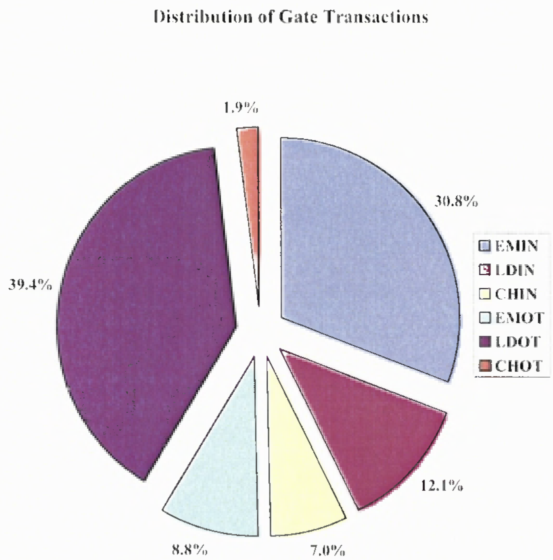


Figure 5.10 Distribution of gate transactions.

5.5 Relationship among Vessel, Gate Transaction, and Truck Volumes

Though the above data provide quite detailed information regarding import/export container volumes, gate transaction, and truck traffic patterns in general, the relationship among them has not been identified yet. One critical question is how many truck trips will be generated for one import/export container. This information will be valuable for port planners and terminal operators. For port planner, the relationship between vessel container volume and the truck trips generated will provide a good foundation in planning access roads to the MCT, in order to accommodate the growing cargo volume. For MCT operators, this relationship will provide a critical operation planning tool in estimating truck volume and gate processing capacity needed. To estimate the truck trips resulting from import/export container activity, it is essential to understand the truck trip generation process. Tables 5.1a and 5.1b illustrate the process and how truck trips are generated.

Table 5.1a Truck Trip Generation (Import Containers)

Import Container	Sequence	Truck Activity	Gate Transaction	Trip Generated
	No. 1	Bobtail in	None	1
	No. 2	Pickup import at MCT and deliver to warehouse	LDOT	1
	No. 3	Empty return	EMIN	1
	No. 4	Bobtail out	None	1
Total	4		2	4

Table 5.1b Truck Trip Generation (Export Containers)

Export Container	Sequence	Truck Activity	Gate Transaction	Trip Generated
	No. 1	Bobtail in	None	1
	No. 2	Pickup empty container and deliver to warehouse	EMOT	1
	No. 3	Export container delivery to MCT	LDIN	1
	No. 4	Bobtail out	None	1
Total	4		2	4

From the above tables, it demonstrates that the maximum number of truck trips generated per import/export container is four. However, the ratio of 1:4 between import/export container and truck trips generated is based on the two conditions: 1) all the containers discharged from and loaded onto ships are full containers and no empty containers are involved, and 2) truckers come to the MCT to undertake one container transaction at a time. In reality, these two assumptions can hardly be held at any time. First, because of trade imbalance, shipping lines have to reposition empty containers back to where inbound cargo is coming from. This is a structural problem that is persistent for a long time unless there is a fundamental change taking place in the international trade. Thus, a portion of empty containers returned to the MCT from import deliveries won't go out for export bookings; rather they will be directly loaded back to the ships. That means, no additional gate transactions and truck trips are generated from these containers. Second, to increase productivity and profitability, many truckers are engaged in a practice called double moves that they come to the MCT to drop off one container on the way in and pickup another one on the way-out. In this way, the number of truck trips generated is reduced.

To identify the relationship among vessel container volume, the number of gate transactions, the number of truck trips generated, the weekly average daily volume, gate transaction volume, and inbound truck volume are compiled and plotted (see Figure 5.11). In the figure, all these three daily volumes are closely correlated, except a few outliers. Taking out the outliers and plotting the probability distribution of the ratios between average daily inbound truck volume by week and the average daily vessel cargo volume by week, the result is that the probability distribution is similar to a normal distribution. The statistics analysis of this ratio yields: mean = 0.987, standard deviation = 0.112, and skewness = -0.314. The estimation of interval of the ratio at $\alpha = 0.05$ ($X = \mu \pm Z_{\alpha} \frac{s}{\sqrt{n}}$) is 0.987 ± 0.033, which is very close to 1.0.

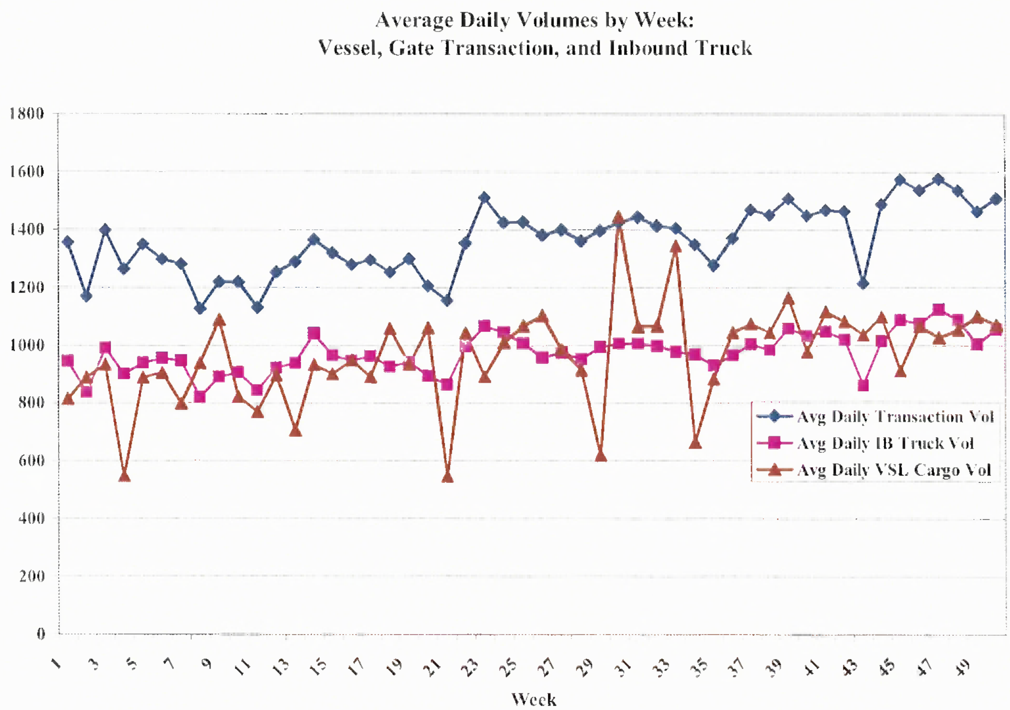


Figure 5.11 Average daily volume by week: vessel, gate transaction, and truck.

The implication is quite significant. It indicates that based on the current trade pattern (the magnitude of trade imbalance) and the customary practice of the trucking industry (the mix of single move and double moves), there will be two truck trips (one inbound trip is matched by an outbound trip) generated for every container (loading on or discharging from a ship). Port planners can utilize this ratio to estimate the number of truck trips generated based on projected container volume for infrastructure planning purposes as well as for traffic management purposes. Terminal operators can also utilize this ratio to estimate inbound truck traffic and gate processing capacity. Simply put, for every load/discharging container on the vessel, one inbound truck is expected.

In addition, the ratio between the number of gate transactions and the number of inbound truck is also identified. Dividing the number of daily gate transactions by the number of inbound trucks, a day-to-day ratio is obtained. The statistical analysis reveals that the distribution of the day-to-day ratios between the number of gate transactions and the number of inbound truck trips is normally distributed. Further, it has the following parameters: mean = 1.397, standard deviation = 0.048, and skewness = 0.126. The statistical estimation of this ratio at α = 0.05 ($X = \mu \pm Z_{\alpha} \frac{s}{\sqrt{n}}$) is 1.397 ± 0.006. Therefore, it can be said that for every inbound truck, there will be 1.4 transactions. Since the relationship between the number of vessel load/discharge containers and the number of inbound truck is 1:1. It also can be inferred that for every load/discharge container on the vessel, there will be 1.4 gate transactions, container movement in and out of the MCT. Because almost all transactions require yard handling and information processing, this ratio provides a good indicator for management regarding the number of yard equipment needed and manpower, as well as allocation of resources.

5.6 Summary

This chapter provides a comprehensive data analysis regarding the behavioral patterns of several key figures: vessel load/discharge container volume, the MCT gate transactions, and truck traffic. In addition, it identifies important relationships among these key figures. The results of the analysis are summarized with the following:

- **Vessel container volume:** the container volume demonstrates a growing trend in general. Due to the differences in vessel sizes and volume routes, important public holidays, and vessel delays, the weekly container volume fluctuates. The total number of vessel calls in the 50 week periods is 335, totaling 241,513 containers and 386,421 TEUs, respectively. Though vessels with less than 250 container moves (load and discharge) per call account for 29.3% of the total vessel calls, they represent only 5.8% of the container volume, the smallest proportion. On the other hand, vessels with more than 1,250 container moves account for only 14.9% of the total calls, but they represent the largest percentage of the total cargo volume, 33.9%. The import/export container activities are the main driver for truck movements in and out of the MCT.
- **Types of truck traffic and gate transactions:** There are four types of truck traffic for each direction: inbound and outbound. Inbound truck traffic includes bobtail in (BTIN), empty in (EMIN), load in (LDIN), and chassis in (CHIN). Out bound truck traffic includes bobtail out (BTOT), empty out (EMOT), load out (LDOT), and chassis out (CHOT). Inbound gate transactions include EMIN, LDIN, and CHIN; outbound include EMOT, LDOT, and CHOT. All transactions need to be processed at the inbound gate as well as outbound gate of the MCT for management purpose.
- **Truck traffic patterns:** Overall, there are 970 inbound trucks coming to the MCT per day on average; the pattern of inbound truck also exhibits a growing trend, driven by an increasing container volume. Truck volume between 900 to 1,099 accounts for close 70% of the total daily inbound trucks. The distribution

of the different types of inbound trucks is: EMIN 43.0% (the highest), BTIN 30.4%, LDIN 16.7% and CHIN 9.7% (the lowest). The distribution of outbound trucks is: LDOT 55.9% (the highest), BTOT 29.1%, EMOT 12.3%, and CHOT 2.6% (the lowest). The distribution of inbound trucks provides a good indication for gate processing (truck service time) requirements; the processing time for different types of inbound traffic is different.

- **Gate transaction patters:** Among the six different types of gate transactions (EMIN, LDIN, CHIN, EMOT, LDOT, CHOT), LDOT accounts for the largest proportion, 39.4% and LDIN accounts for only 12.1% of the total transaction. This demonstrates the lopsided trade; the ratio between import and export is greater than 3:1. That means large portion of the EMIN, the return trip of LDOT, do not go out for export booking. Rather they will be directly loaded back to the ship. The impact of this imbalance of trade is that the number of truck trips generated by container import/export activities is less than what is generally perceived.
- **Relationship among vessel container volume, gate transaction, and truck trips:** Potentially, for every import/export container, it could generate up to four truck trips. Due to trade imbalance and the use of double move practice by harbor truckers, it is found that for every import/export container, it only generates two truck trips (a 1:2 ratio). Also, the number of gate transactions per import/export container is 1.4 (a ratio of 1:1.4). A brief statistical analysis shows that these ratios are very consistent. Further, these ratios are very useful to port planners as well as terminal operators to estimate access road infrastructure needs.

In order to analyze the gate congestion through queuing theory, the two critical variables are the distribution of the truck inter-arrival times and the gate processing/ service time. Unfortunately, the MCT does not record when trucks arrive at the MCT. To analyze the truck arrival pattern, the field observation is the only option. For service time, the MCT only provides an aggregate number that shows how many transactions it processed; it does not provide detailed information on how long it takes to finish one transaction. For example, data obtained only shows time when a transaction is finished; it doesn't show when the transaction began. Therefore field observation is the only way to obtain both the truck arrival pattern and gate service time that are essential to analyze the gate congestion level. Field observation data and statistical analysis are to be presented in the next chapter.

CHAPTER 6

CASE STUDY AND MODEL FITTING

To analyze the gate congestion issue, several parameters need to be obtained; they are the manpower requirements at the gate, labor costs, trucker's waiting costs, truck inter-arrival times and gate processing times. Among them, the truck inter-arrival time and gate processing time are critical in applying the queuing analysis of the waiting time and waiting costs. This chapter is divided into five sections. The most common statistical distribution for inter-arrival times used in queuing models is exponential distribution. To be able to apply the M/M/S or $M/E_k/S$ models, the distribution of inter-arrival times needs to be tested whether it fits the exponential distribution. For service time distribution, it needs to be tested whether it is an exponential or Erlang. Obtaining these two critical parameters, an appropriate model can be chosen to undertake the waiting time analysis.

The chapter is organized in five sections. The first section describes the field data collection and its process. Section two presents the goodness-of-fit tests. Section three is focused on model fitting, model validation, and verification. Section four discusses the implications of the modeling results. Lastly, section five provides a summary.

6.1 Field Data Collection

As mentioned earlier, the MCT does not keep a record of truck arrival times. In general, the truck inter-arrival time is very dynamic; it changes from time to time during the day. Container pickup and delivery activities are dependent on several factors, such as ship arrival and departure schedules, import/export documentation, warehouse operating schedules, and road traffic conditions. Therefore, truck arrivals are a random process.

On the other hand, service time is less dynamic and its processing transaction capability is more or less stable, even though there are still be some variations. The length of processing time depends on the type of transaction. For example, processing a bobtail that comes in to pickup either a bare chassis, or an empty container, or an import container is relatively simple as long as the driver presents the correct information such as equipment number, booking number, bill of lading number. When the driver doesn't have the correct information, verification must be made, which will lengthen the processing time that causes other trucks to wait longer in the line. For inbound equipment such as chassis and containers, physical inspections must be undertaken for liability reasons. For example, when damage on an inbound container is found, it must be recorded in the documentation to clear the MCT from any claims or liabilities for such damage. If the record shows that there was no damage when the container was taken out of the terminal, the shipper or trucker should be held liable for the damage. The damage record as well the estimated cost of repair will be sent to the shipping company and the trucker that handled the container before returning it to the MCT.

To fully evaluate gate operation and congestion, the data collection has three elements: actual field observation to collect sample data, observation through publicly available web cameras, and interviews with management personnel of the terminal. The field observation provides the critical sample data for statistical analysis to identify a specific distribution pattern so as to fit a particular queuing model mentioned in chapter four. To provide better access to gate information, the MCT provides web cameras to capture gate information for the public or the trucking industry regarding its gate operation. Information gathered from the web camera serves to evaluate gate operation conditions such as truck hourly patterns and gate congestion. Lastly, interviews with terminal management personnel help to obtain a macro picture about the overall truck traffic pattern and gate congestion situation.

6.1.1 Truck Arrival Patterns

Several field observations were taken to ensure that truck arrival information was recorded properly. According to terminal management personnel, the MCT is open from 6 a.m. to 5 p.m. Monday to Friday; there is no lunch break between 12 – 1 p.m. In general, no inbound trucks will be accepted after 4:30 p.m. In general, there are always some trucks waiting outside the gate before opening; these are Canadian truckers. They are usually the first to get into the terminal since the journey back to Canada takes a full day of driving. They want to get in the terminal and get the job done and be on the road as soon as possible, avoiding the rush hour so as not to waste time in waiting. When a truck arrived, the time of arrival was recorded; the process continued throughout the day. The unit measurement of time in term of truck arrival was in seconds. There were all types of truck traffic, such as bobtail, chassis, and containers (empty and loaded). For service time, it was measured the differences between the times when trucks entering and leaving service stations, the gate booths.

The observation data was compiled and processed (see Appendices D and E for inter-arrival time and service time, respectively). The inter-arrival time is obtained by taking the difference of arrival times between the second and the first truck, between the third and second trucks, and so on. Based on the observation data, the computer record, and the information provided by the MCT personnel, the number of truck arrivals before 6 a.m. and after 4 p.m. are relatively low; there were only 63 trucks that arrived before 7:00 a.m. This volume would hardly cause any congestion at the gate. Therefore, the truck arrivals between 7 a.m. and 4 p.m. will be used for analyzing the gate waiting time issue. For service time, gate processing is a repetitive process; its capacity does not vary according to the number of truck arrivals. In another word, the speed of gate processing does not vary and is independent of truck arrivals increases. Therefore, the observation did not need to cover the whole day; the observation started from 9:50 a.m. and finished around 1:00 p.m.

There were 975 trucks observed between 7 a.m. and 4 p.m. The following table (Table 6.1) provides descriptive statistics for the inter-arrival time. From the above table, several key factors can be identified. First, it has a skewness of 1.59, meaning the curve skews to the right; that means it is not symmetrically distributed. Second, more significantly it is the relationship between its mean and variance. The mean (β) is equal to 33.26 and the standard deviation is equal to 30.8, the coefficient of variation (the standard deviation divided by the mean) is 0.93. According to the characteristics of exponential distribution, the mean and the standard deviation should be the same. The intuitive judgment is that the distribution of the inter-arrival times observed should be an exponential one. In addition, the observed inter-arrival times are grouped into 6 second intervals and plotted accordingly (Figure 6.1). The graph appears to be an exponential curve.

Table 6.1 Summary Statistics for the Inter-arrival Times

Descriptive Statistics	
Mean	33.26
Standard Deviation	30.88
Sample Variance	953.41
Skewness	1.59
Range	195.00
Minimum	1.00
Maximum	196.00
Count	966.00
Largest	196.00
Smallest	1.00
Coefficient of Variation	0.93

The observed inter-arrival times are divided into 33 groups based on six-second intervals (see Appendix D). Plotting the frequency distribution of the inter-arrival times into a histogram, the shape of the graph provides further evidence of an exponential distribution. It is not a linear curve; its asymmetric shape shows a downward trend and skews to the right (see Figure 6.1).

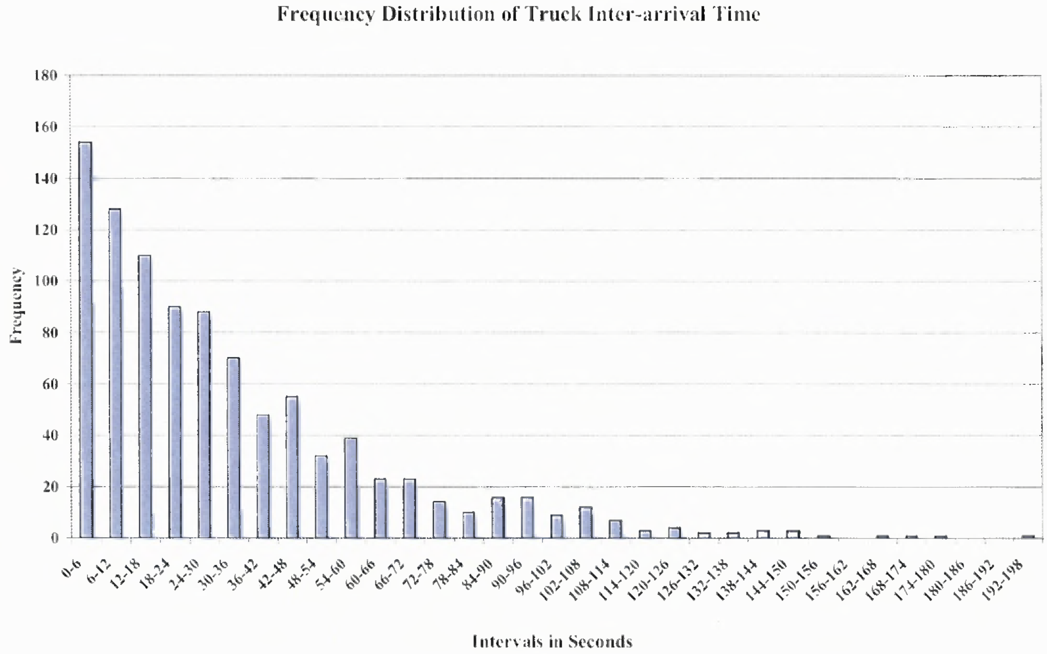


Figure 6.1 Distribution of truck inter-arrival times.

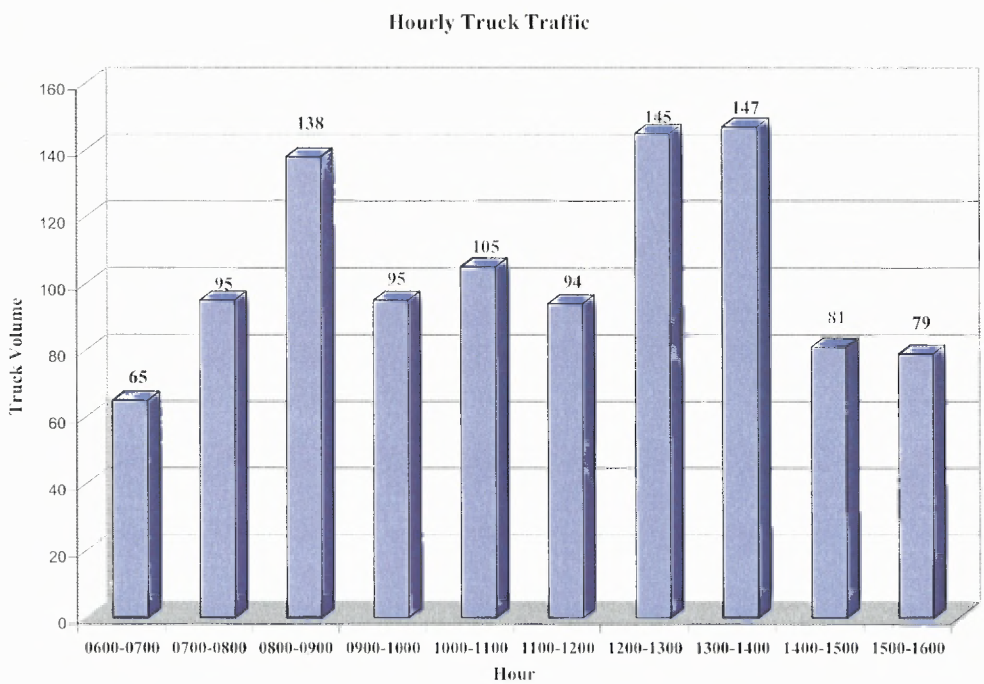


Figure 6.2 Hourly truck traffic.

Also, its hourly arrival pattern is presented in Figure 6.2. The truck traffic started with fairly low volume at 6:00 a.m. The volume increased to 95 per hour. The morning traffic volume was fairly stable between 94 – 105 trucks per hour except from 8 to 9 a.m. with 138 trucks per hour, the morning peak. The afternoon traffic was more fluctuated, but it had two highly contrasting periods; the afternoon peak from 12 to 2 p.m. with 145 and 147 trucks per hours, respectively. Starting from 2:00 p.m., the traffic died down considerably. The truck traffic pattern shows there are three distinctive periods; morning, early in the afternoon, and late afternoon. The peak of the day is actually in the early afternoon. The morning peak is relatively mild. The truck volume in late afternoon is considerably low. The overall pattern seems normal that fits the general behavior of the drayage industry. This provides important information regarding arrival rates to be used in the waiting time and congestion analysis.

Other observations through gate cameras also indicate the pattern of two peak periods (one is the morning around 0800 and the other is early afternoon right after noon time) in a typical work day of MCT gate operations. Interviews with industry executives also confirmed this pattern. Due to the container distribution pattern of the Port of NY/NJ that the majority of them are distributed locally, port drayage truckers usually make two trips a day. They go to the MCTs in the morning to pickup or return containers. Then they deliver containers to warehouses or distribution centers. Then they go back to the MCTs to take another trip. In this way, they are able to earn two trips' pay in a day. The two trips per day pattern serve as an important input in the gate operations analysis and optimization.

6.1.2 Service Time Patterns

After arriving at the gate complex, the truckers usually choose the shortest queue to join, if there is one. Once he joins the queue for a specific service booth, switching lanes is almost impossible due to the high turning radius for the truck and its attached chassis/container. For service time distribution, the original assumption is that it can be either exponential distribution or Erlang distribution. As demonstrated in Chapter 5, distribution of inbound trucks is EMIN, 43%; BTIN, 30.4%; LDIN, 16.7%; and CHIN, 9.7%, respectively. According to the MCT terminal operations manager, based on his experience, the average the processing times for the different types of inbound trucks are different (Table 6.2).

Table 6.2 Rough Estimate of Average Gate Processing Times

Type of Truck	Percentage	Average Processing Time (in minutes)	Weighted Average Processing Time (in minutes)
BTIN	30.4%	1.0	0.304
CHIN	9.7%	1.5	0.146
EMIN	40.3%	2.5	1.01
LDIN	16.7%	5.0	0.835
Total	100%		***2.295***

BTIN requires the least amount of processing time since there is no equipment inspection required; LDIN requires the longest processing time in order to make sure relevant information is in place and the physical condition of the container is properly inspected before the MCT takes custody. Using the information of the percentage distribution of the inbound truck traffic and the respective gate processing time, the weighted average gate processing time is obtained (2.295 minutes). This is a rough estimate for the service time. The actual service times and their distribution need to be analyzed using hypothetical testing.

Since the majority of inbound trucks are EMIN, this implies that the service time distribution may not be an exponential distribution. Table 6.3 is the descriptive statistics for the observed service times.

Table 6.3 Descriptive Statistics for Service Times (in Seconds)

Data Summary	
Mean	2.447
Standard Error	0.065
Mode	1.40
Standard Deviation	1.181
Sample Variance	1.394
Skewness	0.795
Range	5.95
Minimum	0.55
Maximum	6.50
Sum	817.25
Count	334
Largest(1)	6.50
Smallest(1)	0.550

The shortest processing time is 33 seconds, a little bit more than half of a minute, while the longest one is 390 seconds, six and an half minutes. On average, it takes close to 2.5 minutes to process an inbound truck. From Tables 6.2 and 6.3, the sample mean is close to the rough estimated mean. A simple comparison reveals that the sample mean and the standard deviation are quite different; this result eliminates the possibility of an exponential distribution. The distribution of service times is plotted using different intervals. The one with 20 second intervals seems to be a good fit (see Figure 6.3); the shape of the curve confirms the conclusion of a non-exponential distribution. In terms of Erlang distribution, it is a special class of gamma distribution with two parameters: the mean (λ) and the number of stages (k) in the process. If k = 1, it becomes an exponential distribution. If k approaches + ∞, it becomes normal distribution.

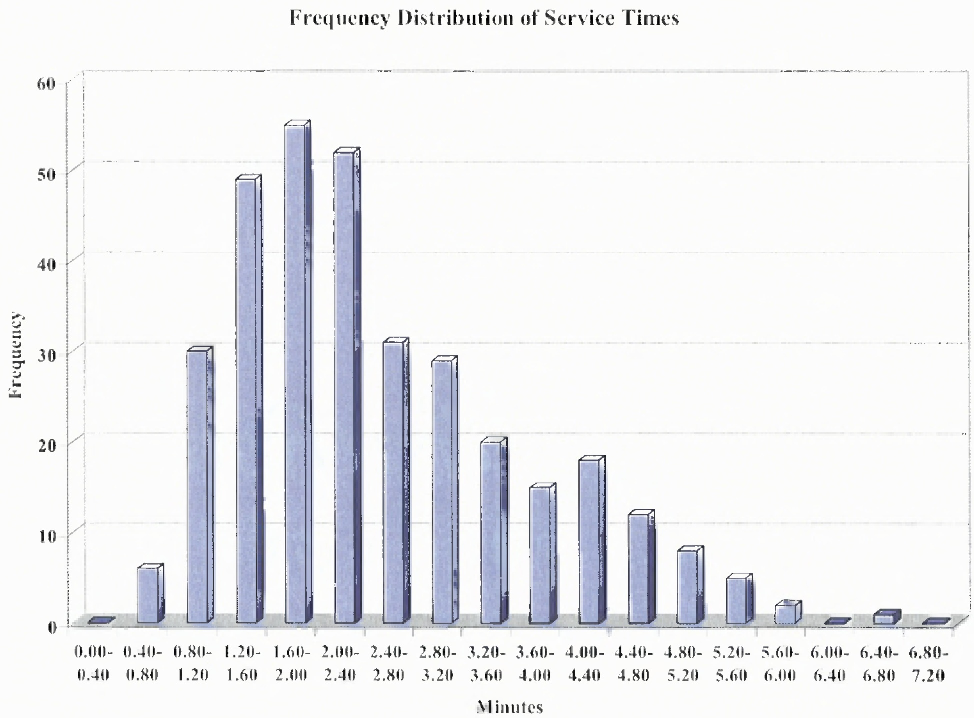


Figure 6.3 Frequency distribution of service times.

6.2 Goodness of Fit Tests

To confirm the distribution function of the inter-arrival time and service time, statistical hypothesis tests (goodness of fit test) are necessary. There are two null hypothesizes in this analysis; one is for the inter-arrival time and the other is for the service time. There are two goodness-of-fit hypothesis tests that are suited for the analysis: chi-square test and Kolmogorov –Simirov test.

Chi-square test can be used in either the continuous or discrete case; it is a comparison of the histogram from the observation data with the fitted density or mass function. The hypothesis in general is the following:

H_0: The observations are IID random variables with distribution function of F

H_a: The observations are *not* IID random variables with distribution function of F

To calculate the chi-square test statistics in the discrete case, first, there are $t_1, t_2, t_3 \ldots t_n$ observed inter-arrival times. Second, entire range of the fitted distribution is divided into k adjacent intervals. Based on k intervals, the number of t's that fall into each interval is determined, which is called e_i. Third, the number of observed t's actually fall into category i is counted, which is called O_i. Fourth, to compute the observed value of the chi-squre statistic (χ^2), the following formula is applied (Winston, 1994, Devore and Farnum, 1999):

$$\chi^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i} \tag{6.1}$$

The value of χ^2 (observed) follows a chi-square distribution with k – 2 degrees of degree of freedom. If χ^2 is small, it is reasonable to assume that the t's are samples from a random variables with density function f(t). Given the value of α (the desired Type I error), the H_0 is accept if χ^2 (observed) $\leq \chi^2_{k-r-1}(\alpha)$ and reject the H_0 if χ^2 (observed) $> \chi^2_{k-r-1}(\alpha)$. r is the number of parameters that must be estimated to specify the distribution. For example, if the inter-arrival times or service times are an exponential, r = 1. If the inter-arrival times and service times follow a normal or an Erlang distribution, r = 2 or greater. When determining the boundaries for the k categories, it is preferable to ensure that e_i is at least, and $k \leq 30$. Furthermore, the e_i's should be kept as equal as possible (Law and Kelton, 2000, and Law, 2006). The value of χ^2 is of importance; the larger the χ^2, the stronger is the evidence the acceptance of H_0.

One drawback for the chi-square test is that sometimes there might be difficulties in specifying the intervals; simply there is no rule governing the number of intervals. The chi-square tests are to compare the histogram of the observed data with the density or mass function of the fitted distribution. To offset this drawback, Kolmgorov-Smirnov (K-S) tests can be used; K-S tests compare an empirical distribution function with the distribution of the hypothesized distribution. Since K-S test do not require to group or divide the data in any way, the detailed information of the data is well kept. Further it eliminates the issue of how to specify intervals. Lastly, another advantage of K-S tests is that they are valid for any sample size if all the parameters are known. Therefore, K–S tests tend to be more powerful than chi-square tests, producing results that are more conservative. The K–S test has been directly applied to both continuous and discrete functions.

The K–S statistic measures the largest vertical distance between the empirical distribution function and the fitted distribution for all values of observation, defined by the following (Law and Kelton, 2000, and Law, 2006):

$$D_n = \sup_x \{ |F_n(x) - F'_n(x)| \} \tag{6.2}$$

where, D_n: K–S test statistic

$F_n(x)$: the empirical distribution function

$F'_n(x)$: the fitted distribution function

Obviously, the smaller the value of D_n, the better fit it is, and vice versa. Therefore, the form of the test is to accept the null hypothesis H_0 if D_n is less than some constant $d_{n, 1-\alpha}$; and reject the H_0 is D_n is greater than $d_{n, 1-\alpha}$.

Based on the above, the hypotheses for inter-arrival time and gate processing time are the following:

1) H_0: the observed inter-arrival time is an exponential distribution

   H_a: the observed inter-arrival time is not an exponential function

2) H_0: the observed service time is an Erlang distribution

   H_a: the observed service time is not an Erlang distribution

Using the Input Analyzer module in the Arena, goodness-of-fit tests are for beta, Erlang, exponential, gamma, Lognormal, normal, and Weibull distribution. The test results show that exponential distribution and Erlang distribution are the most suitable for the inter-arrival times and gate processing times, respectively; the test results are presented in Table 6.4. The results show that all the test statistics of all the parameters for the inter-arrival times (exponential distribution) and the gate processing times (Erlang distribution) are significant. Thus, this confirms that the appropriate model for the gate congestion analysis is the $M/E_k/S$ model.

Table 6.4 Goodness-of-Fit Tests

Chi-square Test	Inter-arrival Time (Exponential)	Service Time (Erlang)
Square Error	0.000925	0.00301
# of Observation	966	334
λ	0.555	0.612
k	1	4
D.F	11	9
Test Statistic	12.0	14.4
Critical Value	17.27	14.68
P-value (>0.10)	0.373	0.111
K-S Test		
Test Statistic	0.0315	0.0366
Critical value	1.308	1.035
P-value (>0.10)	>0.15	>0.15

6.3 Model Fitting, Validation, and Verifications

The next step is to conduct a waiting time analysis since the statistical distributions of inter-arrival time and service time have been determined. As stated earlier, the $M/E_k/S$ model developed in Chapter 4 will be used for the waiting time analysis. The service times of 2.44 minutes per truck, 6 inbound service stations, and the various observed arrival rates are used. The arrival rates range from 90 trucks per hour to 147 trucks per hour. Converting them into the number of trucks per minute, the input arrival rates start from 1.5 per minute to 2.46 trucks per minute (with the assumption that $\frac{\lambda}{\mu s} < 1$). Applying these inputs into the approximation formula, the results of the calculation are shown in Figure 6.3 and Table 6.5.

Table 6.5 Waiting Time Behavior

Arrival Rate λ (per min)	Arrival Rate λ (per hour)	Utilization Rate ρ=λ/μs	Average Waiting Time (min)	Average Queue Length	Total Waiting Time (Hours)
1.50	90	0.612	0.2	0	0.0
1.58	95	0.645	0.2	0	0.0
1.66	100	0.678	0.3	0	0.0
1.75	105	0.714	0.3	1	0.0
1.83	110	0.747	0.4	1	0.0
1.91	115	0.780	0.6	1	0.0
2.00	120	0.816	0.8	2	0.0
2.08	125	0.849	1.1	2	0.0
2.16	130	0.882	1.6	3	0.1
2.25	135	0.918	2.4	5	0.2
2.33	140	0.951	4.2	10	0.7
2.35	141	0.959	5.1	12	1.0
2.36	142	0.963	5.7	13	1.2
2.37	142	0.967	6.4	15	1.6
2.38	143	0.972	7.3	17	2.1
2.39	143	0.976	8.4	20	2.8
2.40	144	0.980	9.9	24	4.0
2.41	145	0.984	12.1	29	5.9
2.42	145	0.988	15.2	37	9.4
2.43	146	0.992	15.4	37	9.6
2.44	146	0.996	20.9	51	17.7
2.45	147	1.000	32.2	79	42.3

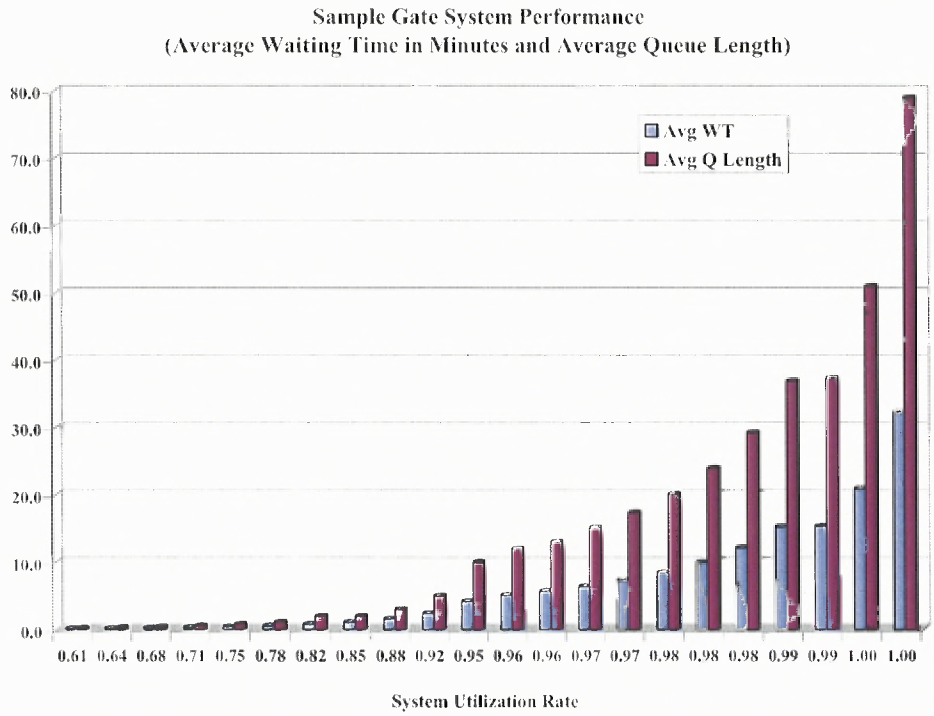


Figure 6.4 System performance vs. utilization rate.

