Evaluation of the Effect of Gate Strategies in Drayage Related Emissions

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16. Abstract 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 research 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.			
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EXECUTIVE SUMMARY

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 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 these 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 on the landside coupled with capacity issues can degrade reliability and performance of the terminal. In addition to these issues, environmental effects stemming from idling trucks has further emerged as a serious problem, as truck emissions have been linked to negative 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, applying 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 gate strategies either through simulation modeling or through before-and-after case studies of terminals which have implemented gate strategies.

This primary objective of this research is to present the development of a traffic simulation model capable of measuring the impact that gate strategies will have on the levels of congestion at IMCT terminal gates. The traffic model was used to quantify travel time, delay, and emission levels within the terminals 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 70% 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 (as well as emissions) was extending the terminal gate hours to divert demand to off-peak hours.

Recommendations for gate strategy implementation are problematic, as each terminal has unique characteristics that will influence the effectiveness of gate strategies. This research does show that appointment systems should be implemented with caution, especially when a limited number of lanes are available. Testing an appointment system with a simulation will let the terminal operators determine both the number of lanes that should be converted to appointment lanes and the percentage of demand that should be making appointments to utilize those lanes most effectively. Extending the gate hours proved to be an effective method of increasing efficiency, especially as the demand for the terminals was increased.

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 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 also need to address increases in emissions that occur as a result of increases in demand and congestion. IMCTs have begun to address this issue by introducing programs such as cold-ironing and electrification which are aimed at reducing emissions of landside and seaside operations. Most current landside operations produce diesel engine exhaust, which is known to contain a number of carcinogens and is 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; drayage movements. Drayage is defined as "*the 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 during the day as possible, which causes demand to peak during certain hours at terminal gates. These peaks are concentrated in the hours prior to the opening of terminal gates, as drayage operators attempt to enter the terminal as early as possible, and evening, as drayage operators try to make their last movement before the gates close. Trucks that arrive prior to the gates open often continue to idle, which increases the 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 at both the beginning of the day and after a weekend period, as demand for drayage movements continues to build over these periods.

Even if demand peaks and operational imbalances did 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 identity verification of both the drayage operator and company, verification of the availability of the container that the drayage operator intends to pick up, equipment inspection, and dispatching yard equipment 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.) 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 by IMCTs to decrease delays at terminal 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 which help to offset the added cost of operating terminal gates over longer time periods and to encourage drayage operators to utilize off-peak hours. The amount of demand which is shifted 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 IMCTs implement to increase terminal gate efficiency is appointment systems. Appointment systems are often accompanied by dedicated lanes whose purpose to minimize delays for trucks with appointments, thereby encouraging more drayage operators to make and keep appointments. Effective appointment systems also allow IMCT operators a measure of control over drayage truck arrivals, as they can specify the number of transactions that will occur on appointment lanes (6). This measure of control is limited by the variability of drayage transactions, 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 which can be used to create a dynamic traffic simulation model that will measure congestion and emissions levels at IMCT terminals before and after the application of gate strategies. To demonstrate the proposed methodology a case study will be developed where two gate strategies are implemented: a) an appointment system, and b) extended hours of gate operations. The Port of Newark/Elizabeth (PNE) was selected as the test-bed for this research due to data availability (Dougherty (8) and Spasovic et al. (9)) and because the port has high levels of demand.

The scenarios that were developed for the PNE included: a) a scenario that represented the current patterns of operation (CPO), b) an appointment scenario, c) an extended gate hour scenario, and d) a flat demand scenario (the flat demand scenario evenly distributed truck demand over a 24-hour period and was used as a best-case scenario). Gate strategy scenarios were compared to the CPO scenario to measure any improvements that resulted from their implementation. The flat demand scenario was used to determine what the best-case scenario would look like for future demand levels. 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 research a significant amount of effort focused in achieving the latter objective utilizing state of the practice software and innovative modeling techniques.

The remainder of this report 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. (10). 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 (11) 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. (9) 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. (12; 13; 14). 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 (15) 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 (7) 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 (16) 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 (17) 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. (18) 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 (19) 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. (20) 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 (21) 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 (21) 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. (22) 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 (8) 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 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 the 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 (23) 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 (24) 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 allowed for the development of a simulation that included logic which simulated drayage movements within the PNE. Paramics also allowed us to measure delays experienced on terminal roadways and at terminal gates, measure travel times throughout the PNE, and to measure emission levels for each scenario. The data from Paramics could be assessed hourly and over the entire 24-hour period.

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. There are three main access roads that service the PNE. Vehicles entering from the south use North Avenue. At the north end of the PNE, vehicles can 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 can pick up or drop off chassis equipment. The APM chassis depot is located within the terminal. Maher and PNCTs both have off-site chassis depots. 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. Trucks traveling to the chassis depot must pass through four signalized intersections to reach the terminal. The PNCT chassis depot is located three miles from the terminal entrance and trucks traveling between the two must pass through seven signalized intersection. Capturing trips to and from the external chassis depots was considered crucial because generated extra trips for trucks and added delay to drayage transactions. A satellite view of the PNE highlighting the physical location of areas crucial to the simulation is shown in Figure 1.

3.3 Physical attributes of the Paramics simulation

Developing a Paramics model required establishing vehicle types, creating zones origin/destination zones, and re-creating the roadway network of the PNE. The following section describes the physical attributes models that represented the CPO, extended hour and appointment scenarios.

3.3.1 Vehicle types

To accurately measure changes that occur due to the application of terminal gate strategies, it was important to develop a detailed set of drayage vehicles. Accurate vehicle lengths were necessary to represent queues at the terminal gates. Different vehicle types were needed to model movements between the terminals and the chassis depots as well as between non-terminal zones within the simulation. Movements between the terminals and the chassis depots were considered vital, 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 from or be destined to "other" zones,
    b) trucks that would originate from or be destined to "other" zones, and
    c) trucks destined to the IMCTs.

For passenger cars, default 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 were given different lengths so that queues at signalized intersections within the PNE could be more accurately represented. The first vehicle type was given a length of 20 ft. and the second was given a total length of 66 ft. (which was divided into a 13 ft. cab and a 53 ft. trailer). The distribution of "other" trucks within the model was such that 85% were represented by vehicles with a length of 20 ft. and the remaining 15% by vehicles with a 66 ft. length.

Drayage trucks were represented by three vehicle types; 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. Operational attributes for these vehicles were defined using default characteristics of an LGV.

Two types of vehicles were used to represent container trucks. The first 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. and the trailers were assumed to be the same as 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. Simulating different lengths of container trucks was considered 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%. This distribution was determined from a limited set of observations obtained from satellite images.

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

Source: http://www.google.com/earth/index.html
FIGURE 1 SATELLITE IMAGE OF THE PNE

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 from which vehicles are either released into or removed. The second type of zone is a strategic waypoint zone, 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 vehicle 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 delay due to 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 to either Maher or PNCTs (i.e. terminals with external chassis depots) were routed to both the terminal and the chassis depot prior to exiting the simulation. The use of strategic waypoint zones ensured that drayage trucks could be tracked as they moved throughout the terminals. Strategic waypoint zones 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.

A total of 39 zones were used to represent origins and destinations within the PNE. To better model the complex traffic movements within PNE, these zones were separated into three 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
  c) zones representing terminals and chassis depots.

Entrances to the PNE were simulated using 18 vehicle sinks (6 zones per entrance). The North Avenue entrance zone configuration is shown in Figure 2. Multiple zones were used to simulate PNE entrances so that traffic assignments to each terminal could be controlled. For example, 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 PNCTs, respectively. Zones 029 and 031 were termini for vehicles exiting via North Avenue from either the Maher or PNCTs. Both Port Street and Doremus Avenue 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.
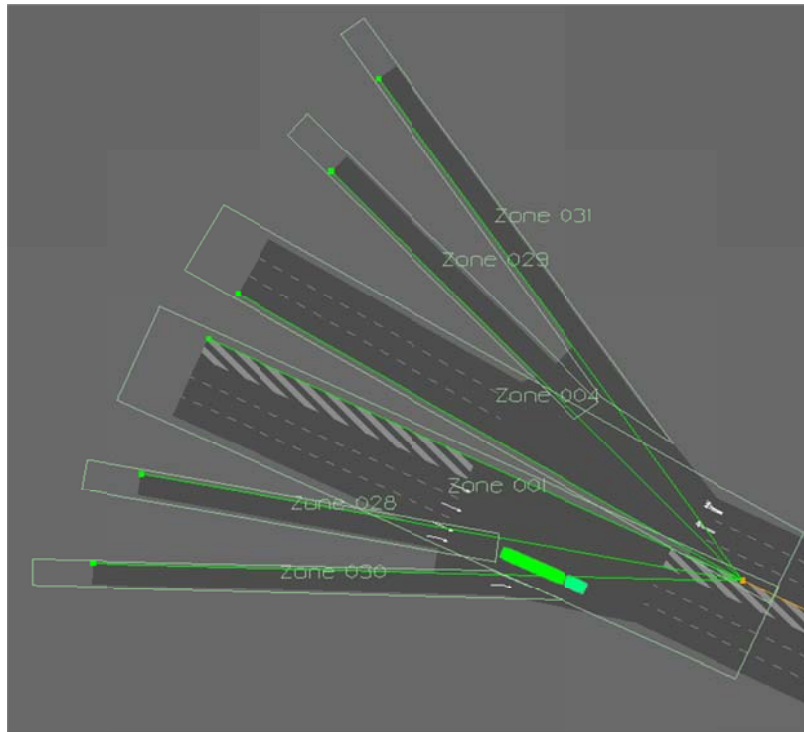
FIGURE 2 ZONES REPRESENTING THE NORTH AVENUE ENTRANCE

Another consideration made at the entrances of the PNE concerned the type of links that were used. On default links, vehicles are released into the simulation at a speed of 5 miles per hour (mph). On a zone connector, vehicles are released at link speed; therefore all of the links at the PNE entrances were zone connectors because vehicle speed is an important factor in calculating both travel times and emissions. Using zone connectors allowed the model 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. A set of 45 waypoint rules defined routes for drayage trucks within the model. 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

12

Table 1 shows the relationship between strategic waypoint rules and the PNE entrances and exits. The routes defined origin-destination (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 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

The even-numbered rules shown in Table 2 were routes for container trucks destined to the Maher terminal. 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 travel distance within the PNE, therefore routes terminating at North Avenue (Rules 11, 17, and 23) were defined so that trucks traveled to the terminal before proceeding to the chassis depot. For trucks originating at North Avenue, the order in which trucks visited the chassis depot and the 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 (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.

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 between the terminals and the chassis depots. Movements between terminals and chassis depots represent a significant portion of demand, therefore the inclusion of these movements was essential to assess the impact that gate strategies would have on congestion and emissions within the PNE.

3.3.3 Base case development

On top of creating logic for vehicle movements, a simulation requires a physical representation of the area. The geometric data used to create the physical representation of the

PNE was collected from Google Earth and from observations made during a visit to the site. Simulating the PNE's roadway network required the use of 370 nodes, which were 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 terminal gates was a crucial component of measuring the effectiveness of gate strategies within the PNE.

Each of the IMCTs at the PNE has a unique set of characteristics which influenced the behavior of drayage operations. Each terminal's physical representation will be described in detail in the remainder of this section.

The southernmost terminal of the PNE is the APM terminal. A satellite image of the 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 for the APM entrance gate, shown in Figure 3, is 15 lanes wide. The PNE's access road at the entrance to the APM terminal is only 4 lanes wide (two lanes for each direction), 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 merge into all 15 lanes. The second section (15 lanes wide) represents 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 quicker inspection times for trucks exiting bobtail. These areas are shown in Figure 4.

