SIMULATING GATE STRATEGIES AT INTERMODAL MARINE CONTAINER TERMINALS

by

Jeffery Karafa

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

Major: Civil Engineering

The University of Memphis

May 2012

Acknowledgements

This thesis would not have been possible without the guidance of Dr. Mihalis Golias. It was because of his encouragement that I decided to attend graduate school. His advice has been instrumental in all my academic endeavors and his support has meant a great deal to both me and my family. I am deeply indebted to Dr. Golias for everything he has done for me.

I would like to thank Dr. Ivey and Dr. Lipinski for the advice they have given me over my academic career and for the opportunity to work and learn through the Intermodal Freight Transportation Institute.

Finally I would like to thank my wife, Shri, and my children, Emma and Seth. Their love and support guides me in everything that I do.

Abstract

Karafa, Jeffery. MSc. The University of Memphis. May 2012. Simulating Gate Strategies at Intermodal Marine Container Terminals. Major Professor: Dr. Mihalis M. Golias.

Intermodal Marine Container Terminals are experiencing growth in container volumes and are under pressure to develop strategies to accommodate increasing demand. One of the major factors contributing to the problem is inefficient gate operations that can cause serious safety, congestion, and environmental problems. There is a plethora of ongoing discussions concerning the implementation of different operational strategies that may relieve the effects of congestion and improve air quality. This thesis presents the development of a traffic simulation model capable of measuring the impact of various gate strategies on congestion at terminal gates. The proposed model is used to quantify both travel time and delay, and emission levels at terminal gates before and after gate strategies have been implemented. To our knowledge this is the first attempt, in the published literature, to capture delays and emissions at the gates of terminals using a traffic simulation model.

Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

1.1 Problem definition

Increasing reliance on global trade has made Intermodal Marine Container Terminals (IMCTs) vital links in our transportation and economic systems. Container volumes at U.S. IMCTs have nearly tripled over the last twenty years (1) and forecasts predict that demand will double sometime in the next ten to fifteen years (2). Rising container volumes have forced many ports to take action or face the risk of exceeding their capacity in the near future. Whenever possible, IMCTs have turned to physical expansion to increase their capacity and accommodate future demand. However, most IMCTs are located in or close-by densely populated urban areas, making physical expansion difficult or impossible. When physical expansion is not an option, planners and engineers need to address increases in demand with corresponding increases in operational efficiency or face the possibility of crippling congestion.

In addition to capacity concerns, terminal operators have to address increase in emissions caused by increase in demand and congestion. IMCTs have begun to address this issue with programs aimed at reducing emissions of landside and seaside operations as they are known to produce diesel engine exhaust, containing a number of carcinogens. The latter are associated with elevated levels of asthma attacks, emergency room visits, hospitalizations, heart attacks, strokes and untimely deaths (3).

Although the need to increase IMCT efficiency extends to both landside and seaside operations, the focus of this research will be on a specific set of landside operations, i.e. drayage movements. Drayage is defined as "t*he movement of containers* *between a port terminal and an inland distribution point or rail terminal*" (4). Drayage operators are typically paid by the move, which creates an incentive for drivers to make as many moves as possible, which causes peaking at terminal gates. Peaking is concentrated in the hours prior to the opening of terminal gates, as drayage operators attempt to enter the terminal as early as possible. Trucks often continue to idle as they wait for terminal gates to open, thereby increasing emissions generated by IMCT landside operations.

Peaking is exacerbated at terminals where an imbalance exists between the operating hours of terminal gates (typical hours are weekdays from 6:00 AM to 5:00 PM) and seaside operations (typically carried throughout the day). This imbalance creates congestion both at the beginning of the day and after a weekend period, as demand for drayage movements continues to build over these periods.

Even if peaking and operational imbalances do not occur, IMCT terminal gates would continue to be a source of congestion due to in-gate processing delays. A typical in-gate process includes the drayage operator identity verification, availability of a container which a drayage operator intends to pick up, equipment inspection, and yard equipment dispatching needed to ready the container. These delays vary according to transaction type, drayage operator experience and degree of automation available at the terminal gate. A typical delay at a terminal entrance gate is 4 to 5 minutes (4). Inbound gate delay is reduced for trucks performing simpler transactions (i.e. trucks arriving bobtail or with a chassis, trucks with appointments, etc.) and transactions at exit gates are typically simpler than transactions at entrance gates. Therefore, delays at exit gates are typically smaller than those of inbound gates (4).

Various strategies have been implemented to decrease delays at IMCT gates. These strategies include use of automated technologies to improve operational efficiencies (5), extending operational hours of terminal gates and creating appointment systems for drayage movements. Extended gate hours are designed to distribute peak hour demand to off-peak hours and can be combined with financial incentives to encourage drayage operators to utilize off-peak hours and offset the added cost of operating terminal gates over longer time periods. The amount of demand which can be shifted from extending terminal gate hours often depends on the length of the extension (i.e. gates that already have longer operational periods experience a smaller shift than those with shorter operational periods).

Another strategy used to increase terminal gate efficiency is truck appointment systems; often accompanied by dedicated lanes for trucks with appointments. The purpose of providing dedicated lanes is to minimize appointment truck delays, thereby encouraging drayage operators to make and keep their appointments. Appointment systems further allow IMCT operators a measure of control over drayage truck arrivals, as they can specify the number of transactions occurring on appointment lanes (6). However, variability of drayage transactions limits this measure of control, as time slots often range from one to several hours. The effectiveness of appointment systems relies on proper planning by terminal operators and by the drayage operators' ability to keep their appointments (7). The latter can be affected by factors out of the drayage operators' control (such as traffic congestion on route to the port or delay at its origin) making truck appointment systems less attractive.

1.2 Research objectives

The goal of this research is to develop a methodology that can be used to create a dynamic traffic simulation model and measure congestion and emissions levels at IMCT terminals before and after a gate strategy implementation. To demonstrate the proposed methodology a case study will be developed where two gate strategies will be implemented as part of this work: a) an appointment system, and b) extended hours of gate operations. In this thesis the Port of Newark/Elizabeth (PNE) was selected as the test-bed for the case study mainly due to data availability and high demand (Dougherty (6) and Spasovic et al. (7) Scenarios were developed for the PNE under which terminal gates operated under extended hours and for which gate operators created appointment systems for specific demand percentages. Gate strategy scenarios were compared to current patterns of operation (CPO) to measure any improvements that resulted from their implementation. We note that to capture the effectiveness of these two gate strategies, the proposed methodology and model should capture the complex logic behind daily IMCT drayage movements as accurately as possible. In this thesis a significant amount of the effort focused in achieving the latter objective utilizing state of the practice software and innovative modeling techniques.

The remainder of this thesis is organized as follows: the next section contains a literature review. Section 3 describes the physical characteristics of both the PNE and the simulation and explains the methodology used to construct the traffic model. Section 4 presents the results and Section 5 presents the conclusions.

2. LITERATURE REVIEW

The importance of drayage operations and their effect on emissions levels at IMCTs is reflected by an increase in the amount of research. This literature review will focus on two types of research: before-and-after case studies at IMCTs that have implemented gate strategies and simulations of IMCTs which include logic for gate strategy implementation.

2.1 Before-and-after case studies of gate strategies

In 2005, a program extending terminal gate operating hours at the Ports of Los Angeles and Long Beach (PLALB) began in response to legislation. This legislation called for terminal operators to take action to reduce congestion and emissions levels of the PLALB. The extended hour program assessed a fee to drayage transactions made during peak hours to encourage a demand shift to off-peak hours and also to offset additional costs of operating terminal gates over an extended time period. The effectiveness of the extended gate hour program was assessed by Giuliano et al. (8). The authors concluded that extended hours at the PLALB shifted 20% of drayage movements from peak hours to off-peak hours.

In a separate study of the extended gate hour program at the PLALB, Fairbank, Maslin, Maullin, and Associates (9) interviewed drayage operators before and after implementation to determine the perceived benefit of effected parties at the IMCT. The survey stated that drayage operators felt that extended operating hours of terminal gates had a positive impact on the overall efficiency of drayage operations at the PLALB.

Extended gate hours were briefly introduced on a trial basis at two of the three terminals at the PNE. A study conducted by Spasovic et al. (7) assessed the effectiveness of extended operational hours at the PNE's terminal gates. The authors concluded that neither experiment was considered a success, as only a small percentage of drayage operators utilized off-peak hours. The authors compared extended hours at the PNE to the program implemented at the PLALB and noted that physical differences in shipper sizes and differences in political structure between the ports represented a challenge for effectively implementing an extended hour program at the PNE.

A gate appointment system was implemented along with the extended hour program at the PLALB in 2005. The appointment system was evaluated in three separate studies by Giuliano et al. (10; 11; 12). In each study, the authors cited an inability of terminals to enforce appointments and a lack of willingness on the part of drayage operators to participate in the program as reasons for a lack of success of appointment systems. Lack of drayage operator participation was due in part to failure to dedicate lanes solely to trucks with appointments. The lack of dedicated appointment lanes led to the system having a limited impact on turn times. Other reasons given for lack of success were that the appointment system was imposed on the terminals from the outside, that other operational changes implemented alongside the appointment system were more effective (i.e. extended hours) and that regulation was imposed on terminal operators instead of truckers.

A study conducted by the U.S. Environmental Protection Agency (13) found that a terminal gate appointment system implemented at the Port of New Orleans improved traffic flow through the IMCT, increased terminal throughput and improved productivity for trucking companies and terminal operators. Morais and Lord (14) conducted a study for the Canadian government which cautioned that an appointment system implemented without support from port operators and truck drivers would have little to no effect on reducing gate congestion. The authors believed that gate appointment systems have the potential to reduce congestion when properly implemented and should be considered as a means for reducing future drayage congestion at IMCTs.

Overall, case studies of gate strategy implementation have led to mixed results. Some strategies have yielded positive results after implementation, while others have not. Each terminal has unique characteristics that affect the outcome of gate strategy success. Establishing a methodology for simulating gate strategy implementation would provide an opportunity for terminal operators to assess various strategies prior to implementation.

2.2 Simulations of IMCTs

Namboothiri and Erera (15) used an integer programming-based heuristic to model an IMCT and determine pickup and delivery sequences for daily drayage operations with minimized transportation costs. The authors found that it is critical for terminal operators to provide drayage firms enough capacity when implementing gate appointment systems (vehicle productivity increased by 10–24% when capacity increased by 30%), that drayage operators must make good appointment selections to maintain high levels of customer service (the authors found that differences between the best and worst selections for capacity distributions resulted in a decrease in the number of customers served by up to 4%) and that duration of appointment windows may affect the ability of drayage firms to provide high levels of service. A multi-queuing model was used by Guan and Liu (16) to quantify gate congestion for inbound trucks, evaluate truck waiting cost and explore alternatives for gate system optimization. The authors looked at optimizing both the supply side and demand side of gate operations. The authors noted the following problems associated with optimization of the supply side: lack of available land, yard congestion due to lack of handling capacity, under-utilization of gate systems during non-peak periods and a need for flexibility in gate personnel due to variations in truck arrival rates. The authors found demand side utilization to be more responsive and to provide more effective control over resource allocation, congestion and system performance.

Chen et al. (17) presented a framework in which vessel-dependent time window optimization was proposed as a measure of gate congestion reduction. Two time window strategies (related to the beginning and end of a time period where export containers arriving by a vessel could be picked up) were compared. The first was a fixed end-point time window and the second was a variable end-point time window. An optimization model was formulated and both strategies were compared to a time window assignment based on a greedy algorithm. The latter attempted to assign the longest time windows possible, using yard capacity as the constraint. Results showed both time window strategies compared favorably to results obtained by the greedy algorithm and that a fixed end-point time window strategy provided similar results to the variable end-point time windows and needed less CPU time.

Huynh and Walton (18) developed a simulation model of the Barbours Cut Terminal in Houston using Arena simulation software. The goal of the simulation was to develop a model that would capture the relationship between yard crane availability and terminal efficiency. The simulation was also used to assess the effect that a terminal gate appointment system would have on terminal efficiency. The simulation began inside the terminal (at a point after the drayage trucks had passed through the entrance gates). Logic was included to simulate container movements that occurred in the terminal yard. Additional logic was included for delays that occurred at terminal exit gates. The appointment system in the authors' model was used to limit the number of arrivals over a specified time period. Due to limitations of Arena software, the model contained no interaction with the IMCT roadway network. The authors concluded that the simulation could be used to determine the number of yard cranes needed to achieve a desired truck turn time at an IMCT terminal.

Fischer et al. (19) created a port travel demand model that compared a combination of different strategies including; extended gate hours, a virtual container yard, a shuttle train, additional on-dock trains and a near-dock container storage yard. QuickTrip was used to create the model. Each scenario was estimated by adjusting input to reflect assumed shifts in demand patterns caused by each scenario's implementation. For extended gate hours, percentage shifts in the overall demand cycle were adjusted to reflect different weekend/weekday shifts. The hourly distribution of drayage traffic patterns was kept the same. The results of this study measured changes in truck trips and did not attempt to capture the details of the IMCT itself, nor did it attempt to use delays within the terminal as part of the analysis.

Moini (20) created a simulation model of a generic marine container using ARENA software. In the simulation, terminal entrance gates were modeled as two-tier systems. The first gate was used to simulate delays for checking driver's paperwork. Logic was included for "trouble" tickets, where trucks were sent to a customer service area and experienced longer delays. The second set of gates was designed to simulate truck and container inspections and also to assign interchange areas for loading/unloading containers in the terminal yard. Service rates at gates were assumed to follow exponential and Poisson distributions. The simulation also modeled transactions occurring within the terminal yard and on the dockside. Delays at exit gates were modeled using the exponential distribution, which is assumed to allow for the occasional mishandling of paperwork or poor physical condition of containers upon exiting (both of which were assumed to cause increases in delay at exit gates).

To simulate an appointment system, Moini (20) assumed that dedicated lanes would be provided for trucks with appointments and that service in those lanes would be reduced, as transactions would be less complicated and would have less variation. Appointment gates were assigned delays with a flat rate of 1-2 minutes. All travel times between gates and yard operations were estimated. The simulation was used to measure truck turn times, queue lengths and delays at specified locations within the simulation.

A simulation of the Pasir Panjang Terminal Extension in Singapore was created by Lee et al. (21) using Paramics simulation software. The goal of the simulation was to determine areas within the terminal that were most likely to experience congestion due to future growth and also to evaluate the optimal size of a truck fleet that would be used to conduct container moves within the terminal yard. The authors used three truck types to create the simulation: trucks without a container, trucks with a 20 foot container and trucks with a 40 foot container. Different sets of logic were developed for each truck (i.e. a truck without a container would have one loaded once it reached its destination, a truck with a container would be unloaded upon reaching its destination, etc.). The model only considered activity within the terminal yard and did not include any logic for terminal gates. Once a truck reached its destination within the terminal yard it was destroyed, leaving the plug-in to control the queues (virtually). This resulted in a lack of physical queues within the simulation. Upon completion of the loading and unloading processes, a truck similar to the one that was destroyed was released onto the terminal roadway network where it would exit the simulation. All vehicle movements within the simulation were controlled using fixed routes.

Dougherty (6) created a dynamic traffic assignment of the PNE using Vissim software. The simulation evaluated the effect that gate strategies would have on the PNE's roadway network. Gate strategies were simulated using the following shifts in demand; a 30% shift in demand to off-peak weekday hours, a 20% shift in demand to off-peak weekday hours, a 20% shift in demand to weekends and a 10% shift in demand to weekends. All vehicles destined to or originating from the terminals were treated as trucks, with no distinction between differing types of drayage operations. 40% of all traffic routed to Maher terminals was given an additional stop at the Maher chassis depot. Travel times and delays that were included in this model were recorded from the time a truck was created (at the origin zone) to the time it was destroyed (at the destination zone). No delay was applied to trucks entering the terminals, therefore transactions at terminal gates were not captured by this model.

Marine container terminal simulations have been carried out using a variety of software platforms and techniques. Some simulations are meant to represent only the actions occurring within the terminal yard, others are meant to capture movements within the port's roadway network. Most simulations have represented gate strategies as shifts in demand and have not combined those demand shifts with actual gate operations. This method fails to capture the affect that gate strategies will have on actual gate operations.

Previous simulations also failed to include movements between chassis depots and terminals and interactions between entrance gate queues and IMCT roadways. The methodology outlined in Section 3 explains how this work captured all of these movements using a Paramics simulation.

3. METHODOLOGY

This section describes the process used to build the traffic simulation model for PNE. The section includes the process that was undertaken to select a software platform, a physical description of the PNE, the development of vehicle types, zones, and demand, a physical description of the simulation for each gate strategy, and the approach used to model and calculate emissions.

3.1 Software selection

Several off-the-shelf dynamic traffic simulation software platforms are available including, but not limited to, CORSIM, SimTraffic, AIMSUN, VISSIM and Paramics. All of these platforms are capable of creating microscopic traffic simulations that can perform project-level analysis. A comparison of traffic simulations conducted by Ratrout and Rahman (22) reviewed various platforms based on a variety of criteria (i.e. ability to simulate signaled intersections, congestion, intelligent transportation systems, etc.). Most evaluations concluded that the simulation platforms performed relatively equally. Quadstone Paramics (23) was selected for this research due to its availability and its ability to model emissions using the Monitor plug-in.

The diversity of Paramics software enabled the development of a simulation that would include the necessary logic to simulate drayage movements within the PNE. Paramics was also used estimate delays experienced on terminal roadways and at terminal gates representing congestion levels within the PNE. These results were used to analyze the different gate strategies and their effect on the entire PNE and each IMCT.

3.2 Physical description of the PNE

The PNE is located east of Newark Liberty International Airport and is bordered by I-95 on the west and I-78 to the north. Container ships enter the port through Newark Bay, located east of the port. The port has three main access roads. Trucks entering from the south use North Avenue. At the north end of the PNE, vehicles enter from either Port Street or Doremus Avenue. Port Street provides direct access to both I-95 and I-78, therefore a majority of vehicles entering from the north use this entrance. The PNE contains three container terminals; APM, Maher, and the Port Newark Container Terminal (PNCT). Each terminal has a chassis depot where drayage trucks pick up or drop off chassis equipment. The APM chassis depot is located within the terminal. Maher and PNCT terminals both have off-site chassis depots. The location of these depots were considered in the model as it was assumed that they would generate extra trips for trucks picking up or dropping off chassis equipment either before or after they visited the terminal. An aerial view of the port and the physical location of areas crucial to the simulation are shown in Figure 1.

Source: http://www.google.com/earth/index.html

FIGURE 1 Satellite Image of the PNE

3.3 Physical attributes of the Paramics simulation

The first step in developing the simulation model was to establish an accurate representation of the roadway network in the vicinity of the PNE. The following section describes the physical attributes of the CPO, extended hour and appointment scenarios.

3.3.1 Vehicle types

Developing a detailed set of drayage vehicles is crucial as it will allow for the accurate representation of queues at the terminal gates and detailed modeling of movements between the terminals and the chassis depots. The latter is vital when estimating congestion delays and emissions, as these movements represented a significant percentage of the total drayage movements within the PNE. Three major categories of vehicles were used to represent the typical traffic stream at the PNE:

a) passenger cars that would originate at or be destined to “other” zones

b) trucks that would originate at or be destined to “other” zones and

c) trucks destined to the IMCTs

For passenger cars, the default car attributes provided by Paramics were used to represent physical characteristics of the vehicles. Two vehicle types were used to represent trucks destined to “other” zones within the PNE. Both vehicles were given the default operational attributes of a Large Goods Vehicle (LGV) but one was given a length of 20 ft and the other was given a total length of 66ft which was divided into a 13 ft cab and a 53 ft trailer. 85% of demand for trucks destined to “other” zones was represented by the 20ft trucks and the remaining 15% by 66 ft vehicles.

Three vehicle types were used to represent trucks destined to the terminals; trucks hauling a container (from now on referred to as container trucks), trucks hauling a bare chassis (from now on referred to as chassis trucks), and bobtail trucks. The operational attributes of these vehicles were all defined using the default characteristics of an LGV. Container trucks were represented by two separate vehicle types. The first type represented a truck hauling a 40 ft container and the second represented a truck hauling a 20 ft container. The cab of each container truck was given a length of 13 ft, whereas trailers were assumed to be the length of the container. Therefore, 40 ft container trucks had a combined length of 53 ft and 20 ft container trucks had a combined length of 33 ft. Assigning different lengths to container trucks was considered important to accurately represent queue lengths at terminal gates. The proportion of 40 ft container trucks to 20 ft container trucks in the simulation was 80% to 20%. These estimates were obtained from a limited set of observations obtained from satellite images.

Chassis trucks were two-part vehicles and consisted of a 13 ft cab hauling a 40 ft trailer. Bobtail trucks were single unit vehicles and were assigned a length of 13 ft. Trucks with an appointment (from now on referred to as appointment trucks) were given the same physical characteristics as non-appointment trucks.

3.3.2 Origin/destination zone development

Paramics simulation software allows the user to create two different zone types, vehicle sinks and strategic waypoints. Vehicle sinks are zones which represent either an origin or a destination within the simulation where vehicles are either released into or removed from the simulation. The second type of zone is strategic waypoints, which must be used in combination with vehicle sinks. Vehicles can travel through any number of assigned strategic waypoints before reaching their destination but must have origins and destinations at sinks. The need to complete a route between an origin and a destination prevents strategic waypoint zones from being placed on dead end streets. Due to this fact, terminals were modeled as circular routes through which travel time is meant to represent yard operations for drayage trucks.

The use of strategic waypoint zones in a simulation requires the development of a set of rules to govern vehicle routes. These routes were used in the simulation of the PNE to direct movements of drayage trucks. Routes within the simulation varied according to the type of movement needed to complete drayage transactions (specified by vehicle type). For example, trucks entering the simulation bobtail or with a chassis and destined for either Maher or PNCT terminals (i.e. terminals with external chassis depots) were routed to both the terminal and chassis depot before exiting the simulation. The use of strategic waypoint zones also ensured that the trucks entering the terminals were the same as those exiting the terminals. In contrast, the use of vehicle sinks to represent terminals would have made it impossible to track vehicles throughout the simulation and calculate the time spent within each terminal for each truck. Strategic waypoints allowed trip times to be recorded from the time a truck was released into the simulation (at the entrances of the PNE) until the time it was removed (at an exit of the PNE). This method also provided a more accurate representation of delays, travel times and emissions occurring within the PNE and within each terminal.