Table 6.5 and Figure 6.4 demonstrate several important points:

1) The characteristics of this particular $M/E_k/S$ model indicates that even with high utilization rate, up to 0.95, the average waiting time and the number of trucks in queue remain quite small, almost negligible. The average waiting time per truck is less than 2.4 minutes, and the total waiting time is about 0.7 hour.

2) As the utilization rate keep increasing beyond 0.95, the average waiting time becomes more and more sensitive. The average waiting time increases disproportionably to the increase in arrival rate or utilization rate.

3) When the utilization rate approaches 1.0, the system is very unstable and extremely sensitive. Even a small increase in arrival rate, it leads to a very sharp increase in queue length and total waiting time by the power of several factors.

Applying the above system characteristics to the observed arrival rates, it yields following results:

1) Most of the time, the gate system was underutilized and not congested. The truck waiting time was very low.
2) There were two peak periods; one in the morning and the other one in the early afternoon. The gate system was congested for about 2 hours of that day (between 12 – 2 p.m.).
3) For the two hours that were congested, the total waiting time for trucks was close to 85 hours. And the system was extremely close to its maximum utilization that a very small increase in arrival time, it could lead to a huge increase in queue and total waiting time.

The above result is based on an actual field observation and sound statistical testing. As mentioned earlier, truck arrivals are subject to numerous factors such as vessel schedule, holiday schedule, weather, regulatory process i.e. customs clearance and approval, availability of truck drivers, and warehouse operations schedules. Truck arrival patterns vary from one day to another; but nevertheless the field observation data represents a typical day of the MCT gate operation. As for model validation and verification, the above results were compared with the actual situation. The results of the analysis were closely matched with what was observed. For example, the terminal was not congested starting from 6 a.m. till noon. There were only a handful of trucks in line. And not all the gates were busy. Between noon and 2 p.m. the terminal was extremely busy; long lines of trucks were waiting at the gate and the queue was slowly dissipated after 2 p.m. Later in the afternoon, there were barely trucks waiting. The number of trucks waiting at the gate was counted and matched what the model indicated. Therefore, the model proves to be quite appropriate and effective. Furthermore, the $M/E_k/S$ model is a widely accepted methodology and was used in different situations such as ship berth capacity and truck terminal analysis as indicated in the literature review.

Using Equations (4.18), (4.19), and (4.23) developed in Chapter 4, Cg (gate operating cost), Ct (trucking waiting cost), and C_{TS} (total gate system costs) are calculated with the following parameters; the $M/E_k/S$ model is used. For λ and μ are based on the field observations. For L_C, based on labor arrangement for the gate system, there are 2.5 persons for each gate booths and the hourly cost for each person is about \$50.30, accordingly to the MCT management personnel. Therefore, the hourly cost per gate booth was \$125.75 (50.3 x 2.5 = 125.75). Based on a study by the Texas Transportation Institute in 2003, the hourly truck waiting cost was about \$32.15 per truck. In addition, $\mu = 0.41$ (1/2.44), and the hourly observed λ and S were obtained. The MCT did not open all six gate booths from the beginning of the day to the finish. Instead, four were open from 6:00 to 8:00 a.m. From 8:00 a.m. onward, two more booths were open until 3:00 p.m. At 3:00 p.m. one gate was closed due to reducing truck traffic. At 4:00 p.m., one additional booth was closed. At 5:00 p.m., all booths were closed. Substituting the values of all the parameters into the above equations, Table 6.6 presents the calculation results with respect to Cg, Ct, Nt, $R_{(TC)}$, and average waiting time per truck in different hours of the day.

From Table 6.6, it illustrates an interesting phenomenon of a typical MCT gate operation. There were two peak periods; one was in the morning from 8:00 – 9:00 a.m. and the other from 12:00 – 2:00 p.m. In most cases, the gate system was underutilized and the gate was not congested. However, during the afternoon peak, the truck waiting cost and waiting time were very high. For example, between 1:00 – 2:00 p.m. the average truck waiting time was 21.37 minutes and the waiting cost for this hour was \$1,672.12 (C_h x N_t = 52.01 x 32.15), the number of trucks waiting was 52, and the total waiting for the hour was 18.52 (21.37/60 x 52.01). Therefore, out of nine hours of gate operating hours, only two to three hours were congested; the rest of the day was not congested at all. As a result, the overall gate system was underutilized but at the same time there were high waiting costs incurred. Apparently, the system was not optimized. In terms of gate operating cost (Cg) and truck waiting cost (Ct), it is obvious that Cg is much higher in most hours except the periods between 12:00 and 2:00 p.m.

Table 6.6 Case Study of Gate Operations

(Nt, Cg, Ct, $R_{(TC)}$, and Average Waiting Time)

Hour	No. of Tk	λ	μ	a	Lc	Ch	S	Nt(m/k/s)	Avg WT	Cg	Ct	C(ts)	R(tc)
0600-0700	90	1.50	0.41	3.68	125.75	32.15	4	6.04	4.02	502.5	194.04	696.54	21.67
0700-0800	95	1.58	0.41	3.88	125.75	32.15	4	15.91	10.05	502.5	511.53	1014.03	31.54
0800-0900	138	2.30	0.41	5.64	125.75	32.15	6	9.32	4.05	753.75	299.75	1053.50	32.77
0900-1000	95	1.58	0.41	3.88	125.75	32.15	6	0.56	0.35	753.75	17.95	771.70	24.00
1000-1100	105	1.75	0.41	4.29	125.75	32.15	6	1.02	0.58	753.75	32.85	786.60	24.47
1100-1200	94	1.57	0.41	3.84	125.75	32.15	6	0.54	0.34	753.75	17.22	770.97	23.98
1200-1300	145	2.42	0.41	5.92	125.75	32.15	6	39.16	16.20	753.75	1258.85	2012.60	62.60
1300-1400	147	2.43	0.41	5.96	125.75	32.15	6	52.01	21.37	753.75	1672.12	2425.87	75.45
1400-1500	81	1.35	0.41	3.31	125.75	32.15	5	0.59	0.44	628.13	18.91	647.04	20.13
1500-1600	78	1.30	0.41	3.19	125.75	32.15	4	1.69	1.30	502.50	54.29	556.79	17.32
1600-1630	25	0.83	0.41	2.04	125.75	32.15	4	0.16	0.19	502.50	5.06	256.31	15.79
Total	1,093									7,160.63	4,077.51	10,991.95	

6.4 Optimization

Apparently, the system was not optimized, given the large amount of trucking waiting and waiting cost; there is room for improvement. Applying Equations (4.28), (4.29), (4.31) and (4.32); the following steps are taken to obtain the optimum number of gate booths.

- Step 1: Calculate the operating cost per gate booth L_C and the truck waiting cost (C_h) ratio r_{gt}. In this case, L_C = 125.75 (50.3 x 2.5), and C_h = 32.15. Then, r_{gt} = 3.91.
- Step 2: Calculate the value of traffic intensity a, based on a = λ/μ. In this case, the values for λ are the same as in Table 6.6.
- Step 3: Using k = 4 and substituting all the above parameters into the equations,

The results are graphed in Figure 6.5.

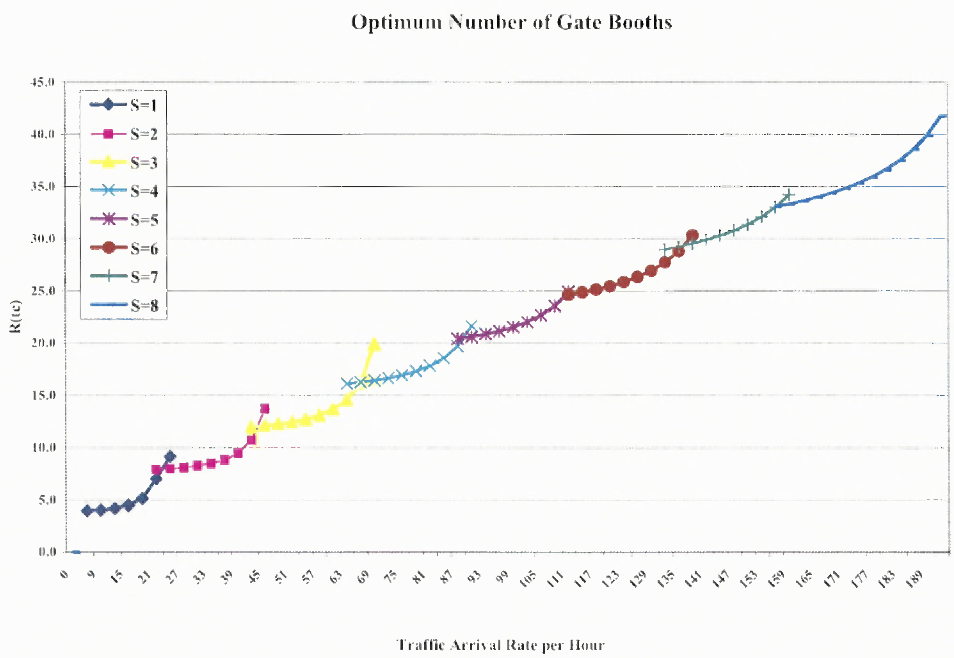


Figure 6.5 Ranges of optimum number of gate booths.

Figure 6.4 illustrates how to obtain the optimum number of gates under different truck arrival rates. It provides the lower and upper bounds for the optimum number of gate booths to operate (also see Table 6.7 below). Accordingly, an optimized hourly gate system is obtained. A comparison of performances between the observed gate system operations vs. the optimized system operations is presented in Table 6.8, Figures 6.5, 6.6, 6.7, and 6.8.

Table 6.7 Optimum Number of Gates and Its Corresponding Truck Arrival Rates

S	1	2	3	4	5	6	7	8
λ	0-21	21-42	42-66	66-87	87-111	111-135	135-156	156-177

Table 6.8 Observed Gate Performance vs. Optimized Gate Performance

Hour	λ	S	Nt	AWT	Cg	Ct	C(ts)	R(tc)	S'	Nt'	AWT'	Cg'	Ct'	C(ts)'	R(tc)'
0600-0700	90	4	6.0	4.0	503	194	697	21.7	5	1.1	0.7	628	35	663	20.6
0700-0800	95	4	15.9	10.0	503	512	1014	31.5	5	1.6	1.0	628	53	681	21.2
0800-0900	138	6	9.3	4.1	754	300	1053	32.8	7	1.3	1.1	879	82	961	29.9
0900-1000	94	6	0.6	0.4	754	18	772	24.0	5	1.6	1.0	628	53	681	21.2
1000-1100	105	6	1.0	0.6	754	33	787	24.5	5	3.2	1.8	628	102	730	22.7
1100-1200	95	6	0.5	0.3	754	17	771	24.0	5	1.6	1.0	628	53	681	21.2
1200-1300	145	6	39.2	16.2	754	1259	2013	62.6	7	3.7	1.5	879	118	997	31.0
1300-1400	146	6	52.0	21.4	754	1672	2426	75.5	7	3.7	1.5	879	120	999	31.1
1400-1500	81	5	0.6	0.4	628	19	647	20.1	4	2.2	1.6	503	71	574	17.8
1500-1600	79	4	1.7	1.3	503	54	557	17.3	4	1.7	1.3	503	54	557	17.3
1600-1630	25	4	0.2	0.2	251	5	256	15.8	3	0.7	0.9	188	24	212	12.5
Total	1,093				6909	4,083	10992					6972	764	7736	

Remarks:

S, Nt, AWT, Cg, Ct, C(ts), and R(tc) are calculated and observed performance indices.

S’, Nt’, AWT’, Cg’, Ct’, C(ts)’, and R(tc)’ are optimized performance indices.

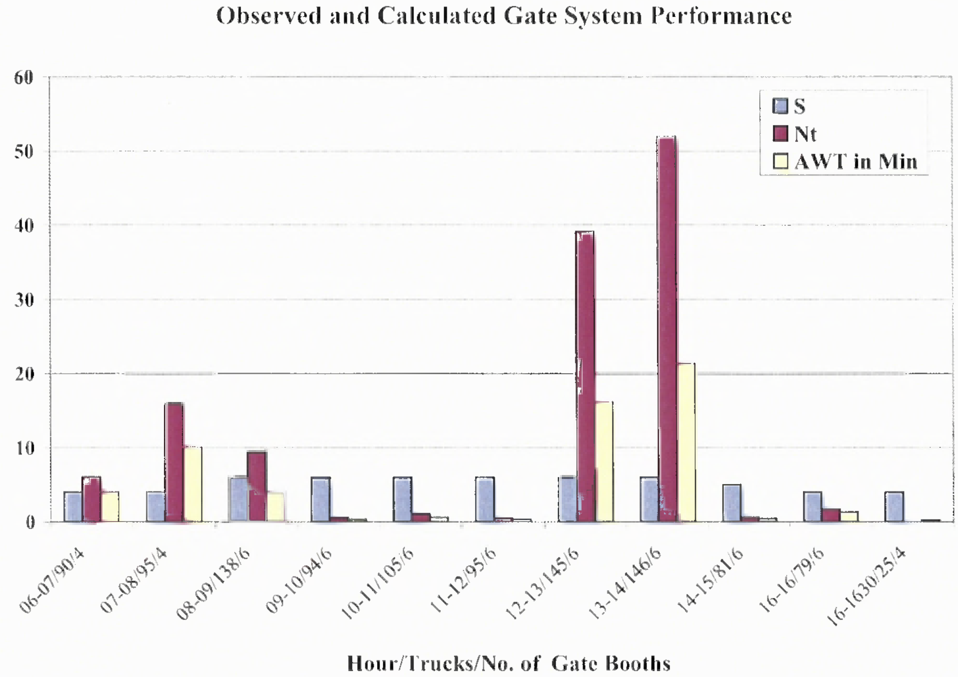


Figure 6.6 Observed and calculated gate system performance.

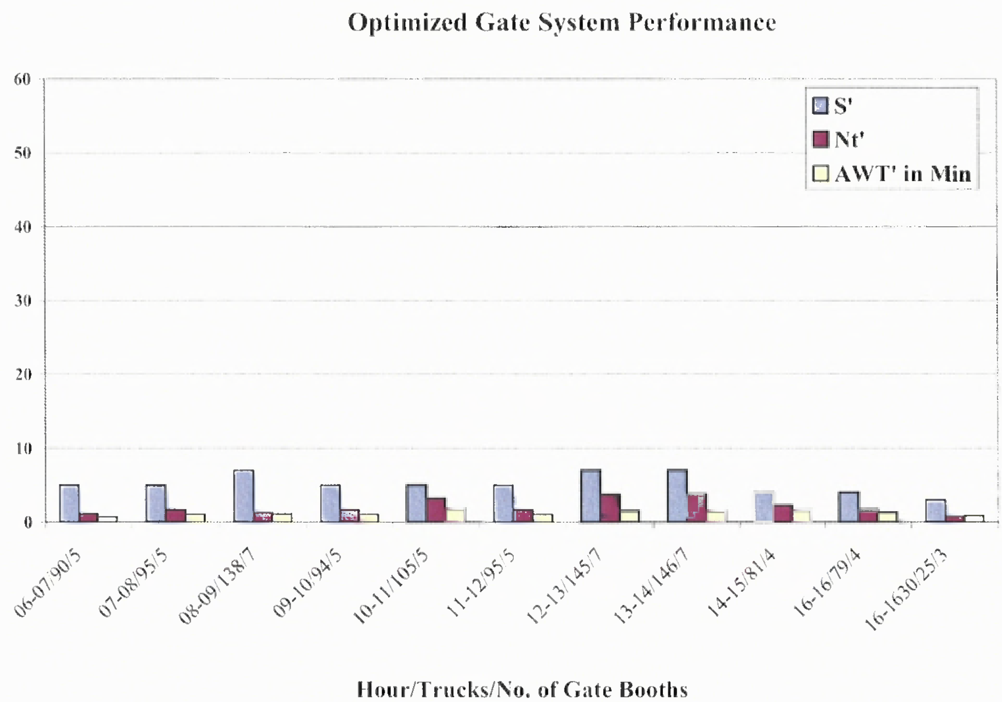


Figure 6.7 Optimized gate system performance.

From Table 6.8, the optimization results show significant improvement. Overall, the total costs are reduced by \$3,255.60 (C_{TS} – C_{TS}' = 10,991.95 – 7,736.35). This is mainly due to the reduction in trucking waiting cost, Ct, during the congested hours between 12 and 2 p.m. On the other hand, there is a slight increase in the gate operating cost, Cg. More significantly, the overall performance of the gate system is improved. Comparing Figures 6.5 and 6.6, the total number of gate booths opened during the day is only slightly larger in the optimized system, for example, the maximum number of gate opened is increased from six to seven during the two peak periods, but reduced during other non-peak periods. In term of the average number of trucks waiting, Nt, and average truck waiting time, AWT, it is obvious, the observed gate system had large number of truck waiting during the peaks hours; there were 16, 39, and 52 trucks waiting between 8:00 and 9:00 a.m., 12:00 to 1:00 p.m. and 1:00 to 2:00 p.m., respectively. Average waiting times per truck were 10.05, 16.20, and 21.37 minutes in those hours, respectively. On the other hand, the optimized system essentially reduces the average number of trucking waiting and trucking waiting time to the minimal. The maximum Nt' is less than four; and the maximum AWT' is less than two minutes.

In terms of the total system costs, C_{TS}, (see Figures 6.8 and 6.9), the optimized system demonstrates significant improvement. Cg in both Figures 6.7 and 6.8 is more or less the same, in the optimized system, Cg' is slightly larger, \$62.81 (6,972.19 – 6,909.38) more than the observed system for the entire day, On the other hand, the reduction in trucking waiting cost is quite large, \$3,318.42 (4,082.58 – 764.16). This illustrates that the gate system has high degree of sensitivity in both ways, a small percentage change in gate capacity leads to disproportional change in the overall system performance. This characteristic will be further explored in the next chapter.

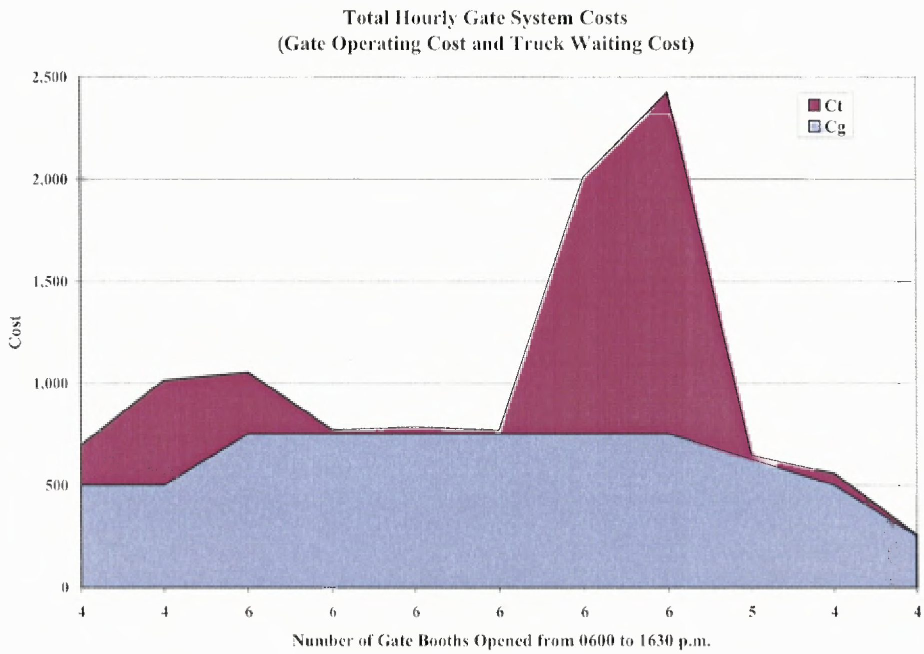


Figure 6.8 Total system costs.

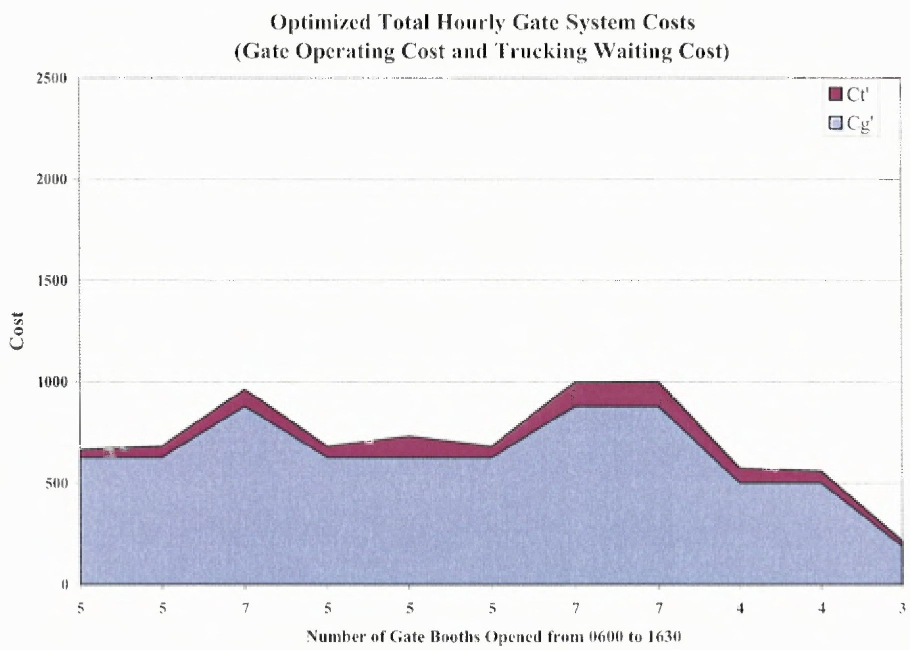


Figure 6.9 Optimized total gate system costs.

In addition, in the observed system, the change in Cg is relatively small; this means the system is not responsive to change in truck arrival rate, resulting in large amount of truck waiting cost as shown in Figure 6.8. On the contrary, the optimized system is more responsive to changes in the truck arrival rate, resulting in less congestion and reduction in overall system costs (see Figure 6.9).

In summary, this section applies the methodology developed in Chapter 4 to optimize the gate system in the case study, using observed data. It provides an optimization method to identify the optimum number of gate booths corresponding to truck arrival rates. It identifies certain system characteristics that are very important for further analysis. The optimization method developed in this section has several advantages. First, it provides a mechanism to identify the optimum number of gate booths matching truck arrival rates. Secondly, it allows the user to change input parameters such as gate operating cost, trucking waiting cost, and service rate, leading to different alternatives for optimization. Lastly, it provides a mechanism to conduct sensitivity analysis to further analyze the gate system for optimization according different criteria.

However, there is one important issue that is not addressed in this optimization process. That is the labor contract constraints regarding the minimum number of hours for labor once they start working. Another area that needs to pay attention is the system utilization. In the preliminary analysis indicates that the gate system is not congested when system utilization in under 95%. In this case study, providing additional gate capacity to reduce truck waiting time leads to system under-utilization. This issue will be addressed in the next chapter.

In the application of the queuing model in measuring truck waiting time, the model may not capture the details of changes in truck waiting time behavior when there are significant changes of truck arrival rates between two time periods. When the truck arrival rate increases from one period to another, the waiting time might increase slower than the model indicates. By the same token, when the truck arrival rate is decreased, the waiting may decrease slower than the model indicates. Therefore, the impacts of changes in truck arrival rate may not affect the overall magnitude of waiting time. Since the focus of the study is on the general approximation of truck waiting behavior, the impact of changing truck arrival rates from one period to another is not taken into consideration in this study.

6. 5 Summary and Implications

This chapter describes the critical process of data collection, field observation, goodness-of-fit tests and model fitting, validation and verification. Also a case study is presented. The result reveals several important indications. First, there are two peaks in the truck arrivals. One is in the morning and the other is in early afternoon right after lunch. This is the result of the confluence of several factors. Because the gate is open at 6 a.m., this helps to reduce the load of morning peak. Therefore, the truck volume for the early afternoon peak is a lot higher than the early morning one. The early afternoon peak indicates that the round trip time to warehouse and distribution centers for the early morning pickup is about four to five hours. If truckers leave the MCT late in the afternoon, it would probably miss the delivery due to the closure of warehouses. Second, truck inter-arrival time is conformed to the exponential distribution due to its randomness. For service time, the truck traffic is not homogeneous. There are different types of truck traffic that require different amount of processing time. Based on the percentage breakdown of the truck traffic and the information provided by the terminal management, the service time distribution turns out to be an Erlang distribution. Using the chi-square and K-S tests, the $M/E_k/S$ model with approximation is chosen. Third, the model seems to fit the actual observed data quite well.

The result of the preliminary analysis reveals several important facts. First, the current system is underutilized most of the time except for the early afternoon peak. The two-hour congestion at the gate imposes a large amount of waiting time on truckers. With increasing container volume, the congestion problem will become more severe. On the other hand, the system is insensitive to arrival rate when the utilization rate is below 0.95; the average waiting time is very low. This provides a powerful tool to optimize the system to lower total system costs including waiting cost and operating cost.

Using the observed data, this section analyzes the gate system performance in detail. It identifies key elements of the gate system and applies queuing models developed in Chapter 4 to calculate key performance indices, such as average number of trucks waiting, average truck waiting time, gate operating cost, truck waiting cost, and total system cost. In addition, it applies the optimization methodology to gate system for the case study. It demonstrates that the system optimization can reduce overall system costs. Further, the system exhibits high degree of sensitivity and it implies a small change in gate capacity results in disproportional change in overall system performance. Lastly, there are two issues needed to be addressed thoroughly, one is the labor contract constraint in the number gate booths opened, and the other is system utilization. The next step is to estimate truck waiting cost, gate operating cost, and total gate system costs, and ultimately; full scale gate system optimization given the various constraints.

CHAPTER 7

TRUCK WAITING COSTS AND GATE SYSTEM OPTIMIZATION

In Chapter 6, statistical tests are undertaken to verify the statistical distribution patterns for truck arrivals and service times. A case study is presented with application of the $M/E_k/S$ queuing model to evaluate gate system performance. Furthermore, preliminary analysis demonstrates that optimization can improve system performance. But there are several issues that need further analysis. First, to analyze the magnitude of truck waiting cost at MCT, variation in truck volume in different times of the year needs to be addressed. Second, truck waiting cost, gate operating cost, and system performance should be evaluated, using models developed in Chapter 4. Third, system utilization should be thoroughly analyzed. Fourth, given the various input parameters, there might be several different ways to optimize the gate system. Also, as illustrated in the case study in Chapter 6, even though there was gate congestion, but the congestion did not last all day long. The optimization results in a very short truck waiting line. This indicates that system utilization might be low. Further exploration in gate system optimization is warranted and sensitivity analysis is necessary to identify which optimization alternative provides the best gain in efficiency and cost-effectiveness. Therefore, this chapter provides an in-depth analysis for all these issues.

This chapter is organized in five sections. The first section analyzes truck volume behavioral patterns over a year and calculates truck waiting costs. Section two discusses labor costs of the gate system operations and calculates the yearly gate operating cost. Section three provides a synthetic analysis of gate system cost and system utilization.

Section four analyzes optimization alternatives and sensitivity of system performance for each alternative. Lastly, a summary is presented.

7.1 Truck Volume Behavioral Pattern and Waiting Cost

As described in Chapters 5 and 6, daily truck volumes vary from day to day and season to season, resulting in daily fluctuation as well as seasonal fluctuation, respectively. Nevertheless, there are two peak periods in daily truck volume. One is the morning around 8:00 a.m. and the other is during 12:00 – 2:00 p.m. This was confirmed by the terminal management. In order to estimate truck waiting cost, the temporal truck arrival pattern must be obtained. On the other hand, due to seasonal fluctuation, it is difficult to undertake field observations every day to obtain an exact count of truck arrival pattern for each day. Assumptions are to be used in truck waiting cost estimation.

7.1.1 Daily Truck Volumes and Seasonal Fluctuation

To ensure such assumptions are as close to reality as possible, the determination of daily truck temporal pattern is based on three elements: field observations, online observations through the MCT's gate cameras, and interviews with the MCT management personnel in charge of the gate operations. The following were confirmed:

1) Slow season starts at the beginning of the year, but in May container volume starts to pickup.
2) Peak season starts around July; October and November are the busiest periods.
3) The gate working schedule usually starts with four booths at 6:00 a.m. and depending on vessel arrival schedule, sometimes one additional booth is open

at 7:00 a.m. At 8:00 a.m. all six inbound booths are open. There is no lunch break; all gates are open through the lunch. Depending on truck traffic volume, if truck traffic seems to tamper off precipitously in late afternoon around 2:00 or 3:00 p.m., one or more gate booths can be closed without violation of labor contract. One important factor is that the labor order (how many men) for the next day's work must be placed before 12:00 p.m. today. Once the order placed, it cannot be changed.

4) There are two peak periods in a day, one in the morning and the other in the afternoon. The peak period in the morning starts around 8:00 a.m. and the afternoon peak starts around 12:00 p.m. It depends on truck volume; the length of peak period varies from time to time.

5) In addition, during peak period, especially in October and November, the peak periods are stretched. Once the holding area is full, truck arrival rates seem to maintain at peak level. This implies that once the holding area is saturated, the peak period is stretched longer, for example, high truck arrival rates might stretch from 2:00 p.m. to 2:30 p.m. But in general, afternoon peak period rarely last beyond 3:00 p.m. There seem to a correlation between truck volume and the length of peak periods.

6) During peak season, there are days that congestion (the holding area is full of truck waiting) last several hours subject to truck volume. Occasionally, truck waiting lines spill over to arterial roadways causing traffic jam during peak periods.

7) With continuing growth of container volume, the MCT is facing increasing congestion during peak season.

Based on the above, Table 7.1 shows the estimation of hourly truck arrival rates according to different categories of daily truck volumes.

Table 7.1 Estimated Hourly Truck Arrival Rates

Estimated Hourly Truck Arrival Rates											
	Categories of Daily Truck Volume										
Hour	875	925	975	1025	1075	1092	1125	1175	1225	1275	1325
06-07	*72*	*76*	*80*	*84*	*89*	***90***	*93*	*97*	*101*	*105*	*109*
07-08	*76*	*80*	*85*	*89*	*94*	***95***	*98*	*102*	*107*	*111*	*115*
08-09	*111*	*117*	*123*	*130*	*136*	***138***	*142*	*148*	*155*	*161*	*167*
09-10	*76*	*80*	*85*	*89*	*94*	***95***	*98*	*102*	*107*	*111*	*115*
10-11	*84*	*89*	*94*	*99*	*103*	***105***	*108*	*113*	*118*	*123*	*127*
11-12	*75*	*80*	*84*	*88*	*93*	***94***	*97*	*101*	*105*	*110*	*114*
12-13	*116*	*123*	*129*	*136*	*143*	***145***	*149*	*156*	*163*	*169*	*176*
13-14	*117*	*124*	*130*	*137*	*144*	***146***	*150*	*157*	*164*	*170*	*177*
14-15	*65*	*69*	*72*	*76*	*80*	***81***	*83*	*87*	*91*	*95*	*98*
15-16	*63*	*66*	*70*	*73*	*77*	***78***	*80*	*84*	*88*	*91*	*95*
16-	*20*	*21*	*22*	*23*	*25*	***25***	*26*	*27*	*28*	*29*	*30*

In Table 7.1, it shows ranges of estimated hourly truck arrival rates corresponding to daily truck volumes. This will be served as primary input to calculate truck waiting cost. However, there is one important issue that needs to be addressed. The developed queuing model is based on one important condition, $\rho \leq 1.0$. Under the current set up, the maximum number of inbound gate booths is six. Therefore, the saturation rate of truck arrival, $\lambda = \mu S = (60/2.44)\ (6) = 148$. However, in the above estimated hourly truck arrival rates, there are some truck arrival rates during peak periods that exceed 148. These will make the queuing model invalid. Similarly, the saturation truck arrival rates for four and five booths are 98 (60/2.44 x 4) and 120 (60/2.44 x 5), respectively. This indicates that if four booths are open, then this will make the queuing model insolvable. The highlighted areas in gray and yellow indicate that there will be calculation problem in applying the queuing model based on the gate opening schedule.

As mentioned earlier that peak period tend to stretch, this implies peak truck arrival rates are maintained until their arrivals temper off. To mitigate such problem in applying the queuing model, a small adjustment is made. A conservative approach is used. When λ is greater than the saturation rate, the saturation rate is used in calculating truck waiting cost. The difference between the estimated λ and the saturation rate will be added to the arrival rate for the next hour to simplify the calculation process. Such adjustment will be made in the trucking waiting cost calculation. Using the truck arrival saturation rate as a guide, a brief look at Table 7.1 indicates that when daily truck volume is more than 1,175, there will be several hours of congestion in a day. This confirms what the terminal management's experience that there is a strong correlation between the daily truck volume and the degree of gate congestion.

After consulting with MCT management, the following assumptions were made:

1) Distribution of daily truck volume in 2005: since the field observation took place in 2005, but the data of daily truck volume was for 2004, simple extrapolation is used to estimate 2005 daily truck volume. According to port statistics of the Port Authority of New York/New Jersey, the annual growth rate was 7% from 2004 to 2005. Therefore, the estimation of daily truck volume of 2005 uses 7% as the growth rate from 2004 to 2005.
2) To simplify waiting cost calculation, the distribution of daily truck volume are divided into 10 categories: <900, 900 – 949, 950 – 999, 1,000 – 1,049, 1,050 –

1,099, 1,100 – 1,149, 1,150 – 1,199, 1,200 – 1,249, 1,250 – 1,299, and 1,300 plus. The midpoint of each category is used to estimate hourly truck volume: 875, 925, 975, 1,025, 1,075, 1,125, 1,175, 1,225, 1,275, and 1,325.