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 chassis trucks (all bobtail trucks are sent to the chassis depot). Lane restrictions were used to guide demand to the entrance gates designed to accept specific truck types.

Entrance Approach

t Gate & pproach

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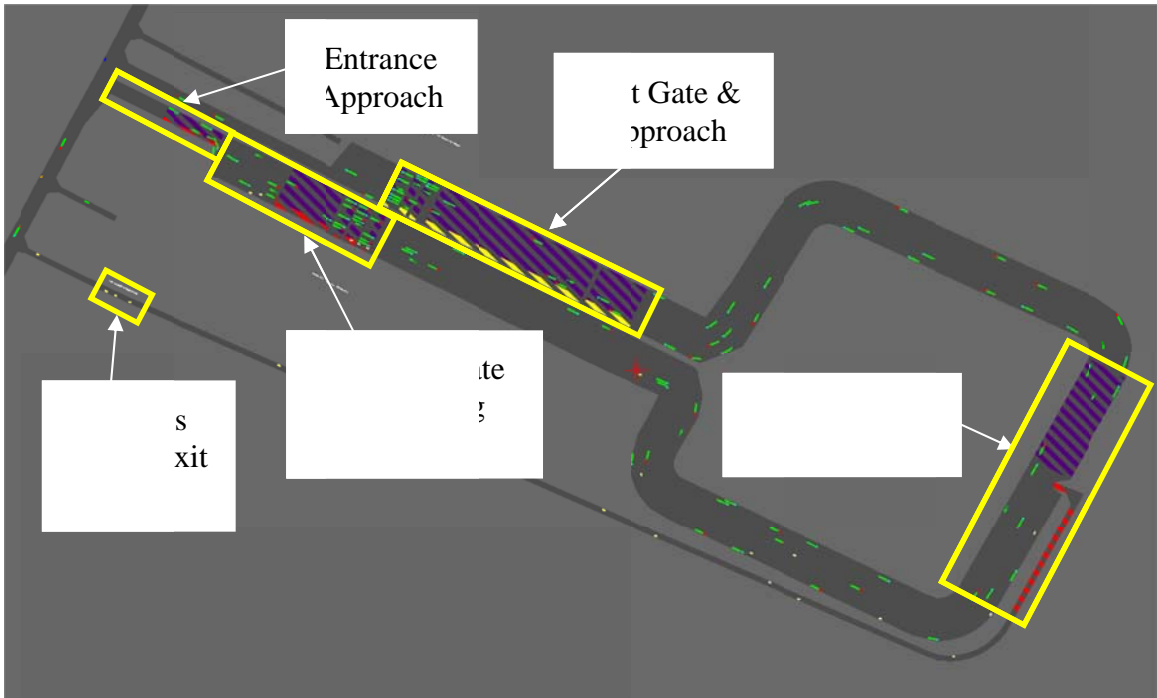
FIGURE 4 APM TERMINAL, CPO SCENARIO

To simulate drayage operations at the APM terminal, it was necessary to separate movements (via lane restriction) into vehicles that travel directly to the exit gates and vehicles that travel to the chassis depot. Bobtail trucks exited the terminal via the chassis depot and container and chassis trucks exited through the main exit gates (Chassis Depot Separation Area, Figure 4).
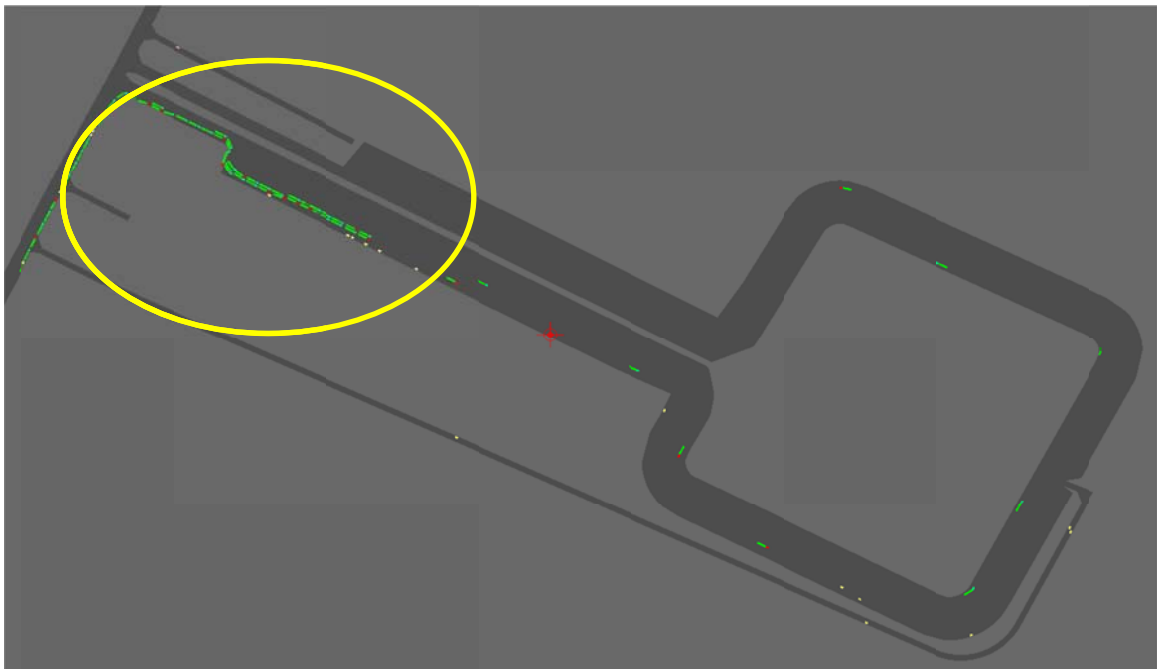

FIGURE 5 UNNATURAL QUEUING AT THE APM ENTRANCE

Lane restrictions alone were not enough to accurately represent drayage movements at the APM terminal, as trucks could not navigate the rapid lane expansion using Paramics default vehicle logic. 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 is obvious that default vehicle lane distributions would 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, which allow the user to adjust the distribution of demand.

Lane choice rules allow 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 from which a vehicle is exiting. Nextlanes also allows a specific range of lanes to be utilized, thus controlling 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 flow.

The first area where lane choice rules were applied was the area labeled Entrance Approach in Figure 4. An image of the links and lane choice rules is shown in Figure 6. The first rule restricted bobtail trucks to lane 1 and 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). These lane choice rules allowed for the creation of a nextlane distribution that would prevent drayage trucks from attempting to access lanes from which they were restricted.

Lanes 2-5
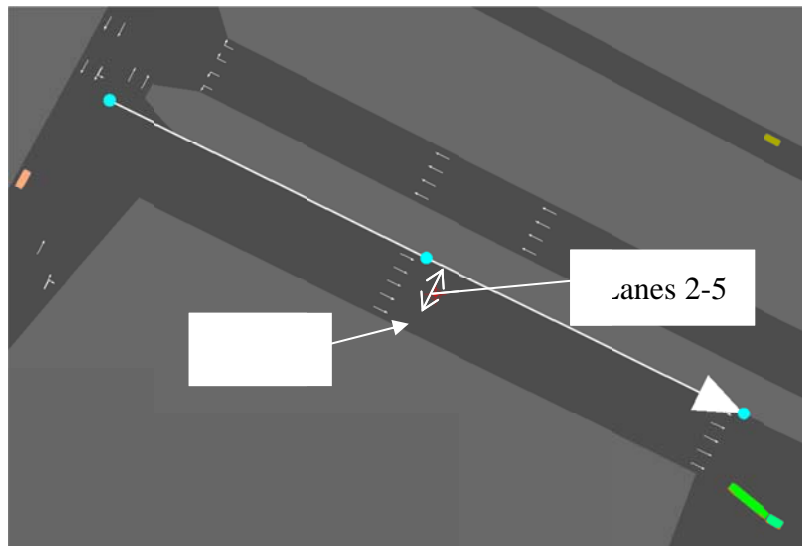
FIGURE 6 APM TERMINAL ENTRANCE LANE CHOICE RULES

The set of nextlane rules that controlled the movements between the Entrance Approach and the Entrance Gate & Queuing Area are 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

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, was also evenly distributed (Table 4).

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.

Lane choice logic at the Exit Gate & Approach included two rules. The first rule 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.
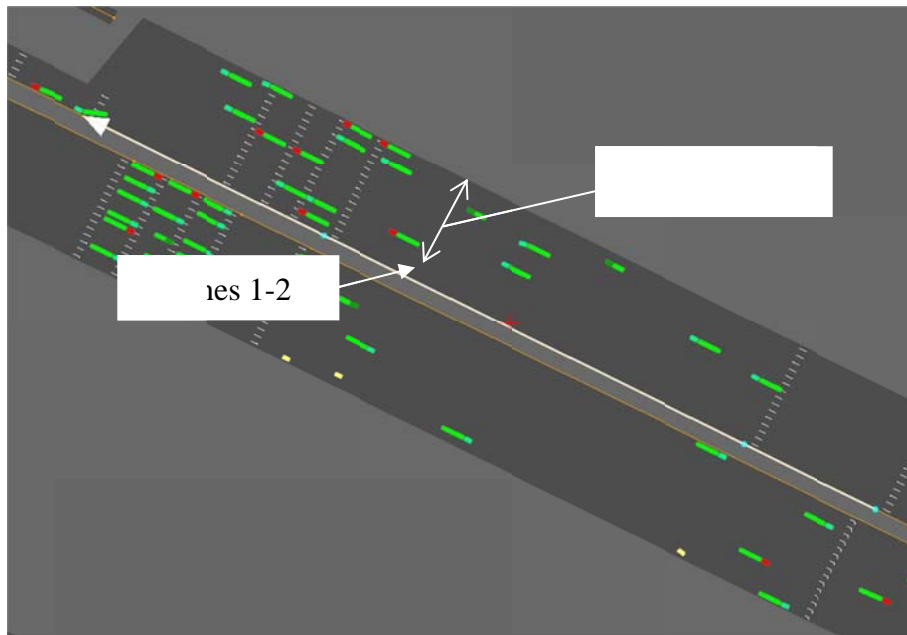
FIGURE 7 APM EXIT GATE LANE CHOICE RULES

Having established the physical and behavioral rules that governed drayage movements at the APM terminal, it was necessary to do the same for the Maher terminal. The Maher terminal is located near the middle of the PNE and is the largest of the three 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 satellite image of the entrance gate shown in Figure 8 reveals that the approach to the queuing area is a short section of roadway that is 5 lanes wide. Upon passing through this section, the terminal entrance expands to a 20 lanes. The exit gates at the Maher terminal are also 20 lanes wide. For the simulation, the entrance and exit gates were simplified to a single-tier configuration, as the exact function of each gate within the multi-tiered configuration of the terminal was unknown. Figure 9 shows the simulation representation of the entrance and exit gates and their respective approaches.

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 (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.

The rapid lane expansion at the Maher terminal entrance required a distribution of demand using a combination of lane choice and nextlane rules, similar to the approach used to simulate the APM terminal. Figure 10 shows the location of the lane choice rules used at the Entrance Approach to the Maher terminal.