Thirty-nine zones were used to represent origins and destinations within the PNE. To better model the complex traffic movements within PNE these zones were broken down into three separate sets:

a) zones representing entrances/exits to the PNE (i.e. North Avenue, Port Street, and Doremus Avenue),

b) zones representing non-terminal origin/destinations and

c) zones representing terminals and chassis depots.

The entrances to the PNE were simulated using 18 vehicle sinks (6 zones per entrance). An example of an entrance zone configuration is shown in Figure 2.

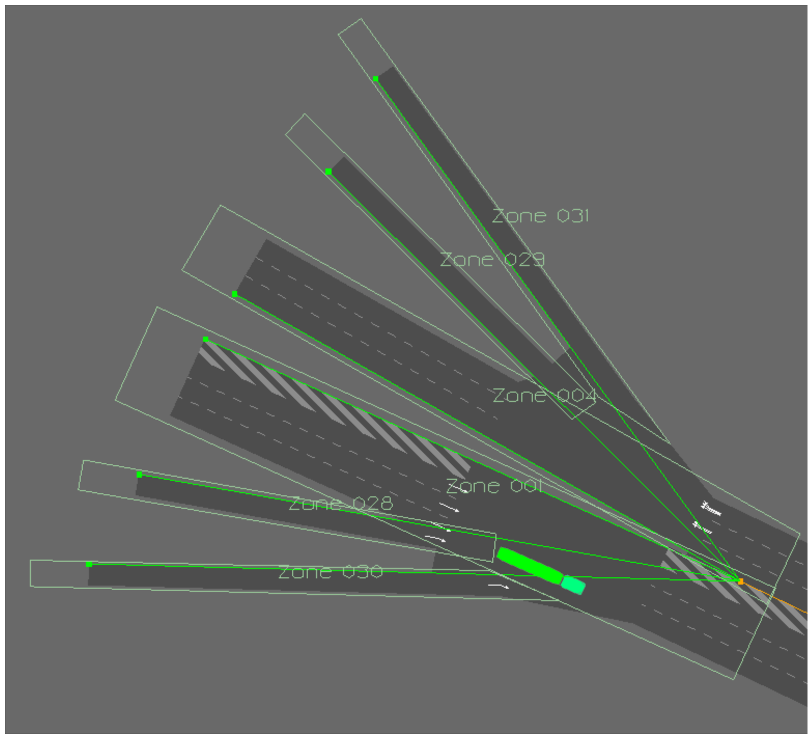


FIGURE 2 Zones Representing the North Avenue Entrance

The example shown in Figure 2 is the entrance at North Avenue. The multiple zones used to simulate the PNE entrances were necessary to control traffic assignments to each terminal. If a truck was destined to the APM terminal and entered via North Avenue, it was released at Zone 001. If that same truck was exiting the simulation after completing its drayage transactions at the APM terminal, it was removed from the simulation once it arrived at Zone 004. Similarly, Zones 028 and 030 were sources for vehicles entering via North Avenue and destined for either the Maher or PNCT terminals, respectively. Zones 029 and 031 were termini for vehicles exiting via North Avenue from either the Maher or PNCT terminals. Both Port Avenue and Doremus Street were represented by similar zone configurations, each having sources and sinks dedicated to movements from individual terminals. The inner zones of the configuration were also used as origins and destinations for all non-terminal traffic within the simulation.

The links at the PNE entrances are zone connectors in lieu of default link types. This approach was adopted as vehicles released into a simulation on default links are released at a speed of 5 miles per hour (mph), whereas vehicles released onto a zone connector are released at link speed. Vehicle speed is an important factor in calculating both travel times and emissions, therefore it was important to accurately represent vehicle speed at the entrances and exits of the PNE.

Non-terminal destinations within the PNE were represented by zones 007-022. Specific information was available for the terminal employee entrances, and this data was used to create demand for these zones (discussed in detail in section 3.5). The remaining zones were "other" zones created for areas where turn count data was available. All demand destined for these zones originated or terminated at a zone that represented an entrance to the PNE.

Zones 023-027 represented the terminals and chassis depots of the PNE. These zones were modeled using strategic waypoint zones. As mentioned earlier, it was necessary to build a set of rules to define the routes of vehicles traveling to strategic waypoint zones. The simulation included a set of 45 waypoint rules which defined routes for trucks destined to terminals and chassis depots. Table 1 shows rules 1-9, which were used to govern routes for trucks destined to the APM terminal.

TABLE 1 APM Strategic Waypoint Routing Rules

Entrance/Exit	North	Port	Doremus
North	1	2	3
Port	4	5	6
Doremus	7	8	9

Table 1 shows the relationship between strategic waypoint rules and the PNE entrances and exits. The routes defined the OD relationships between port entrances and terminals. The APM terminal was governed by fewer rules than the other terminals as its internal chassis depot did not require a separate set of rules for chassis and bobtail trucks.

Rules 10-27 governed routes for trucks destined to the Maher terminal and chassis depot. The relationship of the rules to their respective origins and destinations are shown in Table 2.

TABLE 2 Maher Strategic Waypoint Routing Rules

Entrance/Exit	North		Port		Doremus	
North	10	11	12	13	14	15
Port	16	17	18	19	20	21
Doremus	22	23	24	25	26	27

Even-numbered rules defined routes for container trucks destined to Maher terminals. These routes specified which entrance a container truck would be released from and which exit a container truck would travel to after completing its drayage transaction at the terminal. Odd-numbered rules represented routes for chassis and bobtail trucks. Separate routes were needed for these truck types as transactions at chassis depots were combined with terminal transactions. It was assumed that trucks would enter and exit the terminal in such a way as to minimize the distance traveled within the PNE, therefore routes terminating at North Avenue (Rules 11, 17, and 23) were defined so that trucks traveled first to the terminal and then to the chassis depot. For trucks originating at North Avenue, the order in which trucks visited the chassis depot and terminal were reversed. For the remaining route combinations, the order in which vehicles visited the terminal and chassis depot did not affect travel distance, therefore order of assignment was random.

Strategic waypoint rules which defined routes for trucks destined to the PNCT terminal (rules 28-45) used the same logic applied at the Maher terminal and chassis depot combinations, due a similar proximity to PNE entrances for both the terminal and chassis depot. Table 3 displays the strategic waypoint rules used to define truck interactions with the PNCT terminal.

TABLE 3 PNCT Strategic Waypoint Routing Rules

Entrance/Exit	North		Port		Doremus	
North	28	29	30	31	32	33
Port	34	35	36	37	38	39
Doremus	40	41	42	43	44	45

Waypoint routing rules were a critical part of the simulation, used to add logic which represented complex drayage movements within the PNE. The waypoint routes gave the simulation the capability to record additional movements generated by external chassis depots and to record truck movements from their release until their removal from the network.

The use of both vehicle sinks and strategic waypoint zones were essential to capturing the complex movements of drayage trucks within the PNE. Movements between terminals and chassis depots represent a significant portion of demand, therefore the inclusion of the movements was essential to assess the impact that both extended hours and appointment systems would have on congestion and emissions within the IMCT.

3.3.3 Base case development

Creation of a simulation requires both a physical representation of the area to be modeled as well as the logic representing movement of within the defined physical space of the model. The geometric data used to create the physical representation of the PNE was collected from Google Earth and visual observations from a site visit. The roadway network modeled consisted of 370 nodes connected by links representing 198,884 feet of roadway. Care was taken to accurately represent the roadway network, especially at entrances at the terminals, as interactions of trucks at the terminal gates were considered a crucial component of measuring the effectiveness of gate strategies within the PNE.

The PNE has three terminals, each of which has a unique set of characteristics that influenced the behavior of drayage operations. The first terminal described is the

APM terminal, which is the southernmost terminal of the PNE. A satellite image of the APM terminal entrance and exit gate configuration is shown in Figure 3.

Source: http://www.google.com/earth/index.html

FIGURE 3 Satellite Image of APM Terminal Gate Configuration

The queuing area leading to the APM entrance gate is 15 lanes wide. The main access road at the entrance to the APM terminal is only 2 lanes wide in both directions, therefore trucks must make rapid lane changes to form evenly distributed queues at entrance gates. To accommodate this rapid lane expansion, the simulated entrance of the APM terminal was divided into two sections. The first section of the gates at APM consisted of two links (5 lanes wide shown in figure 4). These links provide trucks approaching the entrance time to shift into all the available 15 lanes. The second section (15 lanes wide) represented the actual geometry of the terminal gates and queuing area. The APM exit gates were 15 lanes wide (Exit Gate & Approach, Figure 4).

In addition to the main exit gates, the APM terminal had a separate exit gate for trucks exiting via the chassis depot (located within the terminal yard). Delays for the chassis depot exit gates were reduced to simulate reduced inspection times for trucks exiting bobtail. These areas are shown in Figure 4.

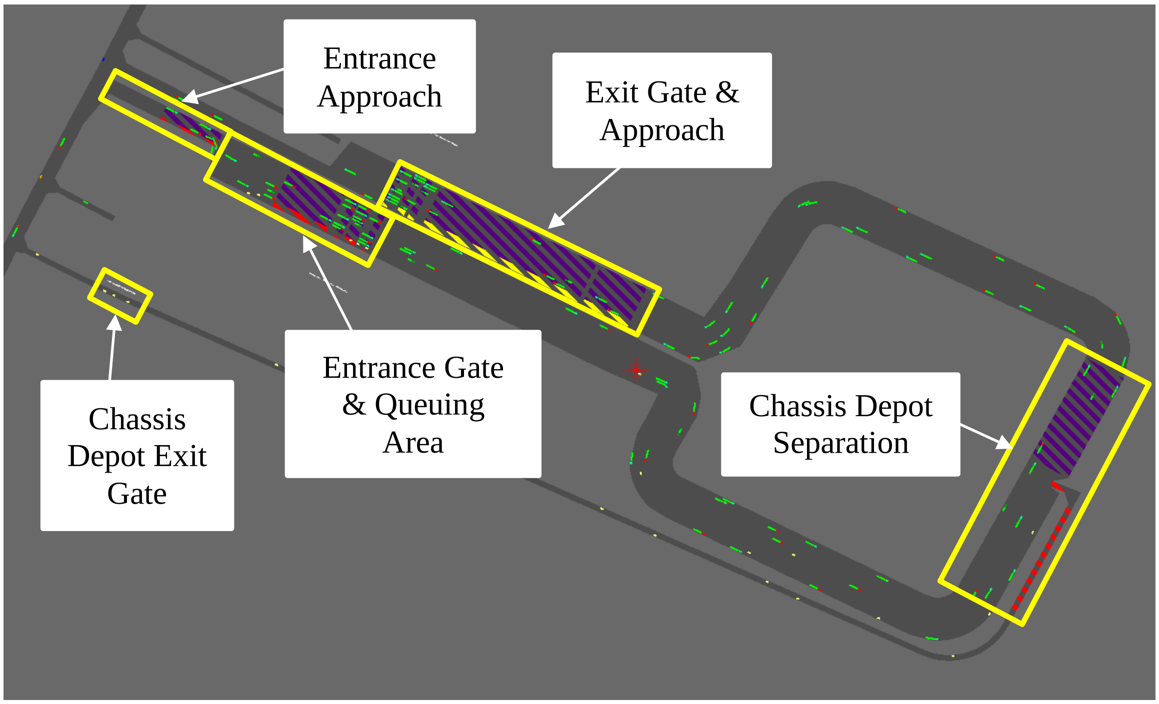


FIGURE 4 APM Terminal, CPO Scenario

The red-hatched lanes in Figure 4 represent lanes available only to bobtail trucks while the purple-hatched lanes represent lanes for all other trucks. The yellow-hatched lanes at the Exit Gate & Approach are restricted to accept only chassis trucks. The length of delays at the entrance gates was a function of truck type, therefore lane restrictions were used to guide demand to the entrance gates where the delay matched gate transactions for specific truck types.

To simulate drayage operations at the APM terminal, it was necessary to separate movements that would result in a vehicle exiting via the main exit gates from vehicles exiting through the chassis depot. Lane restrictions were used to create this separation.

Bobtail trucks were forced to exit the terminal via the chassis depot, whereas all container and chassis trucks were forced to use the main exit gates of the terminal (Chassis Depot Separation Area, Figure 4).

Lane restrictions alone did not provide enough logic to accurately represent drayage movements at the APM terminal. In addition to lane restrictions, it was necessary to adjust the distribution of demand. This was done using two of Paramics' vehicle behavior features; lane choice logic and nextlanes. Lane choice allows the user to adjust vehicle distribution by either an exact percentage, where the user defines the percentage of vehicles utilizing each lane, or by group, where the user defines an acceptable range of lane choices that vehicles can use. Lane choice also allows the user to filter lane usage by vehicle type.

The nextlanes feature allows the user to specify the demand distribution from each lane of a link a vehicle is exiting. Nextlanes also allows the user to specify the range of lanes that can be utilized, thus controlling for movements from one link to the next. This is especially important for links with lane restrictions, as vehicles that enter a lane onto which they are restricted are forced to merge. These forced movements tend to cause congestion, as merging vehicles interfere with traffic attempting to travel through lanes where forced merges are occurring.

The default logic in Paramics does not account for rapid lane expansions, which causes problems when modeling terminal entrances (i.e. vehicles entering APM terminal enter from 1 lane and must be quickly distributed among 15 lanes). The default logic for Paramics vehicle movements concentrates all of vehicles in the lowest numbered lanes, as vehicles do not have enough time to make a move to the upper limits of the lane expansion. Figure 5 provides a schematic of the problem. The queue (highlighted by the yellow circle in Figure 5) formed after 20 minutes of simulation run time. Given that free flow travel time from North Avenue is 4 minutes and the free flow travel time from Port Street is 7 minutes, it becomes obvious that default vehicle lane distributions do not allow the simulation of the PNE to function properly. The vehicle behavior for trucks navigating the APM terminal entrance was adjusted using a series of lane choice and nextlane rules. In the area labeled Entrance Approach in Figure 4, two lane choice rules were created to distribute demand for the CPO scenario. An image of the links and lane choice rules is shown in Figure 6.

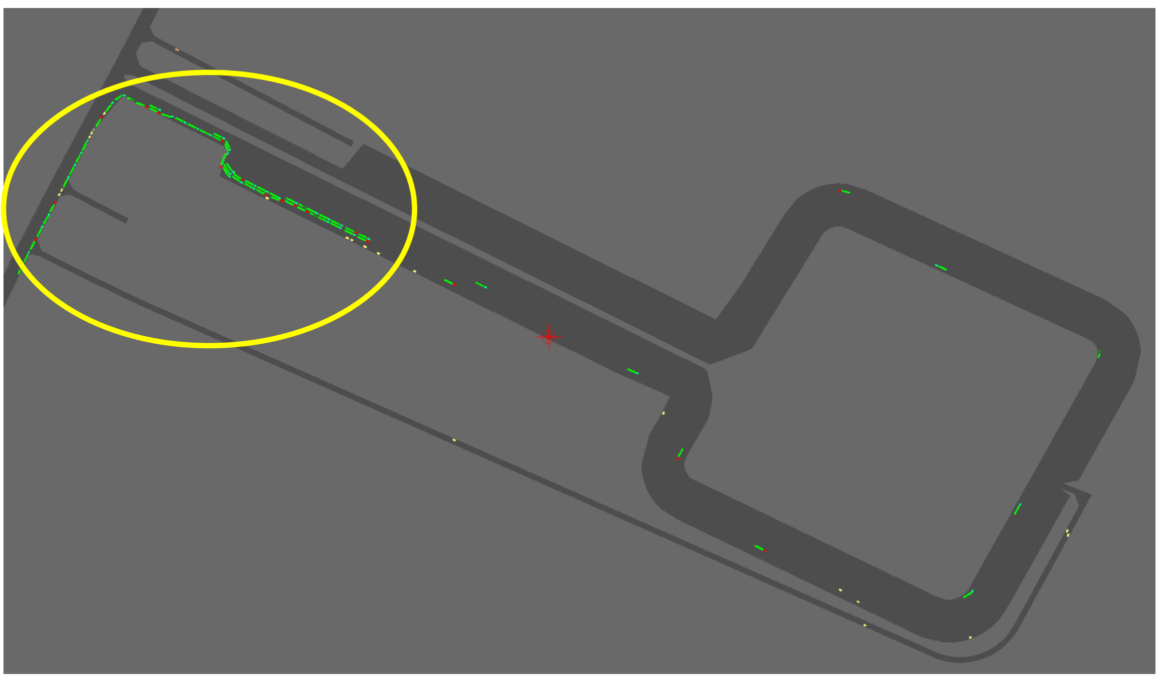


FIGURE 5 Unnatural Queuing at the APM Terminal Entrance

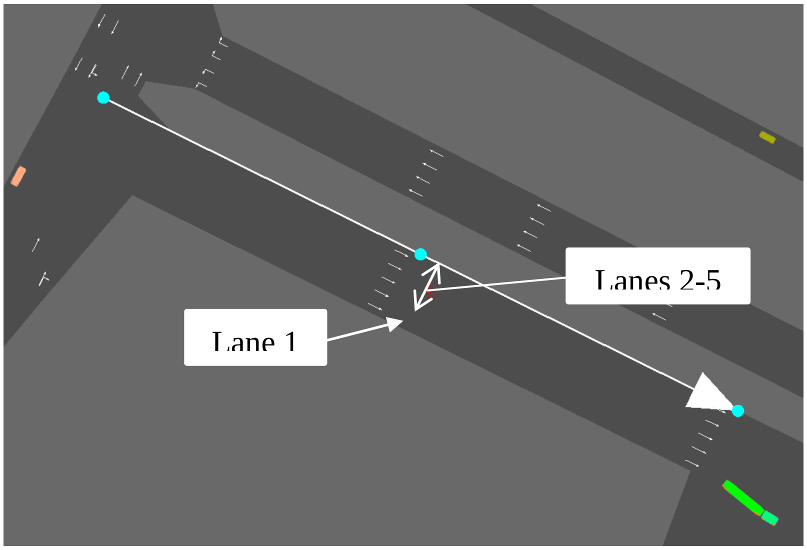


FIGURE 6 APM Terminal Entrance Lane Choice Rules

The first rule restricted bobtail trucks to lane 1. The second rule evenly distributed container and chassis trucks between lanes 2, 3, 4, and 5 (25% of demand entering the approach was assigned to each lane).

Next, a set of nextlane rules was created to control the movements between the Entrance Approach and the Entrance Gate & Queuing Area. Lanes 1 and 2 of the Entrance Gate & Queuing Area were restricted to bobtail trucks; therefore the demand from lane 1 of the Entrance Approach was evenly distributed among these two lanes. The distribution for the remaining lanes, restricted to container and chassis trucks, is shown in Table 4.

Table 4 APM Entrance Nextlane Distribution

Approach Lane	Destination Lanes	Distribution (%)
1	1,2	50,50
2	3,4,5,6	25,25,25,25
3	7,8,9	33,33,34
4	10,11,12	33,33,34
5	13,14,15	33,33,34

The nexlane distribution for the APM terminal was used to distribute demand and provide an accurate representation of the queues forming at terminal gates.

Lane choice rules were also created to distribute demand at the Exit Gate & Approach. The area to which these rules were applied is shown in Figure 7.

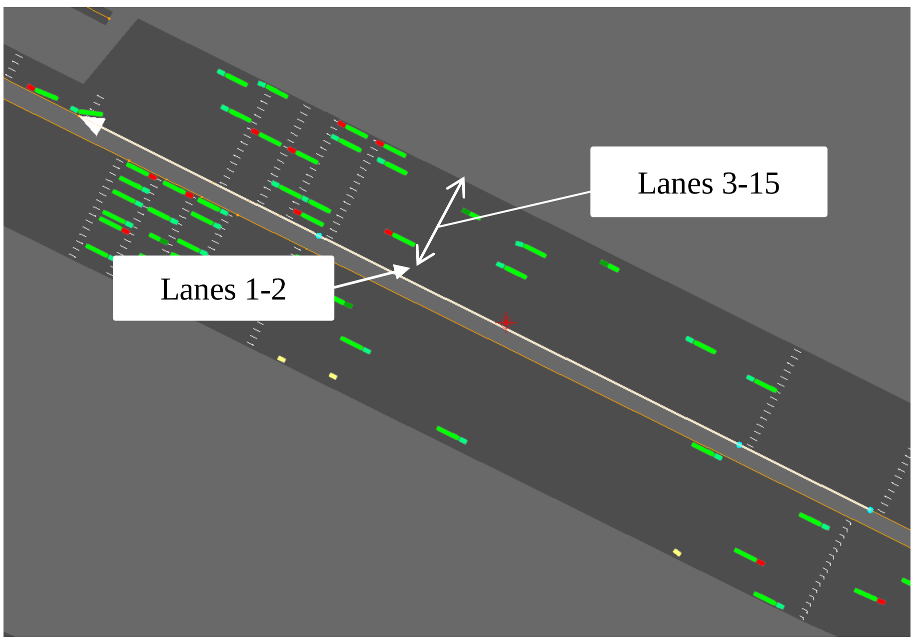
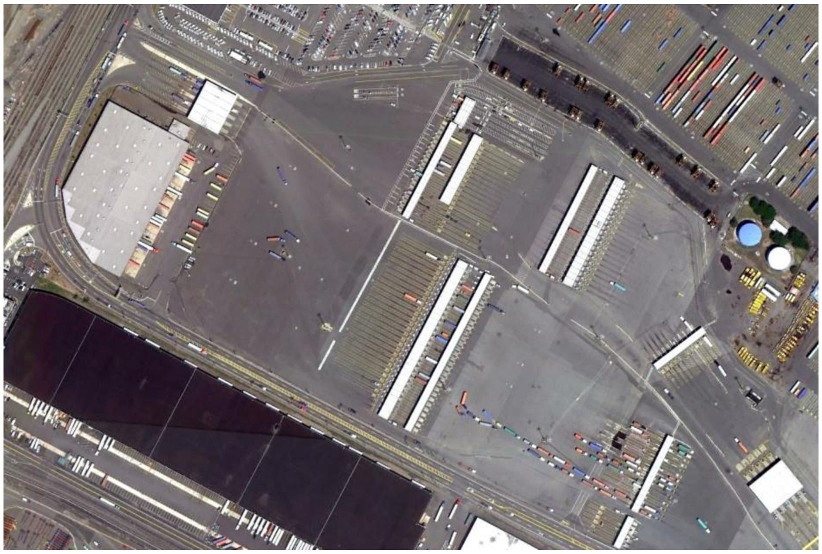


FIGURE 7 APM Exit Gate Lane Choice Rules

Lane choice logic at the Exit Gate & Approach included two rules. The first rule was applied to lanes 1 and 2 and restricted usage to chassis trucks. The second rule was applied to lanes 3-15 and distributed container and chassis trucks evenly among the lanes. Lane choice rules for the Exit Gate & Approach allowed chassis trucks to utilize all 15 lanes but limited container trucks to gates 3-15, which had larger in-gate processing delays.