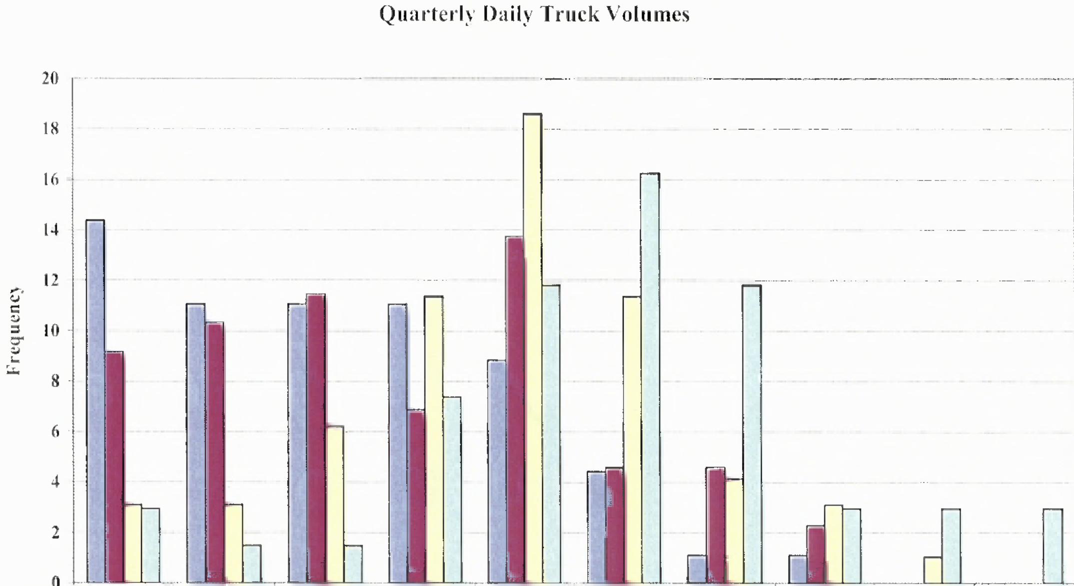
3) The observed hourly truck arrival pattern is used as a baseline; extrapolation is used to estimate the hourly truck arrival rates for different daily truck volumes. For example, in the observed hourly truck arrival data, between 8:00 a.m. and 9:00 a.m., the hourly truck arrival rate is 138, 12.64% of the total daily volume of 1,092. If daily truck volume is 1,199, then the truck hourly arrival rate between 8:00 and 9:00 a.m. is 151.6 (1,199 x 12.64%); the rest of the hourly truck arrival rates can be obtained using the same method.

4) Based on a study for the Federal Highway Administration, undertaken by the Texas Transportation Institute, a very conservative figure for the truck delay due to congestion is $32.15 per hour. It only includes driver's time, fuel use, and company equipment utilization. Full consequences of shippers and receivers and costs of lack of inventory are not considered in this figure (Abbot, 2005). This figure will be used for truck waiting cost calculation. Furthermore, through the interview with Bi-State Motor Carrier Association, a trade association representing harbor drayage truckers, the opportunity cost of waiting can be as high as $55.00 per hour.

5) According to the MCT management, the hourly cost per gate clerk is about $50.30; this figure will be used for the calculation of gate operating cost. The ratio between the number of gate labor and the number of gate booths is 2.5.

This means for every gate booth, there are 2.5 men working, including gate clerks, relief clerks, and supervisor.

Since container volume has seasonal fluctuation, it is necessary to show how daily truck volume progresses and the differences between non-peak season and peak season. Consequently, gate congestion situations vary from season to season. It is important that such seasonal differences are identified and are taken into consideration when dealing with truck waiting cost. Otherwise, an incomplete picture is provided. To provide a full picture of truck waiting cost, it is essential to take the full year data. Since the data set obtained contains only 216 days of truck data, and there are approximately 250 working days in a year, extrapolation is used in estimating the missing data. Then the estimated daily truck volumes are grouped into the ten categories mentioned earlier. The quarterly estimated daily truck volumes for each quarter are presented in Figure 7.1.



	<899	900-949	950-999	1,000-1,049	1,050-1,099	1,10-1,149	1,150-1,199	1,200-1,249	1,250-1,299	>1,300
Q1	14	11	11	11	9	4	1	1	0	0
Q2	9	10	11	7	14	5	5	2	0	0
Q3	3	3	6	11	19	11	4	3	1	0
Q4	3	1	1	7	12	16	12	3	3	3

Range

Figure 7.1 Distribution of daily truck volume by quarter.

Figure 7.1 clearly demonstrates that in the first quarter most of the daily truck volumes are less than 1,099. This quarter has the highest number of daily truck volume below 899. It is expected to experience very little congestion. In the second quarter, the daily truck volume starts to rise. In the third and fourth quarters, it has the highest number of daily volume between 1,055 and 1,099. In the fourth quarter, it has the highest number of daily truck volume in categories above 1,100 per day. It is expected that the congestion level is going to be a lot higher.

7.1.2 Sample Estimation of Truck Waiting Cost and System Performance

Based on the models developed in Chapter 4, the distribution of hourly truck arrival rates, and the distribution of daily truck volumes, and the above input values for λ, μ, S, L_C, and C_h, wide range of system performance is calculated. The following provides an example of the detailed analysis undertaken. To calculate the various critical measures such as average queue length, average truck waiting time, Cg, Ct, system utilization, and total waiting time, Lingo 10 (an OR software) and other models developed in Chapter 4 are used. In order to provide a thorough analysis and gain clear understanding of the trucking waiting pattern and system performance, detailed calculation must be undertaken for each range of truck arrival rates (for ten categories). To simplify the process, a midpoint is chosen. For example, for truck arrival rates between 1,100 and 1,149, its midpoint of 1,125 is chosen to calculate all the relevant measures mentioned above. The following the sample analysis for truck arrival rate of 1,125. The result is shown in Table 7. 2.

Table 7.2 Sample Analysis of Gate System Performance

(Estimated Daily Truck Volume: 1,125)

Hour	Est. λ (1)	Input λ (2)	Spill Over (3)	S (4)	Nt(m/k/s) (5)	AWT (min) (6)	Men per Gate (7)	Cg (8)	Ct (9)	$C_{(TS)}$ (10)	R(tc) (11)	SU (12)	TTL WT (hour) (13)
06-07	93	93	0	4	10.2	6.59	2.50	503	328	831	25.8	94.7%	1.12
07-08	98	98	0	5	1.9	1.14	2.50	628	60	688	21.4	79.9%	0.04
08-09	142	142	0	6	17.0	7.19	2.50	754	548	1301	40.5	96.8%	2.04
09-10	98	98	0	6	0.7	0.41	2.50	754	22	775	24.1	66.6%	0.00
10-11	108	108	0	6	1.2	0.68	2.50	754	39	793	24.7	73.6%	0.01
11-12	97	97	0	6	0.6	0.39	2.50	754	20	774	24.1	65.9%	0.00
12-13	149	146.5	3	6	79.1	32.41	2.50	754	2544	3298	102.6	101.7%	42.74
13-14	150	146.5	4	6	79.1	32.41	2.50	754	2544	3298	102.6	102.4%	42.74
14-15	83	90	0	5	1.1	0.73	2.50	628	35	663	20.6	68.1%	0.01
15-16	80	80	0	5	0.6	0.43	2.50	628	18	646	20.1	65.6%	0.00
16-	26	26	0	4	0.2	0.20	2.50	503	6	508	15.8	52.5%	0.00
TTL	1125	1125		59				7412	6163	13575		77.8%	88.71

Remarks for Table 7.2:

Est. λ: Estimated truck arrival rate.

Input λ: The value of λ used as input to run queuing model, its maximum value is equal to μS. If the estimated λ is greater than μS, μS is used, which is the saturation λ. The difference will be added to the next time period as explained earlier.

Spill over: The difference between estimated λ and μS.

S: The number of gate booths working.

Table 7.2 Sample Analysis of Gate System Performance (Continued)

Nt(m/k/s):	Average queue length based on $M/E_K/S$ model.
AWT:	Average waiting time per truck in minutes.
Men per gate:	Number of persons per gate boo
Cg:	Gate operating cost per hour.
Ct:	Trucking waiting cost
$C_{(TS)}$:	Hourly gate system cost, equal to Cg + Ct.
SU:	Gate system utilization, equal to daily truck volume divided by the maximum number of trucks that can be processed within given certain number of gate operating hours.
TTL WT:	Total waiting time in hour.

In Table 7.2, the estimated λ is obtained from extrapolation based on the field observed data, if it is less than the saturation rate μS, it is used for model input. If it is larger than μS, then is used for the model input. When the estimated λ is larger than μS, the spillover (estimated $\lambda - \mu S$) is added to the next time period. In this case, between 12:00 and 2:00 p.m. the estimated λ (149) is larger than μS ($6 \times 60/2.44 = 147.5$). Therefore, caution has to be taken. Also, as indicated in Chapter 4, as λ approaches and almost is equal to μS, the model becomes extremely sensitive. For example, when $\lambda =$ 147.5, based on the model developed in Chapter 4, the average queue length is 169, which is not realistic according to the field observation. Therefore, after careful calibration and consideration, the value of 146.5 is used as the saturation rate for this model, which results in an average queue length of 79 trucks, which more or less fit the size of the holding area of the MCT.

From the table, the details of the gate system are shown. In the morning from 6:00 to 7:00 a.m., four gate booths were open and there were 93 trucks arrived. With $\mu = 2.44$ minutes, using the queuing model developed, the results are: 10 trucks waiting in line and each of them waiting about 6.59 minutes on average before being processed. For this hour, the terminal gate operating cost was \$503 and truck waiting cost was \$328. The total system costs were about \$831 and total waiting time for trucks was 1.12 hours. The morning is at 8:00 a.m. with 142 trucks arrived; the average number of trucks waiting between 8:00 and 9:00 is 17 and average waiting time is 7.19 minutes. In the afternoon starting at 12:00 p.m., due to high truck arrival rate of 149, severe congestion develops. Between 12:00 and 2:00 p.m., there are 79 trucks waiting in line and the average waiting time per truck is 32.41 minutes. On the other hand, there is very little congestion before

12:00 p.m. and after 2:00 p.m. Therefore, whatever the spillover from 12:00 to 2:00 p.m., it does not have meaningful impact on subsequent gate system performance. As a whole, the system utilization is 77.8%, but most of the time, the system is not utilized except the two severely congested hours with more than 100% utilization rate. Total waiting time is 88.12 hours with $13,575 waiting cost. On the other hand, the gate operating cost is $6,163.

7.1.3 Overall Truck Waiting Cost and System Performance

Applying the same method, detailed system performance for each of the ten categories of daily truck volume is analyzed. Based on Figure 7.1 of the estimated distribution of daily truck volumes in each quarter; a full quarterly system performance analysis is obtained. Tables 7.3a, 7.3b, 7.3c, and 7.3d are the detailed analysis for each quarter. The following are explanations for the terms in these tables.

Range (1): daily truck volume.

EFQ (2): estimated frequency.

NGH (3): number of gate hours per day.

NCH (4): number of congested hours per day, when the holding area is full.

SU (5): system utilization, equal to daily truck volume divided by the maximum number of trucks can be processed within the number of gate hours per day (NGH).

TCg (6): total gate operating cost per day.

TCt (7): total truck waiting cost per day.

CUM TCg (8): cumulative gate operating cost, equal to EFQ (2) x TCg (6).

CUM TCt (9): cumulative truck waiting cost, equal to EFQ (2) x TCt (7).

GTTL (10): grand total, equal to CUM TCg (8) + CUM TCt (9).

WTPD (11): total truck waiting time per day in hours.

CUM WT (12): cumulative truck waiting time, equal to EFQ (2) x WTPD (11).

Table 7.3(a) First Quarter (Jan – Mar) System Performance

Range (1)	EFQ (2)	NGH (3)	NCH (4)	SU (5)	TCg (6)	TCt (7)	CUM. TCg (8)	CUM TCt (9)	GTTL (10)	WTPD (11)	CUM WT (12)
<899	14	58	0	62%	7287	281	104,699	4,039	10,8738	8.74	126
900-949	11	58	0	65%	7286	432	80,532	4,771	85,303	13.42	148
950-999	11	58	0	69%	7286	614	80,532	6,782	87,314	19.04	210
1,000-1,049	11	58	0	72%	7286	1010	80,532	1,1167	91,699	31.38	347
1,050-1,099	9	58	0	76%	7286	2323	64,426	2,0536	84,962	72.17	638
1,100-1,149	4	59	2	78%	7412	6163	32,768	2,7247	60,016	195.20	863
1,150-1,199	1	60	3	81%	7412	9086	8,192	10,042	18,234	293.74	325
1,200-1,249	1	60	4	83%	7538	10381	8,331	11,473	19,804	346.39	383
1,250-1,299	0	60	5	87%	7538	11233	0	0	0	381.20	0
>1,300	0	60	6	90%	7538	15357	0	0	0	496.75	0
Total	63						**460,013**	**96,058**	**556,071**		**3,040**

Table 7.3(b) Second Quarter (Apr – Jun) System Performance

Range (1)	EFQ (2)	NGH (3)	NCH (4)	SU (5)	TCg (6)	TCt (7)	CUM. TCg (8)	CUM TCt (9)	GTTL (10)	WTPD (11)	CUM WT (12)
<899	9	58	0	62%	7,287	281	66,773	2,576	69,349	8.74	80
900-949	10	58	0	65%	7,286	432	75,115	4,450	79,565	13.42	138
950-999	11	58	0	69%	7,286	614	83,461	7,028	90,489	19.04	218
1,00-1,049	7	58	0	72%	7,286	1,010	50,076	6,944	57,020	31.38	216
1,050-1,099	14	58	0	76%	7,286	2,323	100,153	31,925	132,077	72.17	992
1,100-1,149	5	59	2	78%	7,412	6,163	33,960	28,238	62,198	195.20	894
1,150-1,199	5	60	3	81%	7,412	9,086	33,960	41,629	75,588	293.74	1,346
1,200-1,249	2	60	4	83%	7,538	10,381	17,268	23,781	41,049	346.39	794
1,250-1,299	0	60	5	87%	7,538	11,233	0	0	0	381.20	0
>1,300	0	60	6	90%	7,538	15,357	0	0	0	496.75	0
Total	63						**460,765**	**146,571**	**60,7336**		**4,678**

Table 7.3(c) Third Quarter (Jul – Sep) Performance

Range (1)	**EFQ (2)**	**NGH (3)**	**NCH (4)**	**SU (5)**	**TCg (6)**	**TCt (7)**	**CUM. TCg (8)**	**CUM TCt (9)**	**GTTL (10)**	**WTPD (11)**	**CUM WT (12)**
<899	3	58	0	62%	7,287	281	22,589	871	23,460	8.74	27
900-949	3	58	0	65%	7,286	432	22,587	1,338	23,926	13.42	42
950-999	6	58	0	69%	7,286	614	45,175	3,804	48,979	19.04	118
1,00-1,049	11	58	0	72%	7,286	1,010	82,820	11,484	94,305	31.38	357
1,050-1,099	19	58	0	76%	7,286	2,323	135,524	43,199	178,724	72.17	1,342
1,100-1,149	11	59	2	78%	7,412	6,163	84,248	70,054	154,302	195.20	2,219
1,150-1,199	4	60	3	81%	7,412	9,086	30,636	37,554	68,190	293.74	1,214
1,200-1,249	3	60	4	83%	7,538	10,381	23,366	32,180	55,547	346.39	1,074
1,250-1,299	1	60	5	87%	7,538	11,233	7,789	11,607	19,396	381.20	394
>1,300	0	60	6	90%	7,538	15,357	0	0	0	496.75	0
Total	62						**454,735**	**212,093**	**666,828**		**6,786**

Table 7.3(d) Fourth Quarter Performance (Oct – Dec) Performance

Range (1)	EFQ (2)	NGH (3)	NCH (4)	SU (5)	TCg (6)	TCt (7)	CUM. TCg (8)	CUM TCt (9)	GTTL (10)	WTPD (11)	CUM WT (12)
<899	3	58	0	62%	7,287	281	21,513	830	22,343	8.74	26
900-949	1	58	0	65%	7,286	432	10,756	637	11,393	13.42	20
950-999	1	58	0	69%	7,286	614	10,756	906	11,662	19.04	28
1,00-1,049	7	58	0	72%	7,286	1,010	53,779	7,457	61,237	31.38	232
1,050-1,099	12	58	0	76%	7,286	2,323	86,047	2,7428	113,475	72.17	852
1,100-1,149	16	59	2	78%	7,412	6,163	120,355	100,077	220,432	195.20	3,170
1,150-1,199	12	60	3	81%	7,412	9,086	87,531	10,7297	194,827	293.74	3,469
1,200-1,249	3	60	4	83%	7,538	10,381	22,254	30,648	52,901	346.39	1,023
1,250-1,299	3	60	5	87%	7,538	11,233	22,254	33,163	55,416	381.20	1,125
>1,300	3	60	6	90%	7,538	15,357	22,254	45,338	67,592	496.75	1,467
Total	62						**457,498**	**353,781**	**811,279**		**11,411**

There are some common features in Tables 7.3(a)-7.3(d). First, the gate operating costs for all fours quarters are more or less the same. Since the first two quarters have two additional working days than the last two quarters of the year due to holidays, this is reflected in the higher gate operating cost. The difference between the first quarters and the last two quarters does not mean there is significant variation in terms of gate operating cost. Second, the analysis shows that when SU was below 76%, there was no congested hour at the gate (as mentioned above, a congested hour is defined as the holding area of the gate is full with 72 – 80 trucks for one hour depending on the composition of waiting trucks: bobtails, 20' containers, and 40' containers). There might be some trucks waiting, but the holding area was not full. When SU reached 78%, there were two congested hours per day. As daily truck volume increases, so does the number of congested hours proportionally. When daily system utilization reaches 90%, this indicates there are six congested hours in a day, indicating severe gate congestion. Truck waiting time and cost increase dramatically. Accordingly, waiting time per day (WTPD) grows exponentially as daily truck volume increases from 900 to 1,300. As daily SU approaches 90%, the system becomes more sensitive; a small increase in SU results in huge increase in waiting time. On the other hand, when daily SU is below, there is hardly any meaningful congestion.

To compare quarterly truck traffic behavior and gate system performance, daily SU, cumulative gate operating cost, cumulative truck waiting cost, and cumulative truck waiting time are compared.

Daily system utilization and gate congestion: Figure 7.2 provides a comparison of daily truck volume, system utilization (SU), and the number of congested hours (NCH) for the four quarters. In the first quarter, 90% of the time daily SU was below 76%, indicating very little congestion. There was not a single day that the daily SU was more than 83% and the number of congested hour was more than four hours. Only about 5% of the time, the number of congested hours was between three and four hours. In the second quarter, the situation was quite similar to the first quarter, close to 82% of the daily SU were below 76%, meaning no congestion at all; and only 11% of the daily SU were more 78%, two congested hours per day. No single daily SU was more than 83%, more than four hours of congestion. As a result, most of the time in the first two quarters of the year the gate system was congestion free.

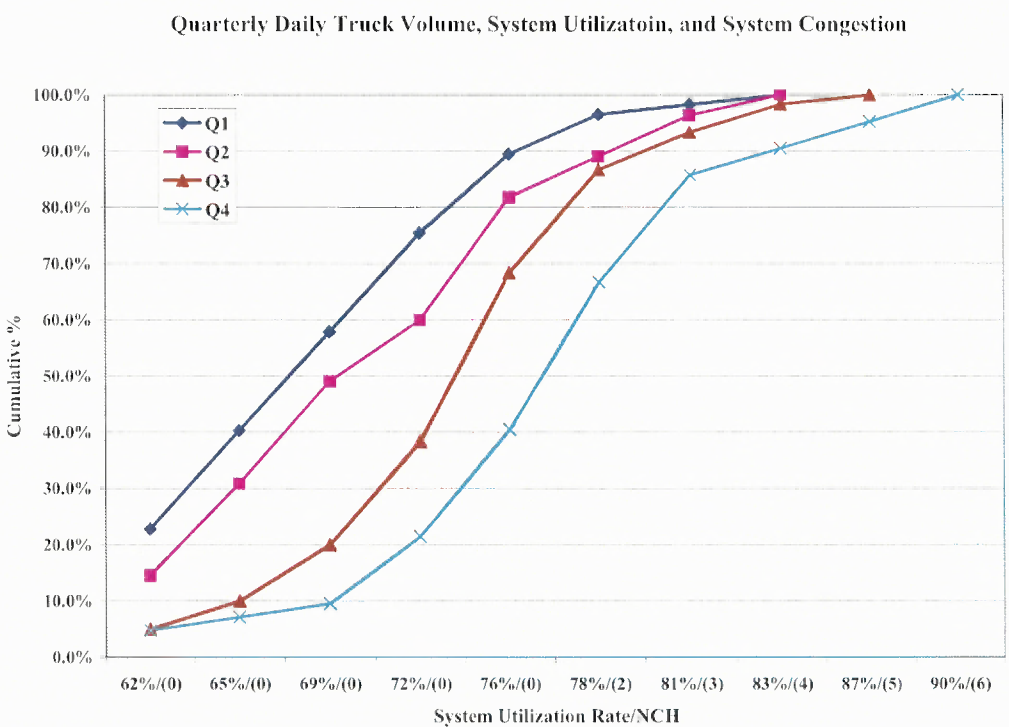


Figure 7.2 Quarterly daily truck volume, system utilization, and congestion levels.

In the third quarter, close to 14% of the time the daily SU were above 78%, two or more congested hours per day and in the fourth quarter close to 34% of the daily SU were above 78%, more than two or more congested hours per day; these indicate that congestion occurred more frequently in the third and fourth quarters than in the first two quarters. In addition, the magnitude of congestion also increased. For example, in the fourth quarter, close to 10% of the time, the number of congested hours was more than four.

Trucking waiting cost and truck waiting time: In terms of truck waiting cost, Ct, Figure 7.3 provides a quarterly comparison. But Ct increased quite rapidly from the first quarter's $96,058 to the fourth quarter's $353,781, exhibiting a similar pattern as in Figure 7.2. Ct in the fourth quarter was almost four times more than the first quarter. The direct annual truck waiting cost was $808,503. This was based on a conservative estimation; if the opportunity cost of $55 per hour is used, the truck waiting cost would be $1,383,131 per year. Corollarilly, cumulative truck waiting time for each quarter closely follows the pattern of gate operating cost (Table 7.2); cumulative truck waiting time for the first quarter was relatively low, 3,040 hours in total, due to lack of congestion. In the fourth quarter, the cumulative truck waiting time increased to 11,411 hours. In total, the annual truck waiting time was 25,915 hours.

The direct cost of waiting time used above is a conservative one. According to harbor trucking executives, there are additional costs incurred while waiting, such as lost business opportunities, higher fuel cost, increase in insurance premium, and driving time restriction imposed by the Hours of Service Rule of the Federal Commercial Motor Carrier Safety Administration, opportunity costs of truck waiting could be as high as $55 per hour. If this cost figure is applied for truck waiting at the gate, the total truck waiting costs is $1,383,131.

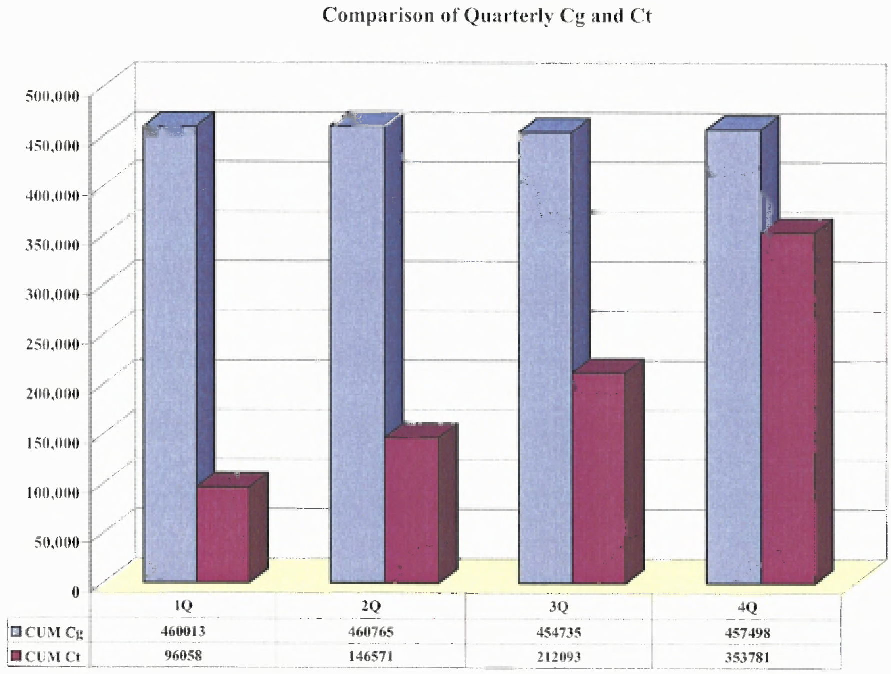


Figure 7.3 Quarterly gate operating costs and trucking waiting costs.

This MCT has a market share of 15% of the Port of New York/New Jersey; there are four other major containers. To put an estimate on the total truck waiting costs for the entire port based on market share and container volume, and similar truck traffic patterns, the total annual truck waiting costs are $5,390,020 (808,503/0.15) in direct cost ($32.15 per hour)and $9,220,873 (1,383,131/0.15) and opportunity cost ($55.00 per hour), respectively. The total annual truck waiting time for the entire port is 172,767 hours (25,915/0.15). Based on the current regulations that a commercial truck driver can only have 10 hours of continuous driving or 14 hours combination of waiting and driving, the 25,915 hours of waiting time is translated into 2,592 net driving days and 1,851 working days for this particular MCT in this study. For the entire port, the total annual truck waiting time amounts to 17,280 net driving days and 12,340 working days. The estimate indicates there were substantial truck waiting cost and time incurred in the MCT gate system for the port, resulting in waste and lost productivity for the port. In particular, the harbor drayage truckers are the party that bears these costs the most.

In summary, this section provides a detailed analysis of gate system performance in terms of gate operating cost, trucking waiting time and cost, capacity utilization, and gate congestion. Due to container volume growth and current system set up, there was large amount of truck waiting time and cost incurred. In particular, the fourth quarter gate congestion accounted for close to 40% of the total waiting time and waiting cost. At the same time, the first and second quarters the gate system experienced very little congestion. This presents a challenging situation; gate system optimization and congestion mitigation alternatives need to be analyzed.

7.2 Gate System Optimization

As demonstrated earlier, the gate system can be optimized through the optimization model developed in Chapter 4. Based on the queuing theory, the key parameters of a queuing system are λ, μ, and S; every one of them has significant impact on system performance. Each of them represents different element of the system. λ represents the demand side of the system, and currently the MCT does not have any control over when individual truckers will arrive at the MCT. Also, due to supply chain variables such customs clearance, warehousing schedule, and inventory control policies, communication among parties involved, and highway congestion, truck arrivals seem to be unpredictable.

μ and S represent the supply side of the system. μ is the productivity of the gate processing, subject to gate technology and labor productivity. S is the footprint of the gate system, subject to land availability. Another factor that has not been discussed is the number of gate operating hours in a day; it is closely tied to labor contract constraints and demand for extended gate hours. In this section, the optimization model developed in Chapter 4 is utilized through analyzing the impacts of all these parameters as well as labor contract constraints and policy issues.

There are four approaches to optimize the gate system, extending gate operating hours, capacity expansion, productivity improvement, and policy based optimization. However, the option of extending gate hours will not be included in this research. The result will provide different alternatives to improve system performance and reduce truck waiting cost.

7.2.1 Optimization through Gate Capacity Expansion

One way to accommodate the growing daily truck volume during peak season is to expand the gate facility by adding more gate booths, thus increasing the gate processing capacity. As demonstrated in Chapter 6, the gate system can be optimized by varying the number of gates based on truck arrival rate through adjusting the number of gates opened corresponding to truck arrival rates. By comparing the existing number of booths and the maximum number of optimized booths, the number of additional booths needed is identified. In addition, sensitivity analysis can be undertaken to examine the dynamics and interaction among different parameters of the gate system. The gate system optimization is a two-step process. The first step is to obtain values of the various parameters. The second step is to substitute these values into the model and run the model. The third step is to obtain the optimum number of gate booths corresponding to truck arrival rates, processing time, and the number of gates working. The fourth step is to analyze the sensitivity of the gate system performance under various optimization schemes. In this process, new results on gate operating cost, truck waiting cost, system capacity utilization, and system total costs are recalculated and comparisons can be made with the performance of the existing system.

To expand the gate facility, there are two alternatives: one is to increase the number of gates booth marginally using the existing footprint of the gate complex for the short term, and the other is to expand the gate complex substantially for the long term. For the first alternative, the cost of installing additional gate booths and computer equipment is quite low. Such marginal facility expansion can be treated as a one-time business expense, and such cost, if amortized over several years, is negligible on a daily basis. On the other hand, major facility expansion for long term development has to take capital cost into consideration. In addition, due to constraints on land availability and environmental concerns, large scale gate expansion may not be feasible. Other optimization alternatives could be more attractive, which will be analyzed later in this chapter.

Marginal gate system expansion: Based on the optimization model, Equations (4.35), (4.36), (4.38), and (4.40), developed in Chapter 4 and the example illustrated in Chapter 6, (Tables 6.7 and 6.8); optimization schemes are developed according to different daily truck volumes, temporal truck arrival rates, and gate processing rates. Based on Table 7.1, there are ten estimated daily truck volume and corresponding hourly truck arrival rates, therefore, there are ten optimization schemes accordingly. Figures 7.4 (a) through 7.4 (j) illustrate the gate system optimization results by varying the number of gate booths according to the different hourly truck arrival rates, assuming there is no change in the current gate system manning schedule.

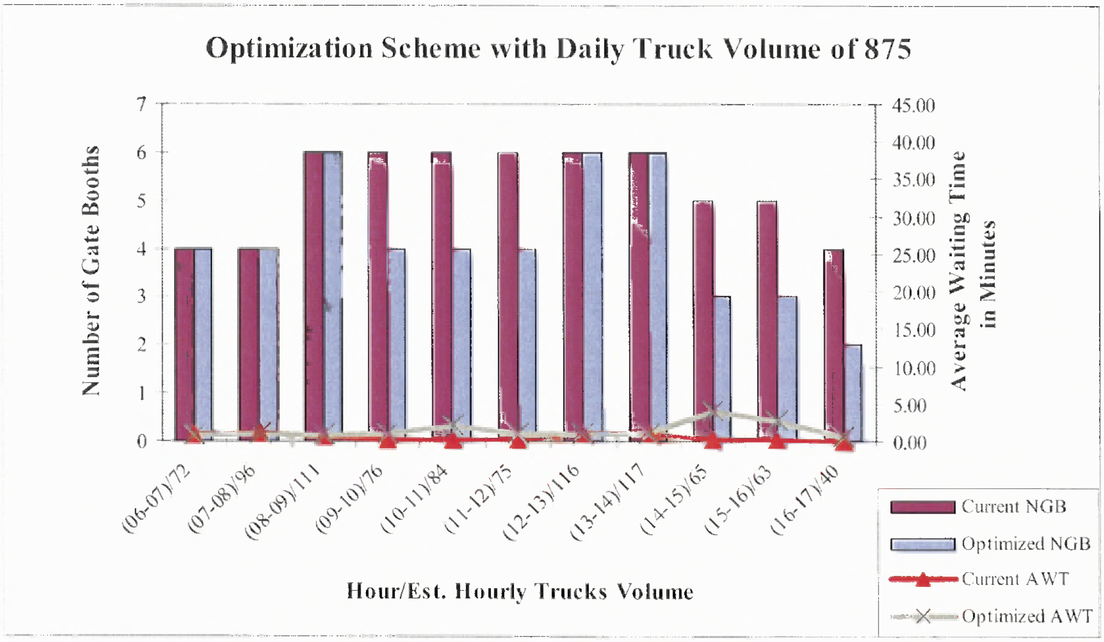


Figure 7.4(a) Gate optimization with daily truck volume of 875.

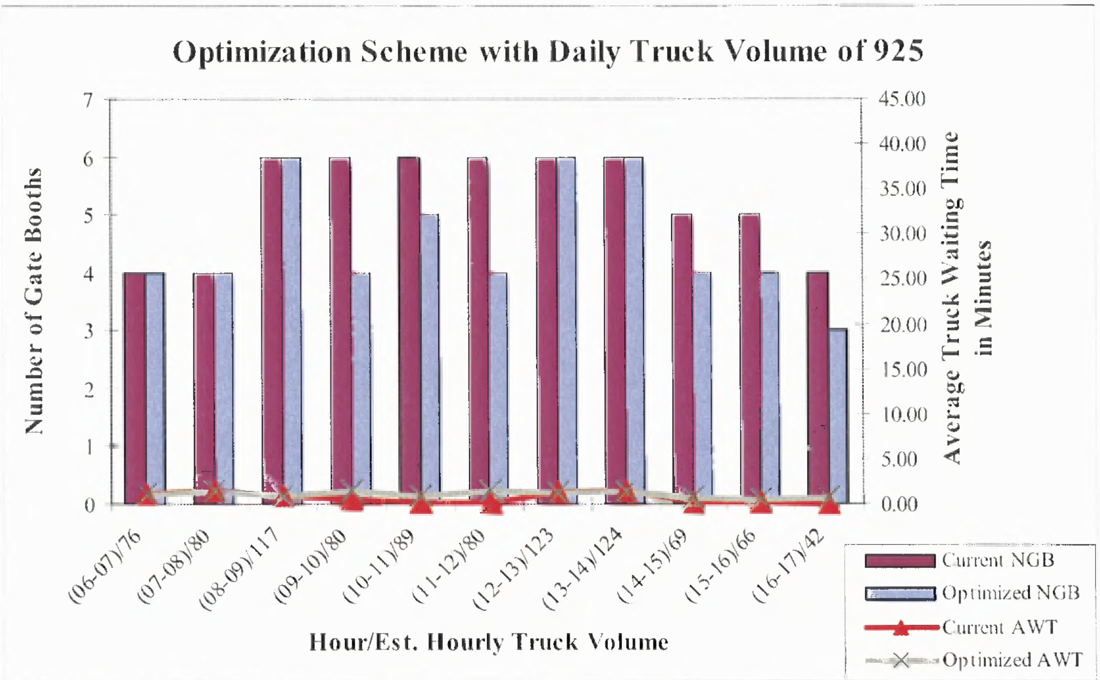


Figure 7.4(b) Gate optimization with daily truck volume of 925.

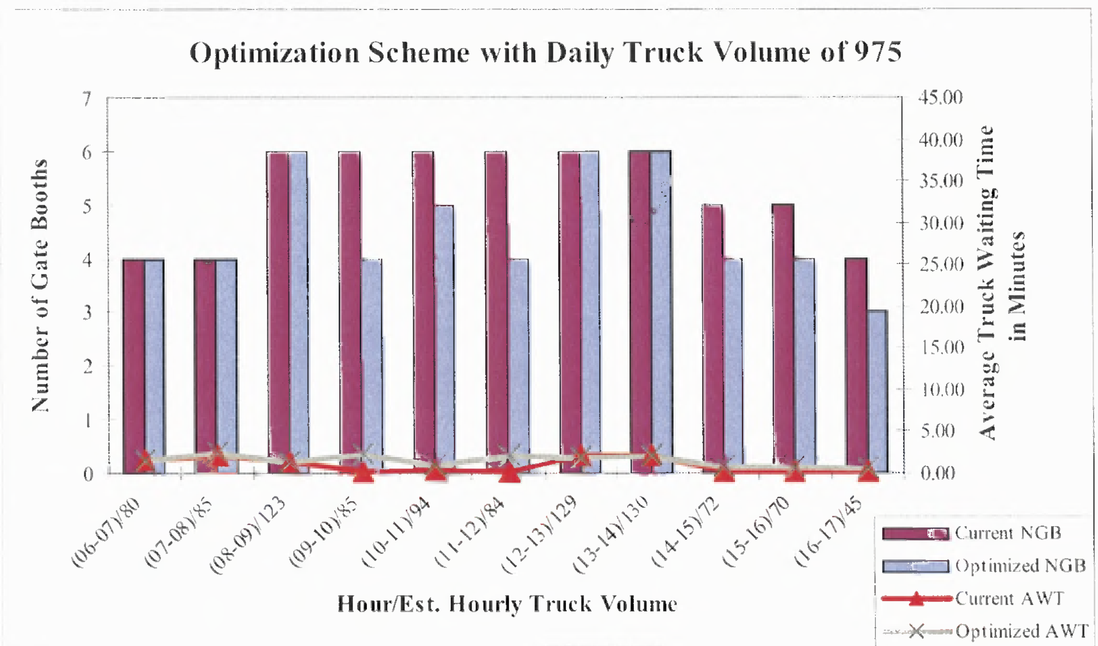


Figure 7.4(c) Gate optimization with daily truck volume of 975.