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 and the second rule distributed 25% of container truck demand to lanes 2, 3, 4, and 5, respectively. The lane choice rule governing the container trucks was particularly important because without it, the container trucks tended to remain in the lower lanes, which effected the queue distribution at the entrance gate.
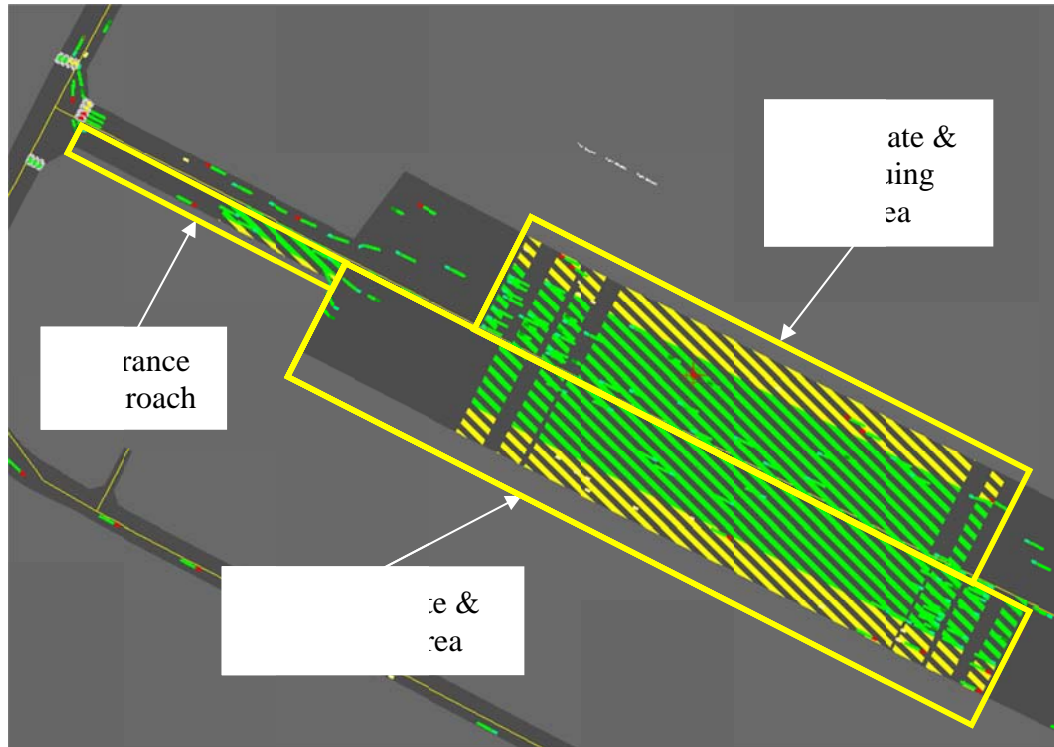
FIGURE 9 MAHER TERMINAL GATE CONFIGURATION, CPO SCENARIO
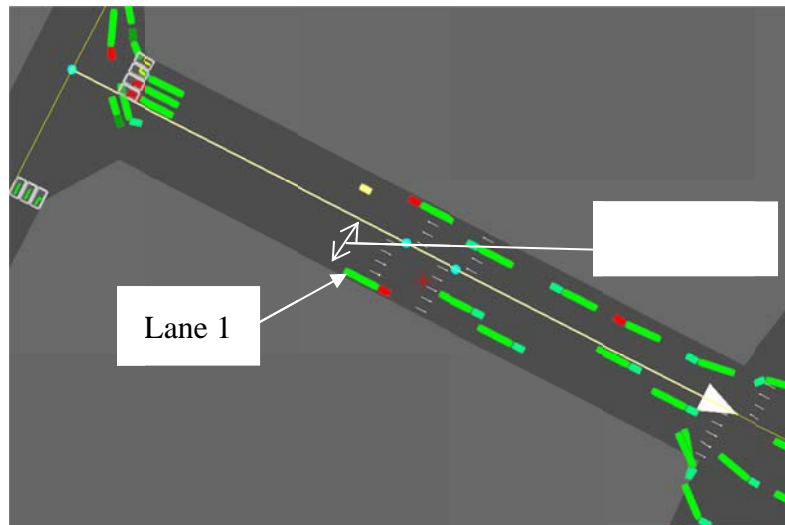
FIGURE 10 MAHER ENTRANCE APPROACH LANE CHOICE RULES

Drayage trucks traversing from the Entrance Approach to the Entrance Gate & Queuing Area were controlled using nextlanes rules, the aim of which was to distribute chassis and bobtail trucks to the first six lanes and evenly distribute container trucks among the remaining lanes. The values used for the nextlane distribution at the Maher terminal Entrance Approach are shown in Table 5.

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 ensure that demand for bobtail/chassis lanes (1-6) and container lanes (7-20) remained equally distributed while approaching the entrance gates. This additional lane choice rule was applied to the Entrance Gate and Queuing Area (Figure 9).

Another set of lane choice rules was used to control the distribution of trucks approaching the Maher exit gates. The Exit Gate & Queuing Area at the Maher terminal is shown in Figure 11. The lane choice rule for lanes 1-6 uses an exact distribution to assign demand for chassis and bobtail trucks (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 demand and lanes 19 and 20 were each assigned 8% of demand. These distributions approximated the even distribution of drayage trucks within queues at the exit gates

Unlike the APM terminal, the Maher chassis depot is located outside the terminal. As mentioned earlier, capturing trips between the terminal and chassis depot is an important part of the simulation. A satellite image of the Maher chassis depot is shown in Figure 12.
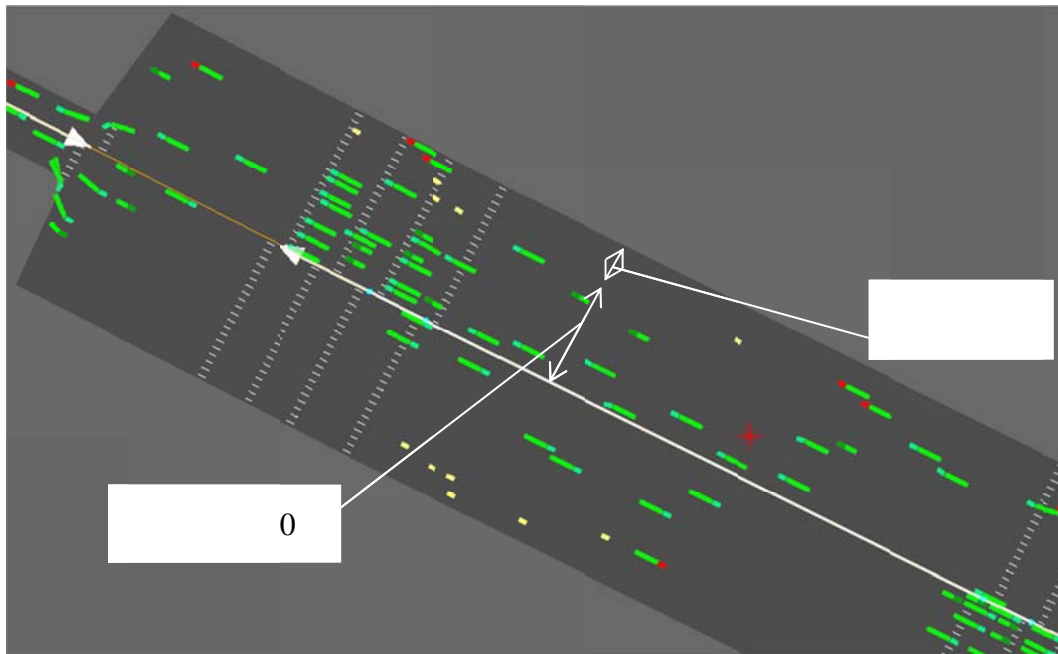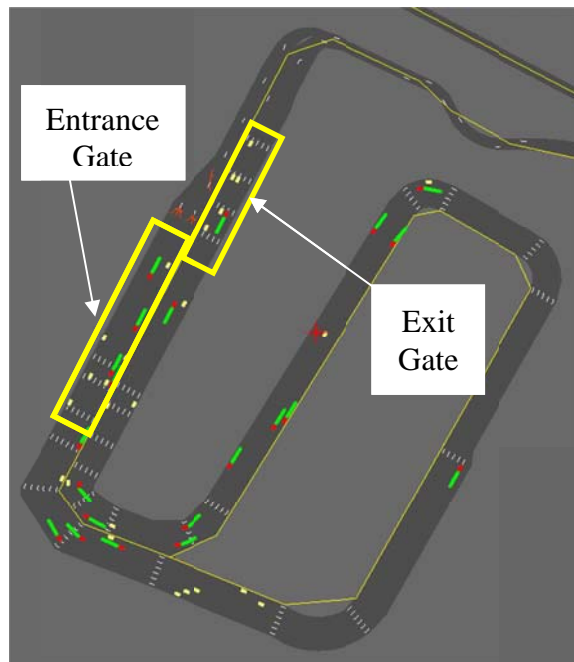

FIGURE 11 MAHER EXIT GATE LANE CHOICES

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 wide to six lanes wide at the entrance gate. Two sets of nextlane rules were needed to control the distribution of drayage trucks approaching the chassis depot entrance gates (shown in Figure 14).

The first rule controlled behavior of trucks 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 occurred between Link 2 and Link 3. The nextlane rule for this expansion 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.

In-gate processing delays for chassis and bobtail trucks destined to Maher terminals were split between the terminal and chassis depot. This was based on the assumption that in-gate processing would not be duplicated at two separate locations.
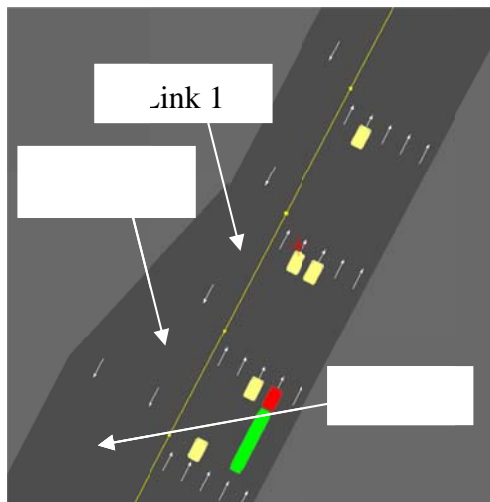
**FIGURE 14 LANE EXPANSION, MAHER CHASSIS DEPOT**

The final terminal for which a physical model was built was the PNCT, which is located near the north end of the PNE. To access the PNCT, drayage trucks must leave the main access road of the PNE and travel down secondary roads. Upon reaching the entrance to the PNCT, the geometry becomes restrictive and causes congestion problems. A satellite image of the entrance and exit gate configuration of the PNCT is shown in Figure 15.

The entrance begins as a road that is 2 lanes wide and expands to 10 lanes wide at the entrance gates, all while following a tight, S-shaped curve. The exit gates at the PNCT are 6 lanes wide. The geometry of the entrance to the PNCT 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 is shown in Figure 16.