The next terminal to be described is the Maher terminal. The Maher terminal is located near the middle of the PNE and is the largest of the three PNE terminals. Figure 8 is a satellite image of the entrance and exit gates of the Maher terminal.



Source: http://www.google.com/earth/index.html

FIGURE 8 Satellite Image of the Maher Terminal Gate Configuration

The approach to the queuing area is a short section of roadway that is 5 lanes wide. The section containing the terminal entrance gates and queuing area is 20 lanes wide. The exit gates at the Maher terminal are also 20 lanes wide. The configuration of the entrance and exit gates in the simulation was simplified to a single-tier configuration, as the exact function of each gate of this terminal was unknown. Figure 9 shows the simulation representation of the entrance and exit gates and their respective approaches.

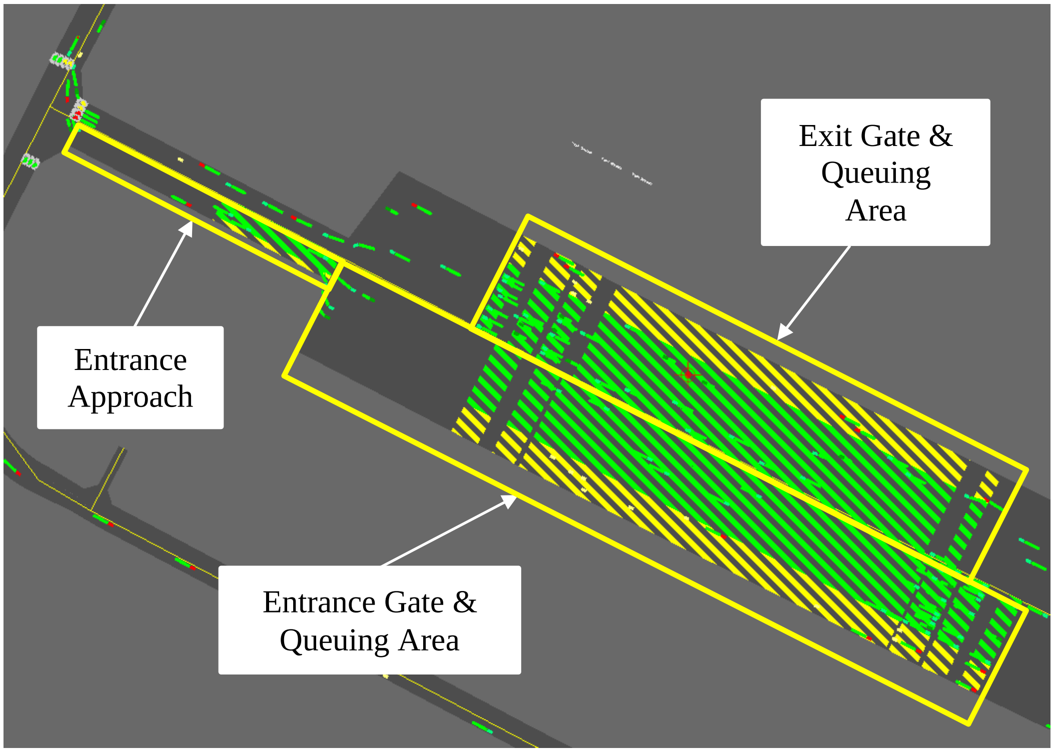


FIGURE 9 Maher Terminal Gate Configuration, CPO Scenario

The areas labeled Entrance Gate & Queuing Area and Exit Gate & Queuing Area in Figure 9 were given the same lane restrictions. The first six lanes were restricted to bobtail and chassis trucks, where delay was reduced (yellow-hatched lanes, Figure 9). The remaining fourteen lanes could only be accessed by container trucks (green-hatched lanes, Figure 9). Restrictions were also applied to the area labeled Entrance Approach in Figure 9. Lane 1 of the Entrance Approach was restricted to bobtail and chassis trucks and lanes 2, 3, 4, and 5 were restricted to container trucks.

Distribution of demand at the Maher terminal was governed using a combination of lane choice and nextlane rules. Figure 10 shows the location of the lane choice rule at the Entrance Approach.

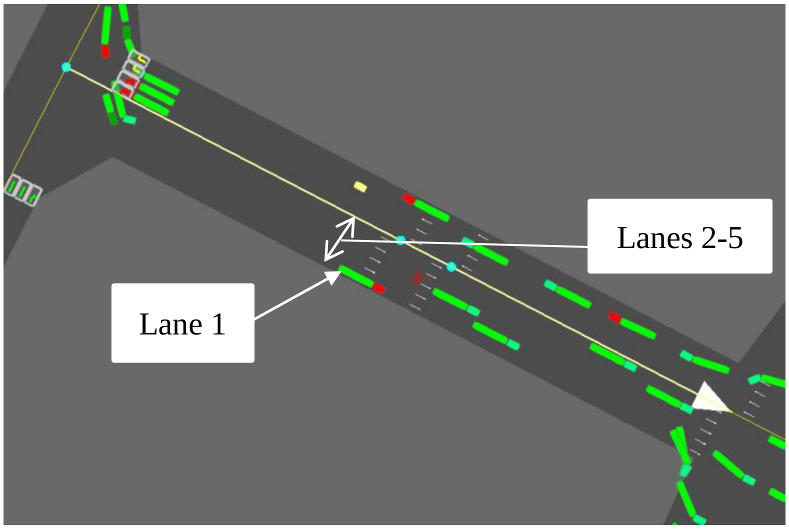


FIGURE 10 Maher Entrance Approach Lane Choice Rules

Two lane choice rules were created to distribute demand among the Entrance Approach. The first rule distributed all bobtail and chassis trucks to lane 1. The second rule distributed 25% of container truck demand to lanes 2, 3, 4, and 5, respectively.

Vehicle movements between the Entrance Approach and the Entrance Gate & Queuing Area were controlled using nextlanes rules. The aim of the nextlane rules was to distribute chassis and bobtail trucks to the first six lanes and evenly distribute container trucks among the remaining lanes. Table 5 shows the values used for the nextlane distribution at the Maher terminal Entrance Approach.

TABLE 5 Maher Entrance Nextlane Distribution

Approach Lane	Destination Lanes	Distribution (%)
1	1,2,3,4,5,6	16,16,17,17,17,17
2	7,8,9,10	25,25,25,25
3	11,12,13,14	25,25,25,25
4	15,16,17	33,33,34
5	18,19,20	33,33,34

The length of the queuing area at the Maher terminal entrance made it necessary to add an additional set of lane choice rules to control the distribution of vehicles. The lane choice rules for the Entrance Gate & Approach ensured that demand for bobtail/chassis lanes (1-6) and container lanes (7-20) remained equally distributed while approaching the entrance gates.

The distribution of trucks approaching the Maher exit gates were controlled using another set of lane choice rules. The Exit Gate & Queuing Area at the Maher terminal is shown in Figure 11.

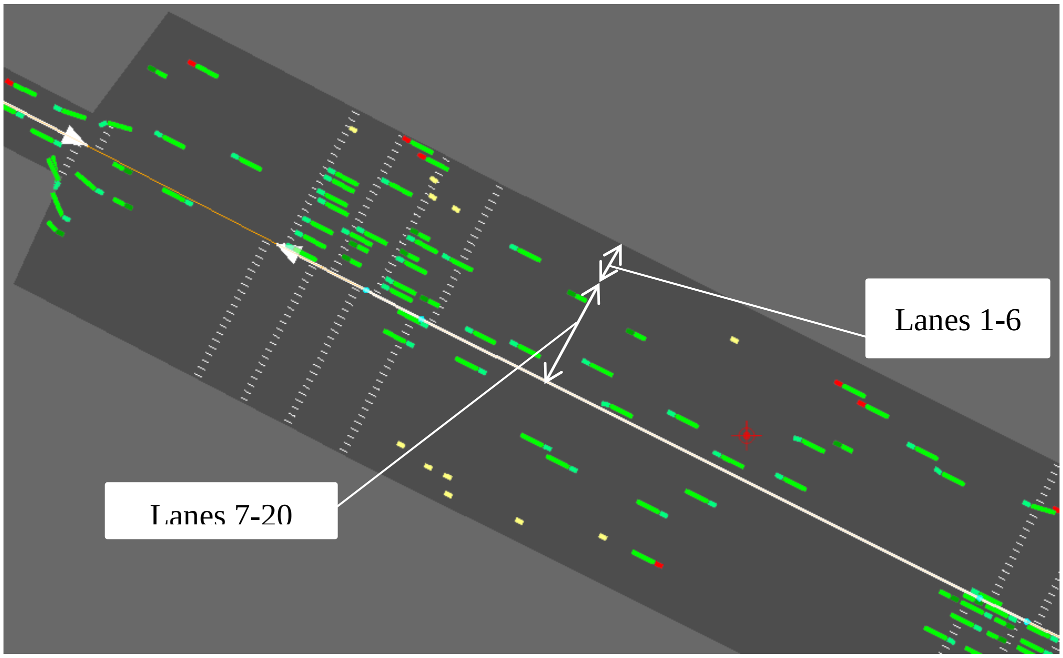


FIGURE 11 Maher Exit Gate Lane Choices

The lane choice rule for lanes 1-6 uses an exact distribution to assign demand for chassis and bobtail trucks, where lanes 1 and 2 were each assigned 16% of the demand and lanes 3-6 were each assigned 17% of the demand. Lanes 7-18 were each assigned 7% of the container truck demand and lanes 19 and 20 were each assigned 8% of demand.

Unlike the APM terminal, the Maher chassis depot is located outside the terminal. The distance between the entrance to the Maher chassis depot and the entrance to the Maher terminal is approximately 1.6 miles, due to the circuitous route of travel that must be taken between the two. A satellite image of the Maher chassis depot is shown in Figure 12.

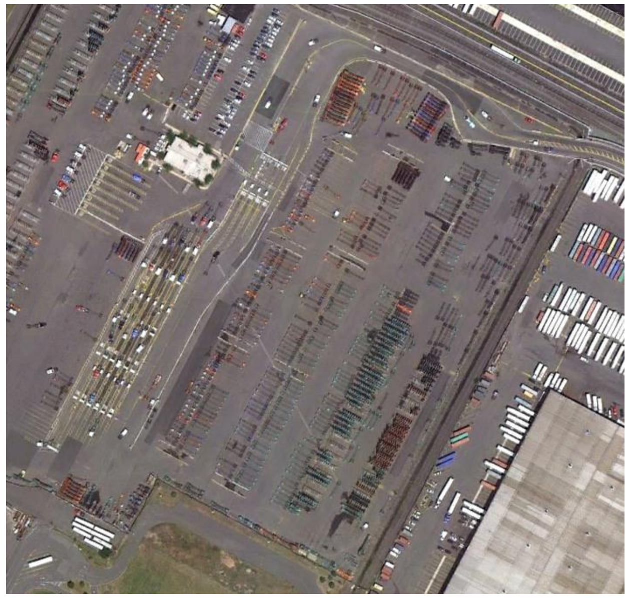

Source: http://www.google.com/earth/index.html

FIGURE 12 Satellite Image of the Maher Chassis Depot

Figure 12 shows that the entrance gates to the chassis depot are 6 lanes wide and that the exit gates are 4 lanes wide. The simulation representation of the Maher chassis depot is shown in Figure 13.

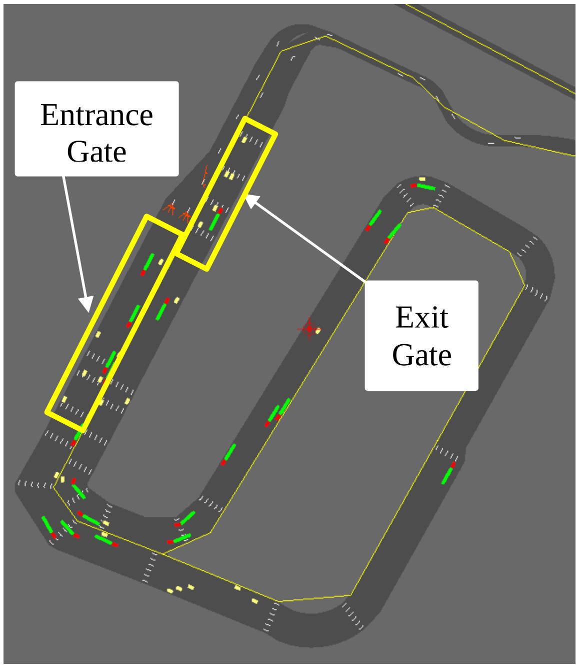


FIGURE 13 Simulation of the Maher Chassis Depot

The approach to the chassis depot widens from one lane to six lanes at the entrance gate, therefore two sets of nextlane rules were needed to control the distribution of vehicles approaching the chassis depot entrance gates (shown in Figure 14).

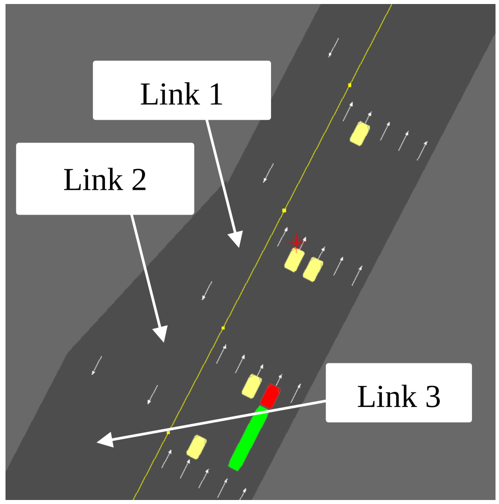
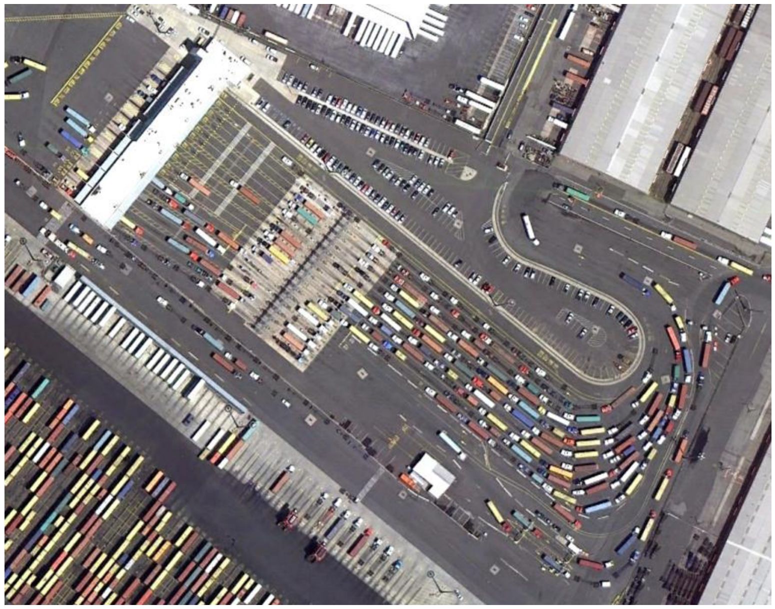


FIGURE 14 Lane Expansion, Maher Chassis Depot

The first rule was used to control the behavior of vehicles traversing from Link 1 to Link 2. The distribution of demand between Link 1 and Link 2 was set at 50% for each lane. The next rule applied to the expansion from two lanes to six lanes, which occurs when the vehicles exit Link 2 and enter Link 3. This nextlane rule distributed 33-33-34% of demand from lane 1 of Link 2 to lanes 1, 2 and 3 of Link 3. Lane 2 of Link 2 also had a 33-33-34% distribution, but demand from this lane was divided between lanes 4, 5 and 6 of Link 3.

The third terminal description is of the PNCT terminal, which is located near the north end of the PNE. Trucks entering the PNCT terminal must leave the main access road of the PNE and travel down secondary roads before reaching the entrance. The geometry of the entrance to the PNCT terminal is constrictive and causes congestion problems. A satellite image of the entrance and exit gate configuration of the PNCT terminal is shown in Figure 15.



Source: http://www.google.com/earth/index.html

FIGURE 15 Satellite Image of the PNCT Terminal Gate Configuration

The first section of the entrance is 2 lanes wide and rapidly expands to 10 lanes wide at the entrance gates, all while following a tight S-shaped curve. The exit gates at the PNCT terminal are 6 lanes wide. The geometry of the entrance to the PNCT terminal plays a critical role in queue formation. To capture this geometry, the entrance to the PNCT was broken into three sections; the Approach, the Entrance Expansion and the Entrance Gate. The approach was two lanes wide and included the initial section of the S-curve. The Entrance Expansion was five lanes wide and was used to represent the remainder of the S-curve. The Entrance Gate included the entrance gates themselves and the queuing area. The simulation of the PNCT terminal is shown in Figure 16.

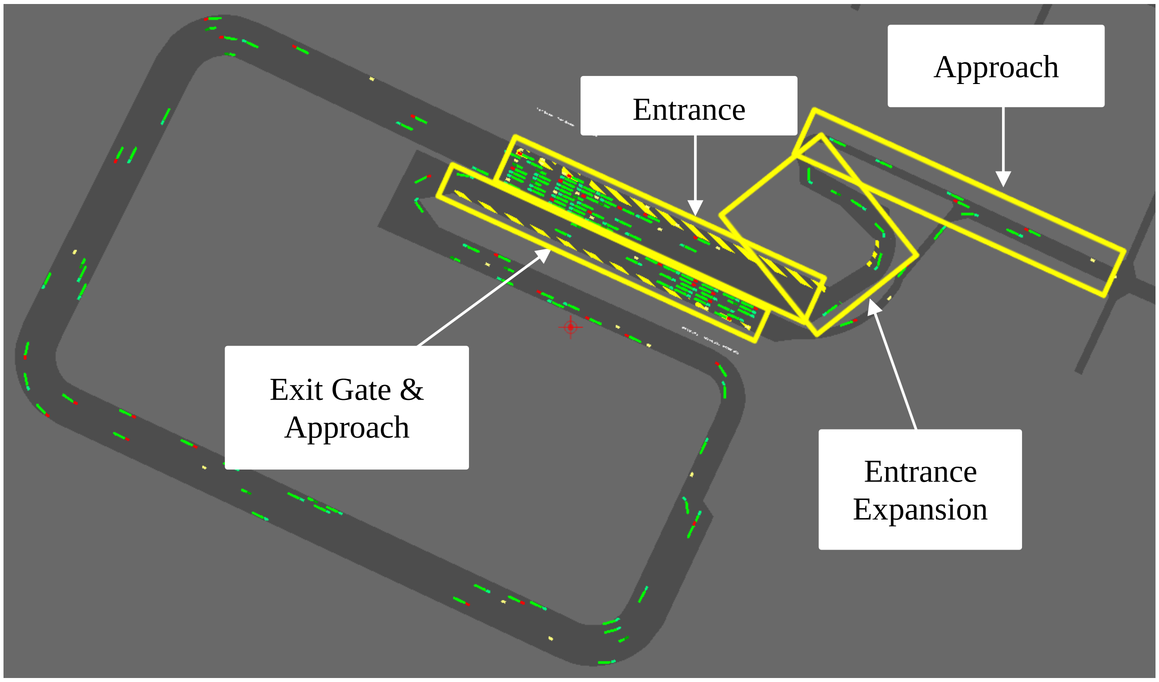


FIGURE 16 PNCT Terminal, CPO Scenario

The area labeled Entrance Expansion (shown in Figure 16) had two sets of lane restrictions. The first restriction was applied to lane 1 and limited access to bobtail and chassis trucks. Lanes 4 and 5 were restricted to container trucks. At the section labeled Entrance Gate, lanes 1 and 2 were restricted to chassis and bobtail trucks (yellow-hatched lanes, Figure 16).

Lane restrictions at the Entrance Expansion were combined with lane choice logic in an effort to mitigate congestion. The lane choice logic for this area consisted of two rules, the first of which directed all bobtail and chassis truck demand to lane 1. The second rule distributed 25% of container truck demand to each of the four remaining lanes. The area affected by the lane choice rules is shown in Figure 17.

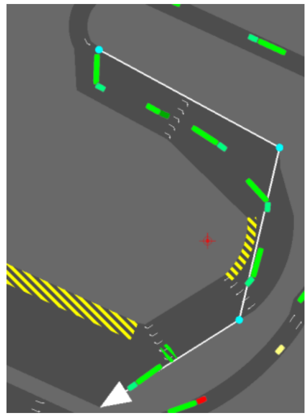


FIGURE 17 Lane Choice Restrictions for the PNCT Entrance Expansion

The entrance gates at the PNCT terminal operated differently than the entrance gates of the other terminals. The first two gates were restricted to bobtail and chassis trucks, while the remaining gates could be utilized by all truck types. To represent this behavior, nextlane rules were created between the Entrance Expansion and the Entrance Gate to control the distribution of trucks queuing at the PNCT gates. No rule was created for the first lane to allow chassis and bobtail trucks to move between every lane approaching the entrance gate. Another reason for not applying a nextlane rule to this lane was that the geometry of the PNCT Entrance Expansion left little room for trucks to maneuver between lanes and, despite restrictions applied to the approach, container trucks occasionally remained in lane 1 as they could not perform the weaving movements in time to avoid the restricted lanes. By not applying a nextlane rule to lane 1, container trucks stuck in lane 1 could maneuver to lane 3 in the queuing area at the entrance gates.