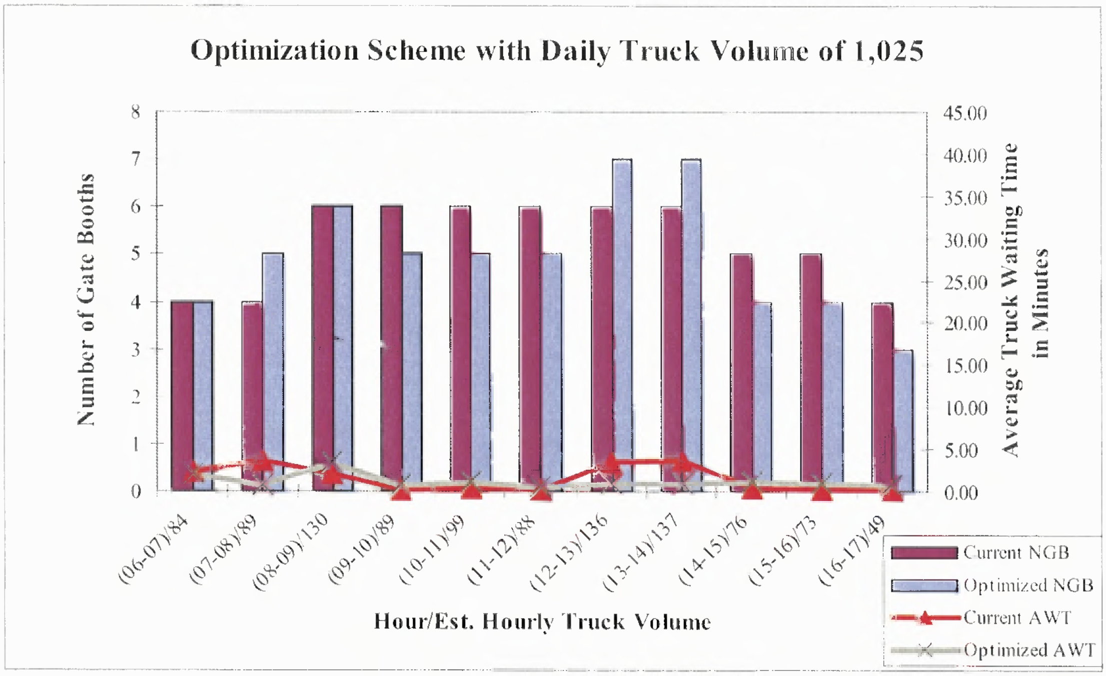


Figure 7.4(d) Gate Optimization with Daily Truck Volume of 1,025.

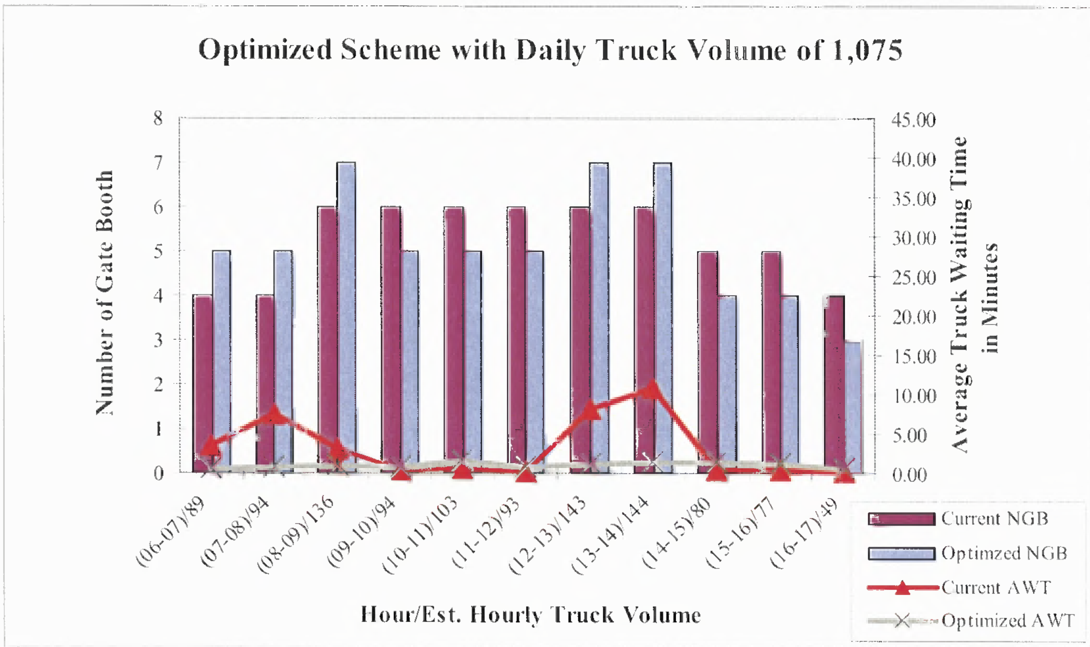


Figure 7.4(e) Gate optimization with daily truck volume of 1,075.

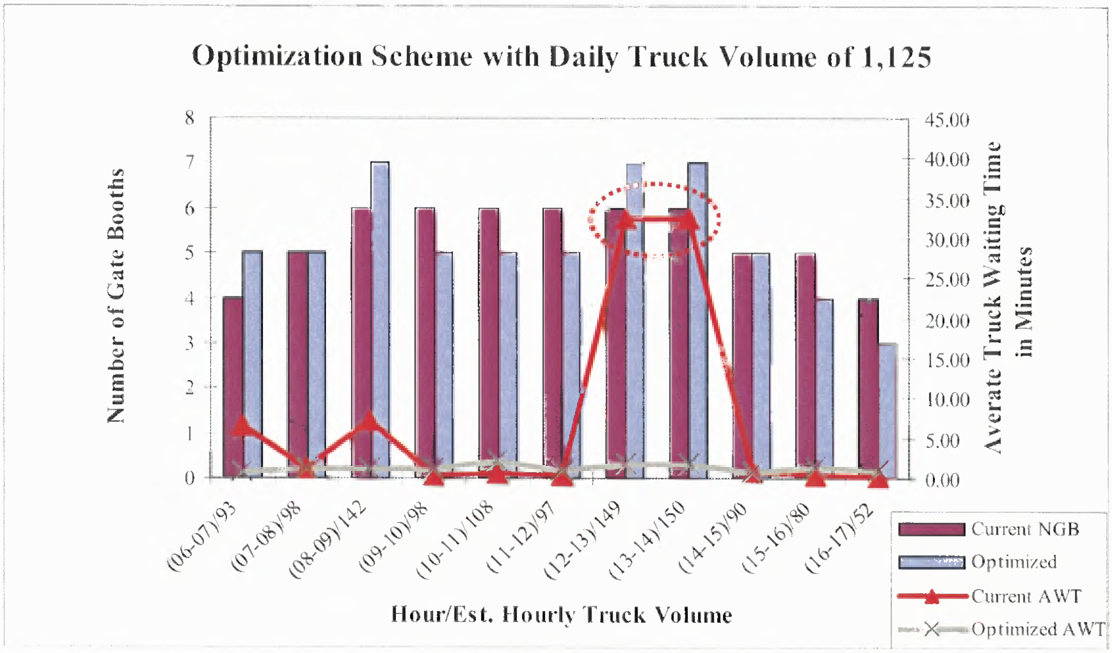


Figure 7.4(f) Gate Optimization with Daily Truck Volume of 1,125.

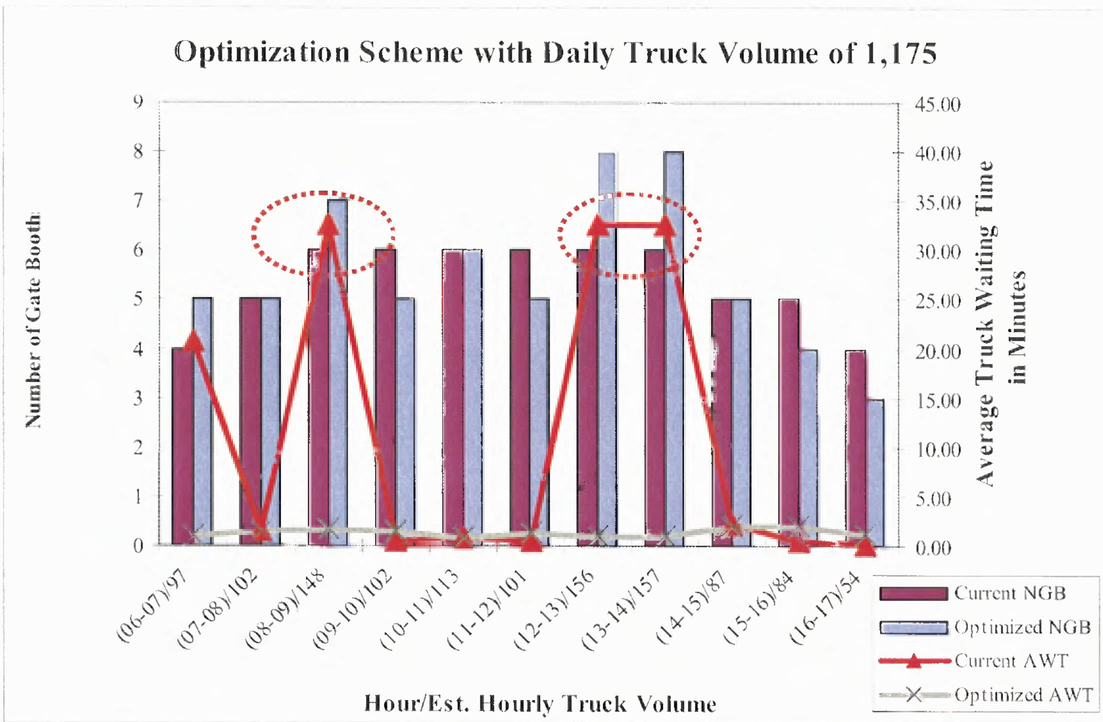


Figure 7.4(g) Gate optimization with daily truck volume of 1,175.

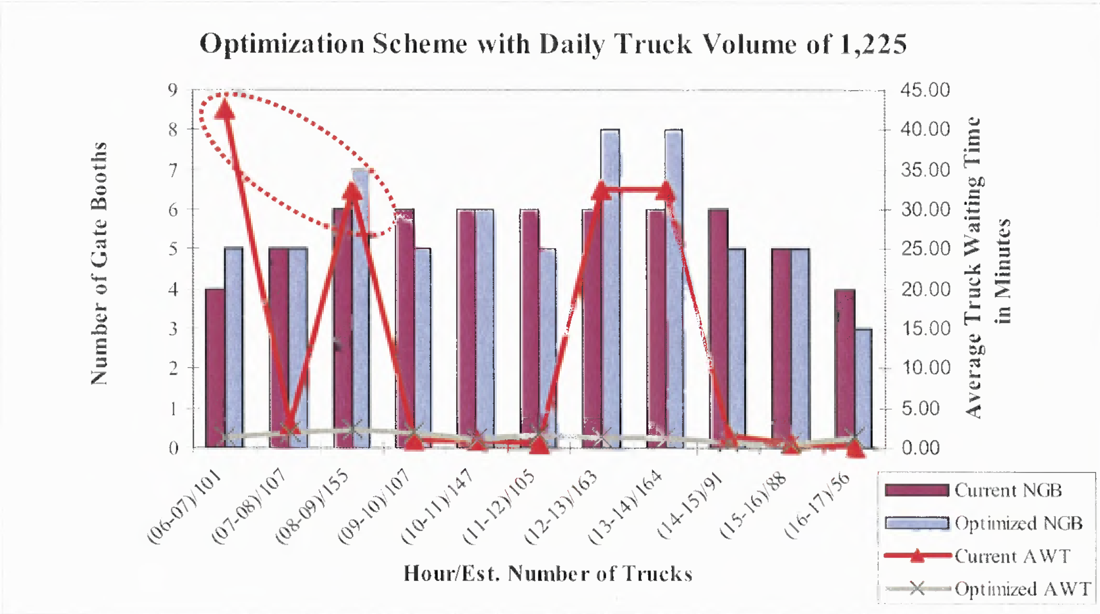


Figure 7.4(h) Gate Optimization with Daily Truck Volume of 1,225.

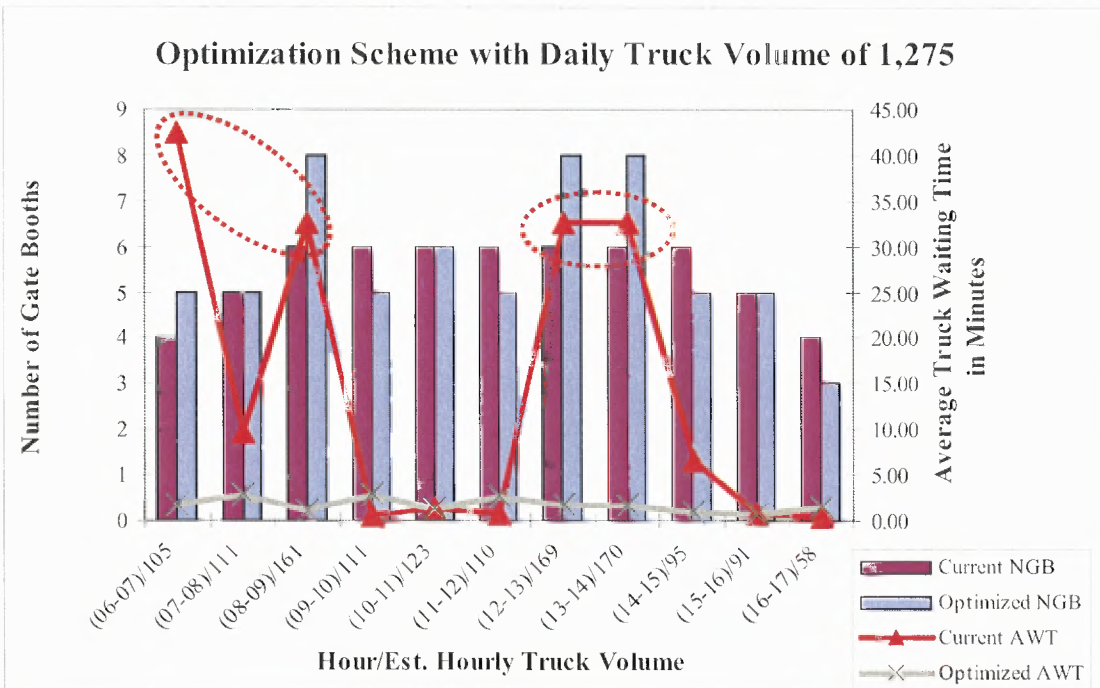


Figure 7.4(i) Gate optimization with daily truck volume of 1,275.

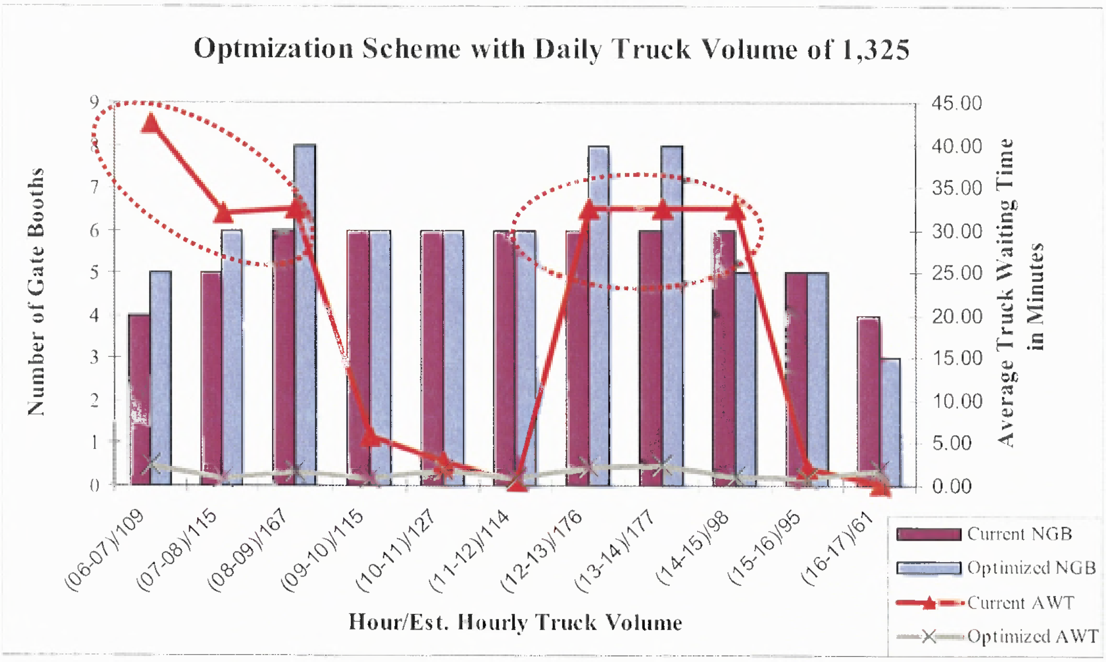


Figure 7.4(j) Gate optimization with daily truck volume of 1,325.

Figures 7.4(a) through 7.4(j) show the comparisons before optimization and after optimization in terms of the number of gate booths and truck average waiting time on an hourly basis. From the above gate system schemes, they clearly demonstrate the following:

a) When daily truck volume is below 1,025, the current system is somewhat underutilized; actually, the number of gate booths should be reduced. This will result in marginal increase in average truck waiting time. On the other hand, when the daily truck volume is more than 1,025, average trucking waiting time during peak periods increases dramatically, indicating the need for more gate capacity during morning peak and early afternoon peak. However, during non-peak hours, the number of gate booths should be reduced as well.

b) Before optimization, the performance of the gate system is not consistent; the average truck waiting time varies from less than one minute to more than 40 minutes depending the hour of the day and its corresponding truck volume. After optimization, the average truck waiting time is very consistent, no more than three minutes during the entire day. This amount of waiting time for truckers is negligible.

c) There is a need for flexibility in terms of the number of gate booths during different periods of the day according the daily truck volumes; this represents a challenge in terms of capacity management.

Overall gate system performance: as described in previous chapters, there are two major cost components in the MCT gate system; the gate operating cost and truck waiting cost. In terms of gate system performance, there are two aspects: operational performance and financial performance shown in Tables 7.4 and 7.5.

Table 7.4 Comparison of Gate System Performance

Daily Truck Volume	Est. Freq.	Nt (max)	*Nt' (max)*	AWT (max)	*AWT' (max)*	NGH	CUM. NGH	*NGH'*	*CUM. NGH'*	WTPD	CUM. WT	*WTPD'*	*CUM. WT'*
<899	30	2.05	*4.50*	1.15	*4.09*	58	1,716	*46*	*1,361*	9	259	*21*	*628*
900 – 949	26	3.03	*3.16*	1.56	*1.53*	58	1,504	*50*	*1,297*	13	348	*19*	*491*
950 – 999	30	4.69	*4.71*	2.21	*2.49*	58	1,751	*50*	*1,509*	19	575	*28*	*837*
1,000 – 1,049	37	8.16	*7.76*	3.74	*3.58*	58	2,127	*55*	*2,017*	31	1151	*23*	*852*
1,050 – 1,099	53	25.94	*3.44*	10.83	*1.48*	58	3,074	*57*	*3,021*	72	3825	*21*	*1,115*
1,100 – 1,149	37	79.13	*4.76*	43.07	*1.90*	59	2,160	*57*	*2,087*	195	7146	*54*	*1,972*
1,150 – 1,199	22	79.51	*4.34*	42.57	*2.87*	59	1,276	*61*	*1,319*	294	6354	*55*	*1,199*
1,200 – 1,249	9	79.51	*6.33*	42.57	*2.06*	60	567	*63*	*595*	346	3273	*68*	*645*
1,250 – 1,299	4	79.51	*5.42*	43.07	*2.62*	60	239	*63*	*251*	381	1519	*84*	*334*
1,300 – 1,349	3	79.51	*7.27*	42.57	*2.51*	60	177	*66*	*195*	497	1467	*89*	*262*
TTL							14,591		***13,652***		25,915		***8,335***

Table 7.4 Comparison of Gate System Performance

(Continued)

Remarks:

Est. Freq.:	Estimated frequency
N_t(max):	Current maximum average number of trucks waiting
N_t'(max):	Optimized maximum average number of trucks waiting
AWT(max):	Current maximum average truck waiting time in minutes
AWT'(max):	Optimized maximum average truck waiting time in minutes
TWT:	Current total truck waiting time per day in hours
TWT':	Optimized total truck waiting time per day in hours
NGH:	Current total number of gate hours per day
NGH':	Optimized total number of gate hours per day
Cum. NGH:	Current Cumulative total number of gate hours per year
Cum. NGH':	Cumulative total number of gate hours per year with optimization
WTPD:	Current total truck waiting time per day
WTPD':	Total truck waiting time per day with optimization
CUM. WT:	Cumulative total truck waiting time
CUM. WT':	Cumulative total truck waiting time with optimization

In Table 7.4, it clearly demonstrates that the optimized gate system performance is improved drastically over the current gate system in every measure; the maximum average number of trucks waiting is less than eight; and the maximum average truck waiting time is less than five minutes. Most importantly, on the yearly cumulative measures, the cumulative total number of gate hours is actually reduced from 14,591 to 13,652; while the cumulative total number of truck waiting time is reduced from 25,915 to 8,335 hours. Also, there is no single hour that is congested based on the results of optimization calculation. Apparently, significant savings can be achieved; Figure 7.5 provides a comparison of financial performance between current and optimized gate system.

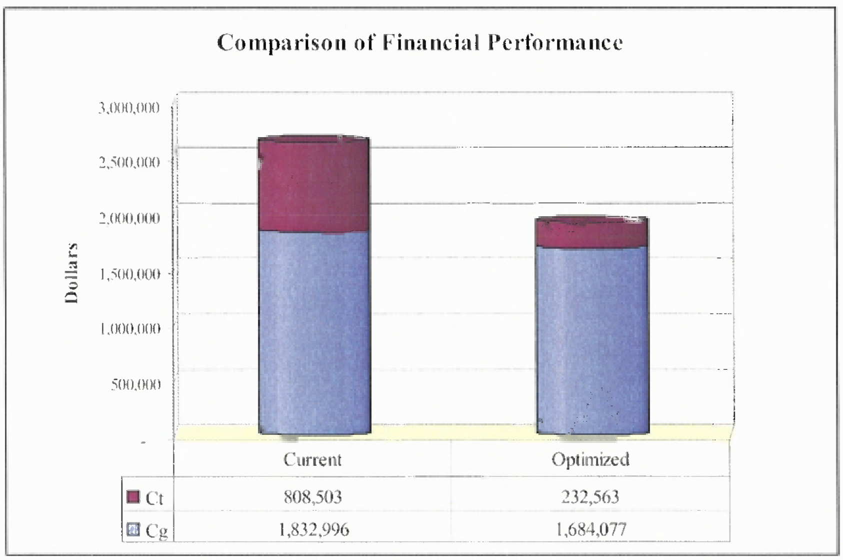


Figure 7.5 Comparison of financial performance (total annual costs).

In Figure 7.5, C_g and C_t are gate operating cost and truck waiting cost, respectively; it clearly demonstrates that the overall system costs can be reduced from $2,641,499 to $1,916,640, a 27% saving through optimization. In particular, direct truck waiting cost is cut by 71% from $808,503 to $242,563; while the total gate system operating cost for inbound trucks is reduced by 8% from $1,832,996 to $1,684,077.

Sensitivity issues: from Figures 7.4(a) through 7.4(i), it is quite obvious that the gate system is not sensitive during non-peak periods; actually the current number of gate booths can be reduced. Increasing or reducing the number of gate booths results in marginal improvement or lowering the performance marginally. However, during peak periods, a small increase in the number of gate booths can lead to a drastic reduction in truck waiting time. This implies that the MCT should focus on peak-period performance and identify ways to obtain the flexibility to management gate capacity in such a way that the gate system can respond to change in truck arrival rate accordingly, resulting in a congestion free gate system.

In summary, to reduce gate congestion, the optimization can help the MCT to identify the amount of additional gate booths needed. It is obvious that the system is not congested all the time. The focus should be on peak periods. One way to deal with the congestion issue on a short term basis is to analyze truck traffic patterns, calculate the number of gate booths needed during different periods of the day, and apply the optimization to mitigate gate congestion. To achieve these optimized results, the management needs to obtain the flexibility in terms of manning scale in responding to the drastic increase in truck arrival rate during peak periods. In addition, the use of a swing gate is highly recommended that during peak periods, one or two outbound gates can be switched to inbound gates, increasing the inbound gate processing capacity temporarily. Or some additional gate booths can be built as reserve based on the current terminal layout; this practice requires labor union cooperation that additional gate clerks are required only for a short period especially during the peak season.

7.2.2 Optimization through productivity improvement

Due to constraints of land availability, physical expansion to optimize the gate system has its limitation; in many cases land for expansion may not be feasible. Gate processing productivity improvement provides a viable means to increase capacity and optimize the gate system. A MCT operator typically chooses new information technologies to improve gate processing productivity, resulting in higher gate system capacity and lower gate congestion. In essence, among the three key elements of gate system, λ and S remain unchanged, but μ is higher. For example, the current gate processing time is 2.44 minutes per truck. Reducing the gate processing time, the gate system will be able to process more trucks in a given period, thus increasing the gate capacity. On the other hand, the use of new information technology requires capital investment. As a result, the gate operating cost will increase, but it will be offset by the increase in gate system capacity and reduction in truck waiting cost. To optimize the gate system, there are changes in two variables that will affect the gate system optimization: C_g and μ. The change in C_g comes from the capital investment required in obtaining new information technology and change in μ comes from the improvement in gate processing technology. The following provides detailed analysis of gate system optimization through gate processing productivity improvement.

Capital investment and C_g: New information technology in gate processing generally is referred to the application of Optical Character Recognition (OCR) technology and related computer software that is integrated into the terminal operating system. Such OCR gate system package includes a number of optical sensors (digital cameras), desktop computers, servers, data cables, and control consoles. It costs between two and a half to three million dollars. Assuming that such a gate system package is $2,750,000 and given ten gate booths (six inbound and four outbound), 11 working hours per day, 250 working days per year, and five-year capital depreciation, the cost of each gate booth is approximately $20 per hour (2,750,000/5/250/11/10 = 20). This additional $20 will be added to the gate labor cost of $50.30 per hour per booth; thus the hourly gate operating cost will be $70.30 (50.30 + 20.00 = 70.30).

Improvement in gate processing productivity: The key to improvement in gate processing productivity is the application of OCR technology. In essence, OCR converts captured images by digital camera into letters or digits accepted by computers. For example, when a trucker pulls into the gate booth, instead of jumping off the truck and handing over the paperwork to the gate clerk, he could simply punch the information via the keypad at the gate pedestal. At the same time, the gate clerk can simply use the control stick to steer the gate digital camera to capture critical information of the inbound truck such as license plate, chassis number, and container number. Then the system converts those images into letters and digits, processes and stores the information, and generates instructions to the trucker as to where to pickup or drop off containers in the yard. This eliminates most of the manual key-in tasks and shortens the amount of time needed to process a gate transaction, resulting in improvement in gate processing productivity.

Gate system optimization schemes: Based on the optimization model in Chapter 4, several optimization schemes are developed corresponding to gate processing productivity improvements of 10%, 20%, 30%, 40%, and 50% shown in Figure 7.6. The optimization schemes are illustrated in a series of relatively flat U shape curves.

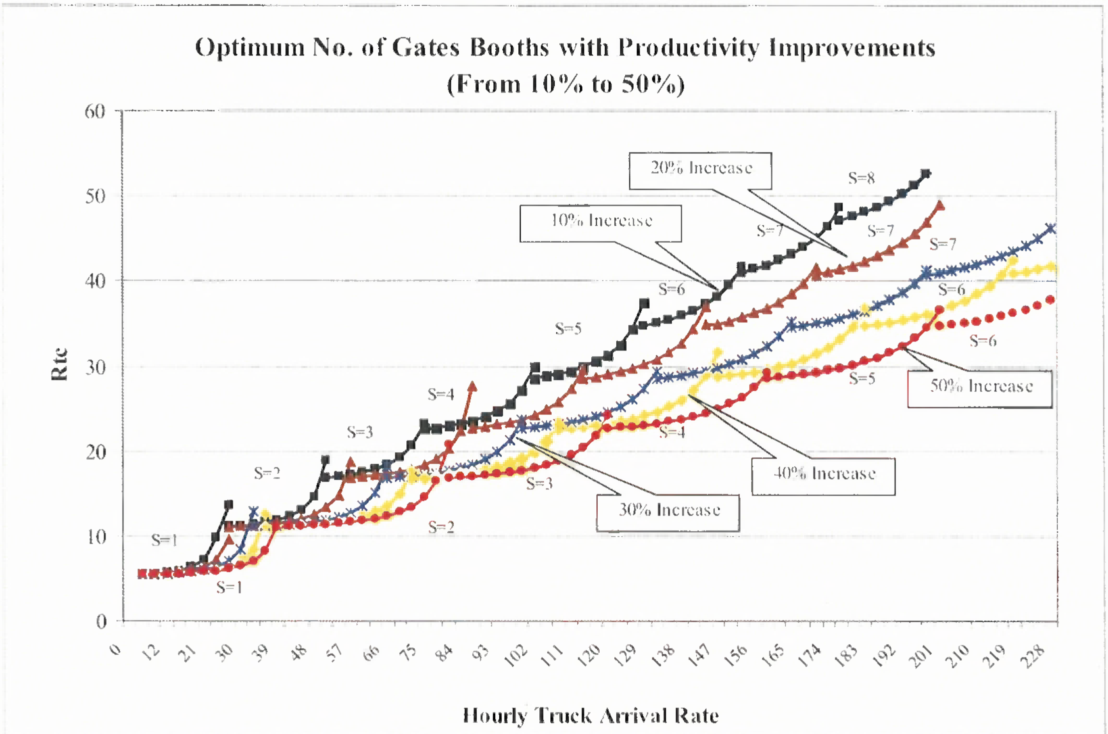


Figure 7.6 Gate system optimizations with productivity improvement.

In Figure 7.6, each U shape curve represents the optimum number of gate booths that corresponds to the prescribed gate processing productivity and specific range of hourly truck arrival rate. For example, the current average gate processing productivity is

2.44 minutes per truck; a 10% improvement will lead to a drop in gate processing time, resulting in 2.196 minutes per truck. Based on 2.196 minutes per truck, an optimization scheme is derived, represented in the top series U shape curves. This optimization scheme provides important information regarding the number of gate booths should be operated under different hourly truck arrival rates. Therefore, if the truck arrival rate is 192 per hour, given 2.196 minutes to process a truck, then the number of gate booths opened should be eight. With further productivity improvement of 20%, 30%, 40%, and 50%, the optimum number of gate booths drops to seven, six, six, and five, respectively. Obviously, the higher the gate processing productivity, the lower of number of gate booths needed to optimize the gate system. Table 7.5 provides the detailed optimization range with respect to the optimum number of gate booths corresponding to different gate processing productivity improvements and hourly truck arrival rates.

Table 7.5 Optimization Schemes with Productivity Improvement

Current AGPP* (2.44 min/truck)		Optimum Number of Gate Booths							
% of Reduction	**Optimum Range**	1	2	3	4	5	6	7	8
10% (2.196 min)		1-26	27-50	51-74	75-101	102-129	129-152	153-176	177-200
20% (1.952 Min)		1-29	30-56	57-86	87-113	114-143	144-170	171-201	202-233
30% (1.708 min)		1-32	33-65	66-98	99-131	132-164	165-197	198-240	241-273
40% (1.464 min)		1-35	36-71	72-107	108-146	147-182	183-218	219-254	255-280
50% (1.22 Min)		1-38	39-80	81-119	120-158	158-200	201-245	246-290	291-331
Note: AGPP - Average Gate Processing Productivity (minutes per truck)									

In Table 7.5, it clearly shows that with increasing gate processing productivity, gate capacity will increase accordingly. For example, it the current inbound gate configuration with six gate booths remains the same, the peak period hourly truck volume of 171 can be optimized with only 20% increase in gate processing productivity of 1.95 minutes per truck. Furthermore, when the gate processing productivity is increased by 50%, the gate system can be optimized up to 245 trucks per hour. This serves as an important function that when additional land is not available for expansion, increasing gate processing productivity is a viable means to accommodate volume growth and mitigate gate congestion. At the same time, total system costs can be optimized. The following section provides an analysis of gate system performances with different optimization schemes.

Gate System Performance: based on Figure 7.6 and Table 7.6, the gate system operational and financial performance are analyzed according to different ranges of productivity improvement, from 10% to 50% over the current average gate processing productivity (AGPP) of 2.44 minutes per truck. In terms of operational performance, the two most critical measures are the number of gate booths and average truck waiting time. Figures 7.7 through 7.16 provide a series of comparisons between the current system and the optimized gate system with productivity improvements ranging from 10% – 50%. Since there are ten categories of daily truck volumes starting from 875 to 1,325 with an interval of 50 and there are six different productivity figures starting with the current AGPP of 2.44 minutes to 50% productivity improvement of 1.22 minutes, it is necessary to use two charts to present the comparison for each category of daily truck volume for the NGB and AWT.

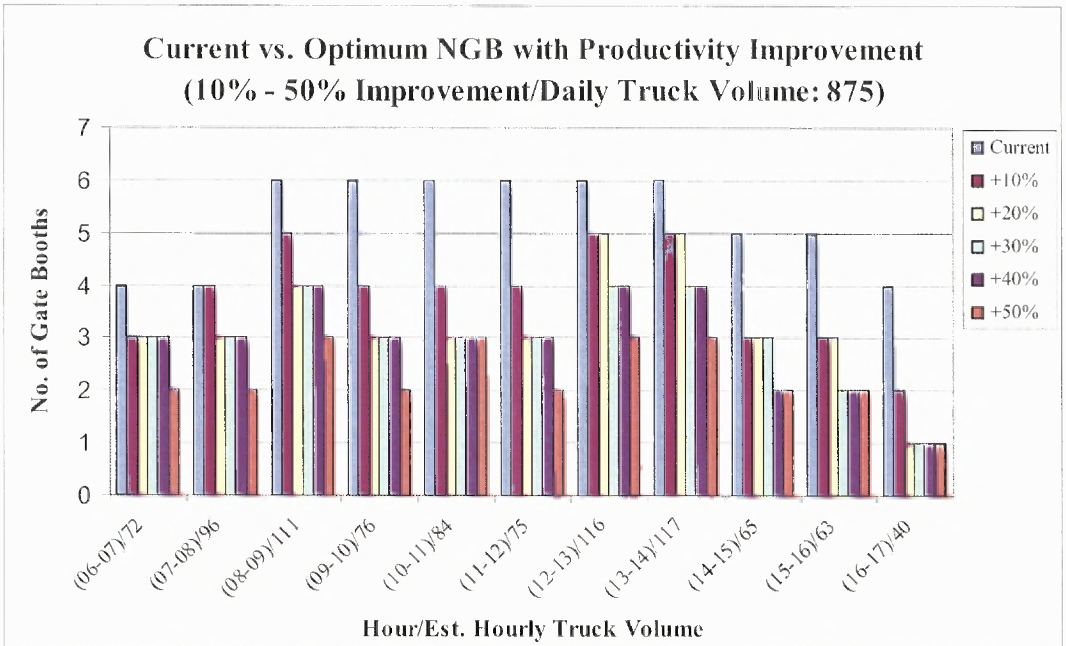


Figure 7.7(a) Number of gate booths with daily truck volume of 875.