Source: http://www.google.com/earth/index.html
FIGURE 15 SATELLITE IMAGE OF THE PNCT GATE CONFIGURATION

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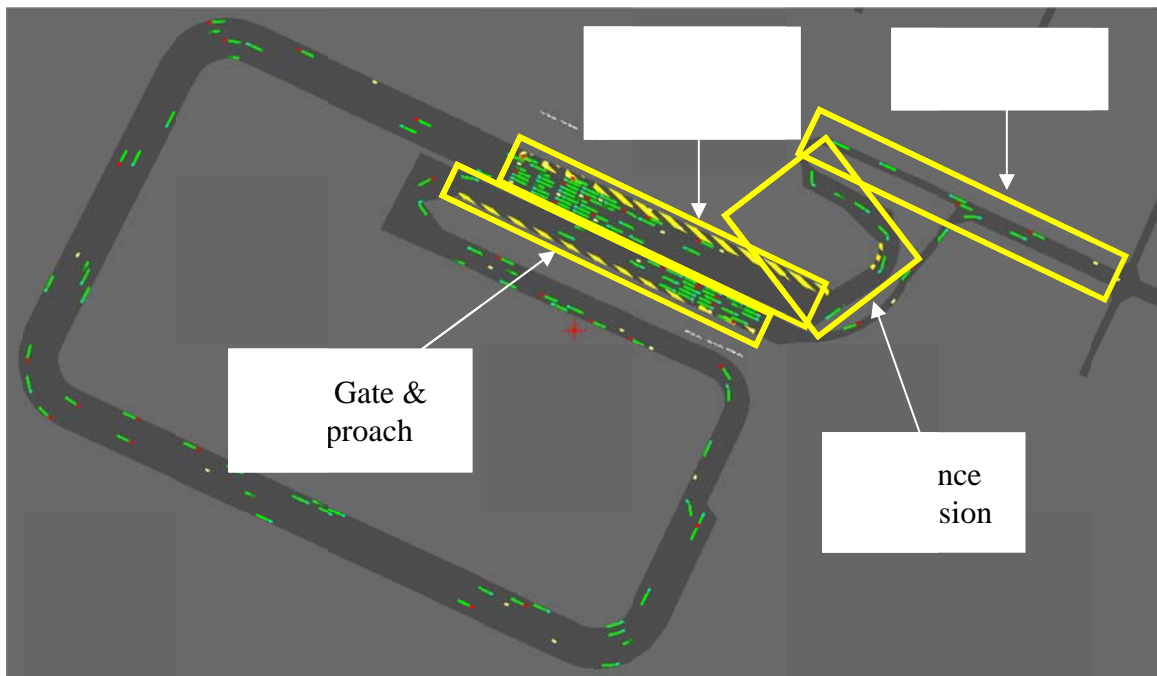
FIGURE 16 PNCT, CPO SCENARIO

The area labeled Entrance Expansion (Figure 16) had two sets of lane restrictions. The first restriction applied to lane 1 and limited access to bobtail and chassis trucks. The second restriction applied to lanes 4 and 5 and restricted access 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). Applying lane restrictions to the PNCT entrance was difficult because of the geometry of the approach. In order to limit congestion caused by lane restrictions at the Entrance Expansion, two lane choice rules were also applied to the area. The first rule directed all bobtail

and chassis truck demand to lane 1, while the second rule distributed 25% of container truck demand to each of the four remaining lanes. The area affected by these lane choice rules is shown in Figure 17.

FIGURE 17 LANE CHOICE RULES FOR THE PNCT ENTRANCE EXPANSION

In addition to its unique geometry, the PNCT also had entrance gates which operated differently than the entrance gates of the other terminals. The first two gates were restricted to bobtail and chassis trucks, but 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.

For the first lane (which could only be accessed by chassis and bobtail trucks) no nextlane rule was applied. This allowed chassis and bobtail trucks the opportunity to move between every lane while approaching the entrance gate. It was also necessary to avoid using a nextlane rule on this lane because the geometry of the PNCT made it difficult for drayage trucks to maneuver between lanes and, despite the application of lane restrictions, container trucks occasionally remained in lane 1 as they could not perform weaving movements in time to avoid restricted lanes. By leaving lane 1 free of nextlane rules, container trucks that found themselves in lane 1 were allowed to maneuver to lane 3 upon leaving the Entrance Expansion (Figure 16).

Consideration of added weaving movements also 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, which was caused by container trucks attempting to change lanes to avoid restrictions. Demand exiting the Entrance Expansion (Figure 16) via lanes 3, 4, and 5 was evenly distributed between the remaining lanes (two lanes per each lane of approach).

Demand distribution at the PNCT's Exit Gate & Approach was controlled through a combination of lane restrictions and lane choice rules. The lane restriction occurred on lane 1 and restricted access to chassis and bobtail trucks (yellow-hatched lane in Exit Gate & Approach, Figure 16). The lane choice rules used at the PNCT exit gates distributed all bobtail demand to lane 1, all container truck demand evenly between lanes 2, 3, 4, and 5, and chassis truck demand was evenly distributed between all six lanes.

In addition to establishing logic for truck movements within the PNCT, it was also necessary to establish rules for the PNCT chassis depot. The PNCT chassis depot is located outside of the terminal on Polaris Street, approximately 3.3 miles from the entrance of the PNCT

near the south end of the PNE. A satellite image of the PNCT chassis depot is shown in Figure 18.

Unlike the Maher chassis depot, no gate configuration could be discerned at the PNCT chassis depot. Therefore, no gate delays occur at the PNCT chassis depot entrance gates. The simulation representation of the PNCT chassis depot is shown in Figure 19.
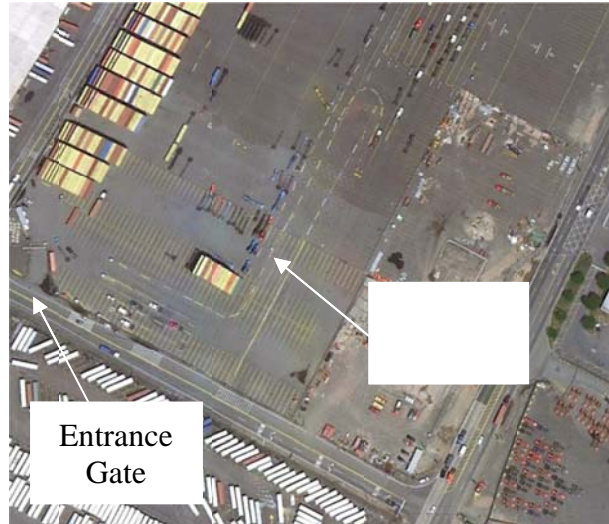
Source: http://www.google.com/earth/index.html
FIGURE 18 SATELLITE IMAGE OF THE PNCT CHASSIS DEPOT
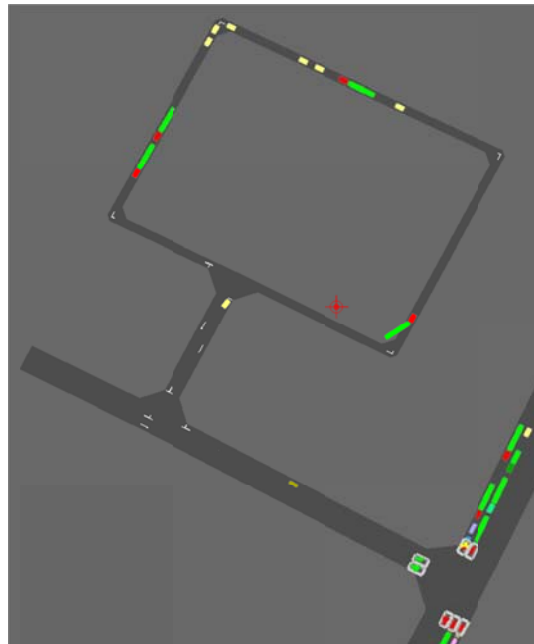
FIGURE 19 SIMULATION OF THE PNCT CHASSIS DEPOT

All delay for drayage trucks visiting the PNCT chassis depot occurs via travel time to the chassis depot and travel time within the traffic depot. Delays representing transactions within the

chassis depot were simulated through the application of a 5 mph speed limit. All gate delays for the PNCT occurred at the entrance gates to the terminals.

Speed limits on the PNE roadway network were obtained from the 2010 Port of New York and New Jersey Port Guide (25). The guide showed that primary roads within the PNE had speed limits of 40 mph and that secondary roads had speed limits of 30 mph. 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 delays due to transactions occurring within terminal yards.

A total of 77 intersections were used to model the PNE, 10 of which were signalized. To determine timings at signalized intersections, a Synchro Studio 7 (26) simulation was created using known turn count data (8). Synchro has an optimization feature which determines the signal timings that yield higher levels of service over a given range. Optimized timings from the Synchro simulation were used as input for signalized intersections in the Paramics model and were held constant for each scenario.

The physical and behavioral aspects used to create the simulation of the CPO were not changed in the extended hour scenario. The only changes made to create an extended gate hour scenario occurred in the OD and will be described in Section 3.5.2. However, creating appointment scenarios required changes to both the OD and the physical and behavioral attributes. These changes are described in the following section.

3.3.4 Creation of appointment scenarios

The most important physical adjustment needed to create the appointment scenarios was determining the number of lanes at each terminal that would be used as appointment lanes (lanes that could only be accessed by appointment trucks). For each appointment scenario, 30% of the lanes at each terminal entrance and exit gate were converted to appointment lanes. The different scenarios represented changes in the proportion of appointment to non-appointment trucks in the OD matrix (this is described in detail in Section 3.5.3). The physical changes made to each of the terminals and chassis depots are described in the remainder of this section. Figure 20 shows the changes made to the APM terminal.

The changes in lane restrictions made to accommodate appointment trucks can be seen in Figure 20. 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 remaining lanes at the Entrance Gate & Queuing Area were restricted to container and chassis trucks. The Exit Gate & Approach had the same proportion of lane restrictions as the Entrance Gate & Approach in the appointment scenarios. A change in lane restrictions was made at the Chassis Depot Separation Area to include bobtail appointment trucks.
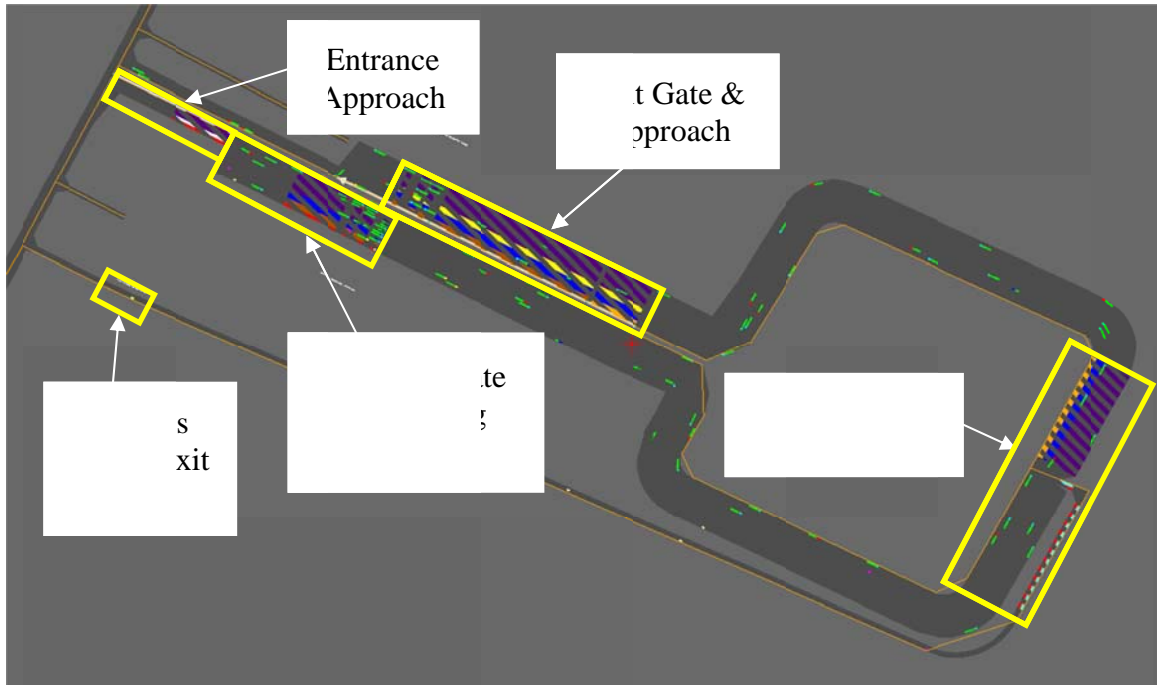
FIGURE 20 APM TERMINAL LAYOUT, APPOINTMENT SCENARIOS

In addition to changes in lane restrictions, changes in lane choice and nextlane rules had to be made to accommodate appointment trucks. Lane choice rules were adjusted so that container and chassis trucks without appointments were evenly distributed among lanes 3, 4, and 5 of the Entrance Approach. Changes in the nextlane distribution were; all bobtail trucks without appointments remained in lane 1, all appointment trucks were evenly distributed between the appointment lanes (lanes 2-6), and all demand from lanes 3, 4, and 5 were evenly distributed between lanes 7-9, 10-12, and 13-25, respectively. These changes ensured that the appointment trucks destined to the APM terminal could navigate through the lane restrictions and form realistic queues at the gates.