Consideration of added weaving movements effected the distribution of vehicles exiting the Entrance Expansion from lane 2. 25% of these vehicles were assigned to lane 3 and the remaining 75% were assigned to lane 4, which helped prevent congestion on lane 3 by weaving container trucks attempting to avoid restricted lanes. The demand exiting the approach via lanes 3, 4, and 5 was evenly distributed between lanes 5-10 (two lanes per each lane of approach).

Vehicle distribution for the Exit Gate & Approach of the PNCT terminal was controlled through a combination of lane restrictions and lane choice rules. Lane 1 of this section was restricted to chassis and bobtail trucks (yellow-hatched lane, Figure 16). Lane choice rules for the exit gates of the PNCT terminal distributed all bobtail truck demand to lane 1 and distributed container truck demand evenly between lanes 2, 3, 4, and 5. A rule was also created to distribute chassis trucks evenly between all six lanes. The area where the lane choice logic was applied is shown in Figure 18.

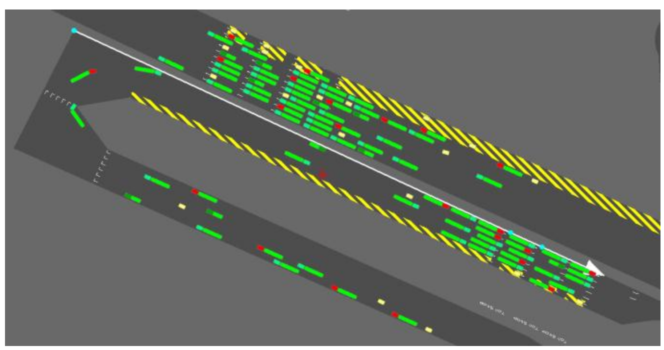
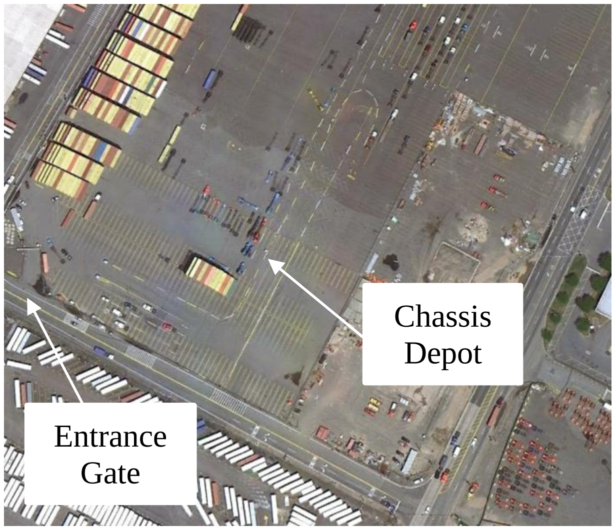


FIGURE 18 Lane Choice Restrictions for the PNCT Terminal Exit

The PNCT chassis depot is located on Polaris Street (approximately 3.3 miles from the entrance of the PNCT terminal) near the south end of the PNE. A satellite image of the entrance to the PNCT chassis depot is shown in Figure 19.



Source: http://www.google.com/earth/index.html

FIGURE 19 Satellite Image of the PNCT Chassis Depot

No gate configuration could be discerned for the PNCT chassis depot. Therefore, all gate delays for chassis and bobtail trucks destined for PNCT terminals were made to occur at the PNCT entrance gates. The simulation representation of the PNCT chassis depot is shown in Figure 20.

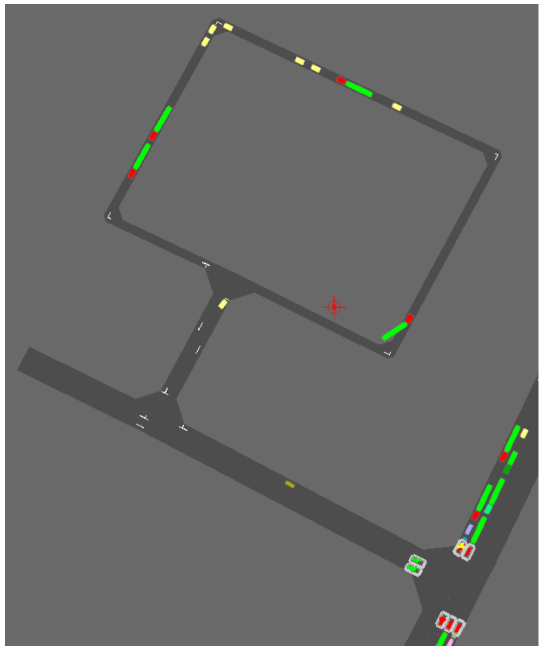


FIGURE 20 Simulation of the PNCT Chassis Depot

The data used to determine speed limits on the PNE roadway network were obtained from the 2010 Port of New York and New Jersey Port Guide (24). The guide included a map of port facilities which showed that primary roads had speed limits of 40 mph and secondary roads had speed limits of 30 mph. The links used to simulate truck movements within terminal yards and chassis depots were given speed limits of 5 mph (the lowest value allowable using Paramics) to approximate transactions within the terminal yards.

The simulation of the PNE included 77 intersections, 10 of which were signalized. To model signalized intersections, known turn count data (6) was used as input for a Synchro Studio 7 (25) simulation. The optimization feature was used to determine signal timings that would yield better levels of service at signalized intersections. The timings taken from the Synchro optimization were then used as input for the signalized intersections of the Paramics model and were held constant throughout each scenario.

The physical and behavioral aspects of the simulation described in this section pertain to both the CPO and the extended hour scenario. The only changes needed to create an extended gate hour scenario were made to the OD. Creating an appointment scenario required changes to be made to both the OD and the physical attributes of the model. These changes are detailed in the following section.

3.3.4 Creation of appointment scenarios

Both the physical attributes and the behavioral logic from the CPO scenario were adjusted to create the appointment scenario. The physical adjustment required a number of lanes to be converted to appointment lanes which would only serve appointment trucks. 30% of the lanes at each terminal entrance and exit gate were converted to appointment lanes. The physical conversion of lanes was coupled with changes in the OD (namely the creation of ODs for appointment trucks). A description of the appointment scenario ODs is given in Section 3.5.3.

Changes made to the APM terminal for the appointment scenario are shown in Figure 21.

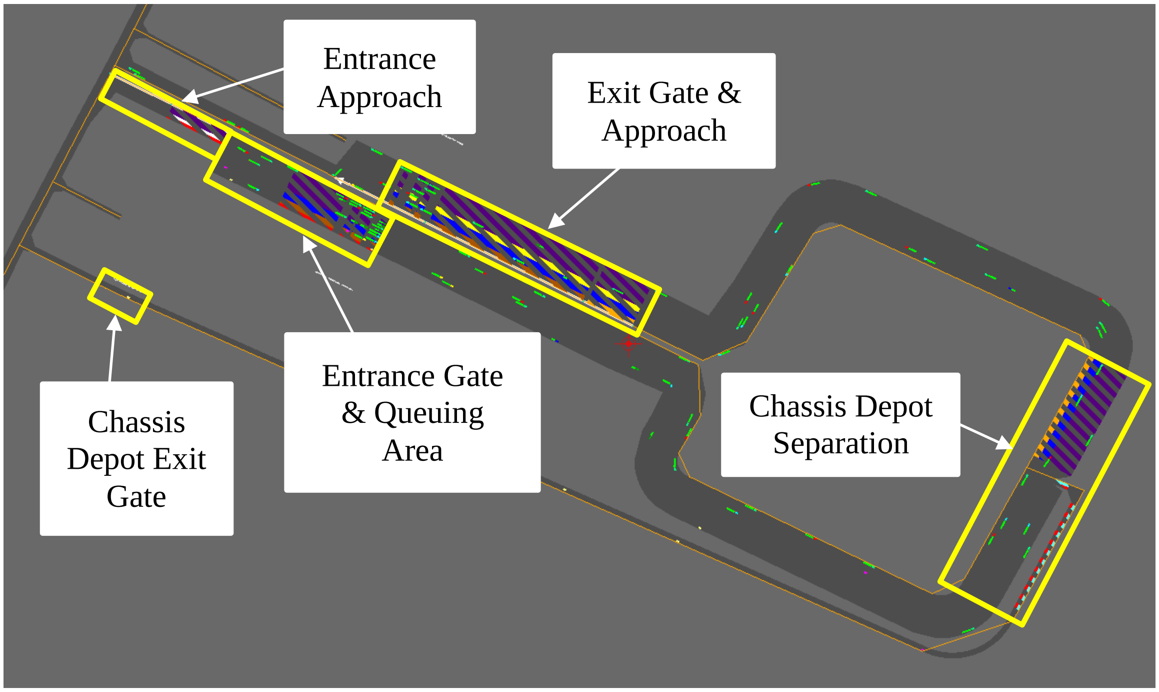


FIGURE 21 APM Terminal Layout, Appointment Scenarios

Figure 21 shows several lane restrictions were changed to accommodate appointment trucks. At the Entrance Approach, lane 2 was converted from a container/chassis truck lane to an appointment lane. At the Entrance Gate & Queuing Area, five of the fifteen lanes were converted to appointment lanes. The restriction on lane 2 was changed from bobtail only to bobtail and chassis appointment trucks. The restriction on lane 3 was changed from container and chassis trucks to bobtail and chassis appointment trucks. Lanes 4, 5, and 6 were changed from container and chassis only to container appointment trucks. The same configuration was used for the Exit Gate & Approach in the appointment scenarios. Lane restrictions at the Chassis Depot Separation Area were also changed to include bobtail appointment trucks.

Changes in lane restrictions were combined with changes in lane choice and nextlane logic. Lane choice logic was changed to distribute container and chassis trucks without appointments evenly between lanes 3, 4, and 5 of the Entrance Approach. The nextlane distribution was changed so that all bobtail trucks without appointments remained in lane 1 and all appointment trucks were evenly distributed between the appointment lanes (Lanes 2-6). Demand from lanes 3, 4, and 5 were each evenly distributed between lanes 7-9, 10-12, and 13-25, respectively, using nextlane rules.

Creation of appointment scenarios also required physcialadjustments to the Maher terminal. These changes are displayed in Figure 22.

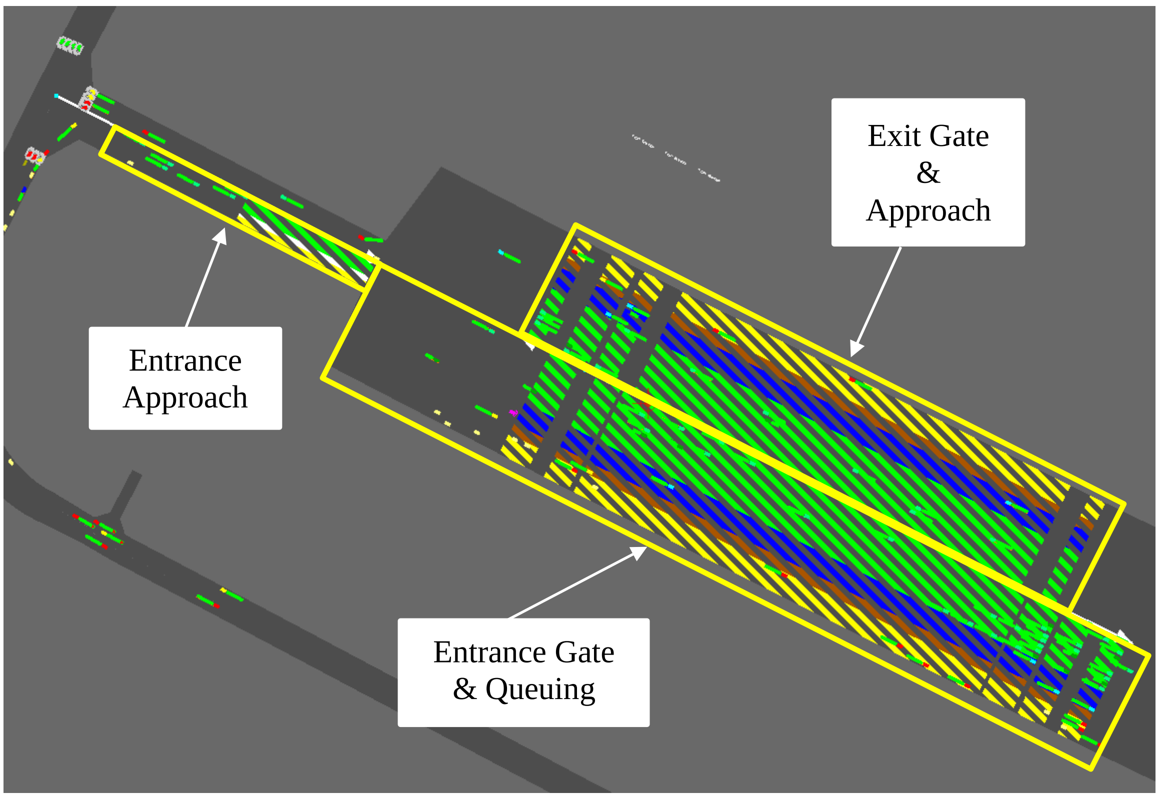


FIGURE 22 Maher Terminal Gate Configuration, Appointment Scenarios

Figure 22 shows that the restriction on the second lane of the Entrance Approach was changed to allow only appointment trucks (white-hatched lane, Figure 22). The lane choice and nextlane rules governing the Entrance Approach were also adjusted for the appointment scenarios. Lane choice rules were changed to guide chassis and bobtail trucks without appointments to lane 1 of the Entrance Approach, appointment trucks to lane 2 and evenly distribute container trucks between lanes 3, 4, and 5.

The nextlane rules were changed so that the demand for chassis and bobtail trucks in lane 1were evenly distributed between lanes 1-4 and appointment trucks (lane 2) were evenly distributed between lanes 5-10. Demand on lane 3 was distributed between lanes 11-14 and demand for lanes 4 and 5 were evenly distributed between lanes 15-17 and lanes 18-20, respectively.

Figure 22 displays the changes in lane restrictions that were made to the Entrance Gate & Queuing Area. The first four lanes (yellow-hatched) were restricted to bobtail and chassis trucks without appointments, lanes 5 and 6 (brown-hatched) were restricted to bobtail and chassis appointment trucks, lanes 7-10 (blue-hatched) were restricted to container trucks with appointments and the remaining lanes (green-hatched) were restricted to container trucks without appointments. The lane choice rules at the Maher entrance gate were adjusted from the CPO case to reflect changes in lane restrictions needed for the appointment scenarios. The rules ensured that demand would be evenly distributed between lanes with similar restrictions (i.e. bobtail and chassis trucks without appointments were evenly distributed between lanes 1-4, etc.). The changes that were applied to the entrance gates were mirrored by changes at the exit gates.

Extensive changes had to be made at the PNCT terminal to accommodate appointment trucks. Figure 23 shows changes made to the PNCT terminal for the appointment scenarios.

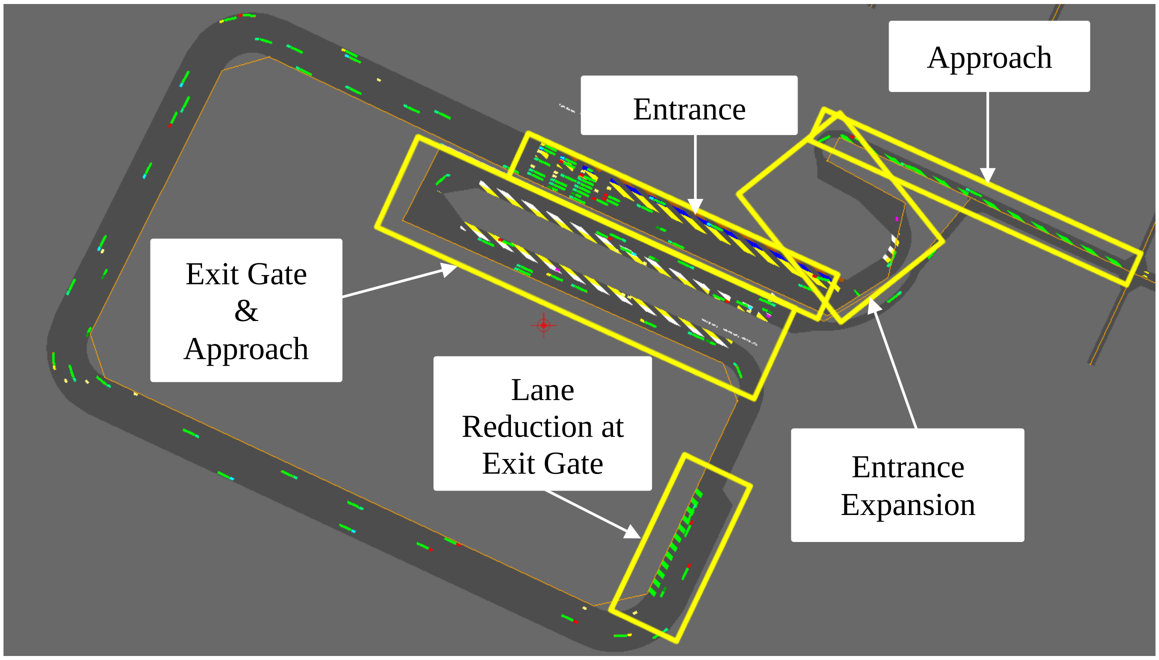


FIGURE 23 PNCT Terminal, Appointment Scenarios

The geometry of the approach to both the entrance and exit gates of the PNCT terminal presented problems when adding appointment lane logic. Several simulation runs were needed to adjust vehicle behavior in a way that prevented the lanes approaching the entrance from becoming congested by vehicles attempting to change lanes.

The first change was the addition of a lane restriction in the section labeled Approach in Figure 23 (green-hatched lane). The restriction was placed on the inner lane of travel and prevented chassis, bobtail and appointment trucks from traveling on this lane. This restriction was added after observation of early simulation runs showed that the approach to the PNCT entrance became congested between the Approach and the Entrance Expansion. This congestion was caused by the inability of trucks to switch lanes due to the constrictive geometry of this area.

In the section labeled Entrance Expansion in Figure 23, the lane restriction in lane 1 was altered from the CPO scenario to accommodate appointment trucks (white-hatched lane). A lane restriction was added to lane 2 to limit access of this lane to chassis and bobtail trucks without appointments (yellow-hatched lane, Figure 23). Moving the bobtail and chassis restriction from lane 1 to lane 2 was necessary to allow these truck types access to unrestricted lanes at the PNCT entrance gate. The only adjustment for the nextlane rules at the Entrance Expansion was to remove the rule which distributed demand exiting from lane 2, thereby allowing chassis and bobtail trucks without appointments access to both restricted and unrestricted lanes at the entrance gates to the PNCT terminal.

In the area labeled Entrance Gates in Figure 23, appointment lanes were simulated by restricting access to lanes 1 and 2. Lane 1 was used for container trucks with appointments (blue-hatched lane, Figure 23) and lane 2 was used for chassis and bobtail trucks with appointments (brown-hatched lane, Figure 23). Lanes 3 and 4 were used for chassis and bobtail trucks entering the terminal without appointments (yellow-hatched lanes, Figure 23). The remaining lanes had unrestricted access and were primarily used by container trucks without appointments.

Excessive congestion at the exit gates of the PNCT terminal also had to be addressed in early runs. In the area labeled Lane Reduction at Exit Gate (Figure 23), vehicle behavior was adjusted by restricting access to lanes 1 and 2 to container trucks without an appointment (green-hatched lanes, Figure 23). Behavior in this area was further modified through the addition of nextlane rules that were applied to the links in which the lane reduction occurred. The nextlane rules were used to keep the container trucks in lanes 1 and 2 in their respective lanes after the lane reduction, lanes 3 and 4 were force to merge into lane 3, lanes 5 and 6 merged into lane 4, lanes 7 and 8 merged into lane 5 and lanes 9 and 10 merged into lane 6. The nextlane rules are illustrated in Figure 24.

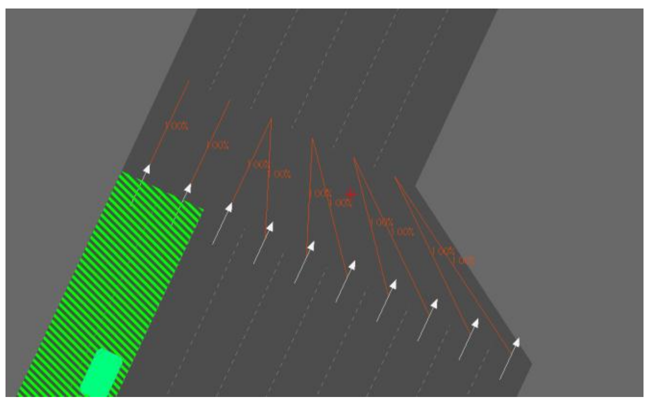


FIGURE 24 Nextlane Rules for PNCT Lane Reduction, Exit Gates

The lane restrictions for the Exit Gate & Approach were expanded to include the links leading up to the queuing area. Lane 1 was restricted to chassis and bobtail trucks without an appointment (yellow-hatched lane, Figure 25) and lane 2 was restricted to trucks with an appointment (white-hatched lane, Figure 25). These restrictions were extended to the approach to reduce the weaving that occurred in this area during early runs. The extension of lane restrictions and the area of application for lane choice logic at the approach to the PNCT exit gates are shown in Figure 25.