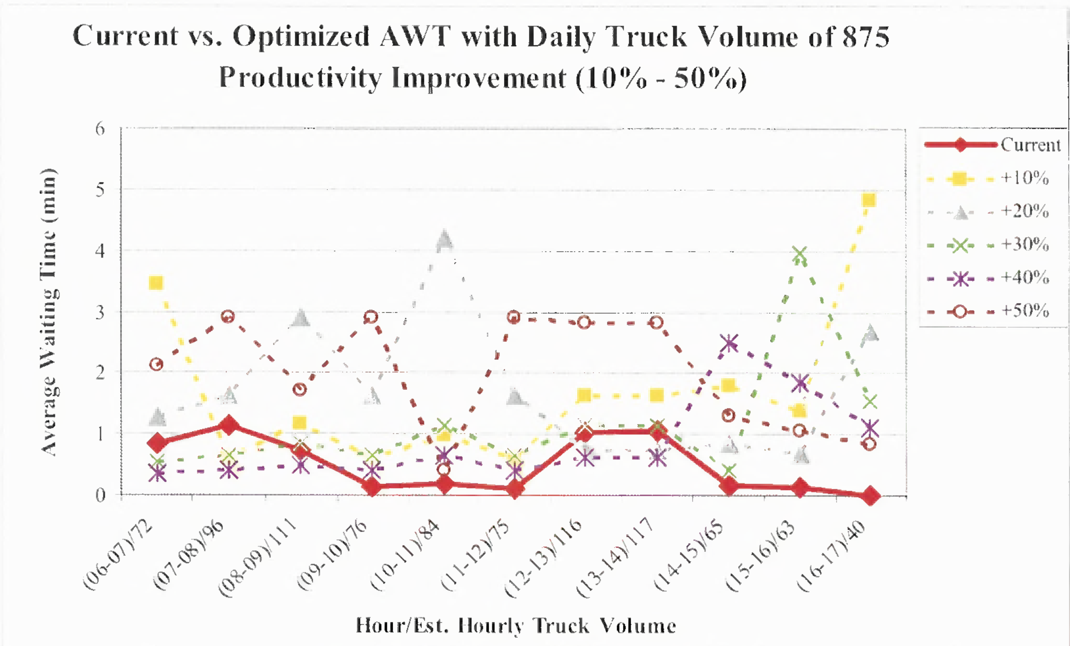


Figure 7.7(b) Average truck waiting time with daily truck volume of 875.

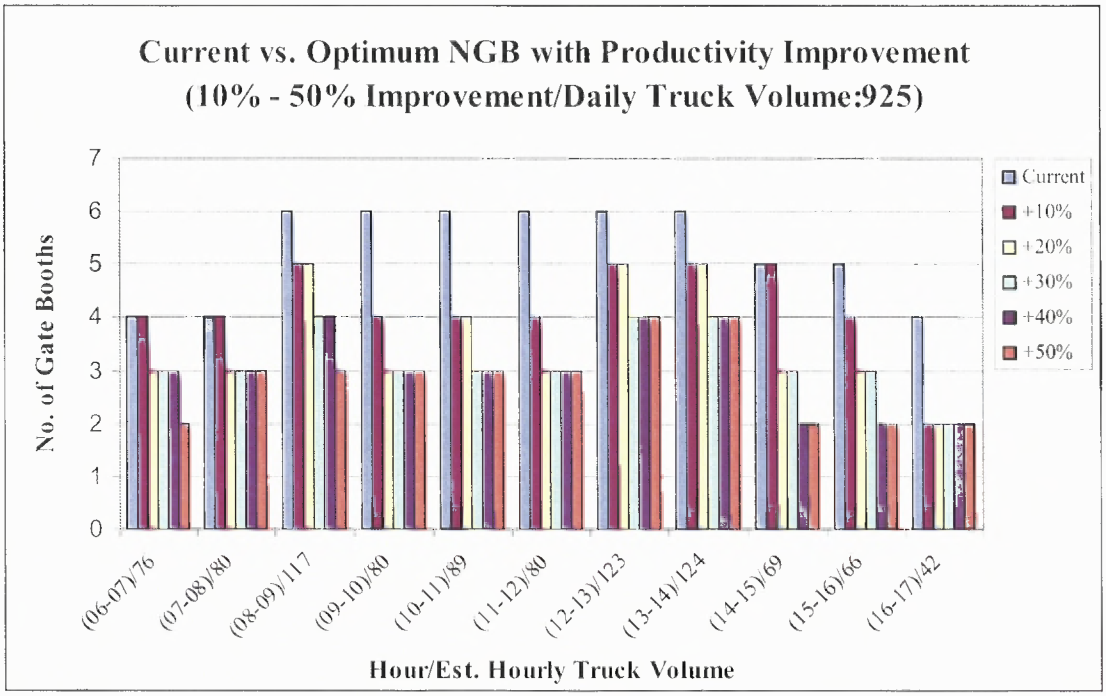


Figure 7.8(a) Number of gate booths with daily truck volume of 925.

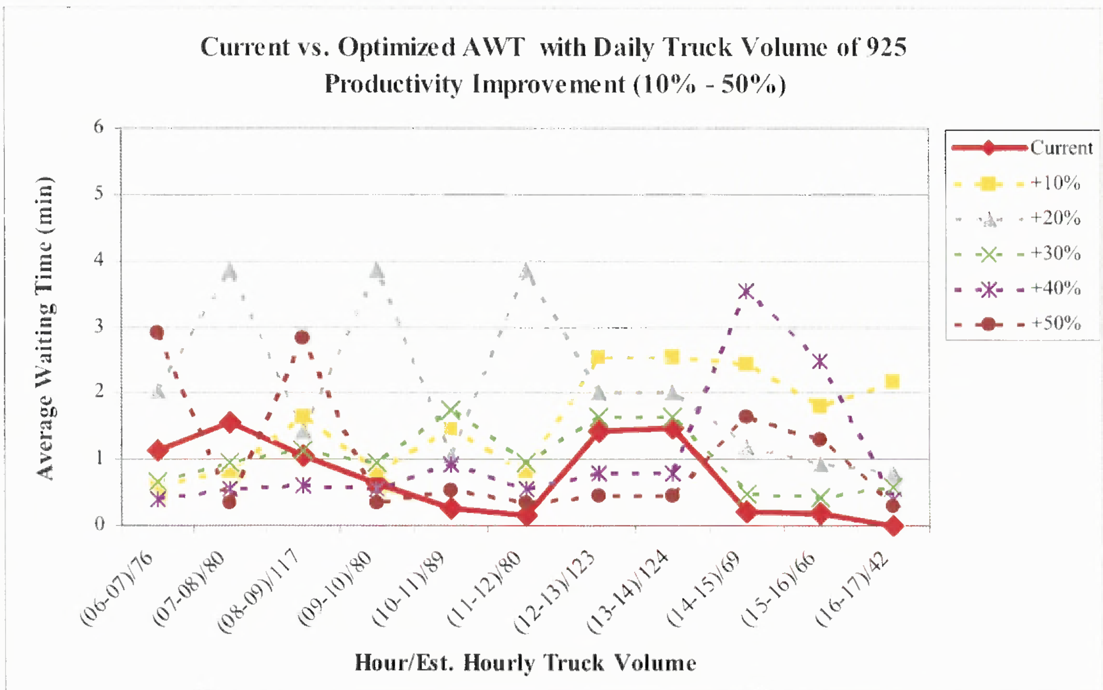


Figure 7.8(b) Average truck waiting time with daily truck volume of 925.

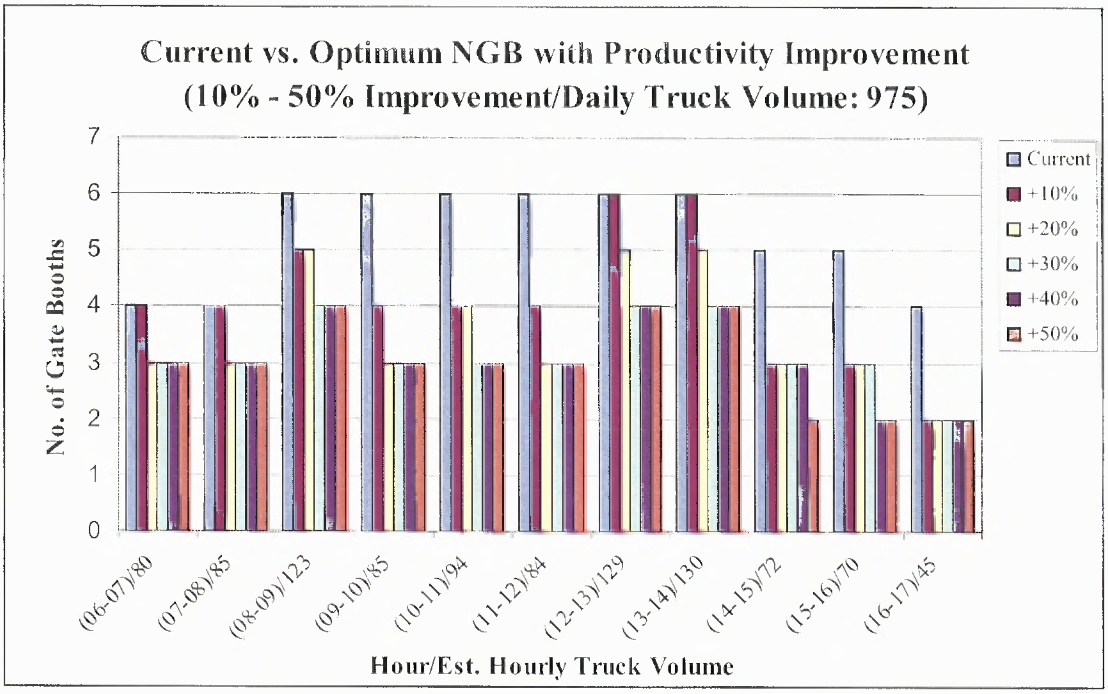


Figure 7.9(a) Number of gate booths with daily truck volume of 975.

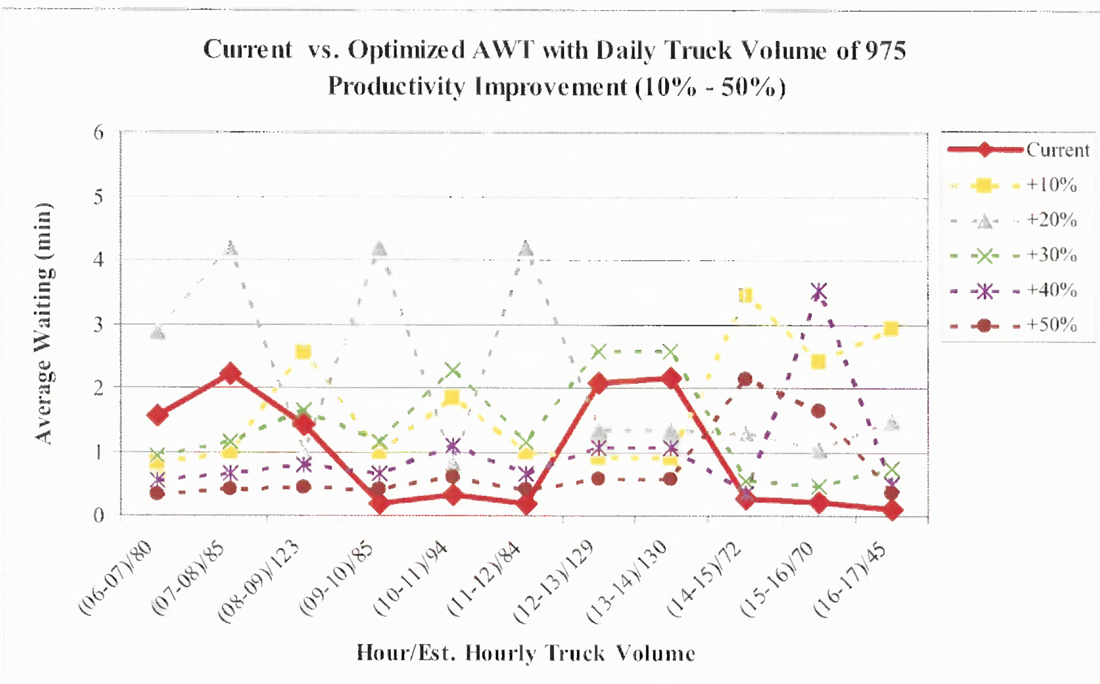


Figure 7.9(b) Average truck waiting time with daily truck volume of 975.

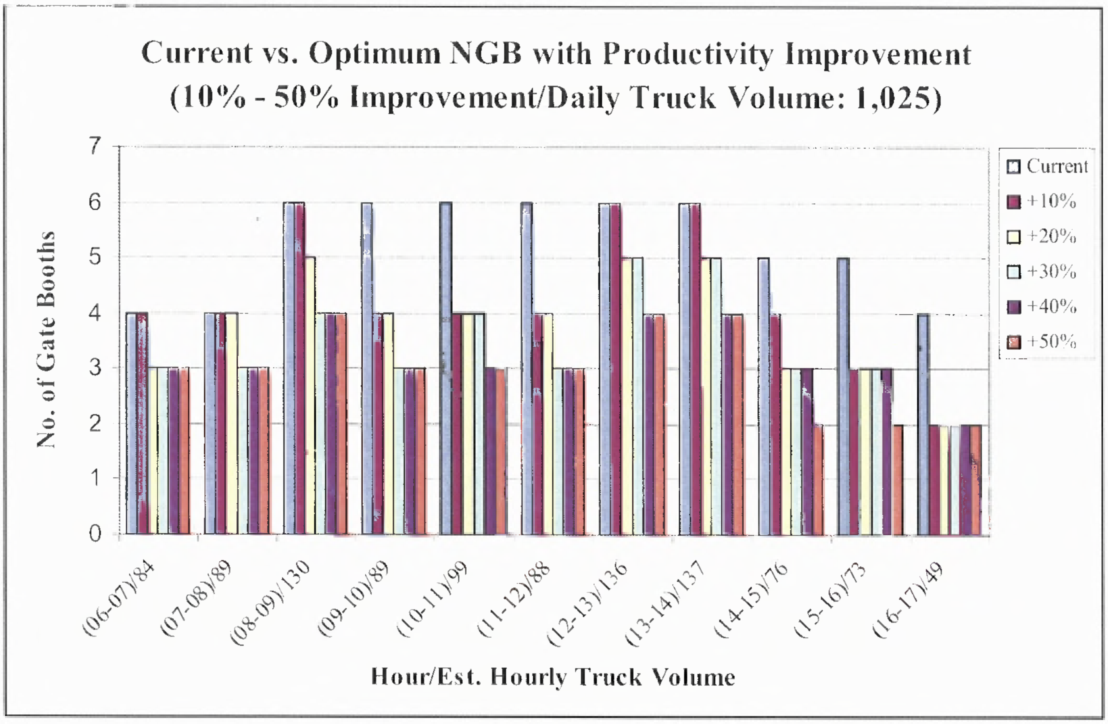


Figure 7.10(a) Number of gate booths with daily truck volume of 1,025.

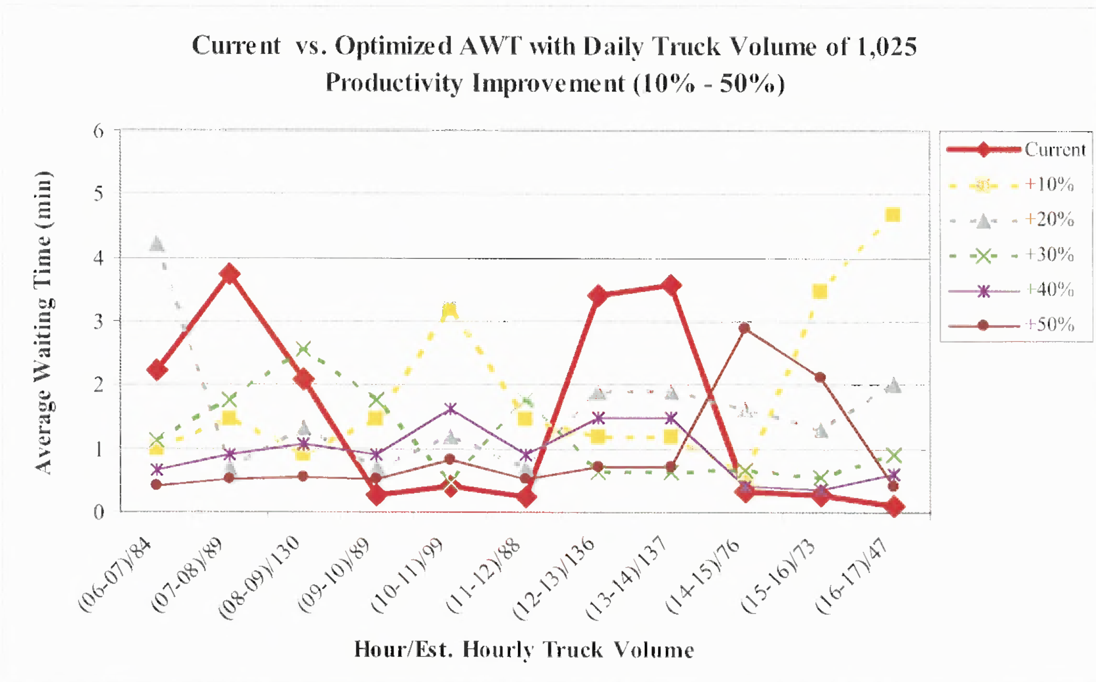


Figure 7.10(b) Average truck waiting time with daily truck volume of 1,025.

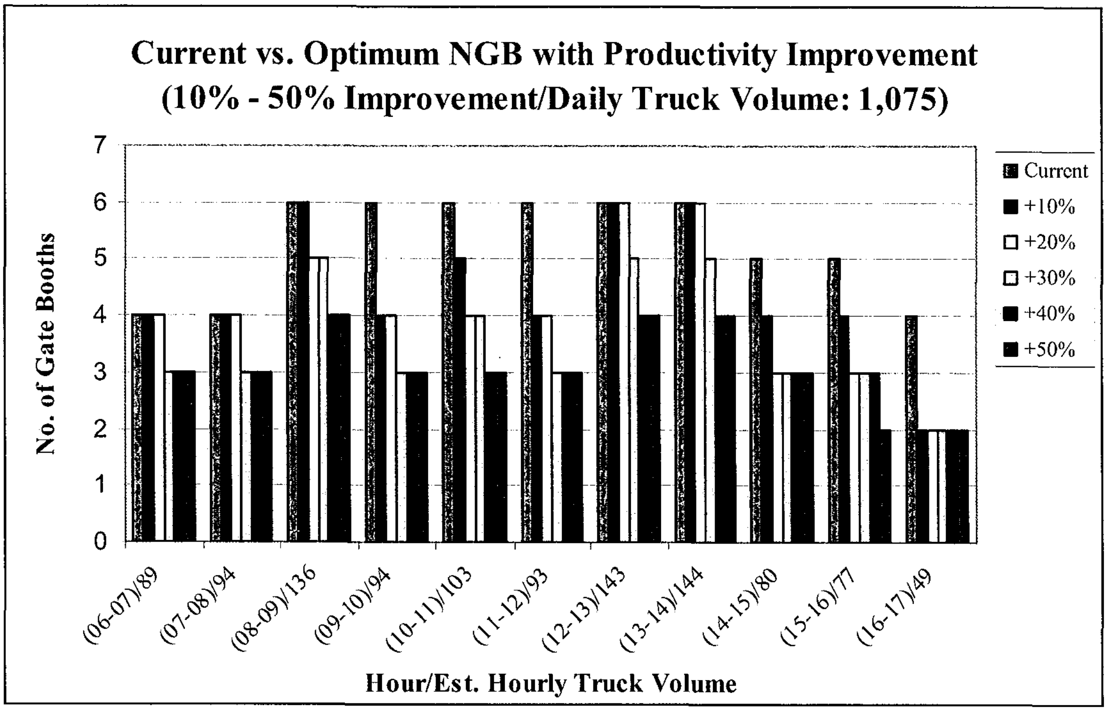


Figure 7.11(a) Number of gate booths with daily truck volume of 1,075.

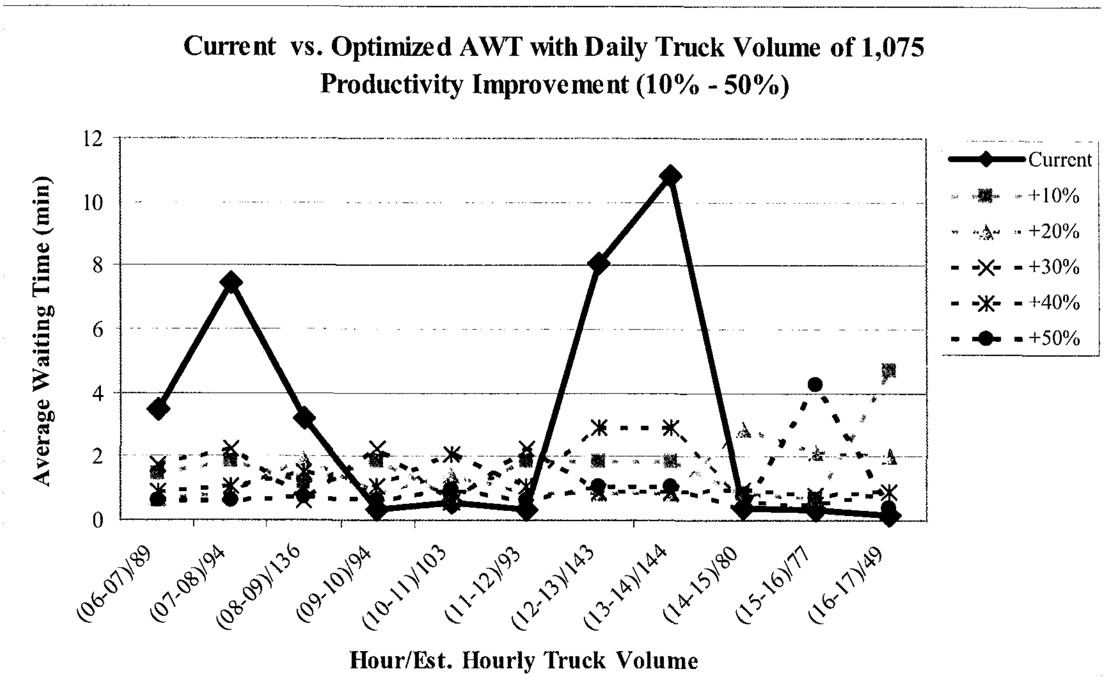


Figure 7.11(b) Average truck waiting time with daily truck volume of 1,075.

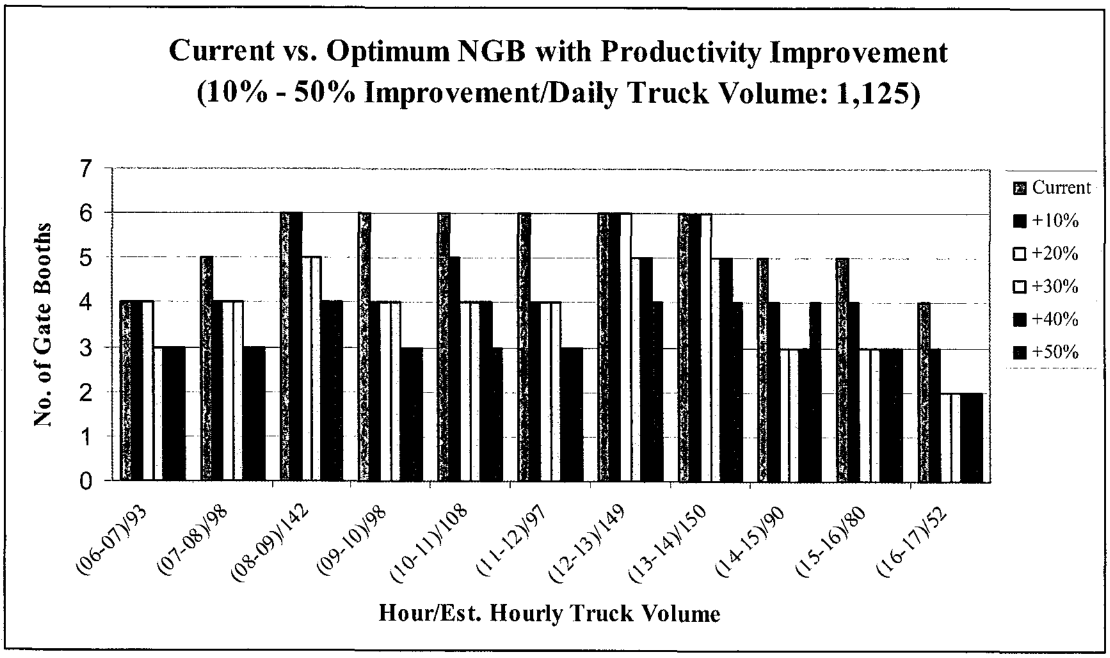


Figure 7.12(a) Number of gate booths with daily truck volume of 1,125.

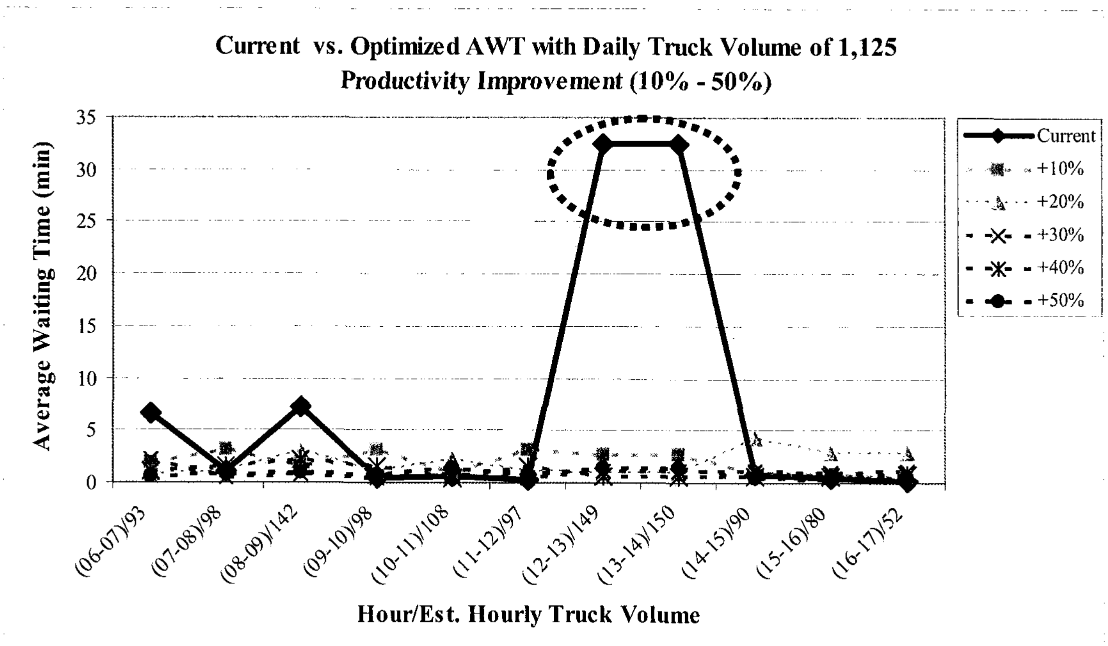


Figure 7.12(b) Average truck waiting time with daily truck volume of 1,125.

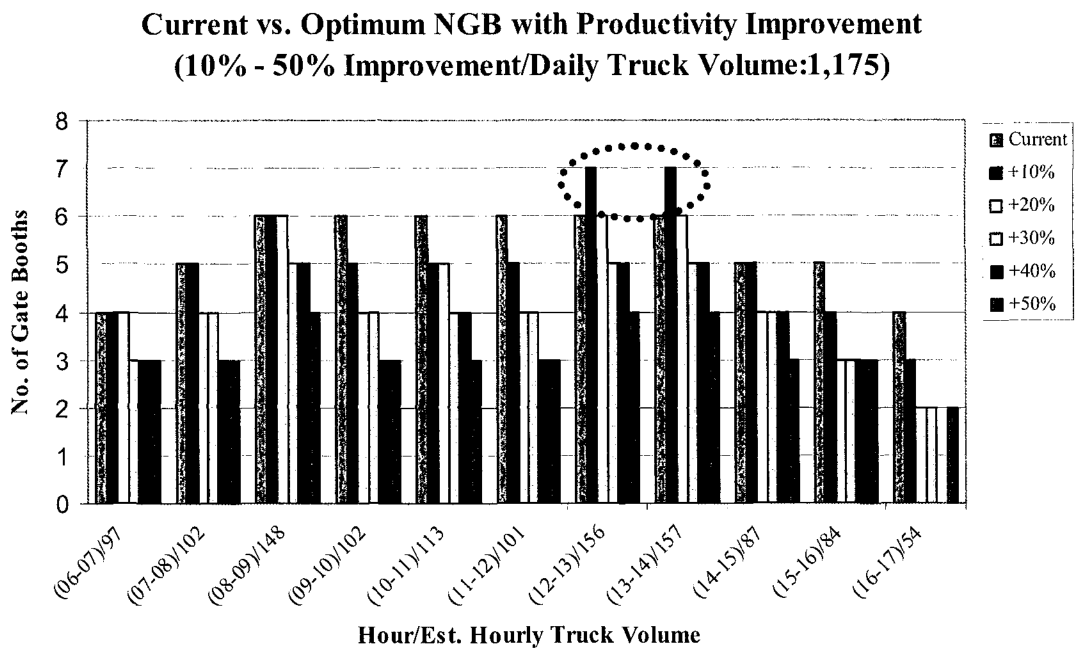


Figure 7.13(a) Number of gate booths with daily truck volume of 1,175.

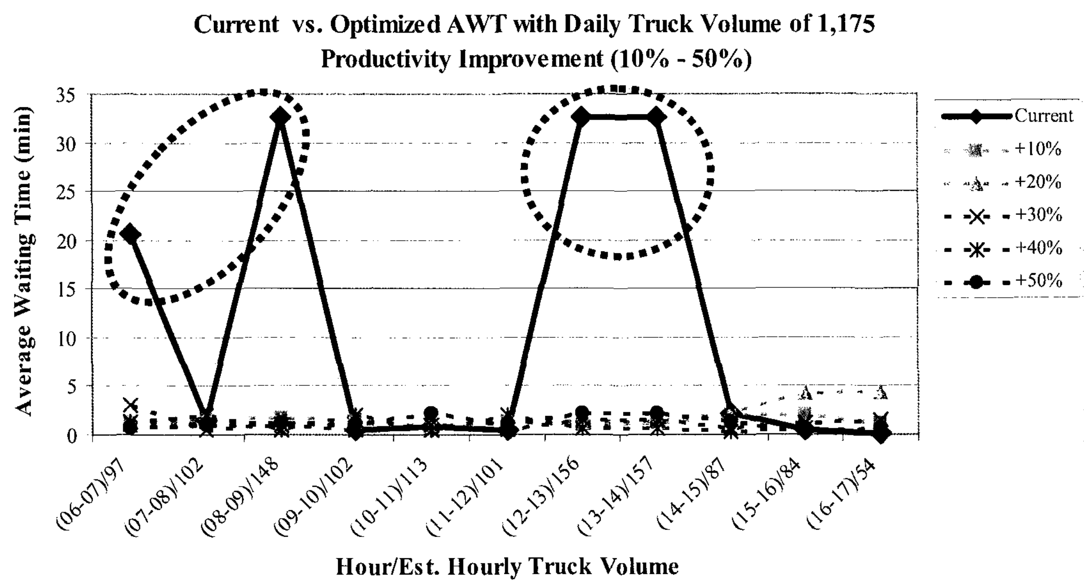


Figure 7.13(b) Average truck waiting time with daily truck volume of 1,175.

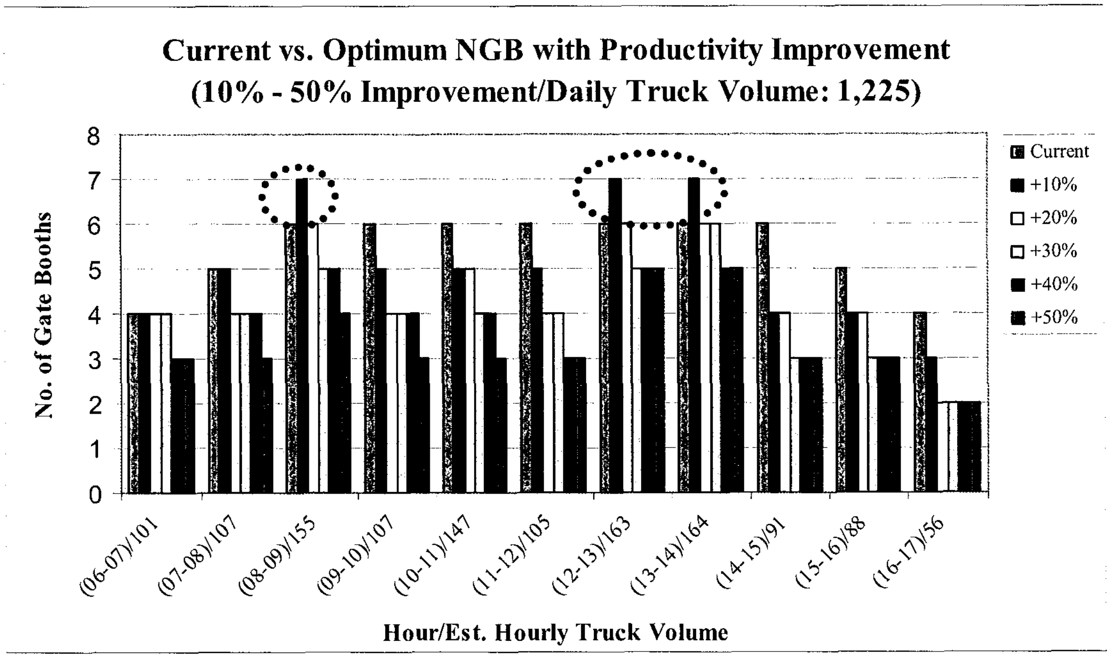


Figure 7.14(a) Number of gate booths with daily truck volume of 1,225.

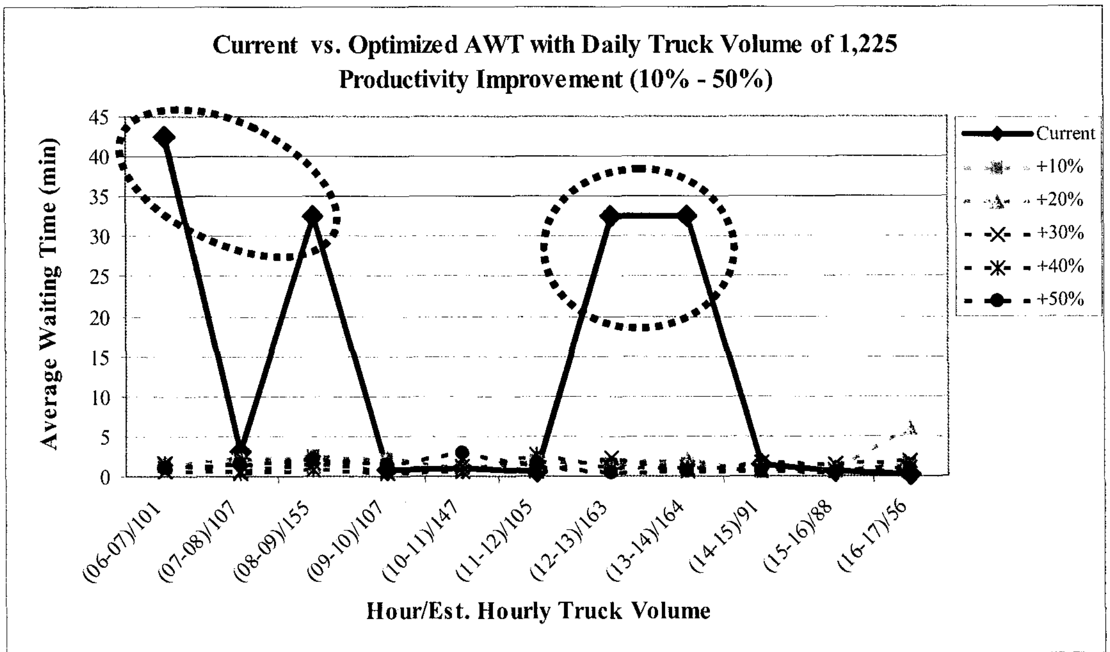


Figure 7.14(b) Average truck waiting time with daily truck volume of 1,225.