Creating an appointment scenario also required making physical and behavioral adjustments to the Maher terminal, including; the lane restriction on the second lane of the Entrance Approach was changed to allow only appointment trucks (white-hatched lane, Figure 21), the first four lanes of the Entrance Gate & Queuing Area (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 restrictions at the Exit Gate & Approach mirrored those of the Entrance Gate & Approach. Changes to the lane restrictions to accommodate appointment trucks can be seen in Figure 21.

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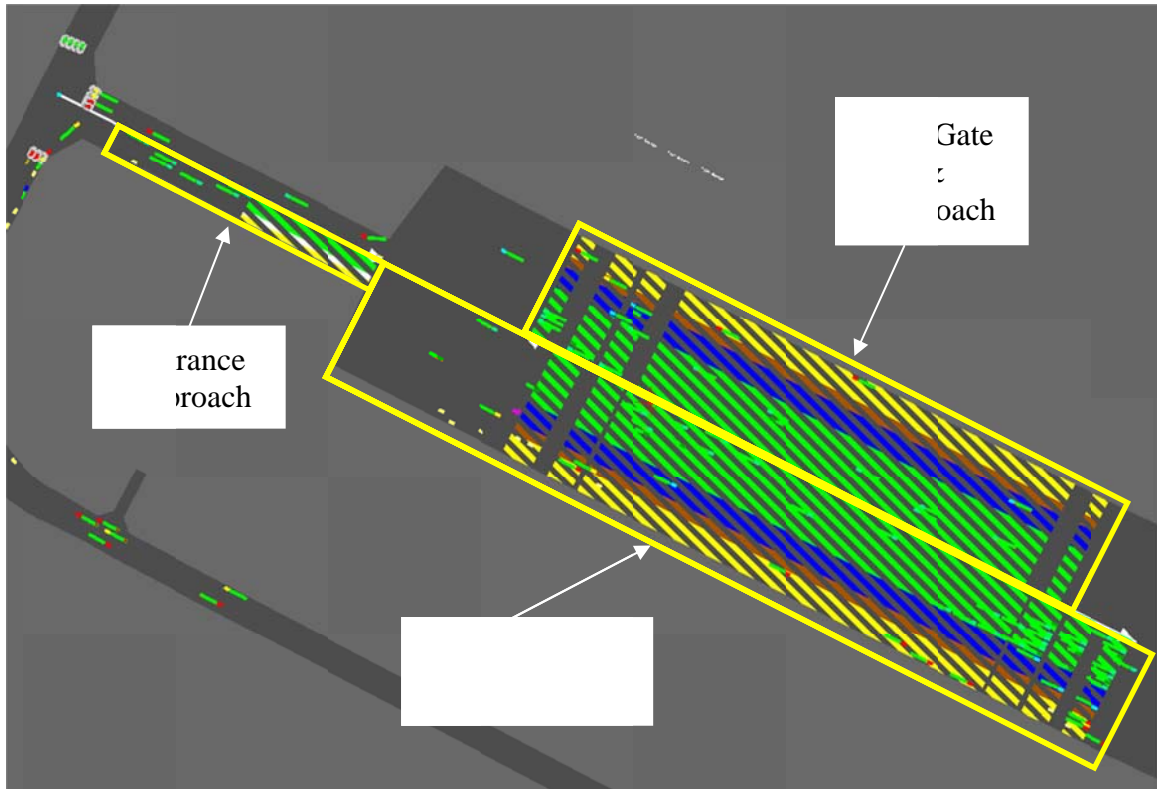
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**FIGURE 21 MAHER TERMINAL GATE CONFIGURATION, APPOINTMENT
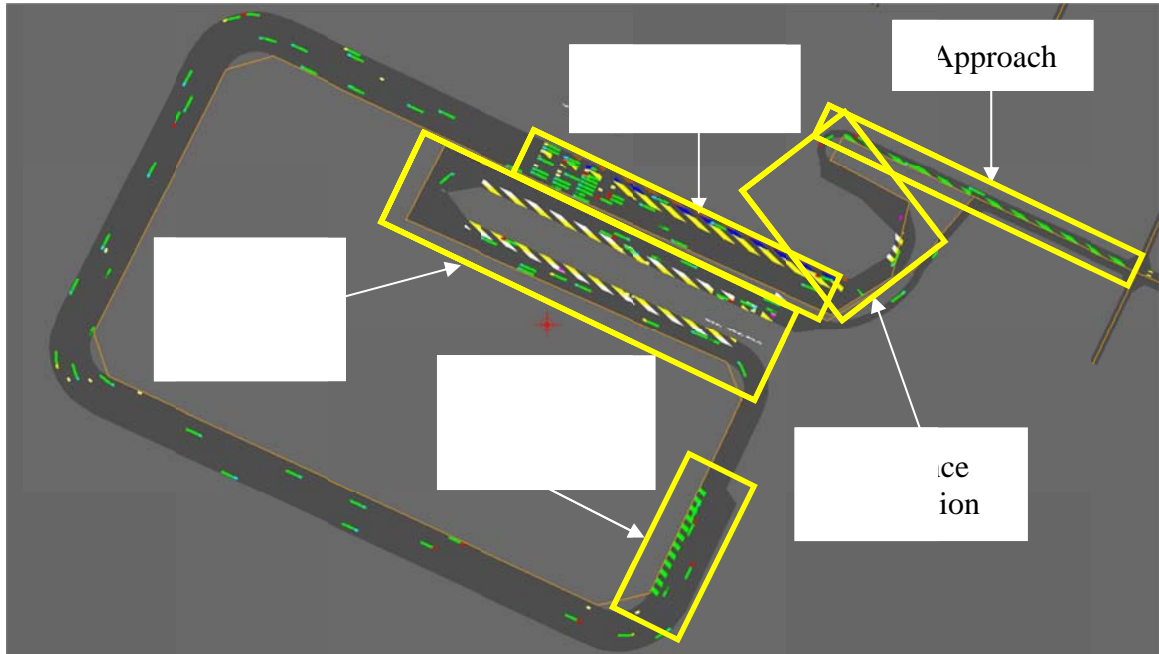SCENARIOS**

In addition to changes in lane restrictions, adjustments to lane choice and nextlane rules
were also necessary at the Maher terminal. At the Entrance Approach, lane choice rules were
changed to guide chassis and bobtail trucks without appointments to lane 1, appointment trucks to
lane 2, and to evenly distribute container trucks between lanes 3, 4, and 5. The nextlane rules
governing the transition between the Entrance Approach and the Entrance Gate & Queuing Area
were changed so that chassis and bobtail trucks exiting the Entrance Approach from lane 1were
evenly distributed between lanes 1-4, appointment trucks (exiting via lane 2) were evenly
distributed between lanes 5-10, and that demand on lanes 3, 4, and 5 was evenly distributed
between lanes 11-14, lanes 15-17, and lanes 18-20, respectively.

A second set of lane choice rules at the Maher entrance gate 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.). Changes made to the lane
choice rules at the entrance gates were mirrored by changes made to lane choice rules at the exit
gates. The only changes made to the Maher chassis depot for the appointment scenarios were that
the lane restrictions were expanded to include appointment trucks.

Accommodating appointment trucks at the PNCT required extensive to both the physical
and behavioral patterns used to create the CPO and extended gate scenarios.

The reason that creating appointment lanes was so difficult at the PNCT stemmed from
the fact that there are a limited number of lanes available at the terminal and that the geometry of
the terminal creates difficulties for drayage trucks attempting to perform lane changes. Several
simulation runs were needed in order to get appointment scenarios to function at the PNCT.

Figure 22 highlights the changes made to lane restrictions at the PNCT for the appointment scenarios.

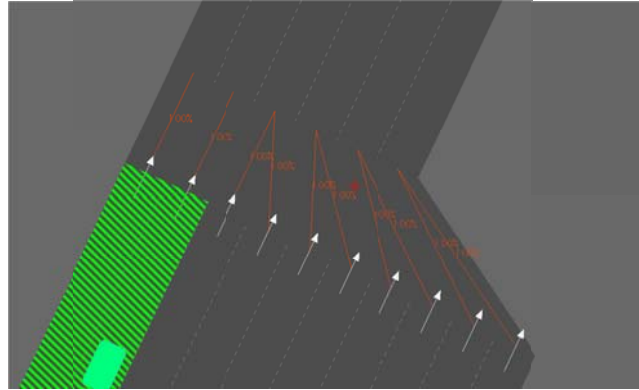**FIGURE 22 PNCT, APPOINTMENT SCENARIOS**

The first change was the addition of a lane restriction in the section labeled Approach in Figure 22 (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 congestion between the Approach and the Entrance Expansion, which was caused by drayage trucks' inability to switch lanes in the constrictive geometry of the area.

In the section labeled Entrance Expansion in Figure 22, lane 1 was restricted to chassis and bobtail trucks. This restriction was moved to lane 2 (yellow-hatched lane, Figure 22) and the lane restriction in lane 1 was altered to accommodate appointment trucks (white-hatched lane). 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 made to the nextlane rules at the Entrance Expansion involved removing the rule which distributed demand exiting from lane 2. This allowed chassis and bobtail trucks without appointments exiting from lane 2 of the Entrance Expansion access to both restricted and unrestricted lanes at the Entrance Gate.

In the area labeled Entrance Gate in Figure 22, 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 22) and lane 2 was used for chassis and bobtail trucks with appointments (brown-hatched lane, Figure 22). Lanes 3 and 4 were used for chassis and bobtail trucks entering the terminal without appointments (yellow-hatched lanes, Figure 22). The remaining lanes had unrestricted access and were primarily used by container trucks without appointments.

Excessive congestion at the exit gates of the PNCT in early runs of the appointment scenarios was addressed. In the area labeled Lane Reduction at Exit Gate, vehicle behavior was

adjusted by restricting access to lanes 1 and 2 to container trucks without an appointment (green-hatched lanes, Figure 22). Behavior in this area was further modified through the addition of nextlane rules, which were applied between the links in which the lane reduction occurs. Nextlane rules were used to keep container trucks in lanes 1 and 2 in their respective lanes, lanes 3 and 4 were forced 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 applied to the lane reduction are illustrated in Figure 23.


FIGURE 23 NEXTLANE RULES FOR PNCT LANE REDUCTION, EXIT GATES

For the appointment scenarios, lane restrictions at the Exit Gate & Approach were expanded to include links that led to the queuing area. Lane 1 was restricted to chassis and bobtail trucks without an appointment (yellow-hatched lane, Figure 24) and lane 2 was restricted to trucks with an appointment (white-hatched lane, Figure 24). Lane restrictions were extended to reduce weaving that occurred in this area during early runs of the simulation. Extension of lane restrictions and the area of application for lane choice rules at the PNCT exit gates are shown in Figure 24.

Lane choice rules at the PNCT exit were adjusted so that all chassis trucks utilized lane 1 and that container trucks without appointments were evenly distributed between lanes 3, 4, and 5. Trucks with appointments and chassis trucks were not governed by nextlane logic in the appointment scenarios to allow them access to all lanes. The length of the approach allowed these unrestricted drayage trucks time to maneuver to lanes with smaller queues. Another reason for limiting the number of lane restrictions was that the limited number of lanes available at the PNCT exit gates made it difficult for queues to form properly when additional restrictions were placed on the lanes.