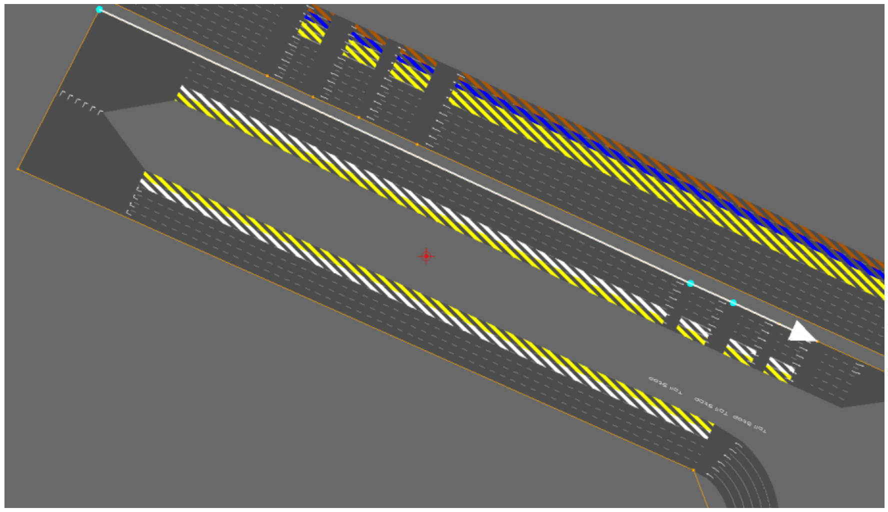


FIGURE 25 Exit Lane Restrictions at the PNCT Terminal, Appointment Scenarios

Lane choice rules at the PNCT terminal exit were adjusted from the CPO scenario so that all chassis trucks utilized lane 1 and that container trucks without appointments were restricted to lanes 3, 4, and 5. Trucks with appointments and chassis trucks were not governed by nextlane logic in the appointment scenarios. The length of the approach allowed these vehicles time to maneuver to lanes with smaller queues. A limited number of lanes at the PNCT exit gates made it difficult for queues to form properly when additional restrictions were placed on vehicle behavior.

Creating appointment scenarios proved to be a difficult task. Both physical and behavioral adjustments were necessary to create the scenario. Additional lane restrictions added complexity to vehicle movements at the entrances and exits, which proved especially troublesome at the PNCT terminal, where space was limited both to narrowness (10 lanes wide at the entrance and 6 lanes wide at the exit) and geometry.

These difficulties highlight the importance of tailoring simulations to individual ports, as differences between terminals will play a role in the effectiveness of gate strategies.

3.4 Modeling delays at terminal gates

Delays at terminal gates occur as a result of in-gate processing. As briefly discussed in the introductory section this process typically includes verifying driver identity, determining availability of the specified container, equipment inspection, delivering instructions to drayage operators for container pick-up and dispatching yard equipment. The median in-gate processing time for a terminal entrance gate is 4.3 minutes and the average in-gate processing time is 5.1 minutes (4). At exit gates, in-gate delays typically consist solely of verifying that the correct container has been picked up. Reduction in the amount of processing needed at exit gates corresponds with lower delays for these gates.

Terminal entrance gates have two standard configurations; one-stage and two-stage. At one-stage entrance gates, all processing transactions are handled at one gate by an employee in a booth. At two-stage entrance gates, drivers complete a portion of paperwork transactions electronically before arriving at a manned entrance gate to complete the entrance process (4). The simulation of the PNE assumed that all entrance gates were one-stage gates.

Paramics includes a tolling feature which allows the user to delay vehicles on a link over a specified range of time. This feature was utilized to simulate processing delays experienced by drayage operators at terminal gates. Paramics limits toll delays to a discrete uniform distribution split evenly between integers that must fall within a range that has a lower bound of 0 seconds and an upper bound of 200 seconds. The delays at the terminal gates were assumed to follow a normal distribution; therefore it was necessary to model each terminal gate using a series of three tolls. According to the central limit theorem, summation of uniformly distributed variables approximates the normal distribution.

The lane restrictions described in Section 3.3.3 allowed for variations in delays based on vehicle type. The mean delay for an entrance gate on a lane which serviced container trucks (including lanes that serviced a combination of vehicle types, of which one type was container trucks) was represented by a normal distribution with a mean of 4.5 minutes. Delay for these lanes was approximated with tolls that had delays ranging 40 and 140 seconds.

Entrance gates that serviced chassis trucks or combinations of chassis and bobtail trucks were given delays with a range between 20 and 70 seconds, which approximated a normal distribution with a mean delay of 2.25 minutes. The reduction in delay for this vehicle type was based on the assumption that inspection times for vehicles without containers would be reduced. Delays were reduced to a range between 10 and 35 seconds for bobtail and chassis trucks destined to the Maher terminal and chassis depot. This reduction in delay was applied because both the terminal and chassis depot had entrance gates with in-gate processing. The summation of delays at both locations would equal the assumed delay of 2.25 minutes for chassis trucks. This was done because it was assumed that in-gate processing occurring at the chassis depot entrance gate would not be repeated at the terminal entrance gate.

Inspection delays for entrance gates servicing only bobtail trucks were reduced to a normal distribution with a mean of 1.25 minutes due to the further elimination of equipment inspection. Exit gate delays were estimated using the assumption that delays applied to entrance gates with corresponding lane restrictions would be reduced by half, as in-gate processing at exit gates is known to be simpler.

On top of in-gate processing delays that occurred at terminal gates, the model was built to capture delay resulting from trucks showing up prior to the opening of the terminal gates. This phenomenon was modeled through the creation of periodic link files, so that links could be configured separately for each period of the simulation (the periods were set in one hour increments). Demand was generated for the terminals between 5:00 AM and 6:00 AM, but the periodic file of the links was adjusted to close all but one lane for each vehicle type (at least one lane had to remain open for each vehicle type representing drayage trucks, otherwise Paramics would generate an error and would not release the vehicles into the simulation). This produced queues during the first hour of the simulation that represented trucks showing up and idling as they waited for the gates to open.

Including a representation of entrance and exit gates allowed the simulation to capture changes that occurred when current patterns of operation were changed. The simulation captured queues forming due to trucks arriving prior to gates opening as well as queues forming due to demand peaks. An accurate representation of terminal gate transactions is the key in assessing the effectiveness of terminal gate strategies.

3.5 OD development

The following data from the work of Dougherty (6) and Spasovic (7) were used to create the base OD of the PNE:

- Hourly demand of the PNE for entering and exiting vehicles.

- PNE entrance demands for peak hours (given as 7:00-8:00 AM, 12:00-1:00 PM, and 3:00-4:00 PM), for entering/exiting vehicles by vehicle type.
- Peak hour demands for terminals within the PNE.
- Peak hour turn counts for intersections within the PNE.

This data was used to divide demand into a set of origins and destinations for the simulation. An algorithm was written using MATLAB 7.7.0 (R2008b) (26) to automate the process of the OD matrices development. The algorithm was developed and used in lieu of the Paramics Estimator to give the user greater control over traffic assignment. In particular, the algorithm allowed for a more concise split of demand between cars and trucks and produced an OD that reflected the assumption that all traffic generated within the PNE would be destined to one of the exits. The algorithm also assumed that no through traffic or intra-port traffic occurred in the simulation (other than trucks using multiple strategic waypoint zones). Therefore, all traffic released into the simulation from an "other" zone would be destined to a zone that represented an exit of the PNE, and conversely, vehicles released into the simulation would be destined either to a vehicle sink representing an "other" zone or would pass through a series of strategic waypoint zones representing the terminals and be removed at a zone representing an exit from the PNE.

3.5.1 CPO OD scenario development

The CPO OD represents known demand patterns at the PNE and was created in the first steps of the algorithm. The hourly demand (D_h) of the PNE was known. The first step of the algorithm was to separate demand by vehicle type (v), where v = 1 represented passenger car and $v = 2$ truck demand. The portion of demand (given as a percentage) of cars and trucks (P_v) was given for peak hours. These percentages were expanded beyond the peak hours using the following assumptions:

- 90% of demand during non-operating hours of the terminals (10:00 PM-6:00 AM) would be passenger cars and the remaining 10% would be “other” trucks.
- Demand distribution for the hours between the opening of the terminals and the AM peak period (6:00 AM-8:00 AM) would be the same as given values for the AM peak.
- The remaining values (8:00 AM-10:00 PM) would be linearly distributed between given values.

Upon expanding vehicle percentages to 24 hours (P_{vh}), the hourly demand was multiplied by vehicle percentages to determine hourly demand for the PNE by vehicle type (D_{vh}). The values for D_{vh} are shown in Figure 26.

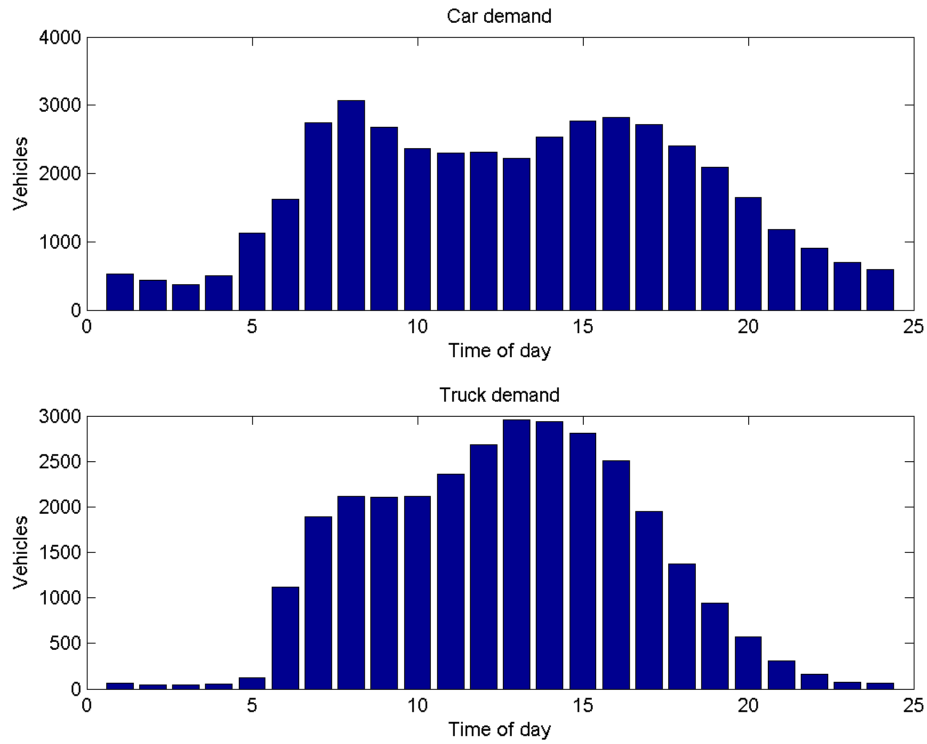


FIGURE 26 Distribution of Vehicles by Type over 24-hour Period

The next step of the algorithm determined the hourly demand by zone and vehicle type (D_{jvh}); where j = 1 represented APM demand, j = 2 represented Maher demand, j = 3 represented PNCT demand and j = 4 represented "other" demand. Demand percentages by zonal and vehicle type (P_{vj}) were given for peak periods. These percentages were expanded over a 24-hour period using the following assumptions:

- No demand would be generated by zones representing terminals during non-operational hours (10:00 PM - 6:00 AM).
- Between 6:00 AM and 8:00 AM, AM peak values were used to represent demand percentages.
- Demand percentages between peak periods would be linearly distributed.

- As each terminal closed (APM = 5:00 PM, PNCT = 7:00 PM, Maher = 10:00 PM), it's percentage of demand was evenly distributed among remaining terminals and "other" zones.

Once demand percentages were extended over a 24 hour period (P_{vjh}), they were multiplied by the overall demand of their respective vehicle type (D_{vh}). The result was the generation of two three-dimensional matrices which represented the 24-hour demand for each zone, vehicle type, and time of day (D_{vjh}). Figure 27 shows the truck demand 24-hour pattern by terminal.

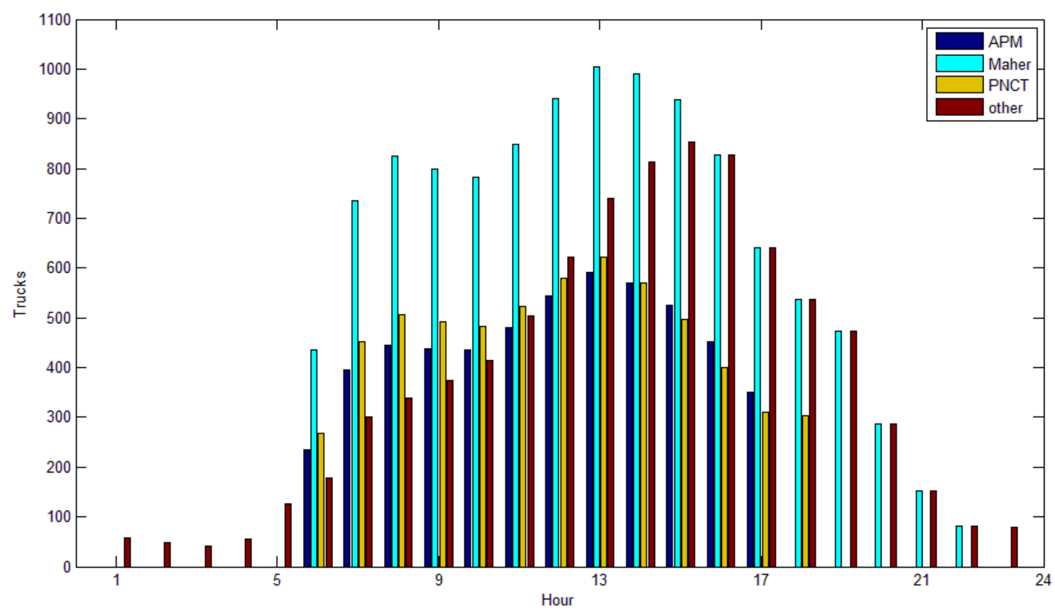


FIGURE 27 Truck Demand Distribution over 24-hour period

Once the 24-hour demand for each vehicle type was determined, the algorithm proceeds with the development of the OD matrices. Each OD represents a different vehicle type. To create the passenger car OD, two variables were created to distribute passenger car demand among the zones. The first variable (E_{jp}) created a distribution for zone type j to PNE entrance p (where p = 1 represented North Avenue, p = 2 represented Port Street and p = 3 represented Doremus Avenue). The percentages used to create E_{jp} are shown in Table 6.

TABLE 6 Entrance Percentages for Passenger Cars by Zone Type

Origin/Destination	North	Port	Doremus
APM	90%	5%	5%
Maher	20%	70%	10%
PNCT	5%	80%	15%
Other	50%	25%	25%

The second variable (X_h) represented hourly percentage of vehicles entering and exiting the PNE. This variable was created to correct congestion at signaled intersections in the middle of the PNE. It was determined that this congestion was caused by demand being released at one end of the PNE and having destinations at "other" zones on the opposite end of the PNE. To correct this problem, a variable (OP_{zp}) was created that would weigh the attractiveness of "other" zones (z) by their proximity to the port entrance (p) which was part of the OD pair. Equation 1 was used to create the OD pairs that represented employee entrances to the terminals and Equation 2 was used to create the OD pairs for "other" vehicle types.

$$D_{vjh} * E_{jp} * X_h \quad (1)$$

$$D_{vjh} * E_{jp} * X_h * OP_{zp} \quad (2)$$

Once the passenger car OD was developed, a second matrix, composed of trucks assigned to “other” destinations within the PNE was created. The algorithm adjusted the value of D_{vjh} from the passenger car matrix to reflect demand for “other” trucks. The values for “other” vehicles were held constant over all of the scenarios (except future scenarios, where values for “other” vehicles were increased), as demand patterns for these vehicles were assumed to be unaffected by the introduction of gate strategies.

Once ODs for “other” vehicle types were created, the algorithm created matrices for trucks destined to terminals within the PNE. Hourly demand for each terminal (D_{vjh}) was determined in previous steps. D_{vjh} was combined with two variables, each of which had a separate function in distributing demand to the terminals. Truck type percentage (T_v) split demand into three truck types (i.e. container, chassis, and bobtail). The values for T_v were 55% for container trucks, 25% for chassis trucks and 20% for bobtail trucks. These values matched the values taken from a limited number of observations made using satellite imagery. The second variable (DP_{je}) distributed demand among zones which represented entrances to the PNE (e) according to the terminal for which demand was generated (j). The values used for DP_{je} are shown in Table 7.

TABLE 7 Distribution of Truck Demand by Type

	Container Trucks			Trucks w/ Chassis			Bobtail Trucks		
Entrance/Exit	North	Port	Dor.	North	Port	Dor.	North	Port	Dor.
APM Terminal									
North	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	80.0%	2.5%
Port	2.5%	80.0%	2.5%	42.5%	40.0%	2.5%	2.5%	2.5%	2.5%
Doremus	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
Maher Terminal									
North	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	80.0%	2.5%
Port	2.5%	80.0%	2.5%	42.5%	40.0%	2.5%	2.5%	2.5%	2.5%
Doremus	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%
PNCT Terminal									
North	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	80.0%	2.5%
Port	2.5%	80.0%	2.5%	42.5%	40.0%	2.5%	2.5%	2.5%	2.5%
Doremus	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%

The values shown in Table 7 represent percentage of truck demand by vehicle type and terminal destination. It was assumed that most trucks would use a route that minimized travel distance, therefore the largest percentage of trucks were distributed to entrances closest to their destinations. Truck ODs were created using the following equation:

$$D_{vjh} * T_v * DP_{je} * 0.65 \tag{3}$$

The use of strategic waypoint zones eliminated demand that originated from the terminals in the traffic counts. This made it was necessary to reduce demand in the truck ODs. The first reduction of terminal demand was 50% but, after attempting to match turn counts in early simulation runs with known turn counts, it became apparent that this reduction excessive. After several iterations, a reduction of 35% of terminal demand was shown to approximate observed turn counts. This reduction prevented the algorithm from doubling the total demand for terminals which would have occurred using the given data due to counts which included both trucks arriving at and departing from terminals.

3.5.2 Extended hours OD

Once the CPO OD was developed, the next step was to create the extended hour scenario OD. The creation of this OD considered the fact that the goal of extended gate hours is to divert a percentage of demand from peak hours to off-peak hours. The results obtained by Giuliano et al. (8), which noted that a second, smaller peak in demand occurred after the original operating hours, were also considered when making the extended hours OD. The hourly distribution pattern used to simulate the extended hour scenario is shown in Figure 28.

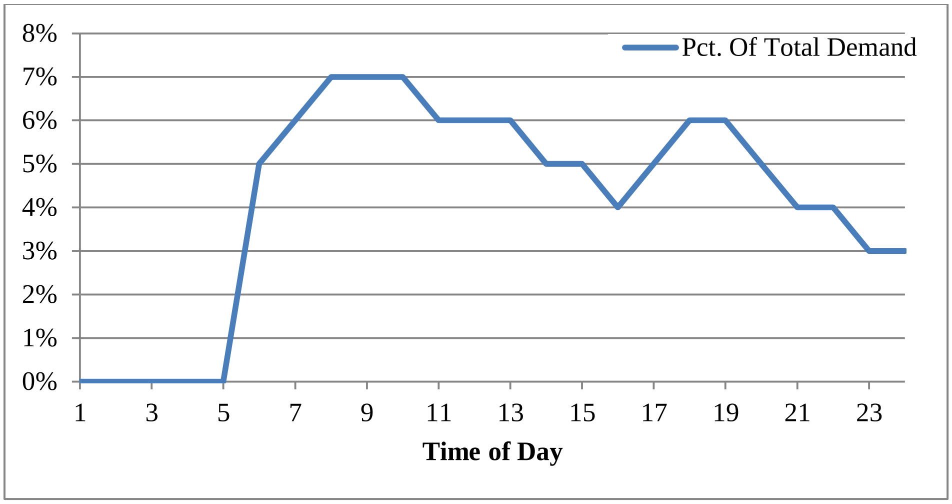


FIGURE 28 Demand Distribution for Extended Hours Scenario

The peak occurring from 6:00 PM to 7:00 PM simulates drayage operators attempting to avoid peak hour fees, as it was assumed that a similar fee would be needed to duplicate the effectiveness of the PLALB extended gate hour program.

Extended gate hour ODs were created by multiplying the 24-hour terminal's demand from the CPO OD by the hourly distribution percentages shown in Figure 28. Equation 3 was utilized to create an OD using adjusted hourly demand (D_{vjh}) (with the distribution variables retaining their original values). Figure 29 compares total demand from the CPO scenario to total demand from the extended gate hour scenario for each PNE terminal.

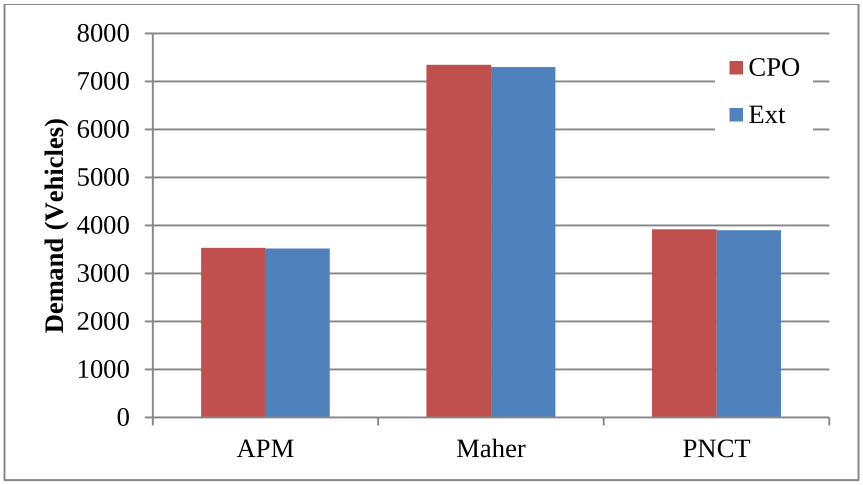


FIGURE 29 Demand Comparison Between CPO and Extended Hour Scenarios

Figure 29 shows that total demand for each terminal was held constant, therefore any difference in delays, travel times or emissions will be the result of the extended gate hours, not as a result of a change in demand at the terminals. It was assumed that the terminals would extend their gate hours to 12:00 AM.

3.5.3 Appointment scenario ODs

Creation of an appointment scenario required adjustment of behavioral logic, as discussed in Section 3.3.4. Creating an appointment scenario also required developing a series of ODs that would represent different demand distributions between appointment and non-appointment trucks. A total of 5 OD scenarios were created to represent different appointment system combinations. In each scenario, the percentage of trucks using the appointment systems was increased by 10%, giving a different combination of scheduled and unscheduled drayage movements. The appointment scenarios ranged from 10% to 50% of terminal demand utilizing appointment lanes (with an increase step of 10%).

Adjustment of the algorithm for the appointment scenarios altered base demand for the terminals (D_{vjh}). D_{vjh} was adjusted by splitting hourly demand of the base scenario (D_{jh}) into percentages of trucks with and without appointments. Equation 3 was used to create an OD for appointment trucks using the adjusted value of D_{vjh} (with the remaining variables unchanged from the base case).