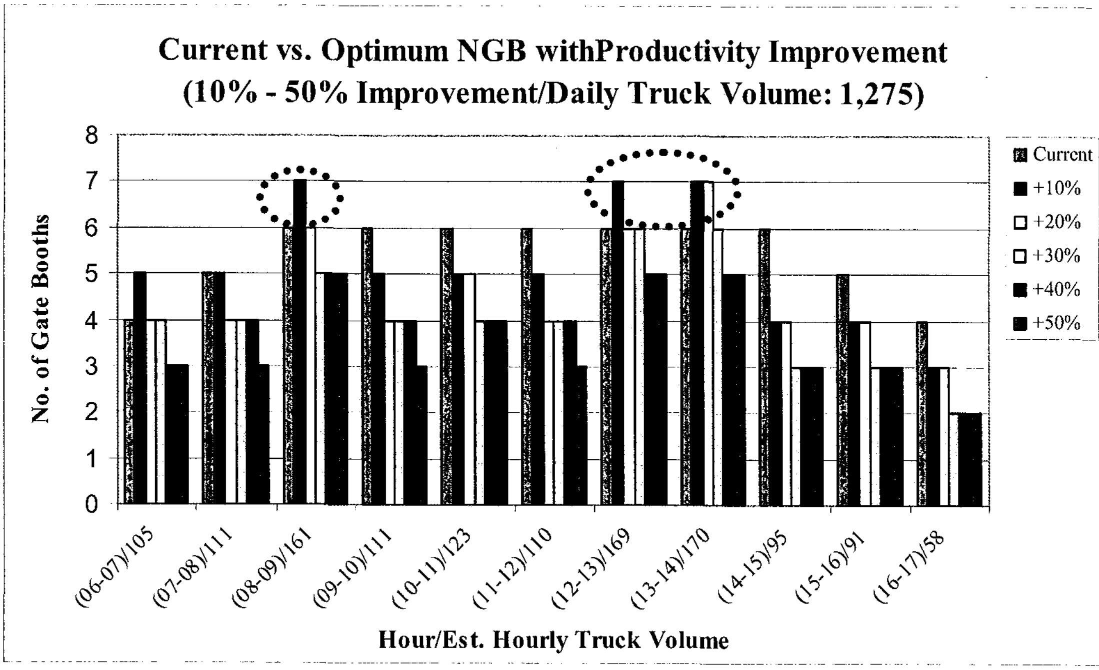


Figure 7.15(a) Number of gate booths with daily truck volume of 1,275.

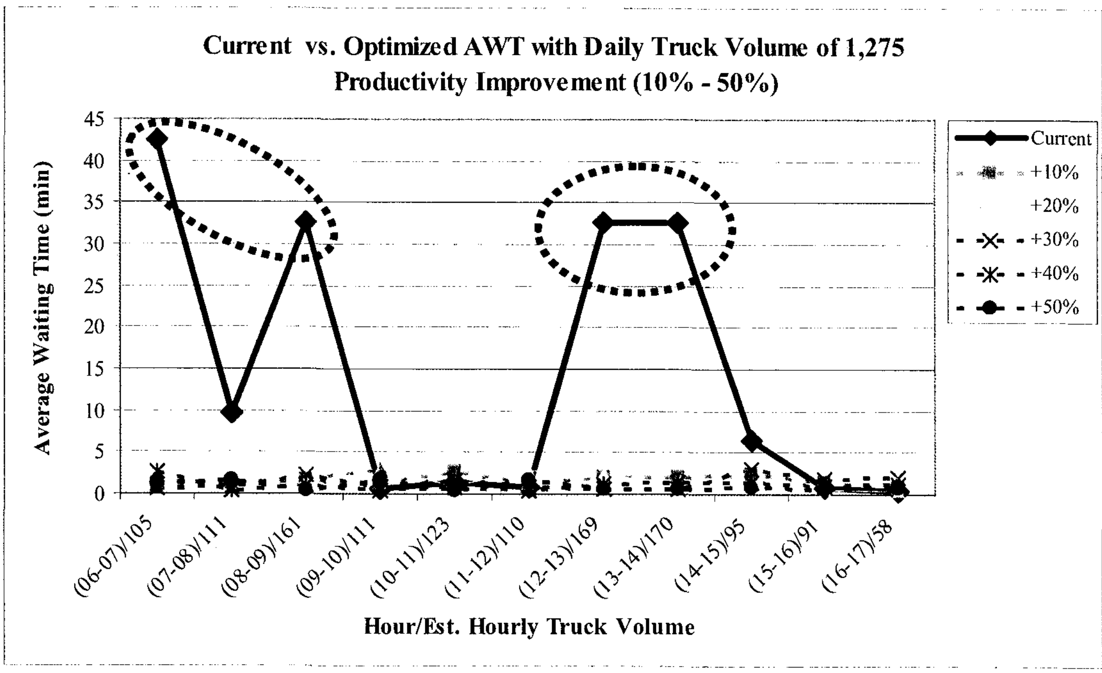


Figure 7.15(b) Average truck waiting time with daily truck volume of 1,275.

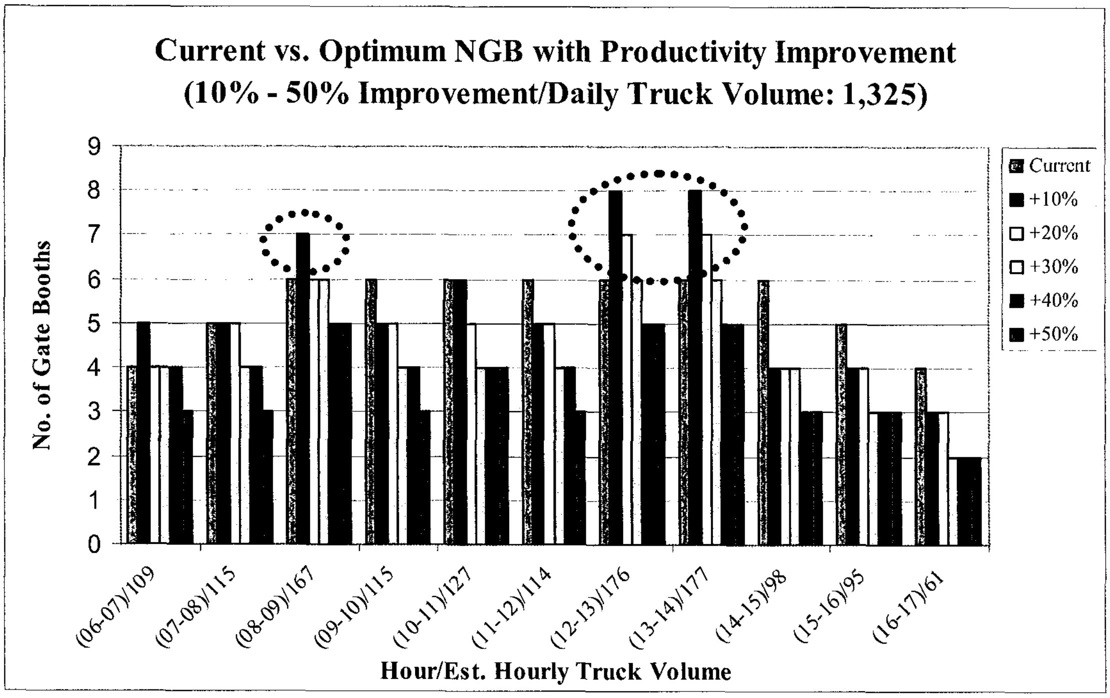


Figure 7.16(a) Number of gate booths with daily truck volume of 1,325.

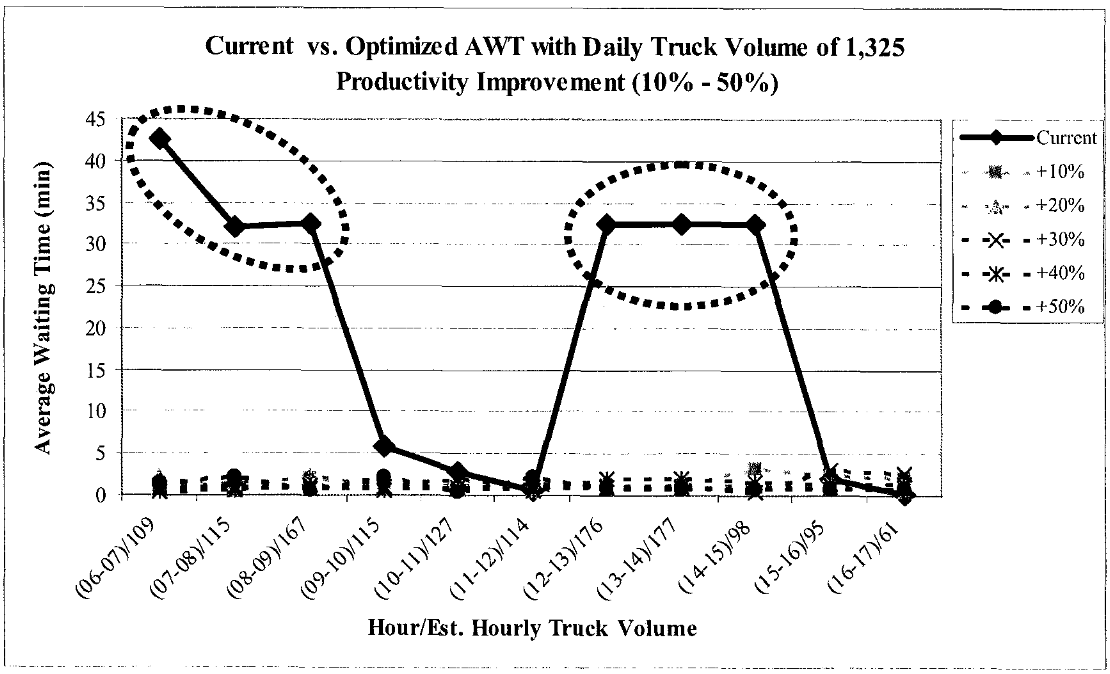


Figure 7.16(b) Average truck waiting time with daily truck volume of 1,325.

Figures 7.7(a) through 7.16(b) clearly indicate that gate system optimization with productivity improvement reduces the number of gate booths required, except on days when truck volume is above 1,175; seven gate booths (one additional gate booth) are needed with 10% improvement in productivity, given the current inbound gate configuration. In all other scenarios in which productivity improvement is more than 20%, the current system configuration provides sufficient capacity to handle all the current traffic volume and beyond and no physical expansion is needed. Furthermore, through gate processing productivity improvement, all optimization schemes are able to control the AWT below five minutes; such AWT is quite favorable to truckers. On the other hand, it is equally important that the number of gate hours needed to achieve these optimization schemes are also less than the current gate hours per day. The results of the gate system optimization with productivity improvement are summarized in Table 7.6.

Table 7.6 Summary of Optimization Results with Productivity Improvement

Daily Truck Volume		Optimization Results with Productivity Improvement									
		875	**925**	**975**	**1025**	**1075**	**1125**	**1175**	**1225**	**1275**	**1325**
Current	NGH	58	58	58	58	58	59	59	60	60	60
	WTPD	8.74	13.42	19.04	31.38	72.17	195.20	293.74	346.39	381.20	497
+10%	NGH	42	46	45	47	49	50	56	56	57	60
	WTPD	21.33	25.34	26.41	29.10	29.28	79.77	55.42	65.41	78.41	75
+20%	NGH	36	39	39	42	45	45	48	49	51	45
	WTPD	24.32	22.55	34.52	27.64	23.81	35.26	32.76	36.09	38.38	27.81
+30%	NGH	33	35	35	38	39	42	43	44	45	47
	WTPD	15.82	17.33	25.82	20.77	22.71	18.63	24.32	25.35	28.57	27.15
+40%	NGH	32	33	34	35	35	38	40	41	42	43
	WTPD	11.16	15.54	16.43	18.20	29.25	20.98	21.33	21.19	23.67	27
+50%	NGH	25	31	33	33	34	36	35	37	39	39
	WTPD	31.03	16.62	11.17	15.39	18.43	18.55	28.19	24.77	19.95	25.88

Remarks:

NGH: Number of gate hours

WTPD: Waiting time per day in hours

Table 7.6 illustrates the effectiveness of the system optimization through productivity improvement in both the number of gate hours and the total waiting time per day. In all optimization schemes, not only is the amount of truck waiting time reduced drastically especially when daily truck volume is high, but also on the number of gate hours. This has important implications for terminal management on resources allocation. As a result, the overall operational and financial performances of the gate system are greatly improved, shown in Figures 7.17(a) and 7.17(b).

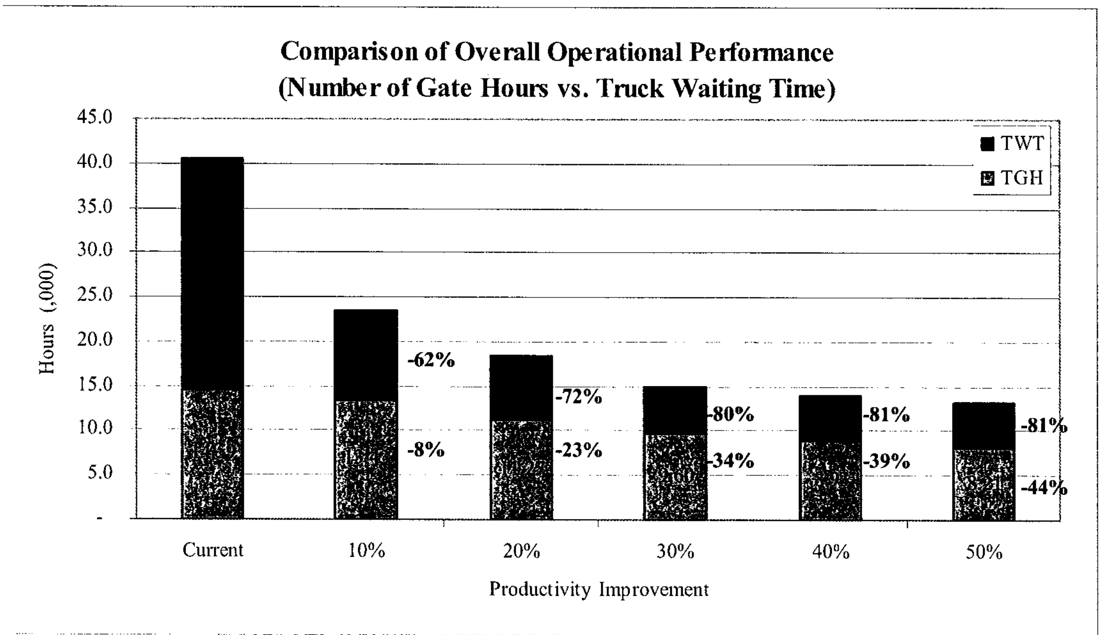


Figure 7.17(a) Overall operational performance.

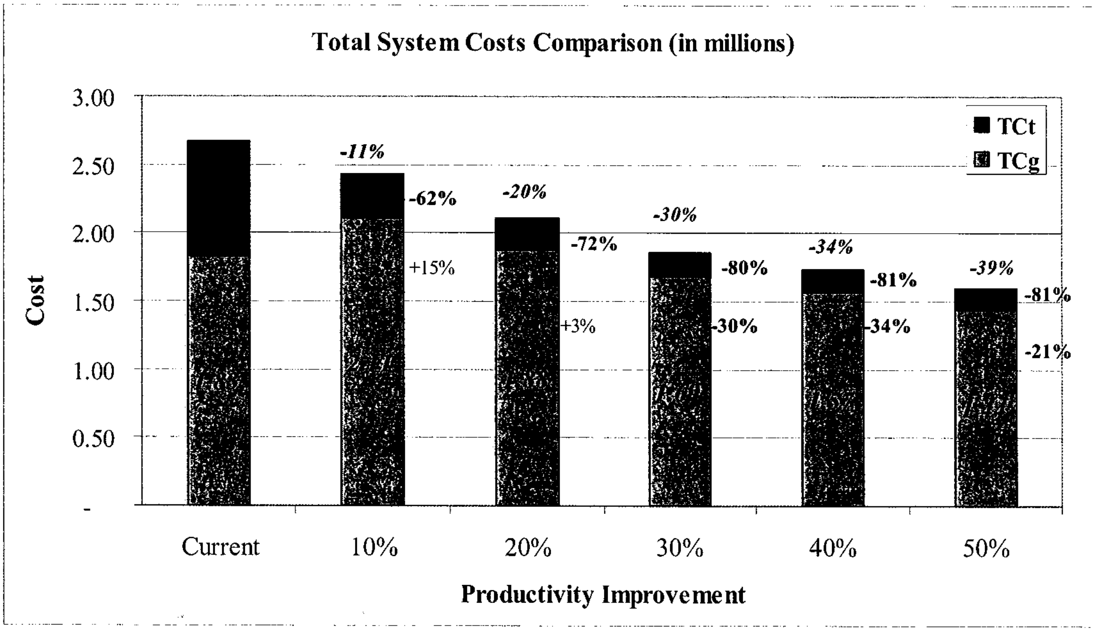


Figure 7.17(b) Overall financial performance.

Remarks:

TGH:	Total Annual Gate Hours
TWT:	Total Annual Waiting Time
TC_g:	Total Annual Gate Operating Costs
TC_t:	Total Annual Truck Waiting Costs

Figure 7.17(a) shows a significant reduction in TWT. The current TWT is 25.92 thousand hours; after optimization, the TWT is reduced to 9.97 thousand hours with 10% productivity improvement; to 4.91 thousand hours with 50% improvement, ranging from 62% to 81% reduction, compared with the current situation. As the same time, the TGH is also reduced ranging from 8% to 44%, respectively. Consequently, both the gate operating cost and truck waiting cost are also reduced substantially. However, due to capital investment in the IT system to improve productivity, the changes in gate operating cost do not have the same percentage as in the number of gate hours shown in Figure 7.16 (b). It indicates that when productivity

improvement is less than 30%, the gate operating cost actually goes up, even though the NGH is down. This demonstrates that for the MCT management, if productivity improvement gained by installing a new IT system for the gate is less than 30%, then it is not cost effective. To achieve operating cost reduction and lower truck waiting cost simultaneously, the productivity gain should not be less than 30% under the circumstances.

In summary, this section analyzes the gate optimization with productivity improvement; it clearly shows productivity improvement can greatly reduce truck waiting time by more than 60% while lowering the number of gate hours required. Most significantly, the average truck waiting time is below five minutes in all scenarios. This is a win-win solution that the MCT can increase its capacity without physical expansion and have a congestion free gate system when they come to the MCT for pickups and deliveries. Given the capital investment needed, the productivity gain provided by the new IT system shouldn't be less than 30%; the gate operating cost would exceed the current one for the MCT operator.

7.3 Optimization by Appointment

In the earlier analysis of gate system optimization, it addresses the issues of how to come up with adequate gate capacity to meet the demand and minimize the total gate system cost; the focus is on the supply side of the issue. Optimization by appointment is a policy based approach to optimize the gate system so that the demand and supply of gate capacity are matched. This can be achieved by managing the truck arrival rate λ through a gate appointment system. In essence, it is a demand management approach.

In general, the MCT operator knows more or less its gate processing productivity and maximum gate capacity. To reduce gate congestion and optimize the gate system, the MCT can manage truck arrival rate in such a way that the average truck waiting time is below certain level. Average truck waiting time can be found in the multi-server queuing model, Equation (4.4) in Chapter 4. According to the $M/E_K/S$ model in Equation (4.4), average truck waiting time T_t is a function of λ, μ, and S. Instead of manipulating μ and S as in the earlier analysis, the objective is to control λ. The following is the procedures of optimization by appointment system.

1) Estimate daily truck volume based on historical data and vessel cargo booking and schedule.
2) Divide the estimated daily truck volume by the number of working gate hours to obtain λ' by appointment.
3) Use the optimization model, Equations (4.28), (4.29), (4.31), and (4.32), to determine the optimum number of gate booths.
4) Use the optimization model to determine maximum targeted truck waiting time.
5) Set limits of hourly truck arrival rates.
6) Let truckers book appointments
7) Compare booked truck arrival rates and optimized truck arrival rates to adjust manning level if necessary. If the former is less than the latter, then the manning level can be reduced.

Following the above procedure, for the different daily truck volumes, λ' can be obtained by dividing the estimated daily truck volume by the number of working gate hours. For example, if the estimated daily truck volume is 1, 025 and the number of gate working hours is 10.5 hours, then the λ' is about 98 (1,025/10.5 = 97.6). To determine the optimum number of gate booths, it is necessary to conduct an analysis because the capital investment is needed to obtain an appointment system. Therefore, C_g will be different, resulting in different $R_{TC(i)}$.

Assuming that the cost of such IT software is \$500,000 and the recovery period is five years, using straight line depreciation method, the annual depreciation is \$100,000. Given 250 working days per year, eleven hours per day, and total of six gate booths, the hourly cost for the appointment system per gate booth is \$6.06 (100,000/250/11/6 = 6.06). Therefore, the new C_g = 50.3 + 6.06 = \$56.36 per hour. Substitute this new C_g into Equation (4.28), (4.29), (4.31), and (4.32), the results are the following:

Table 7.7 Optimum Number of Booths and Its Corresponding Truck Arrival Rates

S	1	2	3	4	5	6
λ'	1-23	24-44	45-68	69-89	90-113	114-134
Max λ	23	47	70	94	117	140

Table 7.7 shows that the ranges of optimum truck arrival rates with respect to the number of gate booths as well as the maximum truck arrival rates that will not cause high truck waiting time. For instance, if λ' = 98, the optimum number of gate booths is five; the saturation truck arrival rate is 123 (5 x 0.4 x 60 = 123). From the earlier analysis in Chapter 6, congestion does not exist until the utilization rate is above 95%. Between 95% and 99.9% utilization, congestion develops exponentially. Therefore, the 95% utilization can be set as the maximum truck arrival rate, which is equal to 117 (123 x 95% = 117). As a result, difference between the λ' and the maximum truck arrival rate is 19 (117 – 98); this will become the buffer to allow extra trucks in case of urgent shipment. The following are optimization schemes for the ten different estimated daily truck volumes ranging from 875 to 1,325, Figures 7.17(a) to 7.17 (j), respectively; Est. λ = estimated hourly truck arrival rate, λ' = hourly truck arrival rate by appointment, AWT = current average truck waiting time, and AWT' = optimized average truck waiting time by appointment.

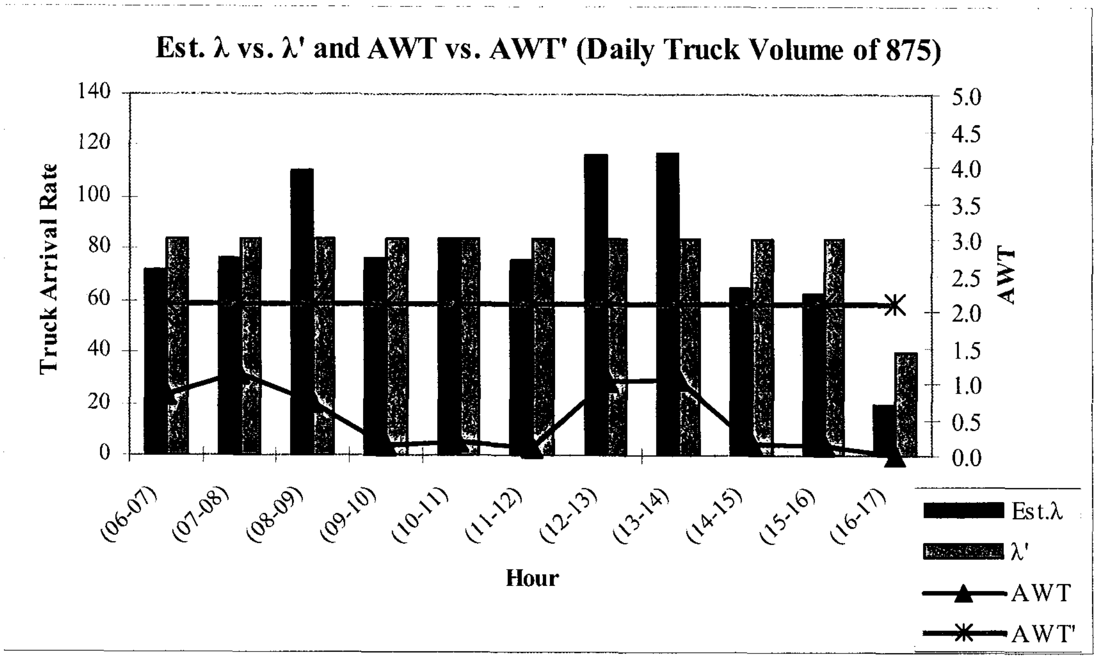


Figure 7.18(a) Appointment system performance with daily truck volume of 875.

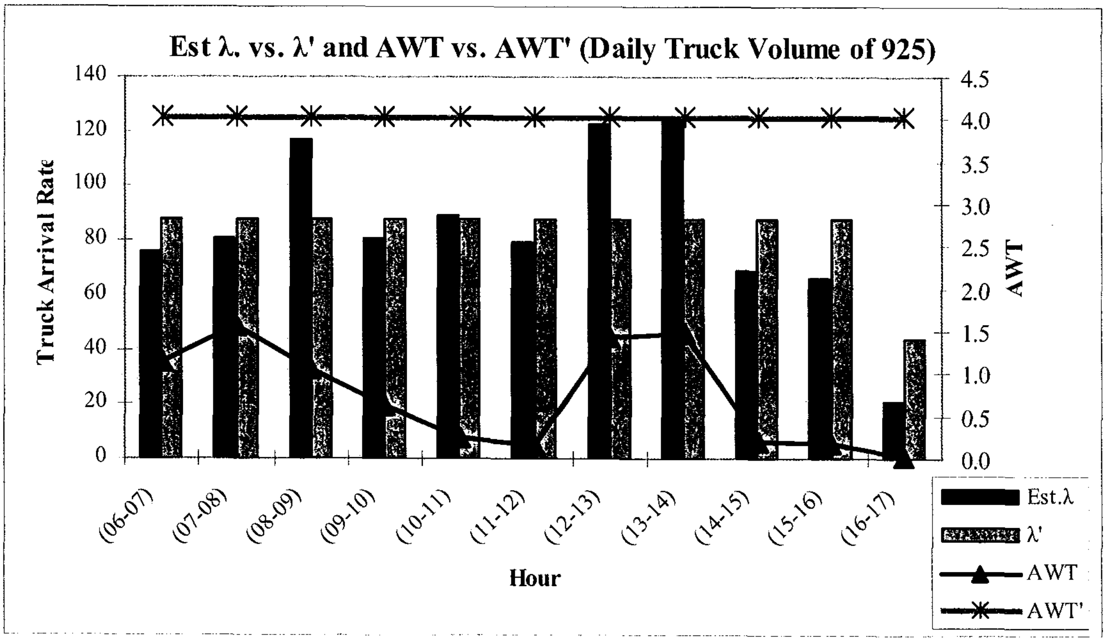


Figure 7.18(b) Appointment system performance with daily truck volume of 925.

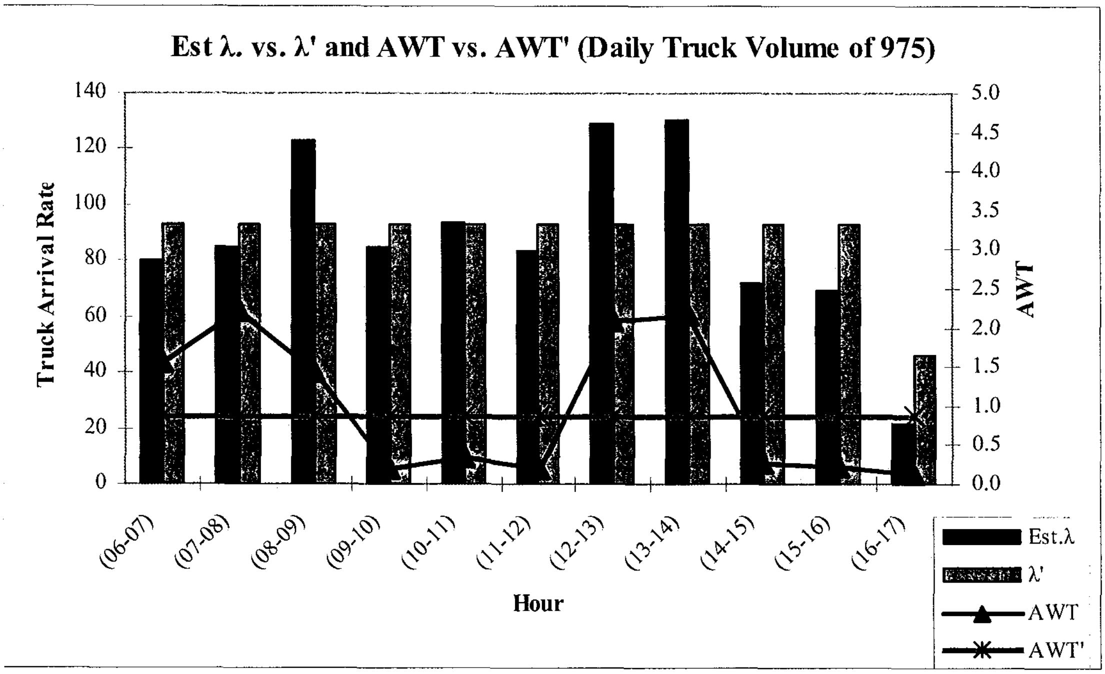


Figure 7.18(c) Appointment system performance with daily truck volume of 975.

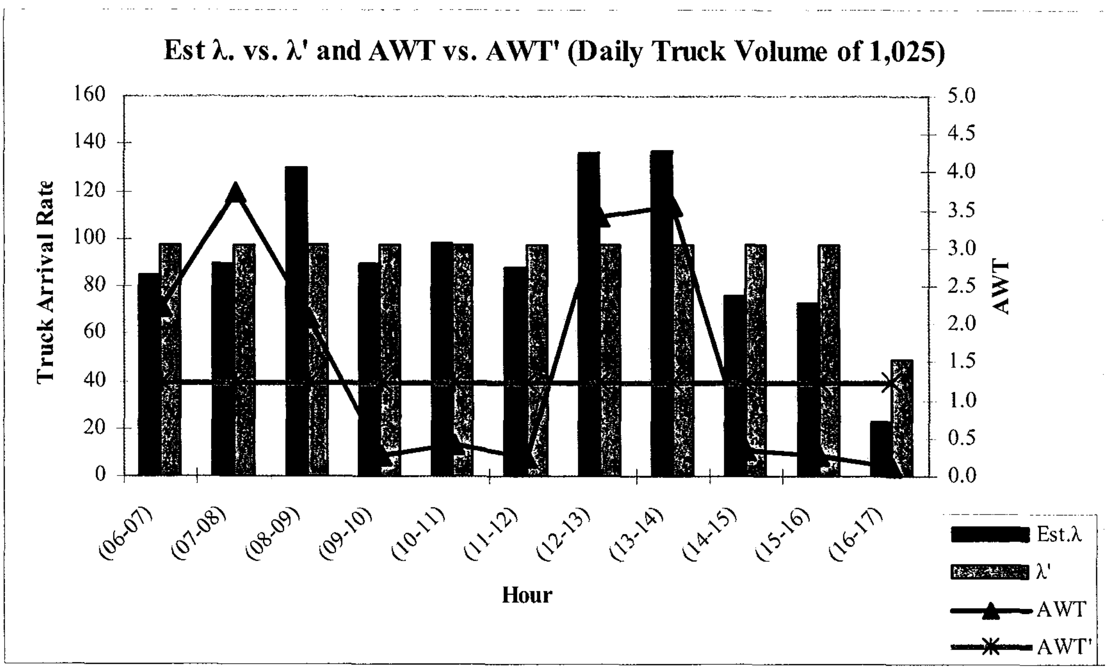


Figure 7.18(d) Gate system performance with daily truck volume of 1,025.

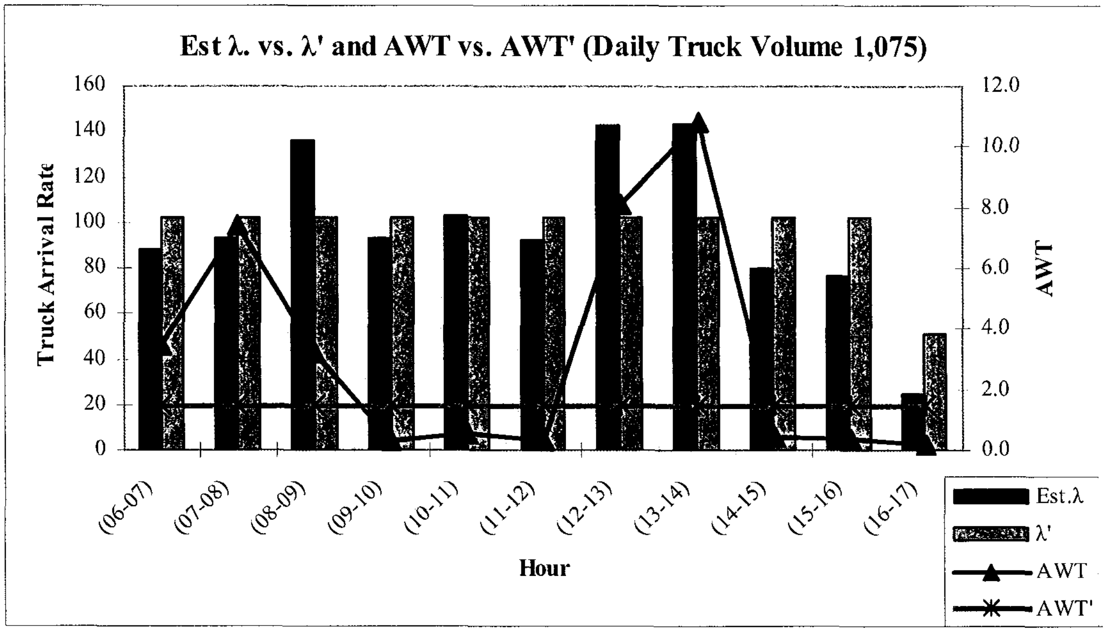


Figure 7.18(e) Gate system performance with daily truck volume of 1,075.

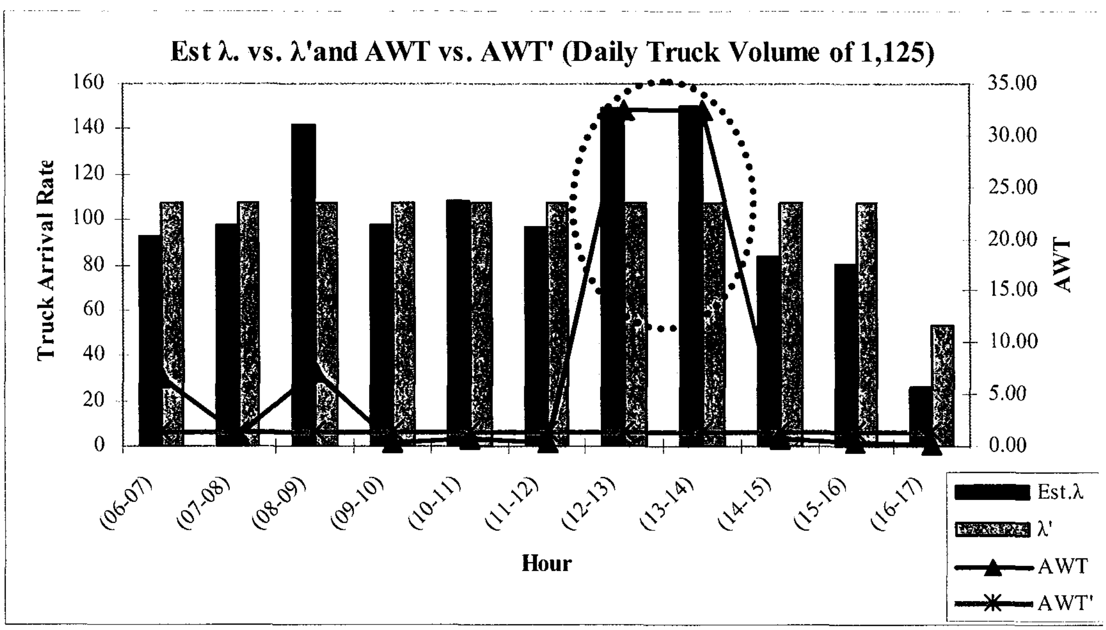


Figure 7.18(f) Gate system performance with daily truck volume of 1,125.