Creating appointment scenarios proved to be a difficult task, as both physical and behavioral adjustments were necessary to create the scenarios. Additional lane restrictions added complexity to vehicle movements at the entrances and exits, which proved especially troublesome at the PNCT, where space was limited due to 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 terminals, as differences play a large role in the effectiveness of gate strategies at individual terminals.
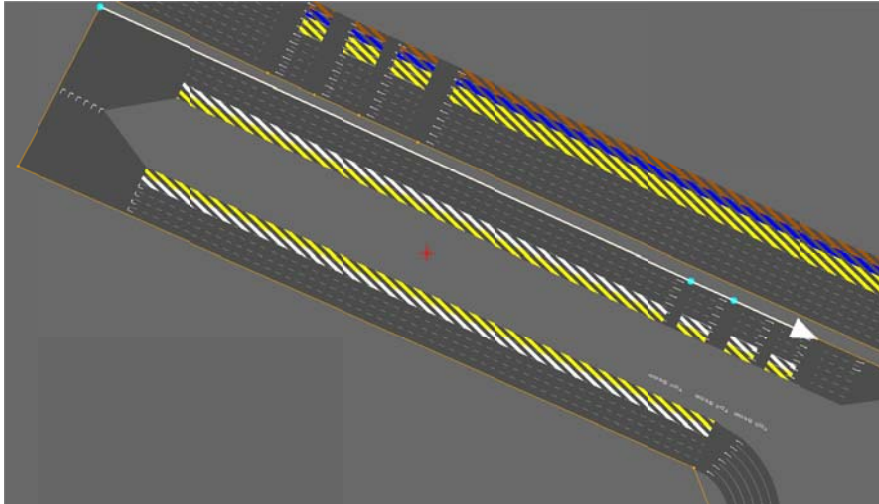
**FIGURE 24 EXIT LANE RESTRICTIONS AT THE PNCT, APPOINTMENT
SCENARIOS**

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, in-gate processing typically includes verifying driver's identity, determining the availability of a specific 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 are stem solely from the verifying that the correct container was 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 employees in booths. At two-stage entrance gates, drivers complete a portion of their 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. Future research should include the expansion of these scenarios to include two-stage gate configurations.

In-gate processing delays were simulated using Paramics' tolling feature. The tolling feature allows the simulation to delay vehicles on specific lanes over a specified range of time. Toll delays within Paramics are limited to a discrete uniform distribution split evenly between integers which must fall within a range with a lower bound of 0 seconds and an upper bound of 200 seconds. Delays at terminal gates were assumed to follow a normal distribution; therefore it was necessary to model each terminal gate using a series of three tolls where, according to the central limit theorem, summation of uniformly distributed delays would approximate 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 (or any combination of drayage vehicles which included 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 with a range from 40 to 140 seconds.

Entrance gates that serviced chassis trucks (or combinations which included chassis 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. For chassis trucks destined to the Maher terminal, delays were split between the chassis depot and the terminal. Therefore, the delay at the terminal and the chassis depot for this vehicle type was simulated with a toll that had a range between 10 and 35 seconds. Summation of delays from the chassis depot and the terminal equaled the assumed delay of 2.25 minutes for chassis trucks. This adjustment was made because it was assumed that in-gate processing which occurred at the chassis depot entrance gate would not be repeated when the drayage truck arrived 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. All exit gate delays were estimated to be half of the delay for the corresponding vehicle type at an entrance gate. This reduction was based on the fact that in-gate processing delays at exit gates are known to be simpler than delays at entrance gates.

In addition to in-gate processing delays terminal gates, the model was built to capture delay resulting from trucks showing up before terminal gates open. This phenomenon was modeled through the creation of periodic link files, which allowed links to be configured separately for each period of the simulation (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 drayage trucks into the simulation). This produced queues during the first hour of the simulation which represented drayage trucks showing up and idling as they waited for the gates to open. The periodic files were removed from the flat demand scenario, as this scenario is meant to represent the best case scenario.

Simulating entrance and exit gates using the Paramics tolling feature allowed the model to capture changes that occurred due to the application of various gate strategies. The simulation captured queues that formed due to trucks arriving prior to the opening of terminal gates as well as queues that formed due to peaks in demand. Accurately representing terminal gate transactions was the key component of this model's ability to assess the effectiveness of terminal gate strategies.

3.5 OD development

Upon establishing the physical aspects of the model, it was necessary to determine where the vehicles within the simulation would be coming from and where they would be destined to. The detailed data made available through the work of Dougherty (8) and Spasovic (9) was used to create the base OD of the PNE. The following is a list detailing the data used to create the base OD for the model:
- Hourly demand of the PNE broken into entering and exiting vehicles.
- Demand at the PNE entrances during peak hours (peak hours were given as 7:00-8:00 AM, 12:00-1:00 PM, and 3:00-4:00 PM), separated by whether the vehicles were entering or exiting as well as by vehicle type.
- Peak hour demands for terminals within the PNE.
- Peak hour turn counts for intersections within the PNE.

This data was used as to create a set of origins and destinations that would cover the 24-hour period of the simulation. An algorithm was written using MATLAB 7.7.0 (R2008b) (27) to automate the OD 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.

Four scenarios were developed for evaluation: the current pattern of operation (CPO), extended hour, appointment, and flat demand scenarios. The CPO scenario was used to represent current gate operations at the PNE. The extended hour scenario is meant to represent the demand shift that would due to both longer operational periods at terminal gates and the application of fees to peak-hour drayage movements. In the appointment scenario, a specific number of lanes were converted from their function in the CPO scenario to appointment lanes. Changes in the gate operations of the appointment scenarios effected both demand patterns and length of delay at terminal gates. The final scenario was the flat demand scenario, which represents a hypothetical demand pattern for which all drayage truck demand was spread evenly over a 24-hour period. This scenario represents the best-case scenario for the terminals and was used to measure the effectiveness of the gate strategies.

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. Hourly demand (D_h) of the PNE was known, so the first step of the algorithm was to separate hourly demand by vehicle type (v). 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 hours between the opening of the terminals and the AM peak period (6:00 AM-8:00 AM) would be the same as the values given for the AM peak hour.
- 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 25.
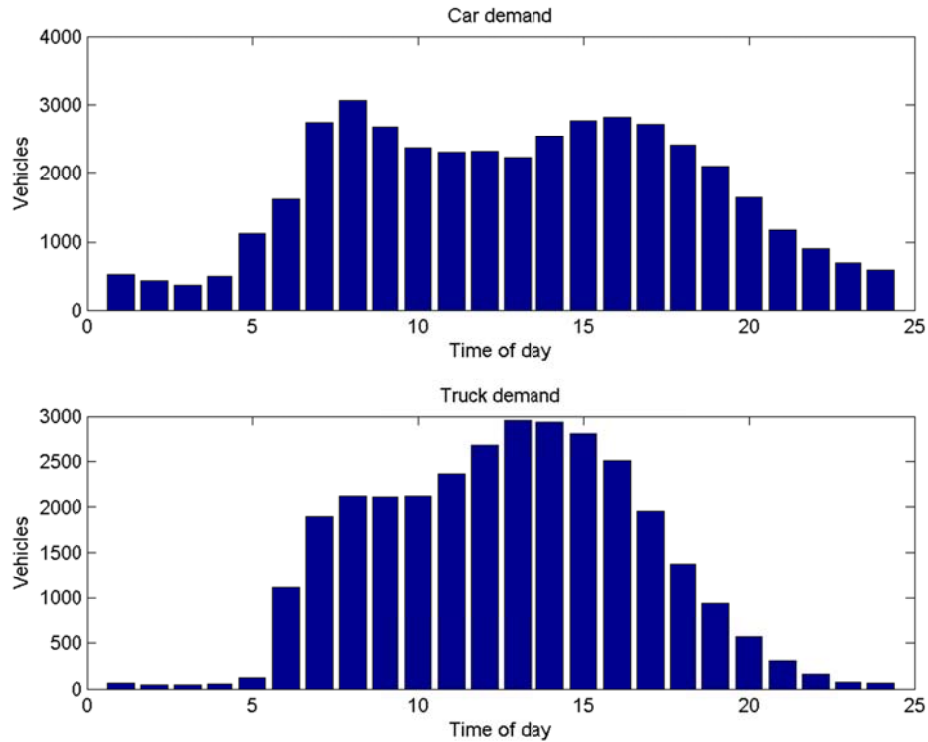
**FIGURE 25 DISTRIBUTION OF VEHICLES BY TYPE OVER 24-HOUR PERIOD**

The next step of the algorithm distributed hourly demand to the simulation zones by 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).
- From 6:00-8:00 AM, AM peak values were used for 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 operating 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 26 shows the truck demand over a 24-hour period for each terminal.

Once the 24-hour demand for each vehicle type was determined, the algorithm developed the OD matrices for the PNE. Each OD represented a different vehicle type. A total of eight OD matrices were used to create the simulation, with ODs representing passenger cars, "other" trucks,

container trucks, chassis trucks, bobtail trucks, container trucks with appointments, chassis trucks with appointments, and bobtail trucks with appointments.
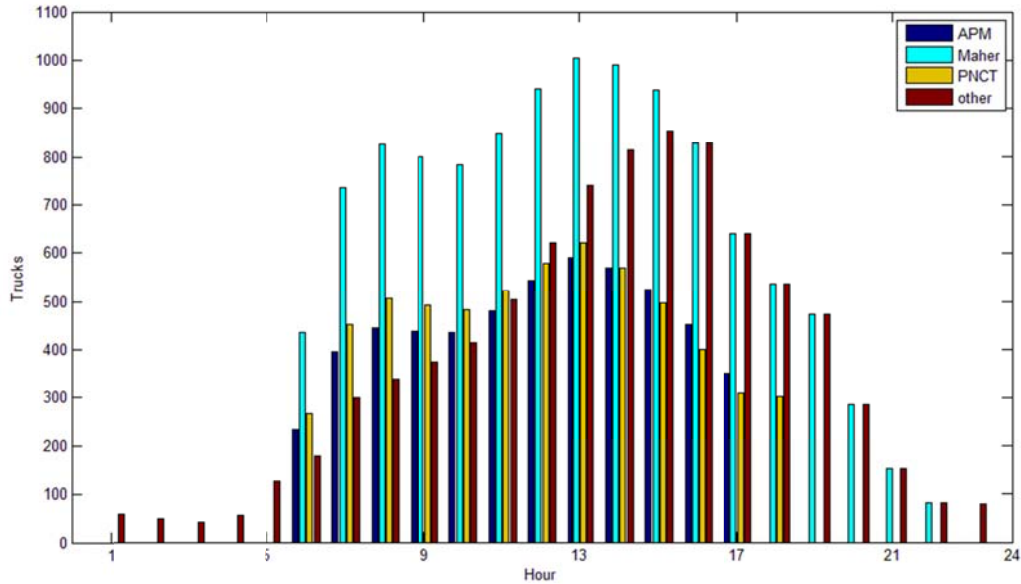
FIGURE 26 TRUCK DEMAND DISTRIBUTION OVER 24-HOUR PERIOD

To create the passenger car OD, 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 the hourly percentage of vehicles that entered and exited the PNE. The final variable used to create the passenger car OD was created to correct congestion at signaled intersections of the PNE. It was determined through visual observations of early simulation runs 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. The variable (OP_{zp}) was created to 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.

$$D_{vjh} * E_{jp} * X_h \tag{1}$$
$$D_{vjh} * E_{jp} * X_h * OP_{zp} \tag{2}$$

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 by the same percentages as drayage trucks), as demand patterns for these vehicles were assumed to be unaffected by the introduction of gate strategies at IMCTs.