The remaining demand was then used to create ODs for appointment trucks. Demand for trucks with appointments was distributed evenly throughout each operational period of the terminals based on the assumption that terminal operators would attempt to use appointment systems to control arrival times of drayage trucks. Change in total demand for each terminal in the appointment scenarios is compared to total demand for each terminal from the CPO scenario in Figure 30.

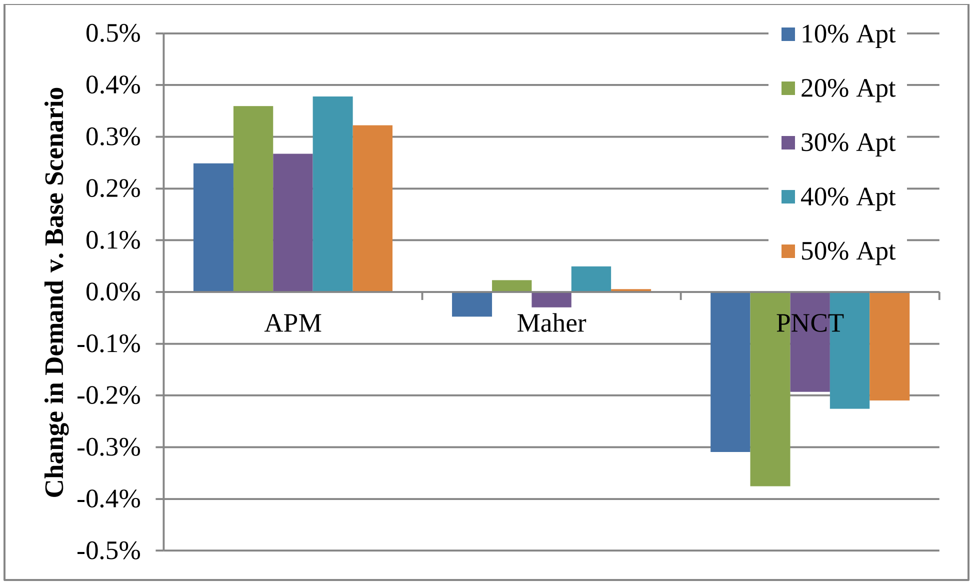


FIGURE 30 Demand Comparison: CPO and Appointment Scenarios

Figure 30 shows that demand was held relatively constant over each appointment scenario. The change in demand stems from rounding in the algorithm (as demand is expressed as integers in the OD matrices) and was held to a change of less than 0.4% for each of the scenarios, thereby all changes in travel times, delay and emissions are a result of the implementation of the appointment scenario and not from a change in demand.

It was necessary to create five ODs for the appointment scenarios to determine the distribution that would best utilize entrance gates for both appointment and non-appointment lanes. The five appointment scenarios were only tested for the base demand, as it was assumed that increasing demand in future scenarios would only exacerbate over-utilization of lanes. The evaluation of different appointment demand combinations are discussed in Section 4.1.

3.6 Modeling emissions

Modeling emissions at the PNE was done for all vehicle types. Three emissions models were considered; the Comprehensive Modal Emission Model (CMEM), the Motor Vehicle Emission Simulator (MOVES) and Paramics Monitor plug-in. All three were capable of calculating emissions for carbon dioxide, carbon monoxide, nitrogen oxide and particulate matter (from diesel trucks).

The first model that was considered was CMEM (27). The model was based on data collected from a set of vehicles meant to represent typical vehicles found in a traffic stream. The CMEM model has a Paramics plug-in capable of calculating vehicle emissions for 28 categories of light-duty vehicles and 3 categories of heavy-duty diesel vehicles. The model was developed to work with Paramics version 5. The reporting interval of the CMEM plug-in could be adjusted using a graphical user interface (GUI) tool. Vehicle types used to calculate emissions were matched with vehicle types defined in the Paramics simulation. The CMEM plug-in was installed in the earliest versions of the PNE simulation and used to produce emissions reports. A report was created after every 10 minutes of simulation (the default setting of the CMEM plug-in), as the simulation of the PNE was created using version 6 of Paramics, which removed the GUI capabilities. Ultimately, CMEM was not used to calculate emissions for the PNE as it was not possible to compile data every 10 minutes over a 24-hour simulation due to CPU capacity restraints.

The next emissions model that was considered was MOVES 2010a, which was developed by the U.S. Environmental Protection Agency (28). There were two reasons that MOVES was not used to estimate PNE emissions. The first reason was that MOVES did not directly interact with output from Paramics. Calculations obtained from MOVES were based on average vehicle speed, average vehicle miles traveled and average vehicle counts per link. The MOVES model does not utilize the vehicle-specific data generated by Paramics, negating one of the advantages of using a microscopic traffic simulation to estimate emissions.

The second reason was that the scale of MOVES was not meant to be adjusted to a microscopic level. Project level data in MOVES scales links in miles. This presented a problem when attempting to integrate MOVES to the simulation of the PNE as none of the links in the simulation were over 1 mile long and most were segments less than 1,000 feet in length. It was assumed that adjusting data from the microscopic level of the PNE simulation to the macroscopic level of MOVES would result in errors when estimating emissions.

The final model that was considered was the Paramics Monitor plug-in. Monitor was based in part on work performed by the Department of Transport in the United Kingdom (23). The data used to create the Monitor plug-in was gathered from tests of emissions outputs of various engine types and was used to relate emissions levels to vehicle speed and acceleration. Default emissions calculations in Monitor are calculated using a speed/acceleration unit (meters^2/seconds^3) and vehicle speed (kilometers per hour). The metric values of the default emissions file were converted to English units to match the units of the PNE simulation. The ease of use and the direct conversion of Paramics data into emissions files were the reasons that the Paramics Monitor plug-in was selected to model emissions for the PNE.

4. RESULTS

As described in the previous sections, the PNE simulations included three scenarios; a CPO scenario that represented gate operations in their current operational state, an extended hour scenario where terminal gate operating hours were extended to 12:00 AM and an appointment scenario where a percentage of the demand was converted to appointment trucks. Each scenario was evaluated by total delay, delay at the gates and emissions generated. Delay was measured by subtracting free flow travel time from the actual travel time of a vehicle (23). Delay is recorded as average seconds of delay per vehicle. The results for every scenario were averages over 15 iterations. For the appointment scenarios, five demand combinations were analyzed using the base OD with the goal of determining the demand combination which would yield the best results for a specific set of gate configurations. These results from the appointment scenario evaluation are described in detail in Section 4.1.

4.1 Appointment scenario evaluations

Appointment scenarios could have been made for a number of different gate configurations (number of appointment VS non-appointment entrance/exit lanes). The gate configuration selected to model the appointment scenarios at the PNE converted 30% of the entrance and exit lanes at each terminal to appointment lanes. A total of five appointment OD combinations were created with the following appointment-to-non-appointment truck demand patterns: 10%-90%, 20%-80%, 30%-70%, 40%-60%, and 50%-50%. Delays per time of day for the entire PNE and for trucks vehicle types only are shown in Figure 31.

Figure 31 shows that hourly delays varied between appointment scenarios. In the appointment scenarios where 10% and 20% of demand was converted to appointment trucks, sharp increases in delay occurred during the afternoon period. Visual observation of these simulations revealed much of that increase resulted from the under-utilization of appointment lanes and over-utilization of non-appointment lanes. Congestion on non-appointment lanes was particularly noticeable at the entrance to the PNCT terminal, where a reduction in available lanes caused queues to reach the PNE's primary access road. This queue delayed all vehicles attempting to enter or exit the PNE from the north entrances.

Appointment scenarios for which 40% and 50% of demand was converted to appointment trucks saw delay increases due to the over-utilization of appointment lanes and the under-utilization of non-appointment lanes. While this did increase overall delays of drayage trucks within the PNE, it did not increase them as much as the 10% and 20% appointment scenarios because the congestion for the 40% and 50% appointment scenarios was occurring on appointment lanes, which had reduced delays.

Each scenario was also evaluated by delays at terminal entrance gates. Figure 32 shows APM entrance gate delays for each appointment scenario.

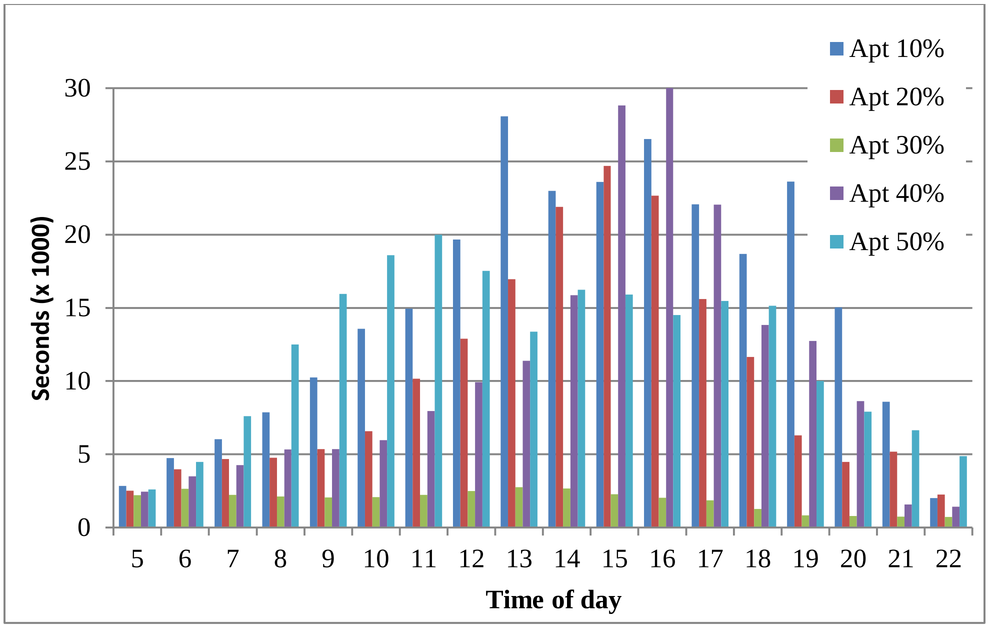


FIGURE 31 Hourly Delays for Appointment Scenarios

Under-utilization of appointment lanes in the 10% and 20% appointment scenarios is made evident by the delay patterns displayed in Figure 32. Delays at entrance gates remained fairly steady over the three remaining scenarios, which indicated that lanes were being properly utilized. The uptick in delay during the periods from 5:00 AM to 6:00 AM was a result of trucks arriving while the terminal is closed. Delays for links representing the entrance to the PNCT terminal are shown in Figure 33.

Delay at the PNCT entrance had the greatest impact on the rest of the simulation. The geometry of the terminal entrance made the PNCT terminal susceptible to congestion problems due to slight shifts in demand patterns, which can be seen in Figure 33. Truck delays for vehicles entering the terminal in the 10% and 20% appointment scenarios remained consistent from 9:00 AM until the terminal closed at 7:00 PM. Consistent delays for these scenarios indicated that queues during these hours extended beyond the entrance and into the PNE's main roadway network, where they were not captured as delay for the entrance gate. Delay patterns for the 40% and 50% appointment scenarios showed a similarly consistent pattern, albeit with a reduction in total delay. This reduction in total delay stems from the fact that a greater amount of demand is shifted to appointment lanes with reduced delay at gates.

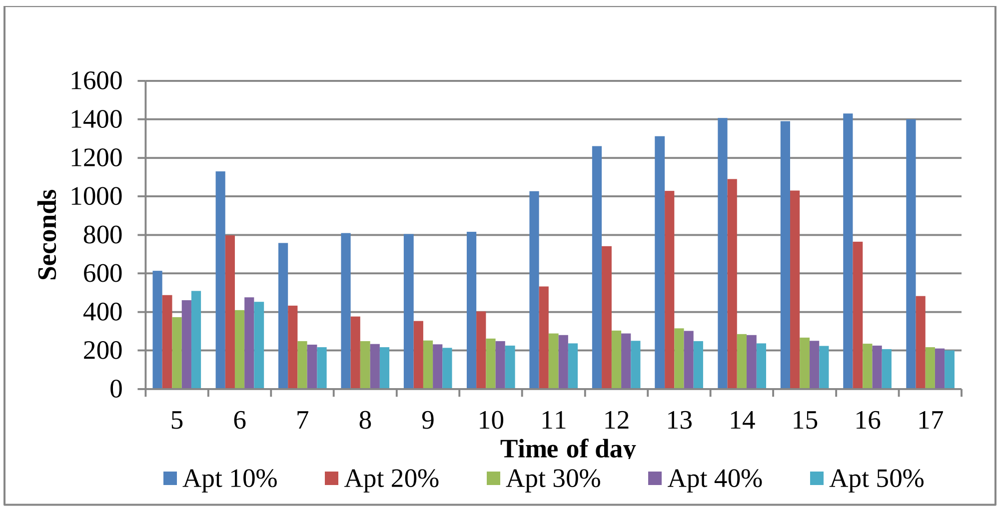


FIGURE 32 Hourly Delay for the APM Entrance Gate, Appointment Scenarios

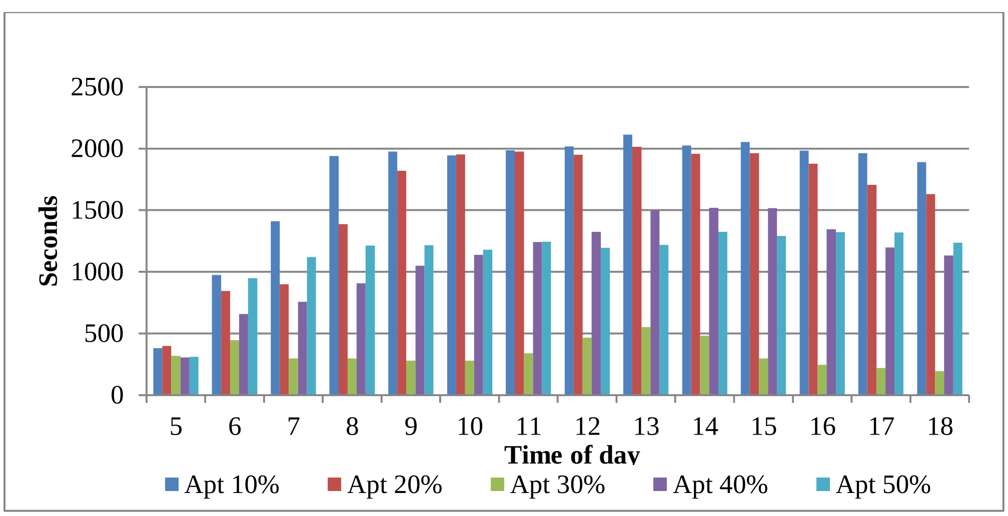


FIGURE 33 Hourly Delay for the PNCT Entrance Gate, Appointment Scenarios

Delays for vehicles at links leading up to and including the entrance gates at the Maher terminal are shown in Figure 34. Figure 34 shows the effect that queues from the PNCT terminal had on overall delay within the PNE. Delay patterns for trucks entering the Maher terminal in the 10% and 20% appointment scenarios show a reduction in delays for the period between 12:00 PM and 6:00 PM. This reduction is counter-intuitive, as total delays for the PNE during these periods increase (Figure 30). The reason that delay reductions occurred at the Maher entrance was that queues from the PNCT entrance extended to the PNE's main access road during this period. This limited the number of trucks that could reach the Maher terminal during these hours. The result was an increase in overall delay of trucks and a reduction in delays at the Maher terminal entrance.

The spike in demand that occurred in the AM period of the 10% appointment scenario and the PM period of the 20% appointment scenario represented a lack of capacity stemming from a reduced number of non-appointment lanes at the Maher entrance. Delays for the remaining appointment scenarios showed that a shift of 30% or more of demand to appointment lanes would produce delays at entrance gates that represent proper utilization.

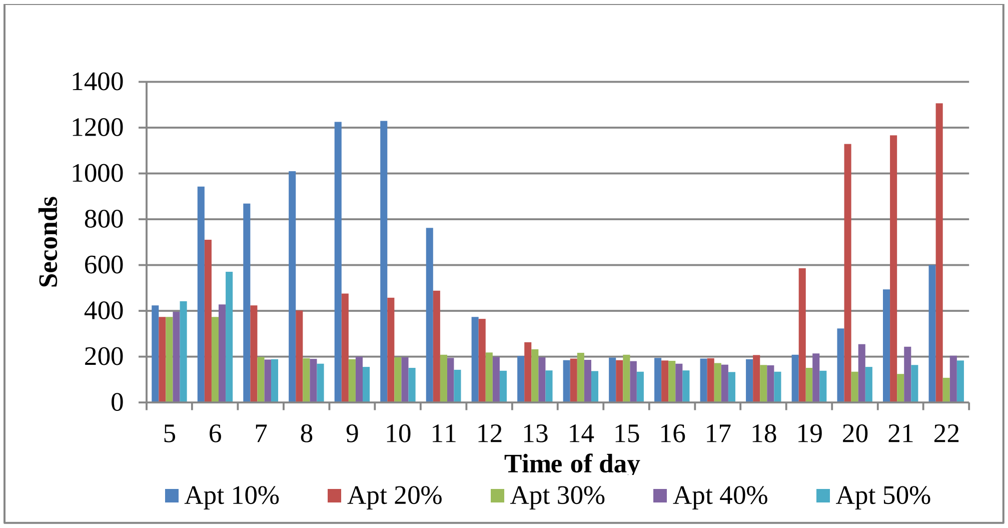


FIGURE 34 Hourly Delay for the Maher Entrance Gate, Appointment Scenarios

The goal of evaluating multiple appointment scenarios was to determine the scenario that produced the greatest reduction in delays at the PNE. That scenario was then used to represent the appointment system for the overall comparison of gate strategies. Evaluation of delays at entrance gates eliminated the 10% and 20% appointment scenarios due to the impact that excessive queue lengths at the PNCT entrance had on the rest of the PNE. Similarly, queues at the PNCT entrance increased total delays for the 40% and 50% appointment scenarios, this time due to congestion from vehicles trying to reach appointment lanes and creating a bottleneck at the PNCT entrance. The 30% demand scenario showed a steady delay pattern for each terminal entrance as well as consistent delay over all links of the PNE. The 30% appointment scenario was also selected as it was the only scenario for which delays were reduced when compared to the CPO scenario.

4.2 Comparison of gate strategies

The simulation of the PNE included three separate gate configurations: the current pattern of operation (CPO), an extended hour and an appointment scenario. Each scenario had a base OD that was created using known data. Five future demand scenarios were developed in which the base OD demand was increased by 10%, 20%, 30%, 40% and 50% respectively. Truck hourly delays over the 24-hour period are shown in Figure 35.

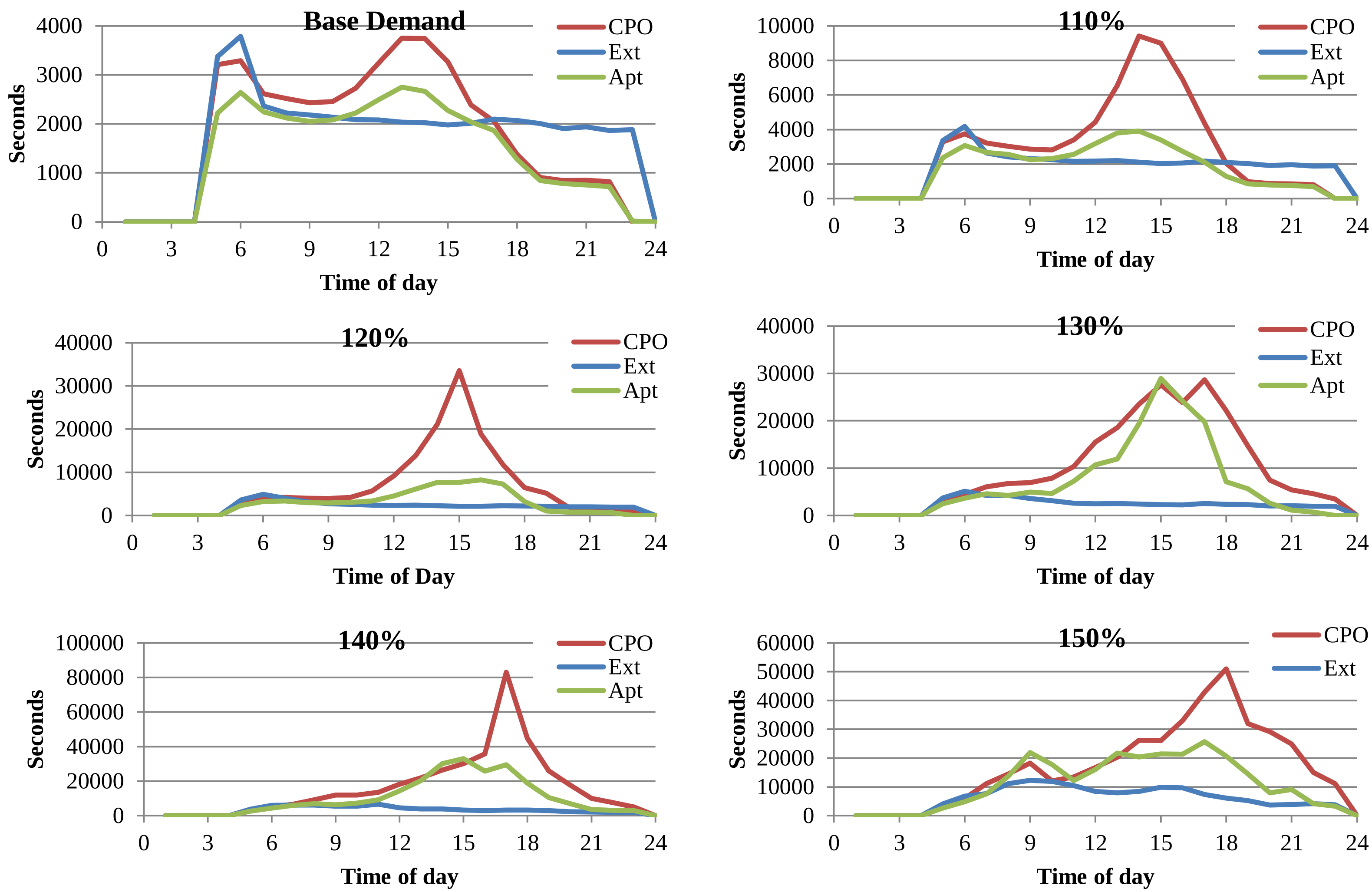


FIGURE 35 Hourly Delay

Figure 35 shows that under the CPO, increases in delay occurred during both the AM and PM peak periods. AM delay was caused by drayage trucks arriving at the terminal gates prior to their opening. Increased delay during the PM period (12:00 PM to 4:00 PM) was a result of heavier truck volumes during these periods. The appointment scenario showed similar patterns of delay, with the hourly reductions being consistently lower than that of the CPO. Extending the gate hours had the effect of smoothing the delay pattern for all demand levels.