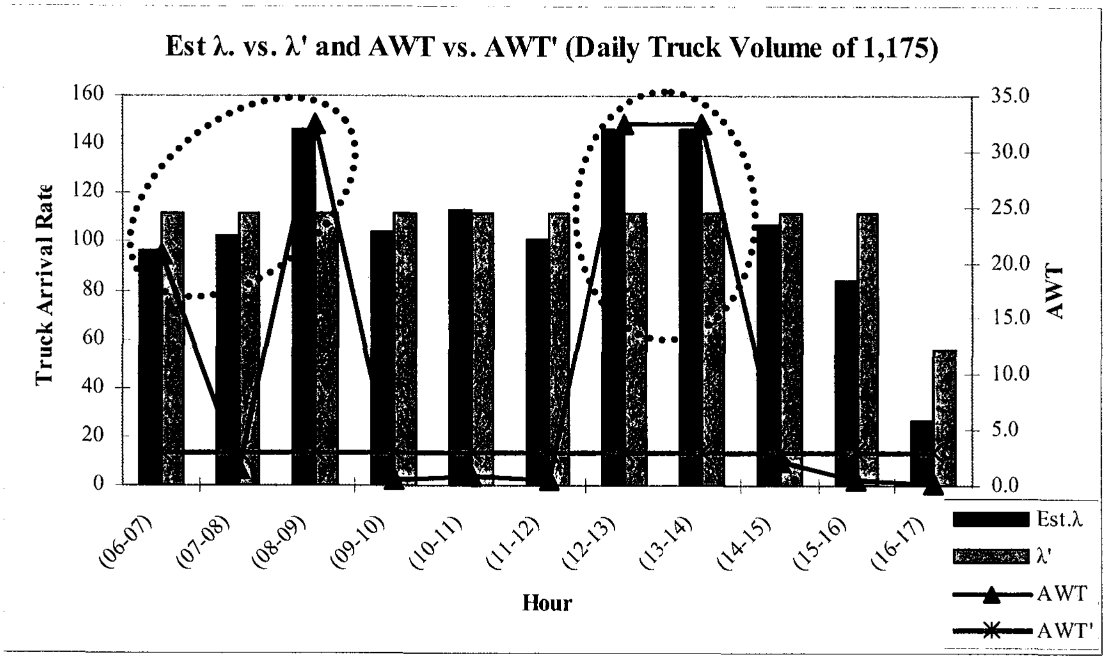


Figure 7.18(g) Gate system performance with daily truck volume of 1,175.

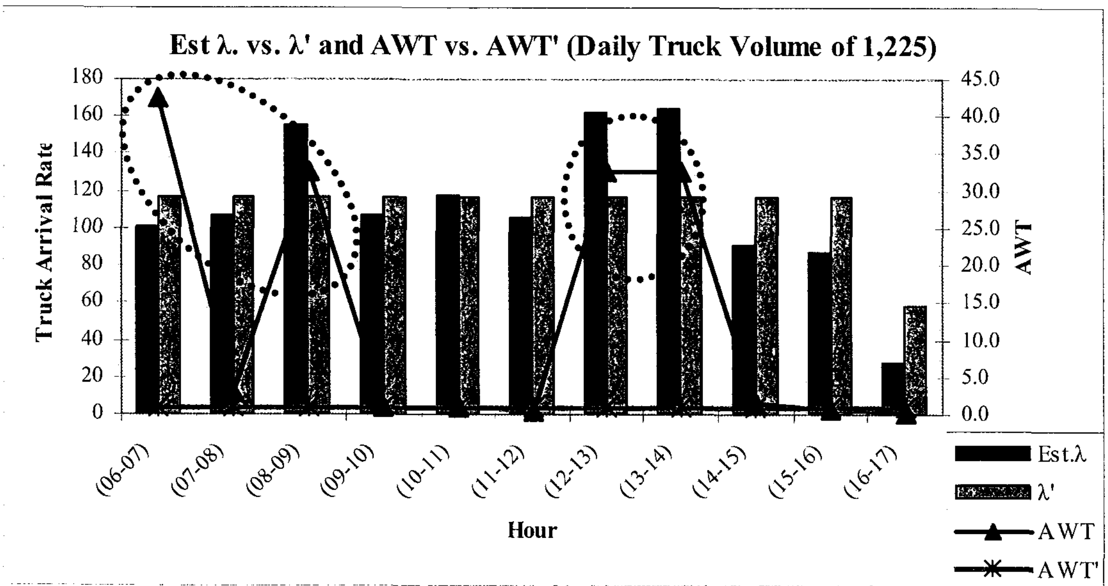


Figure 7.18(h) Gate system performance with daily truck volume of 1,225.

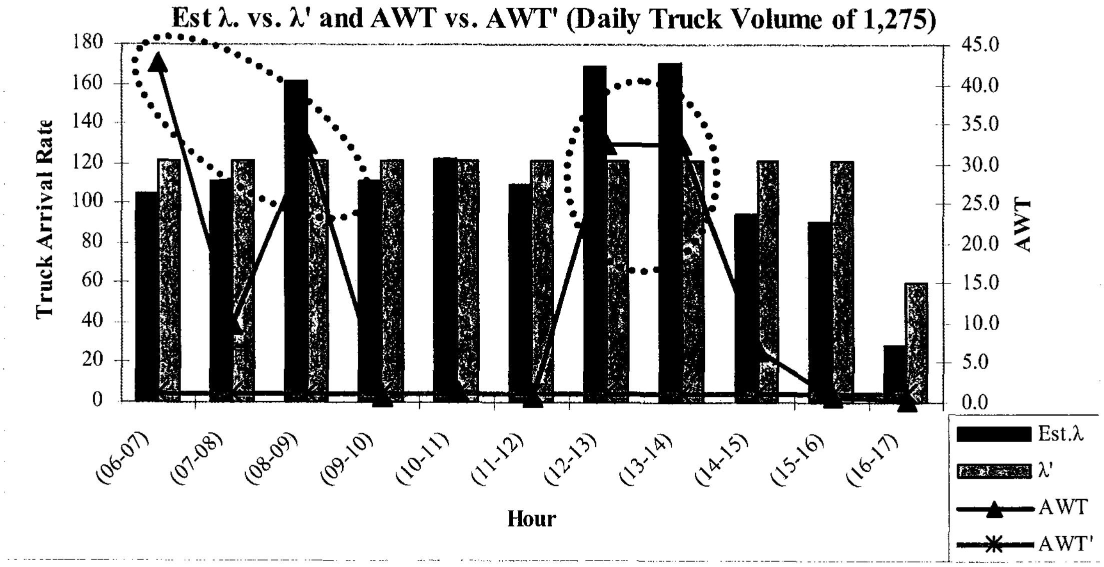


Figure 7.18(i) Gate system performance with daily truck volume of 1,275.

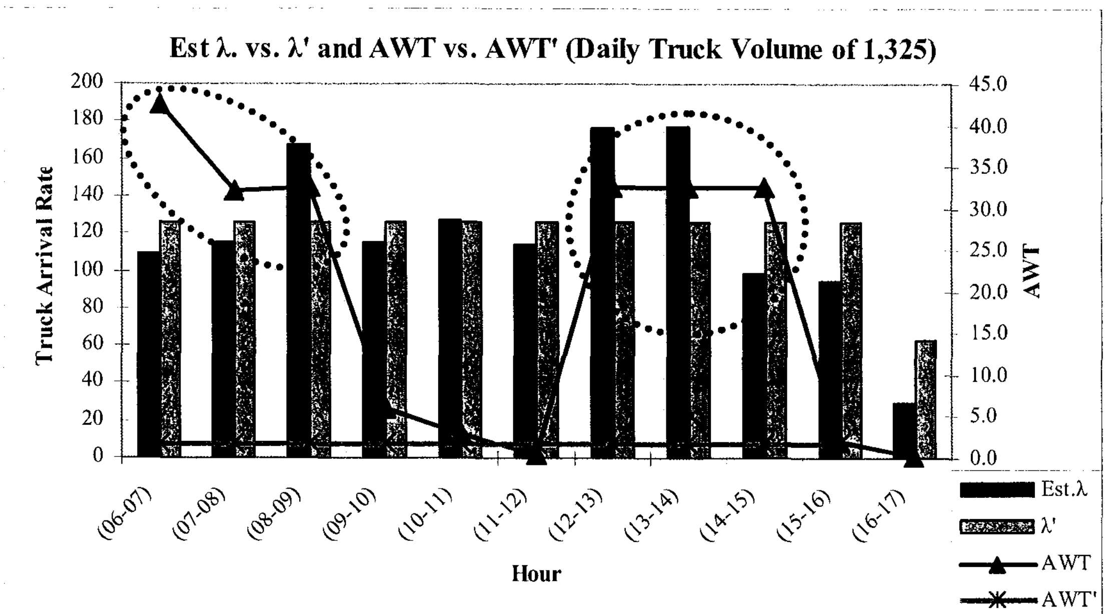


Figure 7.18(j) Gate system performance with daily truck volume of 1,325.

Figures 7.18(a) through 7.18(j) provide a series of comparisons of gate performance between the current system and the optimized system by appointment. By "regulating" the hourly truck arrival rates through an appointment system, the truck arrival rate can be set up in such a way that there is no peak or valley so that the gate system can be optimized. Based on the optimization model, the results show that truck waiting time can be reduced significantly during peak periods. Even though, in days with low truck volume, average waiting time is slightly increased, but the overall average truck waiting time does not exceed five minutes. This amount of waiting time is quite small as compared to more than the average waiting time of 40 minutes during high daily truck volume days. A series of comparison of overall gate system operational and financial performances are presented in Figures 7.19(a) through 7.19(c).

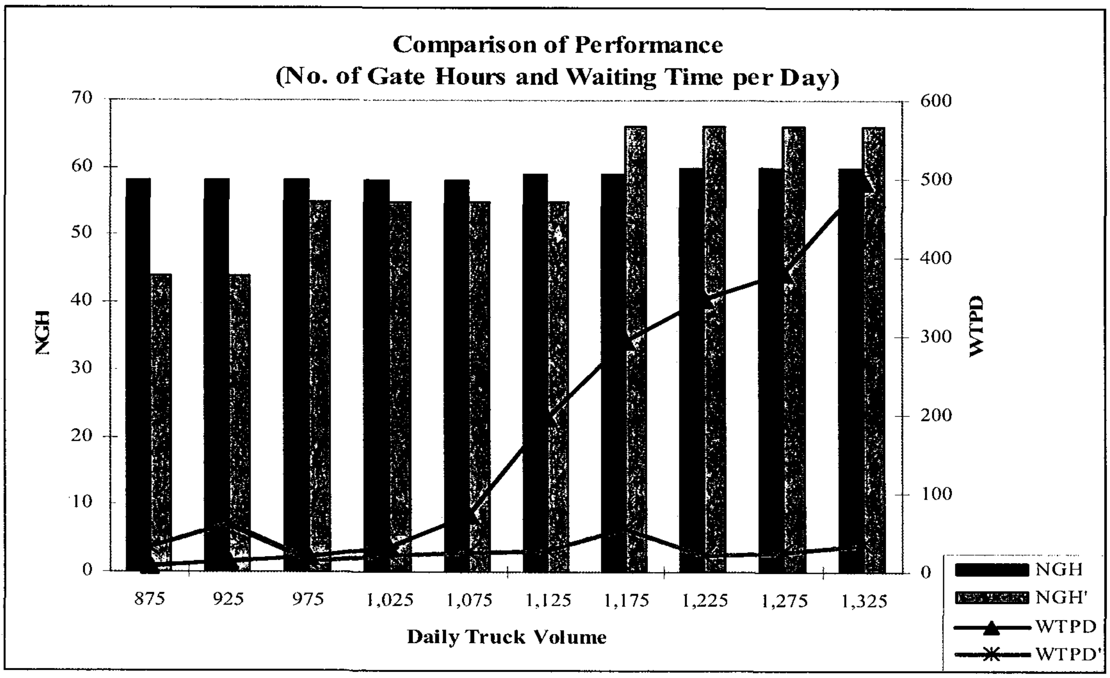


Figure 7.19(a) Comparison of overall system performances.

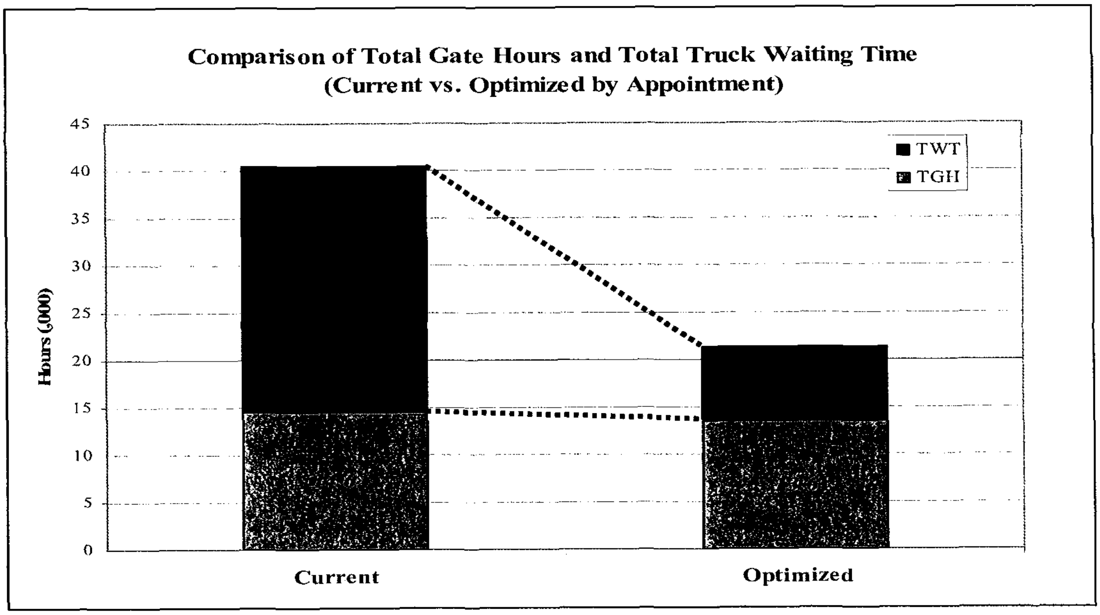


Figure 7.19(b) Comparison of total gate hours and total truck waiting time.

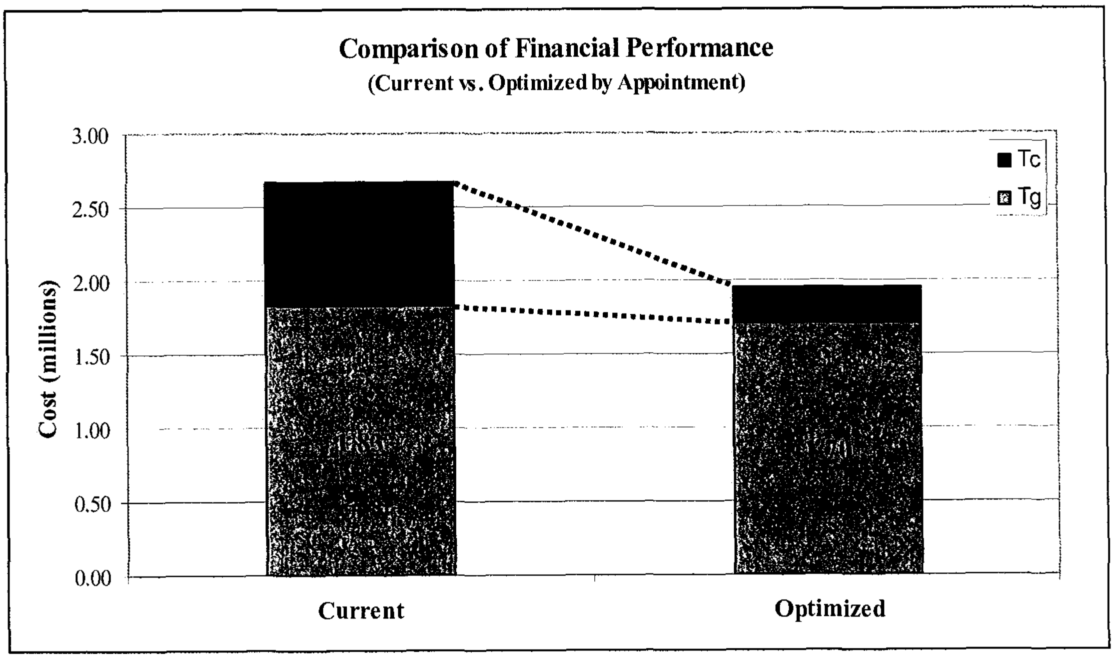


Figure 7.19(c) Comparison of gate operating cost and truck waiting Cost

Figures 7.19(a) through 7.19(c) clearly show that the appointment optimized system provides a mechanism that allows the MCT to control truck arrival rates, the demand side of the gate system. Such an on-demand system enables the MCT to set a target of truck waiting time, allocate gate system resources, improve performance, and reduce costs for both the MCT and truckers. As demonstrated in Figure 7.18(a), the average truck waiting time is quite consistent under all ranges of daily truck volume, and at the same time the gate hours per day are determined according to daily truck volume. This means the gate processing capacity is in synch with demand, therefore, optimizing system resources. As a result, the truck waiting time is reduced by more than two-thirds, so is the truck waiting time cost. Meanwhile, the gate operating cost is also lower by 7.1%. In addition, such optimization by appointment provides the flexibility to have reserved gate capacity to deal with truck arrivals without appointment within the control limit in terms of truck waiting time. Furthermore, it also provides an effective mechanism to allocate yard handling equipment and truck turnaround time, since demand is more predictable so the yard management can optimize container stacks to reduce turnaround time as well. Lastly, when combining such appointment with gate productivity improvement, it will become a very effective tool to control gate congestion and improve overall performance at the same time.

7.4 Summary and Implications

This chapter analyzes the gate system optimization issues, quantifies the truck waiting cost, and provides different optimization alternatives to reduce gate congestion and total system costs. First it provides an estimate of daily truck volume and hourly truck arrival rates based on on-site observations and data obtained from the MCT operator. Using statistical testing, the $M/E_K/S$ model is validated and verified against actual observation. Second, based on the waiting model developed in Chapter 4, the annual gate operating cost, truck waiting cost, and total system costs are calculated. Third, several optimization alternatives are analyzed: physical expansion, productivity improvement, and by appointment. Based on the optimization model developed in Chapter 4, there are three parameters that can be manipulated: S, gate physical capacity (the number of gate booths) μ, gate processing productivity, and λ, truck arrival rate. The results are summarized below.

Truck Waiting Time and Cost: for this particular MCT, most of the time the gate was not congested and truck waiting time is well below 30 minutes. 70% of the time, the gate is not congested; gate congestion occurred mostly during peak season. However, during peak season, the gates system experienced severe congestion. When daily truck volume is below 1,100, truck waiting time is relatively low; but it increases exponentially when the daily truck volume is more than 1,100. The annual direct truck waiting cost is $808,503 using the figure of $32.15 per hour in the 2005 FHWA report. When opportunity cost figure of $55.00 per hour is applied, the annual truck waiting cost becomes $1,383,131. Using a simple extrapolation, this MCT has a market share of 15% of the Port of New York/New Jersey; the estimate on the total truck waiting costs for the entire port based on market share and container volume, and similar truck traffic patterns, the total annual truck waiting costs are $5,390,020 (808,503/0.15) in direct cost ($32.15 per hour). If the opportunity cost is applied, the annual truck waiting cost would be $9,220,873 (1,383,131/0.15). The total annual truck waiting time for the entire port is 172,767 hours (25,915/0.15). Based on the current federal regulations that a commercial truck driver can only have 10 hours of continuous driving or 14 hours combination of waiting and driving, the 25,915 hours of waiting time is translated into 2,592 net driving days and 1,851 working days for this particular MCT in this study. For the entire port, the total annual truck waiting time amounts to

17,280 net driving days and 12,340 working days. These indicate substantial truck waiting cost and time incurred for the port, resulting in waste and lost productivity for the port.

Optimization through physical expansion: using the optimization model developed in Chapter 4, the gate system can be optimized through marginal expansion of its gate capacity by additional gate booths; the focus is on S. The calculation shows that only two additional gate booths are needed and the overall system costs can be reduced from $2,641,499 to $1,916,640, a 27% saving through optimization. In particular, the direct truck waiting cost is cut by 71% from $808,503 to $242,563; while the total gate system operating cost for inbound trucks is reduced by 8% from $1,832,996 to $1,684,077. In addition, the sensitivity analysis indicates that a small increase in gate processing capacity could yield a large reduction in truck waiting time. Most importantly, the average truck waiting time will not exceed five minutes. However, the gate system optimization requires the flexibility in opening and closing gate lanes as well as the use of gate clerks. This might be difficult to obtain due to labor contract requirements. Also, due to scarcity of waterfront land, large scale physical expansion may not feasible.

Optimization through productivity improvement: in this optimization scheme the focus is on μ. A range of gate processing productivity improvement from 10% to 50% is applied to the optimization model developed in Chapter 4. The optimization results indicate that the current annual truck waiting time of 25.92 thousand hours can be reduced to 9.97 thousand hours, a 62% reduction based on 10% productivity improvement and 4.92 thousand hours, an 81% reduction based on 50% productivity improvement, respectively. As the same time, due to additional cost of a new IT system, the gate operating cost will be higher than the current one if productivity improvement is below 30%. When such productivity improvement is increased from 30% to 50%, the gate operating cost will also be reduced from 8% to 44%, respectively.

Consequently, both the gate operating cost and truck waiting cost are also reduced substantially. Meanwhile, the average truck waiting time is below five minutes after optimization. Overall, with 50% productivity improvement, the annual truck waiting cost will be reduced to $160,000, an 81% lower than the current one; the gate operating cost will also be reduced from the current $1.83 million to $1.44 million. The sensitivity analysis indicates that a small improvement in gate processing productivity will result in significant reduction in truck waiting time. Another major advantage is that there is no need for physical expansion to optimize the gate system and the gate system can handle much higher gate volume, accommodating future growth in container volume. On the other hand, this optimization scheme also requires flexibility in gate manpower and the number of gate booths.

Optimization through appointment system: this optimization approach is done through the manipulation of λ. In contrast to the previous two optimization approaches, this one is focused on the demand side of the gate system. The previous two approaches are focused on the supply side of the gate system. The preceding optimization approaches indicate that the gate system reacts to the change in demand, truck arrivals. This optimization approach provides a mechanism to manage the demand for gate system processing capacity. This is achieved by controlling the number of truck arrivals in a given time period so that truck waiting time can be maintained at optimal level. The optimization results indicate that due to effective control of truck arrival rates, average truck waiting time is below five minutes. Both the gate operating cost and truck waiting cost can be reduced from $1.83 to $1.70 million and from $0.83 to $0.25, respectively. Most importantly, the appointment system allows the MCT to match supply and demand for gate processing capacity, and control congestion level at the MCT gate, a more effective way to manage gate resources and congestion.

All the optimization results indicate that there are different ways to improve efficiency of the gate system operations and reduce the truck waiting time. The key for optimization is to come up with an appropriate queuing model to analyze the relationship between truck arrivals and gate processing capacity. Through the manipulation of the three critical parameters: S, μ, and λ in the queuing model, the gate system can be optimized. The optimization results have several important implications, which will be discussed in the last chapter.

CHAPTER 8

CONCLUSION AND IMPLICATIONS

This dissertation has analyzed the MCT gate congestion issues and reviewed the limitations of previous researches on this subject, especially in the quantification of truck waiting cost. A general frame work has been applied to identify gate system components and their relationship. This helps better understand MCT gate system operations and root causes of gate congestion. A total system cost model is developed to measure truck waiting cost and gate system operating cost. Several alternatives are utilized to optimize the gate system operations. The optimization results provide possible solutions to mitigate gate congestion, reduce operating cost, and improve gate system efficiency. The conclusion and implications of this study, practical consideration for implementations, and further research needs are presented in this chapter.

8.1 Conclusion

The major contribution of this study is the analysis of gate system congestion behavior, the quantification of economic cost of gate congestion on harbor truckers and alternatives of gate system optimization. Using a combination of operations research technique and economic analysis, a total system cost model and an optimization model are developed. Data collection and comprehensive data analysis are conducted to test and validate the models developed. The modeling and optimization results are applied to measure gate congestion cost and improve gate system efficiency.

8.1.1 On-site Observation, Data Collection and Data analysis

In the previous studies, there is lack of detailed data analysis regarding MCT gate operations, variation in vessel container volume, daily truck traffic patterns, and gate processing procedure. This study undertakes a comprehensive analysis to identify patterns of vessel container volume, daily truck traffic, and the relationship between them, based on on-site observation, gate camera observation over the internet, and data provided by the MCT.

Since the essential piece of this study is the truck waiting cost at the MCT gate, the on-site observation is fundamental to understand how the gate system works, its operational process, and truck traffic patterns. Based on on-site observations and the characteristics of the MCT gate system, it provides the basic foundation for the application of queuing models. To identify basic parameters of a queuing model, on-site observations and data collection provides first-hand experience and in-depth understanding of the MCT gate system, system operations, and relevant operational processes. Data collected from on-site observations proves to be critical in determining the appropriate queuing model in this study.

To understand truck arrival patterns and the relationship between truck arrival and gate congestion, it is essential to identify the relationship between vessel container volume and truck trip generation, a comprehensive data analysis is undertaken, using raw data provided by the MCT. Such data analysis reveals the critical relationship between vessel container volume and gate truck traffic. It also identifies the patterns of daily truck traffic, which is critical in the calculation of annual truck waiting time and waiting cost.

Furthermore, it helps to understand the magnitude of growing container volume, truck traffic volume, and the impacts on infrastructure requirements and planning.

8.1.2 Determination of Queuing Model and Modeling Results

The application of queuing theory provides an effective mechanism to analyze gate congestion behavior. There are different queuing models. To determine which model to use, the determinants are the statistical distribution of inter-arrival rates and service times. Using on-site observation data and statistical testing, the $M/E_K/S$ model is chosen and validated. This model serves as a base to measure gate congestion: truck waiting time and cost. It also reveals the importance of proper data processing and statistical testing.

Using data from on-site observation data, on-line gate cameras, and interviews with management personnel of the MCT, a case study is used to verify the effectiveness and accuracy of the model. The results of the case study provide an effective tool to measure the magnitude of truck waiting time and waiting cost. More importantly, it indicates that the gate system is very sensitive when system utilization rate is about 95%. On the other hand, there is very little congestion at the gate when the system utilization is below 95%.

Using the total cost model developed in Chapter 4, based on the $M/E_K/S$ model, the modeling results reveal that there is a substantial amount of truck waiting cost incurred during peak periods, meanwhile the gate system is under-utilized during slow season. It indicates that the gate system is not optimized, resulting in high congestion cost and loss of productivity for both the trucking community and the MCT operator. In essence, the magnitude of the truck waiting cost is quantified; it confirms the concerns expressed by the harbor trucking industry.

8.1.3 Gate System Optimization

To optimize the gate system, an optimization model is developed with the objective of minimizing total system costs. Since there are three critical parameters of queuing theory: truck arrival rate, λ; gate processing rate, μ; and the number of gate booths, S, this leads to three optimization approaches: physical expansion, increasing S; productivity improvement, higher μ; and truck appointment system, controlling λ; respectively. The first two are concentrated on the supply side of the system, mainly in providing sufficient gate capacity to meet the demand. On the other hand, the third approach is concentrated on the demand side, mainly in matching the demand with the existing supply of gate capacity. Based on on-site observation and data provided by the MCT, the hourly truck arrival rates and daily truck volumes are estimated. The results are used as the input for optimization.

Expanding the gate capacity requires additional land. Large scale expansion may not be feasible due to scarcity of land; and it also takes a huge amount of capital and long period of time to achieve it. This study uses marginal physical expansion to address the gate optimization issue; it means that the MCT utilizes its existing physical footprint to increase the number of gate booths. Therefore, the capital investment required for such marginal expansion is assumed to be negligible. Applying the optimization model, the results indicate that two additional gate booths are required to deal with peak period truck traffic. The total system costs can be reduced substantially by varying S, responding to different values of λ, but such reduction is mainly from the reduction of the truck waiting cost. The reduction in gate operating cost is relatively small. Most importantly, the results reveal that a small increase in the number gate booths can lead to a large reduction in congestion level, mainly average truck waiting time. Lastly, the optimized gate system leads to no more than five minutes of average truck waiting time in all estimated daily truck volume categories.

To improve gate processing productivity, a robust IT system is required. Such IT system usually involves the use of optical character recognition (OCR) technology and new software and system. Therefore, capital investment is required. Based on the information provided by the MCT management personnel, the capital cost of $2 million is used in this study and several scenarios ranging from 10% to 50% productivity improvement are applied. Using straight line depreciation and a five-year recovery period, the optimization results indicate that the average truck waiting time can be reduced to less than five minutes in all estimated daily truck volume categories. Meanwhile, the gate operating cost can also be reduced. Using productivity improvement for optimization, the reduction in the truck waiting cost is much more significant than that in physical expansion. For example, if the gate processing productivity is increased by 50%, the annual truck waiting cost can be reduced by 81%. On the other hand, regarding the gate operating cost, since capital investment is required, the productivity improvement should be no less than 30% in order to offset the additional cost.

The truck appointment system targets the demand side of the gate system. Rather than responding to random truck arrivals, it manages the truck arrival rates. The objective is to control the truck arrival rate so that gate congestion is unlikely to occur or the congestion level is at an acceptable level. The truck appointment system can be set up based on the optimization model with respect to gate productivity and the number of gate booths, a limit of truck arrival rate can be set to ensure gate congestion would not exceed a certain level. In this way, the MCT can have more control and flexibility to manage its gate system. For example, the MCT can use the lower bound and upper bound in certain optimization scheme to set truck arrival limit while reserving some redundant capacity to deal with random truck arrivals. This enables the MCT to obtain more accurate information regarding truck arrivals in advance, so it can plan gate manning level and streamline the gate operations. The optimization results reveal that the average truck waiting time is less than five minutes in all estimated daily truck volume categories; meanwhile the gate operating cost is reduced.

8.2 Implications and Practical Considerations

This study has revealed several critical issues. First of all, the MCT gate congestion needs to be addressed. With continuing growth of container volume and high fuel costs in recent development, the truck waiting cost issue is going to be more pronounced. In addition, gate congestion also has negative environmental impacts on the MCT and its surrounding environment. Second, this study reveals that the MCT gate system is underutilized in most of the time, especially during slow seasons. Even during peak seasons, there are slacks in system capacity. The occurrence of trucking waiting time longer than 30 minutes is not frequent; this implies that the 30 minute rule implemented in California may not apply in the Port of New York/New Jersey. It is not reasonable to ask the MCT to provide sufficient capacity to meet truck volume when it does not control the shipper's decision for container pickup and delivery, nor does it know in advance specific date and time a trucker comes to the MCT. On the other hand, truckers do face heavy congestion during peak seasons and their waiting time is not compensated. This indicates the need for gate system optimization. The optimization results have several important implications.

8.2.1 Implications

This study has clearly demonstrated that the MCT gate system can be optimized to reduce both the truck waiting time and cost, and the gate operating cost, using an analytical model. The queuing model and optimization model developed in this study provide viable alternatives to manage the MCT gate system more efficiently. Among the three optimization approaches, physical expansion may be the least effective since it requires additional land and such additional capacity is only needed in a limited way. The system capacity is mostly under-utilized. Furthermore, land availability is finite in a port; with population growth and increasing awareness of environmental concern, acquiring additional land for expansion is always difficult. It might be possible to expand the terminal in the long run; but by the time the additional land becomes available, demand might already catch up. The gate congestion problem may not get resolved at all.

Productivity improvement and the truck appointment system provide a much more effective way to optimize the gate system. The productivity improvement enables the terminal to deal with a much larger volume of trucks without increasing the physical footprint of the terminal and reduces the truck waiting time and cost. This can be achieved within the MCT management domain without any interference of any outside party. However, this is a reactive approach because the MCT management still doesn't know truck arrivals in advance; sometimes due to vessel schedule delay and other factors, the gate system still can be overwhelmed with an unpredictable surge of truck arrivals. It is difficult to come up with the additional needed gate capacity.

A truck appointment system is probably the best optimization mechanism amongst the three. First, it provides an effective and proactive tool for the MCT management to control the truck arrival rate so that the truck waiting time or gate congestion level is predictable. Second, the management can plan gate resources more efficiently knowing what to expect. Third, it can also integrate its yard operation with such an appointment system so that the yard equipment can be also optimized. Fourth, it can also standardize service quality due to the more predictable demand. Lastly, the appointment system allows the management to control the gate system utilization to ensure efficient use of gate capacity. However, compared with the other two optimization approaches that truckers can come to the MCT for pickup and delivery at will, the appointment system requires truckers to make advanced appointments with the MCT; the MCT needs to closely work with the harbor trucking community to work out mutually acceptable procedures and business rules; otherwise the successful implementation of the appointment system is in doubt.

8.2.2 Practical Consideration

To implement the gate system optimization strategies in this study, there are some practical considerations that need to be addressed. First, as demonstrated in the analysis, due to the fluctuation in the hourly truck arrival rate it requires flexibility in adding or subtracting gate booths on short notice in order to optimize the gate system in physical expansion and productivity improvement. This poses a serious challenge to the MCT management since the gate system optimization is predicated on the daily truck volume, and more critically, the hourly truck arrival rates. But based on the interviews with terminal management personnel and the author's research, they can only vaguely predict daily truck volume and react to hourly truck arrival rates, much less have a systematic forecasting. The current practice to deal with gate congestion is to have a "swing gate" that is capable of processing both inbound and outbound trucks. When the gate congestion becomes very severe, the swing gate is open to process inbound trucks. However, by this time, the truck waiting time is already increased substantially. According to the sensitivity analysis in this study, a small increase in the gate processing capacity will result in a substantial decrease in the truck waiting time; it is important to recognize the unique characteristics of the gate congestion and understand the effect of such sensitivity. To address this issue, sensors can be installed at some key access roads that give some sort of "early warning" regarding truck arrival rates. Thus the swing gate can be put into action to head off potential gate congestion.

Second, as described earlier, the gate system optimization requires flexibility in gate capacity in physical expansion and productivity improvement responding to changes in hourly truck arrival rates. This implies that the gate manning should be flexible, as well. However, there might be restrictions on the level of flexibility due to constraints of labor contract. The MCT should understand the gate congestion behavior and its sensitivity and prepare a team dealing with gate congestion by targeting critical areas of bottleneck so congestion could be mitigated beforehand.

Third, the appointment system seems to offer the ideal solution to the gate congestion problem. But its implementation requires a community consensus since truckers have to make appointments for container pickup and deliveries. Compared with the current practice that truckers plan their own pickup and delivery schedules without consulting the MCT, the implementation of the appointment system requires the participation of shipping lines, shippers, and truckers so that everyone has a clear understanding of how the system works, what information is available and what information input is required, and what the benefits are. In addition, there has to be a clear set of business rules that govern the appointment process. On the other hand, the MCT has to be prepared that not all the truckers will have an appointment coming to the MCT, and the MCT has to have procedures to accommodate these truckers.