The next set of ODs created by the algorithm represented drayage trucks. Hourly demand for each terminal (D_{vjh}) had been determined in previous steps of the algorithm. 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 that were 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

Entrance/Exit	Container Trucks			Trucks w/ Chassis			Bobtail Trucks		
	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									
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 for each OD combination, separated by vehicle type and terminal. It was assumed that most trucks would use a route which 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:

$$D_{vjh} * T_v * DP_{je} * 0.65 \qquad (3)$$

It was necessary to reduce demand in the truck ODs using a constant because the use of strategic waypoint zones had eliminated demand which originated from the terminals in the given traffic counts. Initially, the constant was set at 0.50 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. Had this constant not been used in the drayage truck OD calculations, the algorithm would have doubled total demand for the terminals using the given data because the traffic counts included both trucks arriving at and departing from terminals.
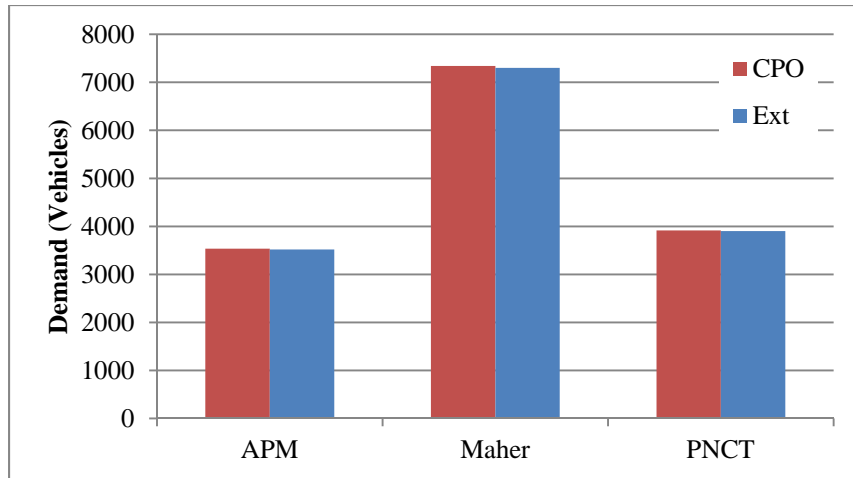
3.5.2 Extended hours OD

Once the CPO OD was developed, the next step was to create a set of extended hour scenario ODs. As mentioned earlier, the only changes that would occur in the creation of an extended hour scenario would be made to drayage trucks. The goal of extending terminal gate hours is to divert a percentage of demand from peak hours to off-peak hours. The most effect extended gate implementation (10) used a fee to encourage movements to occur during off-peak hours. The use of such fees created a second, smaller peak in demand which occurred the first hour during which the fees were not assessed. This second peak occurs from 6:00 PM to 7:00 PM and simulates drayage operators attempting to avoid peak hour fees. The hourly distribution pattern used to simulate the extended hour scenario is shown in Figure 27.
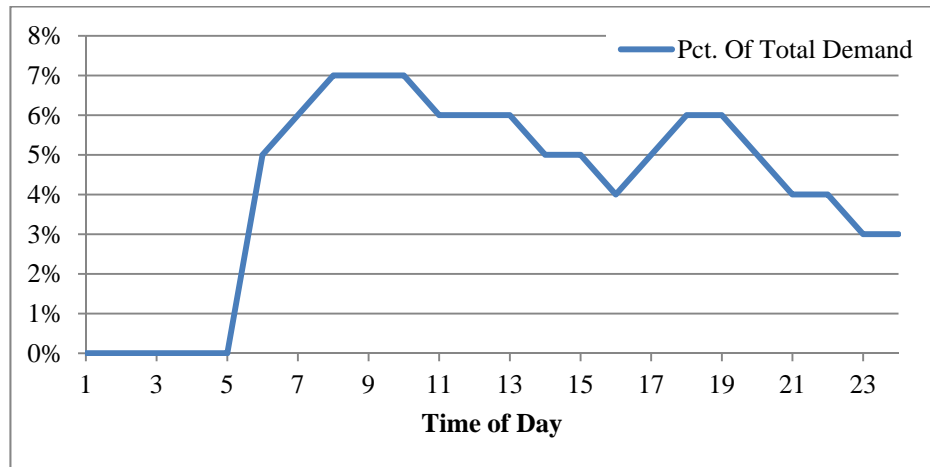
FIGURE 27 DEMAND DISTRIBUTION FOR EXTENDED HOURS SCENARIO

Extended gate hour ODs were created by multiplying the 24-hour value of each terminal's demand from the CPO OD to the hourly distribution percentages shown in Figure 27. The 24-hour demand for each terminal had to remain the same to ensure that the simulation was measuring changes due to gate strategies and not changes due to demand. Figure 28 compares total demand from the CPO scenario to total demand from the extended gate hour scenario for each terminal. The comparison in demand between the CPO scenario and the extended hour scenario shows that total demand for each terminal was held constant, therefore any difference in delays, travel times, or emissions were result of the application of extended gate hours and did not occur as a result of a change in demand.

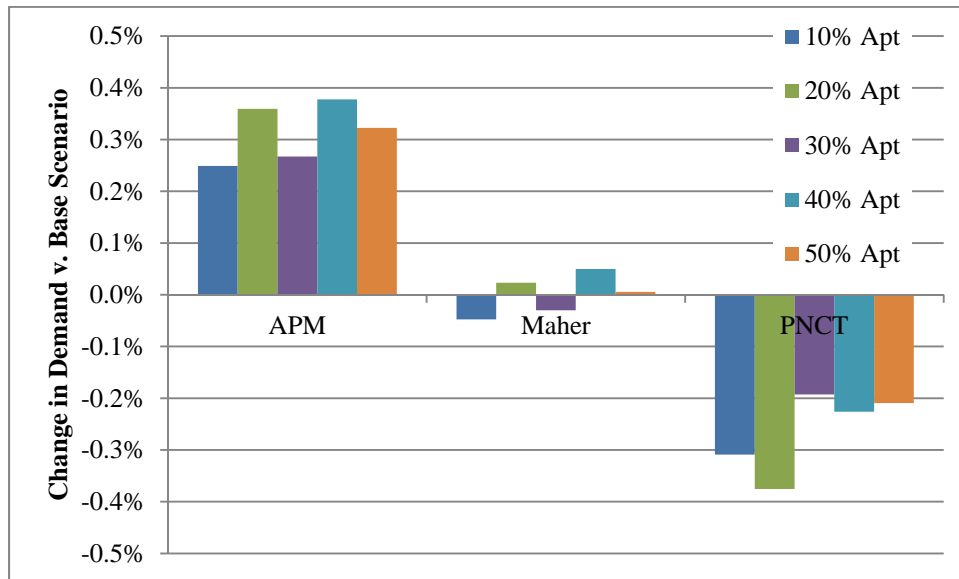**FIGURE 28 DEMAND COMPARISON: CPO AND EXTENDED HOUR SCENARIOS**

3.5.3 Appointment scenario ODs

The next step of the algorithm was to create a series of ODs which would represent various demand combinations between appointment and non-appointment trucks for the appointment scenarios. A total of 5 ODs 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-to-unscheduled drayage movements. The appointment scenarios ranged from a minimum of 10% to a maximum of 50% of terminal demand utilizing appointment lanes, with the remainder of the demand assigned as non-appointment drayage movements.

The algorithm created appointment scenario ODs 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). 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. The total demand for each terminal in the appointment scenarios is compared to total demand for each terminal in the CPO scenario in Figure 29.

Figure 29 shows that demand was held relatively constant over each appointment scenario. The slight difference in demand between the scenarios stems from rounding in the algorithm (as demand must be expressed as integers in OD matrices) and was held to less than 0.4% for each of the scenarios. As demand was held constant, any changes in travel times, delay, and emissions between the CPO scenario and the appointment scenario would be a result of the implementation of the appointment scenario and not occur because of a change in demand.

Five ODs were created for the appointment scenarios to determine which proportion of appointment trucks to non-appointment trucks would best utilize the number of appointment and non-appointment lanes established during the creation of the model. The five appointment scenarios were only tested using base demand, as it was assumed that increasing demand in future scenarios would only exacerbate over- and under-utilization of lanes. The evaluation of different appointment demand combinations will be discussed in Section 4.1.

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FIGURE 29 DEMAND COMPARISON: CPO AND APPOINTMENT SCENARIOS

3.6 Modeling emissions

Emissions calculations for the PNE included all vehicle types. Three different emissions models were considered for estimating the emissions generated by drayage operations at the port; 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 CMEM model (28) was based on data which was collected from a set of vehicles that was meant to represent a typical traffic stream. The CMEM model included 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, where 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 by the user 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 GUI capabilities, thereby removing the capability of the user to adjust the reporting interval of CMEM. Ultimately, CMEM was not used to estimate 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.

MOVES 2010a, which was developed by the U.S. Environmental Protection Agency (29), was also assessed as a possible method for estimating emissions of the PNE. After analyzing MOVES, there were two reasons it was not used for emissions estimations. The first reason was that MOVES did not directly interact with output from Paramics. Calculations obtained from MOVES are 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 that MOVES was not used involved scale. MOVES is not meant to be adjusted to a microscopic level, as project level data in MOVES scales links in miles. This presented a problem when attempting to integrate MOVES to the simulation of the PNE because none of the links in the Paramics model were over 1 mile long. In fact, most were segments of 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, therefore an emissions estimation that could be done in the same scale was preferred over one in which the scale would have to be changed.

The final emissions estimation 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 (24). 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 estimate emissions of the PNE.

4. RESULTS

As described in previous sections, the PNE simulation was comprised of four scenarios; a CPO scenario which represented gate operations in their current operational state, an extended hour scenario where terminal gate operating hours were extended to 12:00 AM, an appointment scenario where a percentage of the drayage truck demand was converted to appointment trucks, and a flat demand scenario which represented a best-case where drayage truck demand would be spread evenly over a 24-hour period. Each scenario was evaluated by total delay, hourly delay, delay at the gates, travel times within the terminals, and emissions generated. Delay was measured by subtracting free flow travel time from the actual travel time of a vehicle (24) and was recorded as average seconds of delay per vehicle. The results shown were taken from the average of 15 iterations of each scenario. A separate evaluation was conducted for the appointment scenarios to determine which of the five demand combinations would yield the best results for a specific set of gate configurations. Details of the appointment scenario evaluation are described in Section 4.1.

4.1 Appointment scenario evaluations

A number of different gate configurations (number of appointment VS non-appointment entrance/exit lanes) could have been used to represent the appointment scenario at the PNE. The gate configuration selected for our model 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%. Hourly delays for drayage trucks for each appointment OD combination are shown in Figure 30.
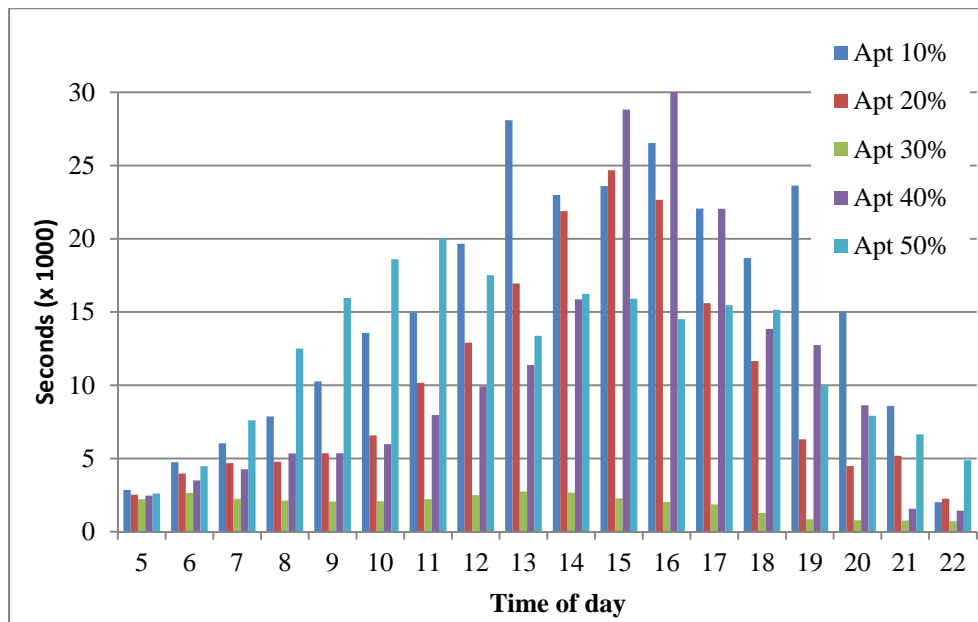
FIGURE 30 HOURLY DELAYS FOR APPOINTMENT SCENARIOS

Figure 30 shows that hourly delays varied between appointment scenarios. In appointment scenarios where 10% and 20% of drayage truck 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 was the result of 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, 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.