For the 110% demand scenario, truck delays under the CPO scenario doubled during the PM peak. Increases in truck delay under the appointment scenario appear to be correlated to the increase in demand. Increasing demand by 10% resulted in minimal increases in delay when terminal gates were operated under extended hours.

For the 120% demand scenario, the PM peak for the appointment scenarios showed a significant increase in delays. Truck delays in the extended hour scenario remained relatively constant over the operational period of the terminals. Truck delay increased noticeably in the appointment scenario for the 130% OD. This indicated that the appointment system was no longer able to stave off congestion within the PNE. For the 120% demand scenario the CPO delay pattern began to spread out, indicating a spread of congestion throughout the peak periods. The extended hour scenario experienced a slight uptick in delay, but continued to operate with the same delay pattern. A large spike in delay during the PM peak for the CPO scenario occurred when demand was increased by 40%. This increase in delay indicated that the PNE is nearing capacity and operations at the terminal gates and roadway network begin to break down. The extended hour scenario continued to display a relatively flat delay pattern. For the last case of 150% demand delays during the PM peak was reduced for the CPO and appointment scenarios. However, delays during all other periods significantly increased, including a large shift of delays to periods extending beyond the original operating hours of the terminal. Delays for the extended hour scenario increased significantly at this level of demand.

A direct comparison of total delay was taken by comparing the total delay from the extended hour and appointment scenarios and comparing it to the equivalent value from the current pattern of operation scenario. The results of this comparison are shown in Figure 36. Figure 36 shows the overall reduction in delays that resulted from the implementation of each gate strategy. For the base OD, the appointment scenario outperformed the extended hour scenario. The reason that the appointment scenario outperformed the extended hour scenario is that congestion at terminal gates is minimal for the base OD, therefore reduction in appointment truck delays had a more significant impact on reducing delays than shifting demand.

When demand was increased by 10%, both the extended gate hour and appointment scenarios reduced delays by approximately 40% when compared to delays under the CPO scenario. The extended hour scenario outperformed the appointment scenario when a 20% increase in demand was applied to the base OD. For all scenarios in which the demand was increased by more than 20%, extending hours was much more effective at reducing delays than the appointment system. Delays for the appointment scenario actually increased when the demand was raised by more than 20%, indicating that the appointment system was unable to control congestion at the PNE beyond these demand levels.

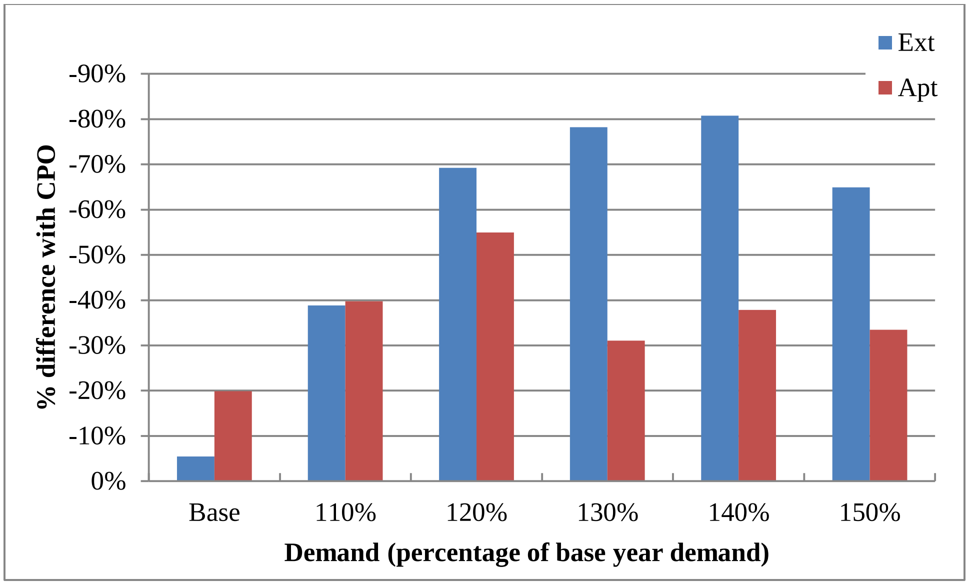


FIGURE 36 Total Delay

To determine the effect that each gate strategy had on delay at individual terminals, a comparison of delay by terminal for links leading up to and including the entrance gates was conducted. Results for the extended hour scenario are shown in Figure 37. Figure 37 shows that delays at each terminal gate were steadily reduced up to a 30% increase in demand. For the 140% and 150% demand increase, the APM terminal entrance gate showed increase delay reductions. Delays for the PNCT terminal entrance gate were lower than the CPO scenario, but were increasing rather than decreasing. At the Maher terminal entrance, delays were actually larger for the 140% and 150% under the extended hours of operation than those experienced during the CPO scenario. These results can be explained by what is occurring outside of the terminals. Observation of simulation runs where demand was increased by more than 30% and the current pattern of operations were used for terminal gates showed that the queues from the PNCT terminal became so large that they extended into the main roadway of the PNE. These queues obstructed vehicles entering the PNE from the north entrance, therefore the number of vehicles able to access Maher terminals during peak hours was limited. Overall, delay increased during the peak hours due to the obstructions on the roadway network. However, delay at the Maher terminal gate was reduced for the CPO scenario as demand was unable to reach the gates during peak hours, which limited congestion during these periods.

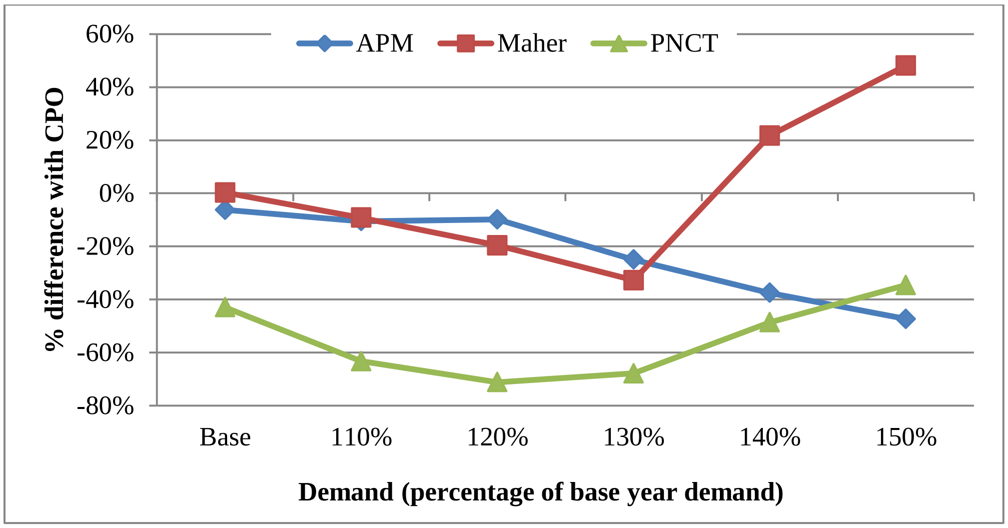


FIGURE 37 Delay at Entrance Gates, Extended Hour Scenario

The shift of demand caused by extended gate hours of operations eliminated this congestion on the roadway, which allowed trucks destined to the Maher terminal to reach their destination with limited delay. Therefore, the increased delays at the Maher terminal entrance actually show that drayage operations for the extended hour scenario are improved when compared to the CPO scenario.

Delays at terminal gates for the appointment scenario are shown in Figure 38. Maher terminal delays for the appointment scenario are similar to those of the extended hour scenario. Delays for the PNCT terminal show that the appointment scenario was less effective for demand increases greater than 20%. Delays at the APM terminal entrance gate showed steadily decreasing benefits as demand increased.

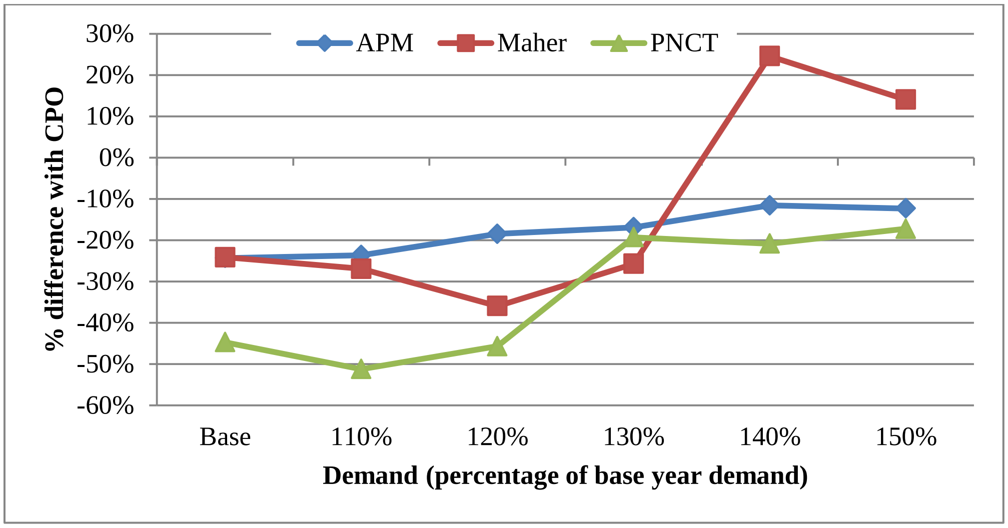


FIGURE 38 Delay at Entrance Gates, Appointment Scenario

The next step in our analysis was to determine how congestion at the PNE affected emissions levels. Hourly measurements were made for carbon monoxide, carbon dioxide, oxides of nitrogen, hydrocarbons, fuel consumption and diesel particulates. Emissions levels were calculated for the base (100%), 110%, 120%, and 130% ODs. Emissions for the 140% and 150% ODs were omitted, as demand levels exceeded the capacity during these simulations, thereby skewing the emissions data. Hourly emissions for carbon monoxide are shown in Figure 39.

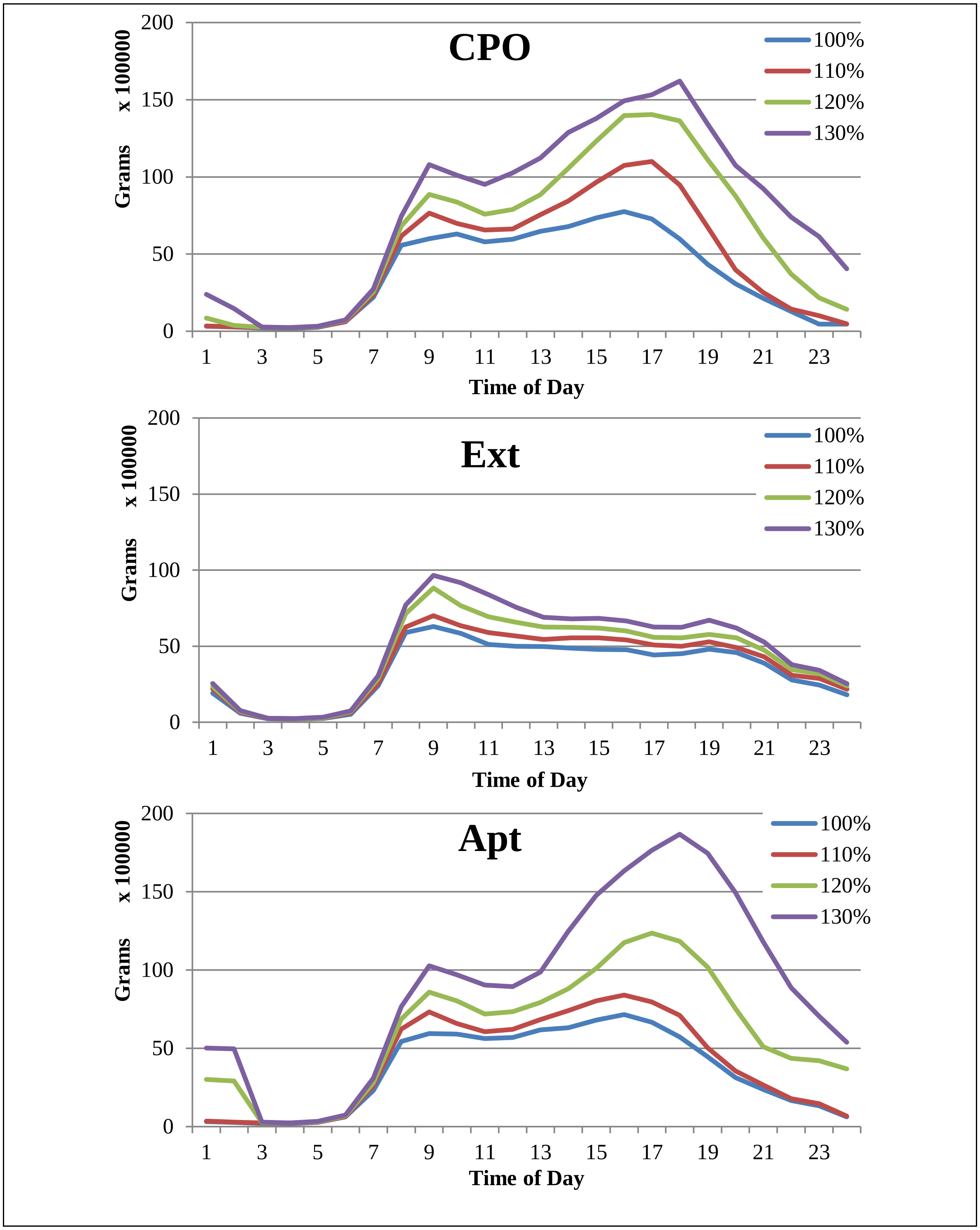


FIGURE 39 Hourly Carbon Monoxide Emissions

Figure 39 shows that hourly emission patterns resembled hourly delay patterns. The AM and PM peaks can be seen under both the CPO and appointment scenarios. Hourly emissions from the extended hour scenario show the same characteristics as delay, having a consistently smooth pattern for each demand level. Hourly patterns for the remaining emissions categories mimic those of carbon monoxide and are included in the Appendix.

Hourly emissions data was used to create a 24-hour emission output for each level of demand (i.e. base (100%), 110%, 120%, and 130%). These values were compared with the CPO scenario and are displayed in Table 8.

TABLE 8 Emissions Totals

Carbon Monoxide			Carbon Dioxide			Total Hydrocarbons		
Demand	Ext.	Apt.	Demand	Ext.	Apt.	Demand	Ext.	Apt.
Base	-4.7%	-2.2%	Base	-5.5%	-3.4%	Base	-5.6%	-3.6%
x 1.1	-16.8%	-12.1%	x 1.1	-18.8%	-14.3%	x 1.1	-18.7%	-15.4%
x 1.2	-30.3%	-3.6%	x 1.2	-32.8%	-8.4%	x 1.2	-32.4%	-10.4%
x 1.3	-38.4%	12.4%	x 1.3	-41.9%	8.8%	x 1.3	-41.7%	6.3%
Oxides of Nitrogen			**Fuel Consumption**			**Particulate Matter**		
Demand	Ext.	Apt.	Demand	Ext.	Apt.	Demand	Ext.	Apt.
Base	-5.8%	-4.2%	Base	-5.5%	-3.3%	Base	-5.5%	-3.9%
x 1.1	-19.1%	-15.1%	x 1.1	-18.8%	-14.2%	x 1.1	-18.2%	-14.4%
x 1.2	-32.8%	-13.5%	x 1.2	-32.9%	-7.9%	x 1.2	-31.4%	-13.6%
x 1.3	-42.5%	3.2%	x 1.3	-41.9%	9.4%	x 1.3	-41.1%	2.2%

Table 8 shows some clear patterns for gate strategy effectiveness. First, extending gate hours becomes more effective as demand increases. Emission reductions for the base OD were minimal (less than 6%). As demand increased, so did the benefit of extending hours. The appointment system had an inverse relationship between demand and emission reduction. The appointment system was most effective on small increases in demand. Once demand reached levels that caused congestion within the port, the appointment system did not reduce emissions. In fact, converting lanes to "appointment only" appears to have had a negative impact once congestion becomes a factor, as emissions levels for a 30% increase in demand were higher for the appointment scenario than for the CPO scenario.

Results from the simulation led to the conclusion that establishing appointment systems at terminal gates can be a risky procedure. A balance must be achieved between non-appointment and appointment lane demand that best utilizes demand. Failure to reach this balance will increase delays and emissions, rather than reduce them. In contrast, if extended gate hours successfully shifts demand it will allow the IMCT to more effectively deal with increases in demand.

5. CONCLUSIONS AND FUTURE RESEARCH

Despite the recent economic downturn, forecasts continue to predict that Intermodal Marine Container Terminals (IMCTs) will experience growth in container volumes. The growth in container volumes is expected to result in substantial increases in congestion for both seaside and landside terminal operations. IMCTs are under pressure to come up with the strategies to accommodate the increasing demand. One of the major factors contributing to the congestion problem is that terminal gates are open during certain hours of the day. Consequently, trucks are forced to pick-up and deliver containers during specific hours of the day, resulting in high demand over certain periods. This phenomenon has led to inefficient gate operations that can spill traffic over to the surrounding roadway network and cause safety and congestion problems. The problem of congestion may also extend to the terminal yards where, high demand peaks for service at the landside coupled with capacity issues can degrade reliability and performance of the terminal. In addition to these issues the environmental effects stemming from idling trucks has further emerged as a serious problem in recent years as truck emissions have been linked to health conditions. Different solutions have been proposed to reduce the amount of air pollution from drayage operations including new technologies, operational strategies and financial mechanisms. Due to the limited and very expensive right of way in the area surrounding IMCTs, implementing low cost and quickly implementable approaches to address mobility constraints at IMCTs becomes more viable than physical capacity expansions. Different operational strategies have been suggested (e.g. gate appointment systems, extended hours of operations for terminal gates, and advanced technologies for gates and terminals) to relieve the effects of congestion and help improve air quality. The impact of gate strategies (either at the tactical or operational level) on drayage operation efficiency is not very well understood, and is an area where researchers and practitioners have become increasingly involved. A number of researchers have attempted to evaluate the effects of different types of gate strategies either through simulation modeling or through before-and-after case studies of terminals where gate strategies have been implemented. This thesis presented the development of a traffic simulation model capable of measuring the impact that various gate strategies will have on the levels of congestion at IMCT terminal gates. The traffic model was used to quantify both travel time and delay and emission levels at the terminal gates and on the roadway network in the vicinity of the IMCTs before and after gate strategies have been implemented. To our knowledge this is was the first attempt in the published literature to capture delays and emission levels at the gates of terminals using a traffic simulation model. These delays contribute to the inefficiency of drayage operations within IMCTs, and knowledge as to how various gate strategies affect efficiencies could prove valuable for future planning of IMCTs. Based on results from a case study, it was concluded that the majority of delays experienced by drayage trucks occurs at the terminal gates and that omission of terminal gates should be discouraged as it can lead to a 90% underestimation of the delay. Results from the case study further indicate that the most effective gate strategy for reducing congestion at terminal gates as well as within the roadway network and at the same time reducing emissions was extending the terminal gate hours and thus diverting demand to off-peak hours.

The methodology presented herein can be improved with the following future research. First, the dataset from which the vehicle distributions and ODs were determined can be expanded to improve the accuracy the model represents vehicle movements occurring at an IMCT. Establishing the logic behind drayage movements between terminals and chassis depots, particularly for specific vehicle types, would also improve the functionality of this model. Second, future research should consider the development of a delay function within the terminal yard. The current model uses vehicle speed to represent terminal yard transaction times which may not accurately capture delays and most importantly emissions. Establishing a delay function to represent yard transactions could improve the quality of the simulation. We note that adopting this approach would result in emissions estimation as a post-simulation process. Finally, an additional step for future research would be to include delays that occur within chassis depots.

6. ACKNOWLEDGEMENT

This material has been partially supported by the Intermodal Freight Transportation Institute, University of Memphis. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Intermodal Freight Transportation Institute or the University of Memphis.

REFERENCES

1. American Association of Port Authorities. (2011). *North American Container Traffic (1990-2010).* Retrieved July 15, 2011, from Port Industry Statistics: http://www.aapa-ports.org

2. U.S. Maritime Administration. (2009). *America's Ports and Intermodal Transportation System.*

3. Hill, L. B. (2005). *An Analysis of Diesel Air Pollution and Public Health in America.* Boston, MA: Clean Air Task Force.

4. The Tioga Group, Inc. (2011). *NCFRP Report 11: Truck Drayage Productivity Guide.* Washington, D.C.: Transportation Research Board.

5. Maguire, A., Ivey, S., Golias, M. M., & Lipinski, M. E. (2009). *Relieving Congestion at Intermodal Marine Container Terminals: Review of Tactical/Operational Strategies.*

6. Dougherty, P. S. (2010). *Evaluating the Impact of Gate Strategies on a Container Terminal's Roadside Network Using Microsimulation: The Port Newark/Elizabeth Case Study.* New Brunswick, NJ. 2010.

7. Spasovic, L. N., Dimitrijevic, B., & Rowinski, J. (2009). *Extended Hours of Operation at the Port Facilities in New Jersey: A Feasibility Analysis.* Newark: New Jersey Institute of Technology.

8. Giuliano, G., O'Brien, T., Clark, A., Linder, A., Rohmer, J., Tan, W., & Zhou, J. (2008). *Evaluation of Extended Gate Operations at the Ports of Los Angeles and Long Beach.* METRANS.

9. Fairbank, Maslin, Maullin & Associates. (2006). *PierPASS: Los Angeles/Long Beach Harbor Truckers Follow-up Survey.*

10. Giuliano, G., & O'Brien, T. (2007). Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach. *Transportation Research Part D, 12*, 460-473.