8.3 Limitations

The models developed in this study rely on the applications of queuing theory; there are several limitations. First of all, the $M/E_K/S$ model has a constraint that is $\lambda/(\mu S) < 1.0$. This indicates that when $\lambda/(\mu S) \geq 1.0$, the model is not workable; average truck waiting time becomes infinite. In reality this may not be true since hourly truck arrival rates vary from time to time. That means there are some errors in the truck waiting time calculation, however, this is on the conservative side. Second, the limited on-site observations may not cover all situations regarding hourly truck arrival rates; this tends to generalize truck arrival patterns. In situations due to vessel delays and holidays, some variation in truck arrival patterns may not be captured. Third, in the calculation of the truck waiting time and cost, the truck arrival rates are emulated for the queuing model input; this may not capture the dynamic transition from one arrival rate to another. To fully address the detailed congestion behavior, an extensive simulation is warranted, but not within the scope of this study.

In the analysis of the truck appointment system, the optimization uses a relatively simple assumption that the hourly truck arrival is obtained by dividing the estimated daily truck volume by the number of gate operating hours. This is an ideal situation where the terminal could control truck arrival rates at a constant level so it would optimize both the gate and yard operations. In reality, this should be a more interactive process that the truck hourly arrival rates are based on actual appointment made.

In broader perspective, another limitation is that the cost figure used in waiting cost calculation is from 2005. Since last year, the fuel cost has increased drastically and the diesel price is more than double. In addition, according to the American Trucking Association, insurance rate has also increased substantially. Therefore, the actual waiting cost in today's term is much higher. Lastly, this study is only focused on the issue of the MCT gate congestion; it does not address the container yard operation that is related to truck waiting time. As a result, the impacts of gate system optimization on the yard operation are not analyzed. Since the amount of trucks processed by the MCT gate represents the demand for yard handling in a given period, it is important to include it in future studies, which will be discussed in the next section.

8.4 Future Research and Suggestions

This study has analyzed the MCT gate congestion problem, quantified truck waiting cost, and provided several alternatives of gate system optimization. The results are applied only to one part of the overall MCT terminal operations due to limitation in data collection and information access. To address freight congestion issues and overall efficiency of MCT operations, there are a number of issues that need further study and research analysis.

First, the waiting cost model developed in this study provides a basic framework for the MCT congestion problem. In addition, the optimization model in this study lays the foundation for congestion mitigation. But the impacts of gate system optimization on the container yard operation are not addressed. Since the gate truck traffic has a direct bearing on yard equipment requirements to accommodate container pickup and deliveries, future studies should integrate the gate operation and yard operation together. Further data collection should include yard handling system characteristics, truck arrival rates in the yard, equipment and space allocation, truck waiting time in the yard, and yard handling productivity. The gate operation should be integrated with the yard operation so that the total truck waiting time will be optimized. The possibility of using a two-stage queuing model should be considered. The integration of the two operations into single model would provide an opportunity to analyze the overall MCT operational behaviors and better understanding of the overall MCT congestion and its mitigation.

Second, as illustrated in this study that the gate system optimization requires flexibility in the manning level in response to variation in truck arrival rates and this will have an impact on the labor contract. The detailed rule of gate system manning should be analyzed to come up with possible solutions to provide the needed flexibility for gate system optimization.

Third, this study is concentrated on the gate congestion issues and gate system optimization under the assumption that the MCT gate opens from 6:00 a.m. to 5:00 p.m., Monday to Friday. It does not analyze the option of extending the gate hours. Obviously, there are additional gate capacities that can be utilized. It would seem to be an easy solution to gate congestion by simply extending the gate operating hours into the evening. In this way, no physical expansion is needed and gate congestion will be eased since truckers could come to the MCT for pick-up and delivery in the evening or weekends instead of normal business hours. However, this issue is not as simple as it seems on the surface, due to several reasons. Due to labor contract constraints, any work beyond 5:00 p.m. will trigger overtime premium pay. The question of who will pay for the additional overtime costs remains unanswered. In addition, most of the warehouses in the region do not operate during evenings and weekends; there are certain city ordinances that restrict truck movements within certain time periods during the day. Furthermore, the issue of trucker compensation when driving beyond straight time is another challenge. Therefore, the address the gate congestion issue, further study is needed to explore the alternative of extended gate hours. These related issues need to be addressed.

Fourth, to mitigate gate congestion, the idea of using financial incentive/penalty should be explored. The idea is to charge the user a fee or the party that contributes congestion so that the revenue generated can pay for the operating cost of the transportation facility during non-peak hours. Lately, the Port of Los Angeles and the Port of Long Beach have implemented a PierPass program to mitigate gate congestion during day time. The program charges shippers/truckers a fee if they come to the MCT to pickup or deliver containers. The revenue generated is used to pay for overtime operating cost at the MCT. In conjunction with the extended gate hour alternative, such a congestion pricing alternative should be analyzed for its feasibility and applicability in the Port of New York/New Jersey.

Fifth, as demonstrated in the study, the congestion level is sensitive to small change in arrival rate or gate processing capacity when the system utilization is above 95%. To capture the full details of congestion behavior dealing with changes in truck arrival rates, an extensive simulation is needed. Currently, more than 80% of the containers are distributed through local trucking, the share of intermodal rail and short sea shipping for container distribution is relatively small. If more containers can be distributed through intermodal rail or short sea shipping, the MCT gate volume will be reduced. Future study should analyze the increasing use of intermodal rail and short sea shipping and their impact on gate congestion.

Sixth, the data analysis of gate truck traffic in this study reveals that empty containers account for a large percentage of gate truck traffic. However, empty containers do not have to be handled at the MCT; they can be handled at an off-dock site to facilitate cargo movement. A study is needed to explore the option of having an off-dock site to exclusively handle empty containers; so that the MCT can concentrate on handling loaded containers. As a result, truck traffic at the MCT gate could be drastically reduced.

Lastly, the MCT gate congestion issue is an important one for the freight community as well as for the public sector. Understanding its behavior and root cause is the first step. This study provides a comprehensive analysis of this issue including the quantification of the congestion cost, and provides several alternatives to mitigate the congestion. It is hoped that this study provides an in-depth understanding for the freight community, the public sector, and the research community so that sensible solutions can be found. The MCT management can use different tools or mechanisms to mitigate the problem; it needs to weigh trade-offs and carefully make its decision in the most cost-effective way. As for the public sector policy makers, the MCT congestion issue is a complicated one; it needs to balance the requirement for congestion relief and the constraints facing the MCT operator and the harbor trucking industry. It takes a community effort to tackle the MCT gate congestion problem and ensure freight movement efficiency.

APPENDIX A

VESSEL CONTAINER VOLUMES (2004)

Vessel Call	Date	Day	Load - Discharge	Vessel Call	Date	Day	Load - Discharge
1	1/2	F	104	35	2/8	Su	664
2	1/3	S	1,321	36	2/9	M	909
3	1/5	M	549	37	2/10	Tu	783
4	1/6	T	275	38	2/11	W	674
5	1/6	T	148	39	2/13	F	135
6	1/7	W	848	40	2/14	Sa	1,421
7	1/7	W	725	41	2/14	Sa	274
8	1/7	W	106	42	2/16	M	150
9	1/12	M	960	43	2/16	M	1,117
10	1/13	T	1,565	44	2/19	Th	901
11	1/14	W	1,088	45	2/20	F	1,305
12	1/14	W	688	46	2/20	F	120
13	1/14	W	141	47	2/21	Sa	708
14	1/17	S	1,398	48	2/24	Tu	168
15	1/17	S	139	49	2/25	W	668
16	1/19	M	215	50	2/25	W	871
17	1/20	Tu	1,101	51	2/26	Th	852
18	1/20	Tu	920	52	2/27	F	1,271
19	1/21	W	774	53	2/27	F	139
20	1/22	Th	118	54	2/28	SA	565
21	1/23	F	1,043	55	3/2	Tu	131
22	1/26	M	175	56	3/2	Tu	667
23	1/27	Tu	836	57	3/3	W	933
24	1/27	Tu	184	58	3/3	W	615
25	1/28	W	684	59	3/4	Th	877
26	1/30	F	113	60	3/4	Th	244
27	1/30	F	1,328	61	3/5	F	1,085
28	2/2	M	824	62	3/6	Sa	136
29	2/2	M	316	63	3/9	Tu	935
30	2/4	W	818	64	3/10	W	672
31	2/4	W	732	65	3/10	W	906
32	2/5	Th	174	66	3/11	Th	377
33	2/5	Th	135	67	3/12	F	1,302
34	2/6	F	1,491	68	3/13	Sa	87

APPENDIX A
(Continued)

Vessel Call	Date	Day	Load - Discharge	Vessel Call	Date	Day	Load - Discharge
69	3/16	Tu	860	103	4/20	Tu	170
70	3/17	W	199	104	4/21	W	1,012
71	3/17	W	570	105	4/21	W	313
72	3/17	W	841	106	4/22	Th	153
73	3/19	F	160	107	4/22	TH	399
74	3/20	Sa	1,346	108	4/23	F	1,461
75	3/21	Su	346	109	4/27	Tu	937
76	3/22	M	770	110	4/27	Tu	160
77	3/23	Tu	175	111	4/28	W	862
78	3/24	W	880	112	4/28	W	648
79	3/24	W	692	113	4/28	W	383
80	3/25	Th	114	114	4/30	F	158
81	3/26	F	1,342	115	4/30	F	1,689
82	3/29	M	323	116	5/1	Sa	538
83	3/29	M	760	117	5/4	Tu	876
84	3/30	Tu	187	118	5/4	Tu	348
85	3/31	W	919	119	5/4	Tu	108
86	4/2	F	1,569	120	5/5	W	688
87	4/2	F	160	121	5/5	W	887
88	4/6	Tu	900	122	5/7	F	152
89	4/6	Tu	124	123	5/9	Su	1,581
90	4/7	W	857	124	5/11	Tu	977
91	4/7	W	695	125	5/12	W	960
92	4/8	Th	357	126	5/12	W	103
93	4/9	F	150	127	5/13	Th	898
94	4/9	F	1,466	128	5/14	F	416
95	4/12	M	806	129	5/15	Sa	144
96	4/13	Tu	122	130	5/17	M	1,020
97	4/14	W	907	131	5/18	Tu	159
98	4/14	W	637	132	5/18	Tu	794
99	4/14	W	417	133	5/19	W	661
100	4/16	F	146	134	5/19	W	1,682
101	4/17	Sa	1,598	135	5/20	Th	153
102	4/19	M	951	136	5/20	Th	274

APPENDIX A
(Continued)

Vessel Call	Date	Day	Load - Discharge	Vessel Call	Date	Day	Load - Discharge
137	5/24	M	915	171	6/28	M	1,170
138	5/25	Tu	125	172	6/29	Tu	1,071
139	5/26	W	670	173	6/30	W	697
140	5/27	Th	1,033	174	7/1	Th	369
141	5/28	F	137	175	7/1	Th	117
142	5/29	Sa	1,463	176	7/2	F	122
143	5/31	M	1,751	177	7/3	Sa	1,742
144	6/1	Tu	143	178	7/5	M	893
145	6/2	W	828	179	7/6	Tu	143
146	6/3	Th	896	180	7/7	W	933
147	6/4	F	650	181	7/8	Th	764
148	6/4	F	1,005	182	7/8	Th	325
149	6/4	F	143	183	7/9	F	133
150	6/6	Su	339	184	7/10	Sa	1,744
151	6/8	Tu	871	185	7/13	Tu	771
152	6/8	Tu	147	186	7/14	W	1,160
153	6/8	Tu	683	187	7/14	W	674
154	6/9	W	623	188	7/15	Th	93
155	6/11	F	1,800	189	7/19	M	93
156	6/14	M	162	190	7/20	Tu	930
157	6/14	M	850	191	7/20	Tu	339
158	6/15	Tu	944	192	7/20	Tu	917
159	6/16	W	140	193	7/21	W	695
160	6/16	W	696	194	7/22	Th	126
161	6/17	Th	325	195	7/23	F	1,969
162	6/17	Th	128	196	7/24	Sa	1,784
163	6/18	F	2,145	197	7/26	M	1,021
164	6/21	M	881	198	7/26	M	135
165	6/22	Tu	130	199	7/27	Tu	501
166	6/23	W	1,124	200	7/27	Tu	925
167	6/24	Th	772	201	7/28	W	758
168	6/24	Th	280	202	7/29	Th	131
169	6/25	F	152	203	7/30	F	257
170	6/26	SA	1,945	204	7/30	F	1,787

APPENDIX A
(Continued)

Vessel Call	Date	Day	Load - Discharge	Vessel Call	Date	Day	Load - Discharge
205	8/2	M	154	239	9/7	Tu	184
206	8/2	M	864	240	9/8	W	1,004
207	8/4	W	820	241	9/8	W	596
208	8/4	W	1,112	242	9/9	Th	135
209	8/5	Th	122	243	9/10	F	407
210	8/5	Th	212	244	9/12	Su	1,831
211	8/6	F	1,802	245	9/13	M	959
212	8/10	Tu	1,076	246	9/14	T	175
213	8/10	Tu	111	247	9/15	W	1,123
214	8/10	Tu	1,054	248	9/15	W	758
215	8/11	W	762	249	9/16	Th	118
216	8/11	W	386	250	9/18	Sa	2,034
217	8/12	Th	144	251	9/18	Sa	481
218	8/14	Sa	1,913	252	9/21	Tu	942
219	8/17	Tu	924	253	9/21	Tu	968
220	8/17	Tu	142	254	9/21	Tu	142
221	8/18	W	1,177	255	9/22	W	660
222	8/19	Th	650	256	9/24	F	147
223	8/19	Th	1,790	257	9/24	F	2,230
224	8/19	Th	135	258	9/26	Su	441
225	8/23	M	344	259	9/27	M	1,001
226	8/24	Tu	939	260	9/28	Tu	1,101
227	8/24	Tu	95	261	9/28	Tu	159
228	8/24	Tu	606	262	9/30	Tu	614
229	8/25	W	1,212	263	9/30	Tu	138
230	8/26	Th	141	264	10/1	F	1,777
231	8/31	TU	983	265	10/4	M	1,122
232	9/1	W	977	266	10/5	Tu	124
233	9/1	W	647	267	10/5	TU	1,086
234	9/2	Th	1,821	268	10/6	W	632
235	9/3	F	129	269	10/7	TH	159
236	9/3	F	1,767	270	10/8	F	2,415
237	9/4	Sa	411	271	10/10	Su	351
238	9/6	M	1,003	272	10/11	M	932

APPENDIX A
(Continued)

Vessel Call	Date	Day	Load - Discharge	Vessel Call	Date	Day	Load - Discharge
273	10/12	Tu	139	305	11/15	M	728
274	10/12	Tu	961	306	11/16	Tu	242
275	10/13	W	643	307	11/18	Th	1,179
276	10/14	Tu	142	308	11/18	Th	678
277	10/16	Sa	537	309	11/18	Th	108
278	10/18	M	758	310	11/20	Sa	1,885
279	10/19	Tu	121	311	11/21	Su	431
280	10/20	W	960	312	11/23	Tu	988
281	10/20	W	753	313	11/23	Tu	203
282	10/21	Th	2,150	314	11/24	W	930
283	10/21	Th	136	315	11/24	W	698
284	10/24	Su	1,624	316	11/26	F	128
285	10/25	M	903	317	11/26	F	1,981
286	10/26	Tu	652	318	11/29	M	778
287	10/26	Tu	152	319	11/30	Tu	144
288	10/27	W	1,063	320	11/30	Tu	542
289	10/27	W	667	321	12/1	W	671
290	10/28	Th	121	322	12/2	Th	1,033
291	10/30	Sa	1,715	323	12/3	F	139
292	10/31	Su	594	324	12/4	Sa	1,895
293	11/2	Tu	1,164	325	12/6	M	316
294	11/2	Tu	90	326	12/7	Tu	1,097
295	11/3	W	1,004	327	12/7	Tu	172
296	11/4	Th	806	328	12/8	W	1,125
297	11/4	Th	122	329	12/9	Th	762
298	11/6	Sa	1,892	330	12/10	F	139
299	11/8	M	913	331	12/13	M	2,091
300	11/10	W	1,047	332	12/14	Tu	1,289
301	11/11	Th	717	333	12/14	Tu	1,043
302	11/12	F	1,679	334	12/15	W	681
303	11/12	F	116	335	12/16	Th	111
304	11/13	Sa	601				

APPENDIX B

DAILY GATE TRANSACTION AND TRUCK VOLUMES (2004)

Date	Day	Number of Transactions	Number of Trucks	Date	Day	Number of Transitions	Number of Trucks
1/2	F	1,490	1,047	2/24	Tu	993	722
1/5	M	1,352	948	2/26	Th	1,138	816
1/6	Tu	1,270	867	2/27	F	1,202	857
1/7	W	1,337	945	3/1	M	1,201	882
1/8	Th	1,331	921	3/2	Tu	1,220	896
1/9	F	1,350	979	3/3	W	1,243	930
1/12	M	1,283	918	3/4	Th	1,228	887
1/13	Tu	1,305	931	3/5	F	1,406	1,025
1/14	W	1,208	868	3/8	M	1,175	874
1/15	Th	705	486	3/9	Tu	1,114	821
1/16	F	984	737	3/10	W	1,242	953
1/19	M	1,635	1,120	3/11	Th	1,162	865
1/20	Tu	1,481	1,041	3/12	F	1,288	967
1/21	W	1,460	1,033	3/15	M	1,250	941
1/22	Th	1,431	1,022	3/16	Tu	1,057	778
1/23	F	1,330	953	3/17	W	950	722
1/27	Tu	1,316	908	3/18	Th	1,115	819
1/28	W	1,149	821	3/19	F	1,042	805
1/29	Th	1,260	919	3/22	M	1,306	955
1/30	F	1,196	860	3/23	Tu	1,120	835
2/2	M	1,195	812	3/24	W	1,440	1,025
2/3	Tu	1,498	1,038	3/25	Th	1,362	993
2/4	W	1,546	1,057	3/26	F	1,215	883
2/5	Th	1,314	928	3/29	M	1,498	1,078
2/10	Tu	1,343	986	3/30	Tu	1,232	901
2/11	W	1,235	898	3/31	W	1,289	950
2/12	Th	1,317	983	4/1	Th	1,218	885
2/13	F	1,363	995	4/2	F	1,478	1,135
2/17	Tu	1,156	849	4/5	M	1,452	1,065
2/18	W	1,279	947	4/7	W	1,166	921
2/19	Th	1,331	1,000	4/12	M	1,344	996
2/20	F	1,301	967	4/13	Tu	1,259	914
2/23	M	1,078	780	4/15	Th	1,353	988

APPENDIX B
(Continued)

Date	Day	Number of Transactions	Number of Trucks	Date	Day	Number of Transitions	Number of Trucks
4/16	F	1,234	917	6/4	F	1,578	1,111
4/19	M	1,419	1,053	6/7	M	1,458	1,055
4/20	Tu	1,209	880	6/8	Tu	1,529	1,064
4/21	W	1,197	880	6/9	W	1,482	1,038
4/22	Th	1,335	1,001	6/11	F	1,489	1,086
4/23	F	1,287	971	6/14	M	1,501	1,121
4/26	M	1,197	878	6/15	Tu	1,439	1,030
4/27	Tu	1,219	895	6/16	W	1,391	1,028
4/28	W	1,395	1,013	6/17	Th	1,306	962
4/29	Th	1,380	1,062	6/21	M	1,434	1,055
4/30	F	1,457	1,128	6/22	Tu	1,424	1,024
5/3	M	1,333	972	6/23	W	1,377	959
5/4	Tu	1,196	869	6/24	Th	1,479	990
5/5	W	1,151	832	6/28	M	1,402	990
5/6	Th	1,128	836	6/29	Tu	1,036	711
5/7	F	1,334	998	6/30	W	1,442	997
5/10	M	1,281	914	7/1	Th	1,649	1,138
5/12	W	1,313	961	7/2	F	1,511	1,025
5/13	Th	1,272	902	7/6	Tu	1,390	976
5/14	F	1,215	904	7/7	W	1,343	933
5/17	M	1,241	942	7/8	Th	1,352	967
5/18	Tu	982	727	7/9	F	1,268	898
5/19	W	1,217	893	7/12	M	1,341	967
5/20	Th	1,376	1,004	7/13	Tu	1,310	930
5/21	F	1,422	1,055	7/14	W	1,294	883
5/24	M	1,214	901	7/15	Th	1,590	1,088
5/25	Tu	1,102	811	7/16	F	1,611	1,046
5/26	W	1,092	833	7/19	M	1,580	1,148
5/27	Th	942	723	7/20	Tu	1,378	994
5/28	F	1,098	835	7/21	W	1,133	849
6/1	Tu	1,371	996	7/22	Th	1,290	937
6/2	W	1,425	1,075	7/23	F	1,193	847
6/3	Th	1,524	1,081	7/27	Tu	1,398	1,001

APPENDIX B
(Continued)

Date	Day	Number of Transactions	Number of Trucks	Date	Day	Number of Translations	Number of Trucks
7/28	W	1,482	1,049	9/17	F	1,469	1,001
7/29	Th	1,628	1,133	9/20	M	1,485	994
7/30	F	1,529	1,080	9/21	Tu	1,439	987
8/2	M	1,500	1,031	9/22	W	1,425	976
8/3	Tu	1,491	1,047	9/23	Th	1,443	966
8/4	W	1,296	912	9/24	F	1,574	1,081
8/5	Th	1,399	961	9/27	M	1,561	1,095
8/9	M	1,359	982	9/28	Tu	1,402	992
8/10	Tu	1,399	985	9/29	W	1,495	1,067
8/11	W	1,536	1,057	10/1	F	1,408	1,014
8/12	Th	1,361	971	10/4	M	1,436	1,022
8/16	M	1,396	983	10/5	Tu	1,479	1,073
8/17	Tu	1,446	993	10/6	W	1,384	962
8/18	W	1,365	959	10/7	Th	1,540	1,095
8/19	Th	1,412	984	10/8	F	1,440	1,053
8/20	F	1,322	982	10/12	Tu	1,445	1,019
8/23	M	1,330	960	10/13	W	1,419	1,033
8/24	Tu	1,317	932	10/14	Th	1,565	1,092
8/25	W	1,404	1,005	10/15	F	1,482	1,048
8/26	Th	1,378	965	10/18	M	1,424	962
8/27	F	1,407	1,040	10/19	Tu	1,568	1,092
8/30	M	1,419	1,014	10/20	W	1,460	1,030
8/31	Tu	1,403	1,018	10/21	Th	1,381	978
9/1	W	1,013	747	10/25	M	1,346	933
9/2	Th	1,149	839	10/26	Tu	1,094	783
9/3	F	1,099	798	10/27	W	1,208	875
9/7	Tu	1,394	994	10/29	F	1,368	939
9/8	W	1,487	1,045	11/1	M	1,444	994
9/9	Th	1,503	1,034	11/3	W	1,465	1,016
9/13	M	1,373	902	11/4	Th	1,670	1,123
9/14	Tu	1,556	1,068	11/5	F	1,353	960
9/15	W	1,514	1,058	11/8	M	1,511	1,050
9/16	Th	1,439	989	11/9	Tu	1,859	1,256

APPENDIX B
(Continued)

Date	Day	Number of Transactions	Number of Trucks
11/12	F	1,532	1,052
11/15	M	1,459	1,035
11/16	Tu	1,502	1,026
11/17	W	1,537	1,092
11/18	Th	1,663	1,184
11/19	F	1,745	1,221
11/22	M	1,547	1,088
11/23	Tu	1,435	1,066
11/26	F	1,649	1,168
12/7	Tu	1,555	1,138
12/8	W	1,462	1,022
12/9	Th	1,479	1,025
12/10	F	939	691
12/13	M	1,596	1,051
12/14	Tu	1,652	1,105
12/15	W	1,591	1,091
12/16	Th	1,544	1,087
12/17	F	1,507	1,057

APPENDIX C

BREAKDOWN OF DAILY GATE TRANSACTIONS

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
1/3	479	206	32	330	76	651	46	249
1/5	506	126	33	283	57	573	57	244
1/6	462	121	28	256	78	525	56	201
1/7	420	129	53	343	87	613	54	171
1/8	429	129	42	321	147	528	56	177
1/9	431	195	48	305	132	508	36	275
1/12	439	159	68	252	81	480	56	282
1/13	456	142	49	284	100	537	21	257
1/14	413	160	51	244	96	461	27	272
1/15	233	86	10	157	55	318	3	108
1/16	302	187	39	209	75	387	19	243
1/20	551	200	70	299	85	682	47	275
1/21	499	140	58	344	101	659	27	225
1/22	457	180	95	301	113	572	43	267
1/23	428	203	114	277	93	540	53	428
1/26	446	188	64	255	88	523	21	297
1/27	519	122	48	219	99	500	28	269
1/29	373	111	76	261	136	427	27	223
1/30	437	176	44	262	139	409	56	292
2/2	409	177	89	185	92	376	53	409
2/3	366	113	116	217	133	447	20	205
2/4	384	123	213	318	198	553	27	318
2/5	414	187	138	318	195	588	24	236
2/10	417	133	112	266	167	474	11	257
2/11	397	167	73	349	157	532	17	276
2/12	429	173	56	240	132	387	58	296
2/13	391	221	64	307	122	445	74	329
2/17	479	179	35	302	128	515	27	313
2/18	350	180	46	273	113	414	53	267
2/19	365	157	106	319	114	441	96	264
2/20	345	198	176	281	146	433	33	383
2/23	353	163	91	360	101	526	67	279
2/24	304	145	65	266	148	395	21	207

APPENDIX C
(Continued)

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
2/25	256	171	50	245	135	333	48	204
2/26	273	163	71	309	134	465	32	186
2/27	287	189	85	296	98	514	29	217
3/1	383	176	55	268	113	437	37	287
3/2	384	156	84	272	113	411	72	305
3/3	325	194	136	275	141	414	33	331
3/4	307	146	128	306	123	492	32	239
3/5	324	217	101	383	93	586	85	265
3/8	370	153	55	296	89	477	31	262
3/9	316	145	121	239	76	415	41	285
3/10	309	172	102	370	115	514	30	289
3/11	326	160	98	281	135	407	36	293
3/12	335	183	73	376	118	544	41	245
3/15	321	142	164	314	112	496	15	309
3/16	283	132	136	227	104	396	6	280
3/17	264	141	102	215	84	306	53	277
3/18	304	164	100	251	92	397	58	277
3/19	230	211	108	256	90	364	39	319
3/22	311	162	85	397	92	597	59	209
3/23	310	128	78	319	74	469	61	215
3/24	342	174	154	355	123	597	50	284
3/25	339	146	154	354	153	490	80	283
3/26	276	160	104	343	124	492	59	230
3/29	371	212	99	396	218	568	30	271
3/30	332	140	143	286	122	484	11	273
3/31	358	152	127	313	95	528	29	279
4/1	356	148	98	283	154	447	15	264
4/2	375	191	189	380	109	585	29	399
4/5	442	162	93	368	99	602	54	307
4/7	313	138	204	266	99	407	5	402
4/12	403	176	93	324	94	564	14	311
4/13	372	123	113	306	117	514	20	251
4/15	368	132	136	352	95	613	9	352

APPENDIX C
(Continued)

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
4/16	414	146	111	246	87	463	13	346
4/19	454	143	82	374	101	630	9	301
4/20	423	111	94	252	100	475	6	290
4/21	393	129	85	273	132	440	18	279
4/22	426	151	102	322	190	459	7	337
4/23	350	163	120	338	110	527	17	310
4/26	360	153	47	318	79	513	45	251
4/27	336	138	122	299	112	472	39	266
4/28	399	163	159	292	165	498	13	319
4/29	548	154	44	316	114	512	8	409
4/30	516	259	56	297	65	543	18	470
5/3	442	153	77	300	64	570	27	204
5/4	360	135	127	247	84	463	27	287
5/5	318	150	102	262	125	451	5	241
5/6	337	130	94	275	96	463	8	260
5/7	371	213	101	313	145	490	14	342
5/10	361	183	70	300	146	499	22	246
5/12	379	140	157	285	126	501	10	321
5/13	360	155	101	286	118	522	16	234
5/14	401	172	70	261	118	450	13	317
5/17	334	159	149	300	158	416	25	335
5/18	299	111	92	225	92	372	16	299
5/19	330	136	106	321	125	499	21	240
5/20	361	149	127	367	118	598	23	260
5/21	395	211	163	286	95	525	33	404
5/24	357	172	111	261	98	447	29	317
5/25	355	127	82	247	98	411	29	269
5/26	403	169	49	212	126	305	40	356
5/27	315	158	44	206	101	288	36	291
5/28	326	200	61	248	103	398	10	301
6/1	410	149	93	344	74	616	29	250
6/2	414	127	185	349	96	589	14	357
6/3	412	143	181	345	136	649	6	269

APPENDIX C
(Continued)

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
6/4	437	195	127	352	108	672	40	271
6/7	482	177	98	298	64	628	10	318
6/8	491	137	123	313	114	628	36	270
6/9	434	136	106	362	160	633	13	231
6/11	445	217	103	321	108	598	18	350
6/14	464	192	110	355	139	577	19	378
6/15	429	123	166	312	118	569	34	304
6/16	414	184	120	310	150	508	15	314
6/17	374	192	136	260	105	479	20	348
6/18	401	216	104	334	97	591	25	331
6/21	421	161	112	330	88	637	5	269
6/22	452	150	77	280	96	586	16	246
6/23	449	178	109	331	141	570	32	307
6/24	384	185	116	305	183	506	28	258
6/28	328	124	33	226	85	461	5	154
6/29	441	151	84	321	99	664	3	213
6/30	447	184	174	333	180	637	27	286
7/1	408	187	171	259	211	538	5	268
7/2	399	193	114	270	144	539	1	275
7/6	405	139	65	324	115	615	4	201
7/7	419	121	108	319	149	567	18	236
7/8	391	135	83	289	110	540	9	230
7/9	398	194	114	261	87	550	8	301
7/12	398	161	74	297	58	615	4	244
7/13	419	112	94	258	115	547	8	202
7/14	548	146	96	298	158	608	34	266
7/15	500	166	104	338	162	634	45	244
7/16	447	236	109	356	142	628	18	337
7/19	502	151	97	244	155	465	8	318
7/20	351	140	128	230	107	384	23	306
7/21	420	141	110	266	93	514	12	294
7/22	380	130	113	224	104	441	25	274
7/23	404	195	86	316	96	609	8	267

APPENDIX C
(Continued)

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
7/26	455	174	72	348	91	680	10	240
7/27	506	149	117	361	117	730	9	261
7/28	423	196	129	332	98	668	15	276
7/29	451	165	111	304	97	643	33	254
7/30	406	221	93	327	87	665	19	262
8/2	417	175	76	244	72	551	5	269
8/3	478	129	85	269	117	581	9	242
8/4	470	141	75	296	125	542	6	298
8/5	466	151	67	301	141	563	11	246
8/9	464	208	114	271	86	648	16	286
8/10	462	155	86	268	86	550	22	301
8/11	444	142	69	328	105	619	17	230
8/12	488	134	85	286	164	542	33	245
8/16	477	164	81	237	99	537	7	294
8/17	508	129	69	278	118	561	27	244
8/18	393	149	146	294	133	458	43	323
8/19	364	149	131	316	161	507	18	257
8/20	403	181	52	296	146	524	11	234
8/23	414	170	111	310	134	557	18	262
8/24	403	126	149	287	124	532	44	255
8/25	374	170	134	362	148	538	43	294
8/26	412	166	136	300	110	575	20	301
8/27	388	233	88	309	147	533	14	316
8/30	296	162	79	210	113	352	11	246
8/31	318	143	115	263	182	373	18	254
9/1	345	141	81	231	104	421	7	250
9/2	386	143	119	346	98	646	5	231
9/3	409	231	90	315	82	664	16	264
9/7	503	128	94	309	90	658	30	220
9/8	478	138	61	225	87	591	18	225
9/9	496	148	86	338	108	668	50	207
9/10	475	220	83	280	120	593	23	293
9/13	535	147	44	263	104	600	9	265

APPENDIX C
(Continued)

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
9/14	535	138	33	295	140	588	35	238
9/15	483	164	47	300	154	613	24	195
9/16	467	178	40	302	151	581	22	230
9/17	438	196	50	292	116	592	33	214
9/20	497	133	49	287	102	643	19	191
9/21	530	114	87	350	113	699	31	204
9/22	520	152	114	309	99	632	44	296
9/23	505	179	56	252	125	527	10	315
9/24	482	200	75	310	114	610	14	307
9/27	518	165	44	287	109	560	12	325
9/28	510	132	82	298	117	580	15	294
9/29	519	161	87	306	157	549	6	351
9/30	532	134	56	240	126	530	6	289
10/1	511	205	45	334	129	640	10	311
10/2	525	220	43	265	105	542	5	383
10/5	527	124	90	278	104	547	53	298
10/6	458	162	97	316	128	559	15	310
10/7	389	164	212	327	120	566	5	327
10/8	369	243	124	312	118	623	5	291
10/12	447	137	89	289	99	646	6	202
10/13	526	145	107	314	134	644	12	291
10/14	506	164	82	278	104	592	12	317
10/15	417	227	84	250	148	480	25	322
10/18	413	194	93	233	153	463	30	280
10/19	365	122	76	220	138	375	18	247
10/20	368	166	62	279	131	470	11	249
10/21	403	139	87	310	119	613	7	191
10/25	496	139	38	321	146	612	13	228
10/26	495	137	44	340	120	666	3	236
10/27	563	166	48	346	133	758	2	221
10/29	419	213	47	281	105	549	20	270
11/1	455	191	87	317	175	592	11	259
11/3	522	235	125	374	148	824	5	282

APPENDIX C
(Continued)

Date	Empty-in	Load-in	Chassis-in	Bobtail-in	Empty-out	Load-out	Chassis-out	Bobtail-out
11/4	443	174	140	295	118	645	12	267
11/5	429	227	93	286	102	588	20	314
11/8	469	178	74	305	129	647	5	255
11/9	536	153	98	305	136	603	11	341
11/12	497	268	57	362	118	703	10	325
11/15	604	206	71	340	154	698	12	334
11/16	548	163	88	289	106	593	52	331
11/17	509	171	137	249	107	501	10	412
11/18	562	159	111	336	121	669	27	335
11/19	447	228	115	348	142	603	20	360
11/22	487	174	46	315	111	615	29	254
11/23	500	169	93	263	91	576	50	293
11/26	284	134	57	216	36	394	34	210
12/7	588	115	65	283	115	688	25	202
12/8	562	146	110	287	167	651	16	255
12/9	488	145	160	298	190	595	13	276
12/13	491	160	115	321	138	595	45	301
12/14	509	156	116	276	137	561	28	319
12/15	578	155	43	292	130	610	12	294

APPENDIX D

OBSERVED TRUCK INTER-ARRIVAL TIMES

Inter-arrival Time (in seconds)	Number of Trucks
0-6	154
6-12	128
12-18	110
18-24	90
24-30	88
30-36	70
36-42	48
42-48	55
48-54	32
54-60	39
60-66	23
66-72	23
72-78	14
78-84	10
84-90	16
90-96	16
96-102	9
102-108	12
108-114	7
114-120	3
120-126	4
126-132	2
132-138	2
138-144	3
144-150	3
150-156	1
156-162	0
162-168	1
168-174	1
174-180	1
180-186	0
186-192	0
192-198	1

APPENDIX E

OBSERVED GATE SERVICE TIMES

Interval (in seconds)	Frequency
0.00-0.40	0
0.40-0.80	6
0.80-1.20	30
1.20-1.60	49
1.60-2.00	55
2.00-2.40	52
2.40-2.80	31
2.80-3.20	29
3.20-3.60	20
3.60-4.00	15
4.00-4.40	18
4.40-4.80	12
4.80-5.20	8
5.20-5.60	5
5.60-6.00	2
6.00-6.40	0
6.40-6.80	1

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