11. Giuliano, G., O'Brien, T., Dell'aquila, P., & Hayden, S. (2006). *The Terminal Gate Appointment System at the Ports of Los Angeles and Long Beach: An Assessment.*

12. Giuliano, G., Hayden, S., Dell'aquila, P., & O'Brien, T. (2008). *Evaluation of the Terminal Gate Appointment System at the Los Angeles/Long Beach Ports.* METRANS Project 04-06.

13. U.S. Environmental Protection Agency. (2006). *A Glance at Clean Freight Strategies: Terminal Appointment Systems for Drayage.*

14. Morais, P., & Lord, E. (2006). *Terminal Appointment System Study*.

15. Namboothiri, R., & Erara, A. L. (2008). Planning local container drayage operations given a port access appointment system. *Transportation Research Part E, 44*, 185-202.

16. Guan, C. Q., & Liu, R. (2009). Modeling gate Congestion of Marine Container Terminals, Truck Waiting Cost, and Optimization. *Transportation Research Record, 2100*, 58-67.

17. Chen, G., Yang, Z., & Jiang, L. (2009). Reducing Marine Container Terminal Gate Congestion with Vessel-Dependent Time Windows For Truck Entries. *TRB Annual Meeting.* Washington D.C.

18. Huynh, N. N., & Walton, C. M. (2005). *Methodologies for Reducing Truck Turn Time at Marine Container Terminals.* The University of Texas at Austin, Center for Transportation Research.

19. Fischer, M. J., Hicks, G., & Cartwright, K. (2006). *Performance Measure Evaluation of Port Truck Trip Reduction Strategies.*

20. Moini, N. (2010). *Modeling the Interrelationship Between Vessel and Truck Traffic at Marine Container Terminals.* New Brunswick: Rutgers, The State University of New Jersey.

21. Lee, D.-H., Wu, X., & Jin, J. G. (2011). *A Micro-Simulation Model for the Analysis of Traffic Flow in a Container Port.* Washington, D.C.: Transportation Research Board.

22. Ratrout, N. T., & Rahman, S. M. (2009). A Comparative Analysis of Currently Used Microscopic and Macroscopic Traffic Simulation Software. *The Arabian Journal for Science and Engineering, 34*(1B).

23. Quadstone Paramics Ltd. (2012). *Quadstone Paramics*. Retrieved January 27, 2012, from http://www.paramics-online.com

24. The Port Authority of NY & NJ. (2010). *The Port of New York and New Jersey Port Guide.* Newark, NJ: SEAPORTS Publications Group.

25. Husch, D., & Albeck, J. (2006). *Synchro Studio 7: Synchro plus SimTraffic and 3D Viewer.* Sugar Land, TX: Trafficware, Ltd.

26. The MathWorks Inc. (1994). *Matlab: The Language of Technical Computing*. Retrieved September 13, 2011, from http://www.mathworks.com

27. Scora, G., Barth, M., An, F., Younglove, T., Levine, C., Ross, M., & Wenzel, T. (2006). *Comprehensive Modal Emissions Model (CMEM), version 3.01: User's Guide.* Riverside: University of California, Riverside.

28. United States Environmental Protection Agency. (2010). *Motor Vehicle Emission Simulator (MOVES).* Washington, D.C.

APPENDIX

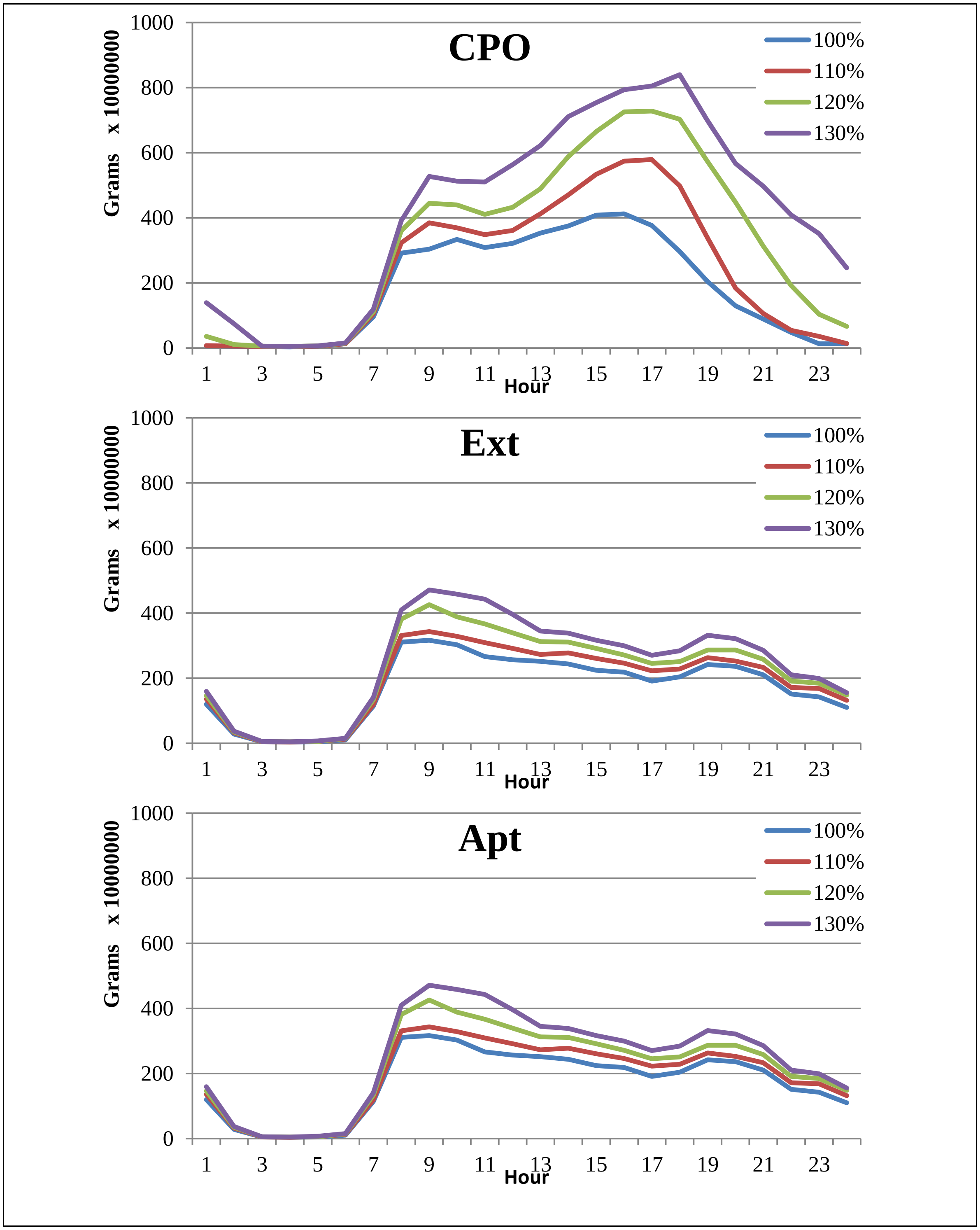


FIGURE A-1 Hourly Carbon Dioxide Emissions

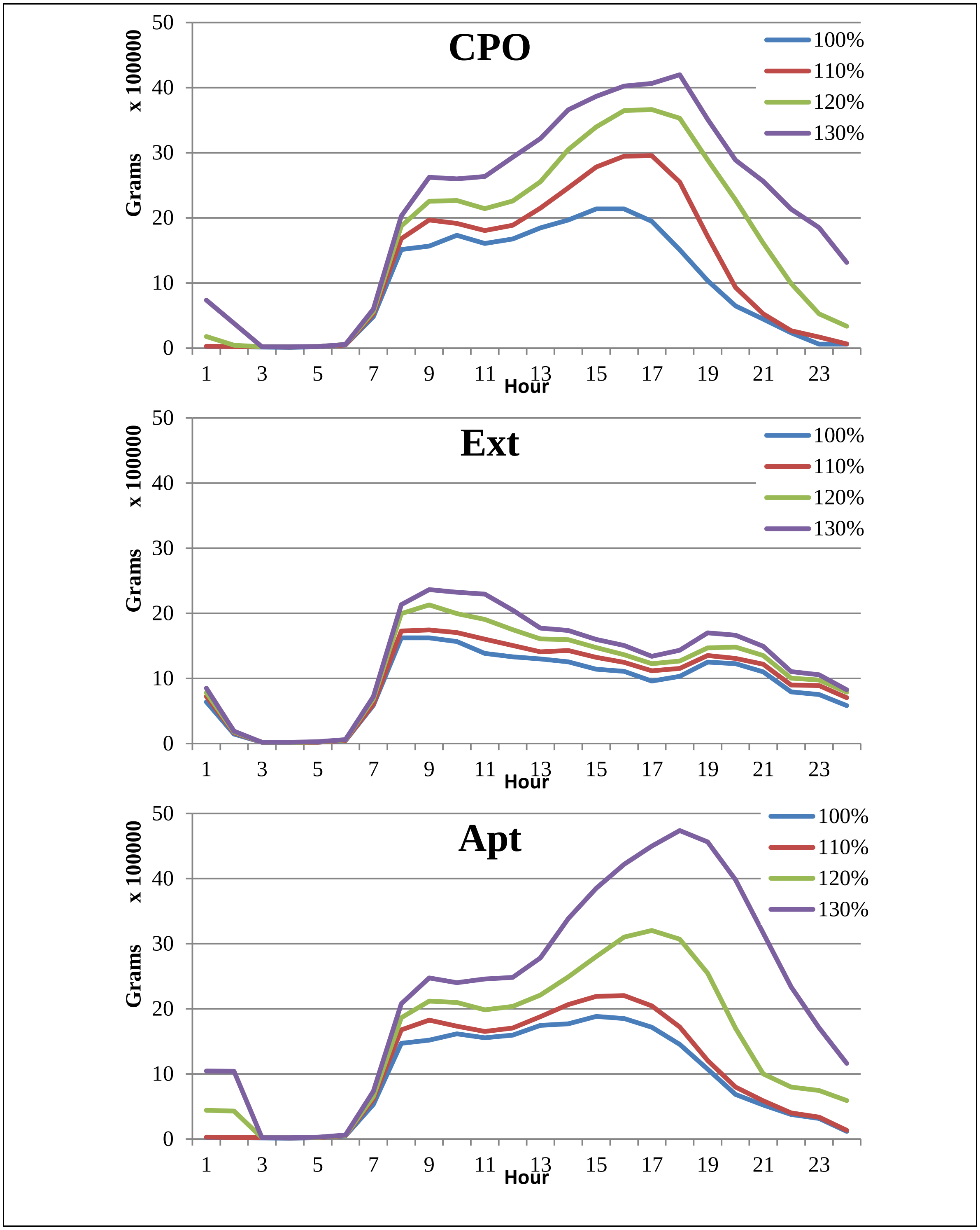


FIGURE A-2 Hourly Hydrocarbon Emissions

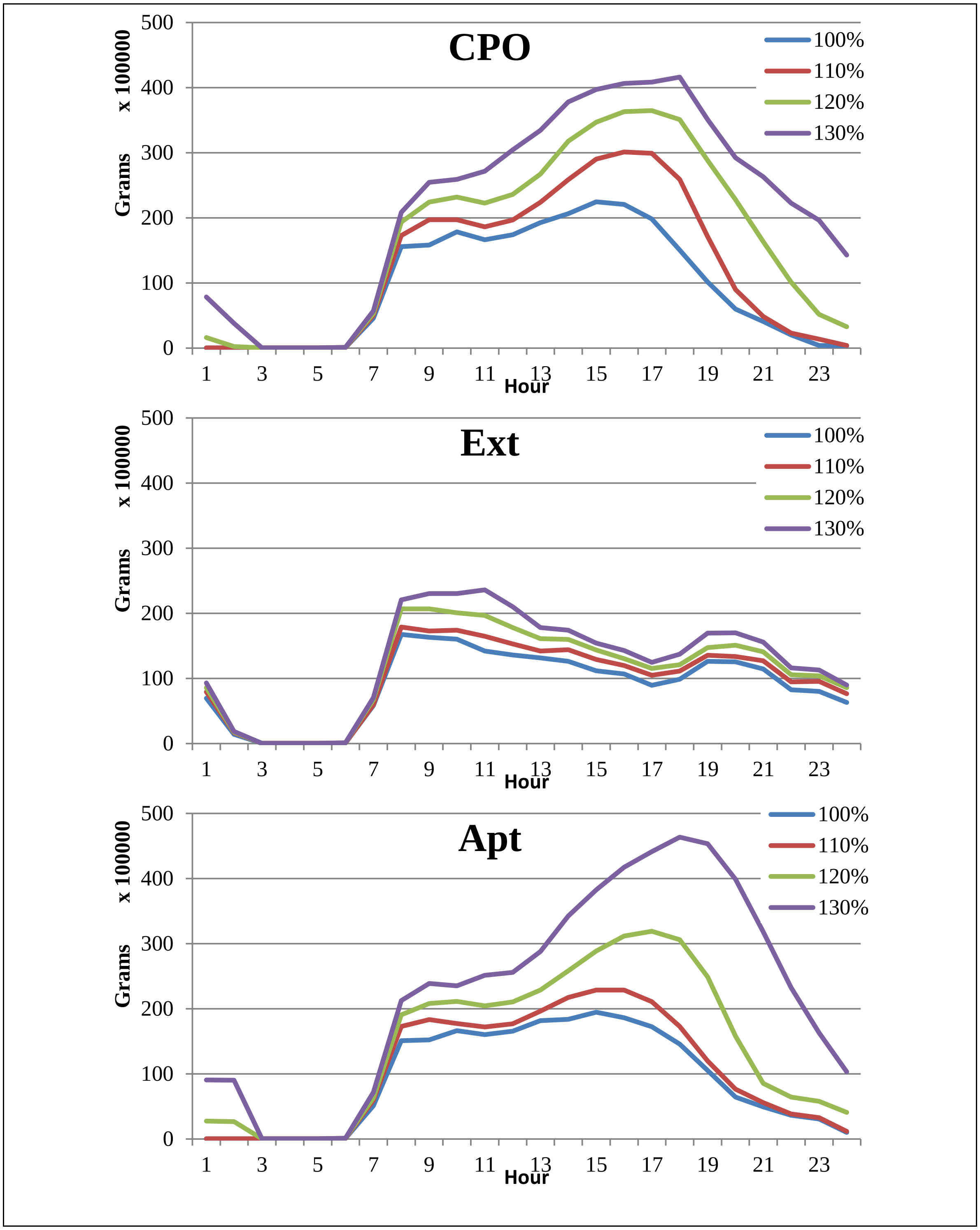


FIGURE A-3 Hourly Nitrogen Oxide Emissions

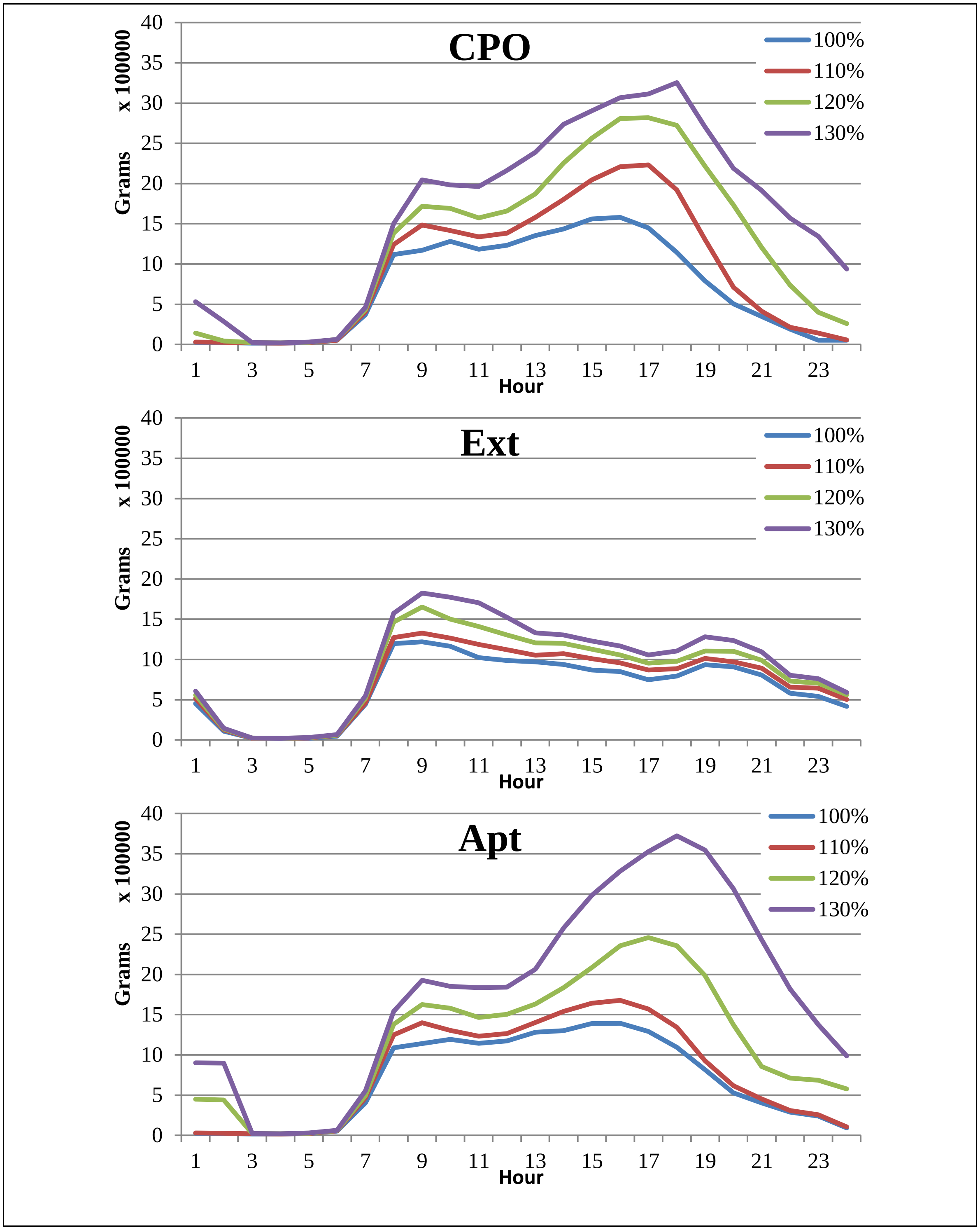


FIGURE A-4 Hourly Fuel Consumption

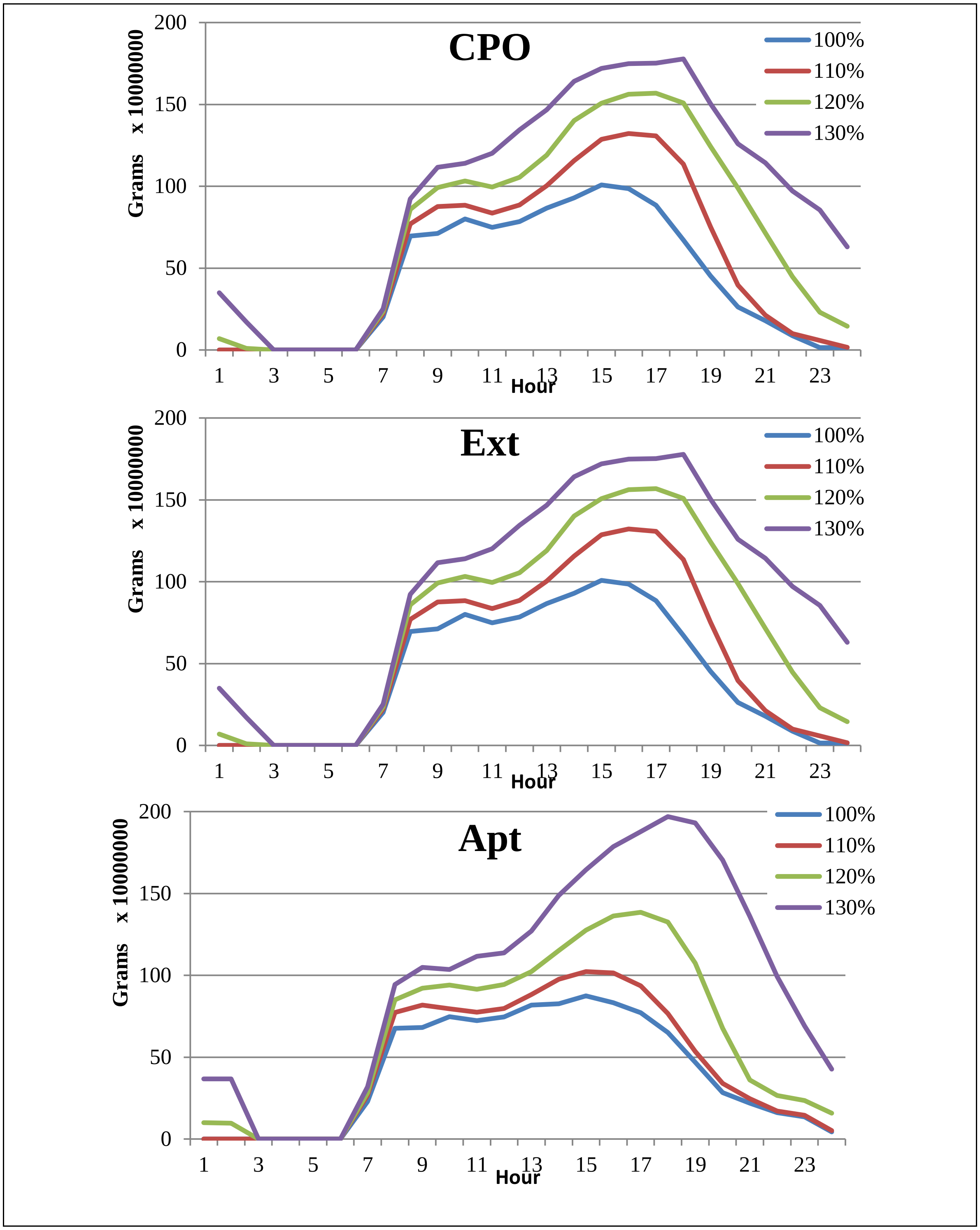


FIGURE A-5 Hourly Diesel Particulate Emissions