Conversely, appointment scenarios for which 40% and 50% of drayage truck 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. The overall increase in delays for the higher demand combinations was lower because congestion was occurring on appointment lanes where in-gate processing delays were reduced.

Each scenario was also evaluated by delays at terminal entrance gates. Figure 31 shows APM entrance gate delays for the appointment scenarios. Under-utilization of appointment lanes in the 10% and 20% appointment scenarios results in the increased hourly delays for these scenarios. Delays at entrance gates remained fairly steady over the three remaining scenarios, which indicated proper lane utilization. An uptick in delay from 5:00 AM to 6:00 AM can be seen for each of the scenarios and is a result of trucks arriving before the terminal opens.
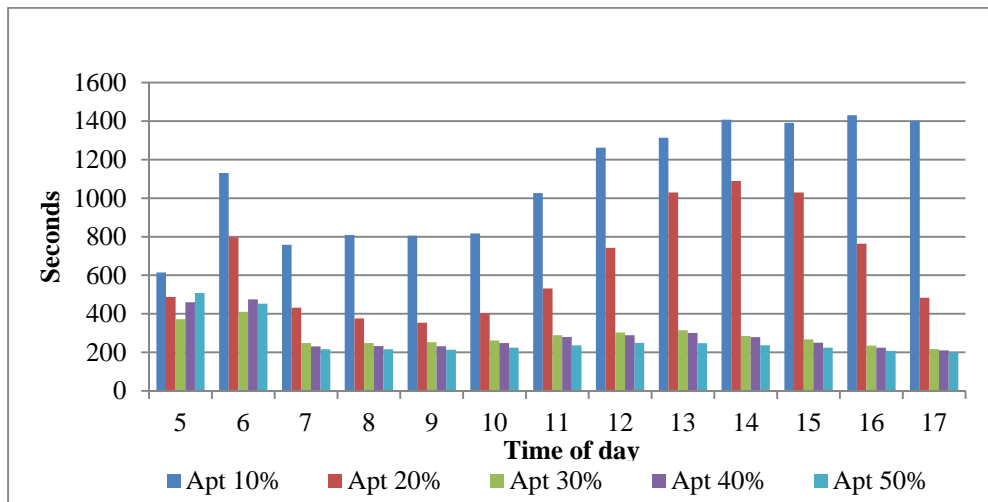
FIGURE 31 HOURLY DELAY FOR THE APM ENTRANCE GATE, APPOINTMENT SCENARIOS

Delays for links representing the entrance to the PNCT are shown in Figure 32. Delays at the PNCT entrance had the greatest impact on the rest of the simulation because the geometry of the terminal entrance made the PNCT susceptible to congestion problems due to slight shifts in demand patterns. Truck delays for vehicles entering the terminal in the 10% and 20% appointment scenarios remained consistently high from 9:00 AM until the terminal closed at 7:00 PM, which indicated that queues during these hours extended beyond the entrance and onto the PNE's main roadway network. The fact that much of the delay was occurring on the PNE's access road meant that they were not captured as delay for the entrance gate. Delay patterns for the 40% and 50% appointment scenarios showed a reduction in total delay. This reduction in stemmed from the fact that a greater amount of demand was shifted to appointment lanes with reduced delay at gates.
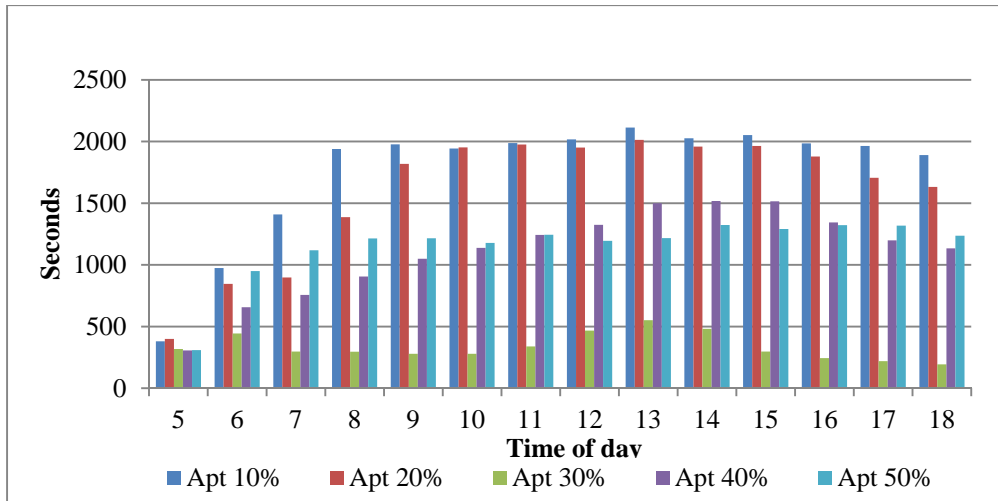
FIGURE 32 HOURLY DELAY FOR THE PNCT ENTRANCE GATE, APPOINTMENT SCENARIOS

Delays for vehicles at links leading up to and including the entrance gates at the Maher terminal are shown in Figure 33. Queues from the PNCT had an effect on delay patterns at the Maher terminal. The 10% and 20% appointment scenarios at the Maher terminal showed a reduction in delay between 12:00 PM and 6:00 PM. This reduction is counter-intuitive, as total delays for the PNE increase during these periods (Figure 29). Visual observation of the appointment scenario showed that delay reductions occurred at the Maher entrance because queues extending from the PNCT entrance reached the PNE's main access road during this period and restricted the number of trucks that could reach the Maher terminal during these hours.
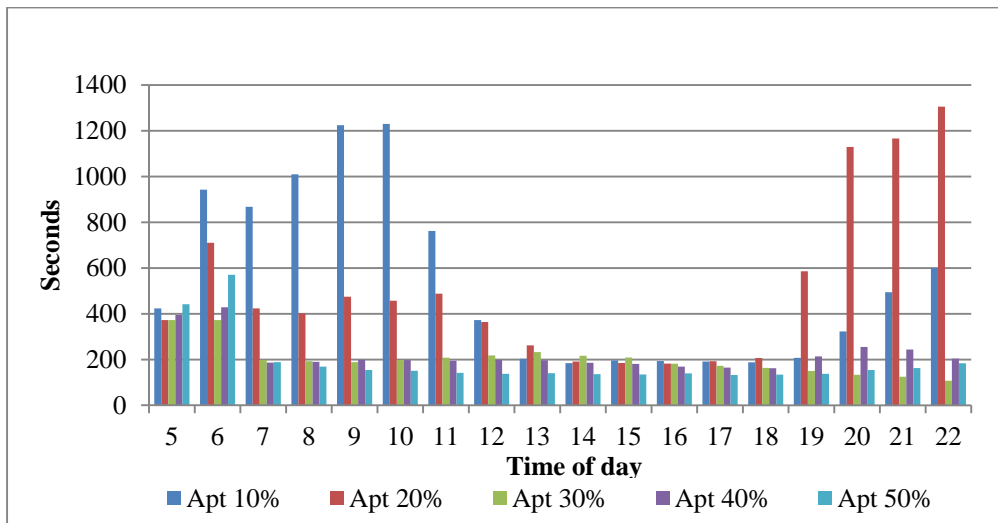
FIGURE 33 HOURLY DELAY FOR THE MAHER ENTRANCE GATE, APPOINTMENT SCENARIOS

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 proper lane utilization.

The goal of evaluating multiple appointment scenarios was to determine which scenario produced the greatest reduction in delays at the PNE. The 10% and 20% appointment scenarios were not selected because excessive queue lengths at the PNCT entrance in these scenarios had a negative impact on delays for 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 best results from the appointment scenarios occurred when 30% of the drayage truck demand was assigned to appointment trucks. This 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 the only scenario for which total delays were reduced when compared to the CPO scenario. In all subsequent gate strategy comparisons, the appointment scenario will refer to a scenario in which 30% of the drayage truck demand is appointment trucks and the remaining 70% of drayage truck demand is non-appointment trucks.

4.2 Comparison of gate strategies

The simulation of the PNE included three separate gate configurations: the current pattern of operation (CPO), extended hours of operation, and an appointment system. Each scenario had a base OD which was created using known data. Five future scenarios were developed in which base demand was increased by 10%, 20%, 30%, 40%, and 50%, respectively. Hourly delays for drayage trucks over the 24-hour period of the simulation are shown in Figure 34.

Figure 34 shows that under the CPO, increases in delay for the base demand OD 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 hourly delays being consistently lower than that of the CPO. Extending the gate hours had the effect of smoothing the delay pattern for all demand levels.

When demand was increased to 110%, truck delays for the CPO scenario doubled during the PM peak. Increases in truck delays under the appointment scenario appear to be correlated to the increase in demand. Minimal increases in delay occurred in the extended hour scenario. Increasing drayage truck demand to 120% of the base caused a significant increase in delays during the PM peak for both the CPO and the appointment scenarios. Delays for the extended hour scenario remained relatively constant over the operational period of the terminals.

Increasing demand by 30% caused further increases in delay for the CPO and the appointment scenarios. The increased delay for drayage trucks in the appointment scenario indicated that the appointment system did not reduce delays within the PNE enough to stave off congestion. The delay pattern for the CPO began to spread out, which indicated that congestion was starting to build prior to the PM peak and was taking longer to dissipate afterwards. The 30% increase in demand produced a slight uptick in delay in the extended gate hour scenario, but the overall delay pattern remained consistently low.

Increasing demand by 40% produced a large spike in delay for the CPO scenario. This indicated that the PNE was nearing capacity under current patterns of operation. Hourly delays in the appointment scenario began to spread out with the 40% increase in demand, indicating that congestion was beginning to occur prior to the PM peak. The extended hour scenario continued to display a relatively flat delay pattern.
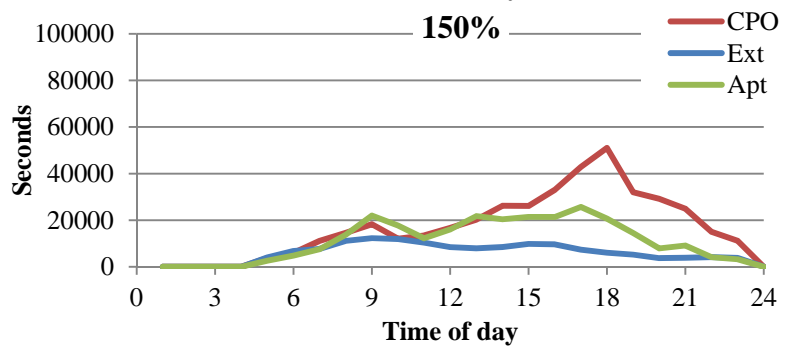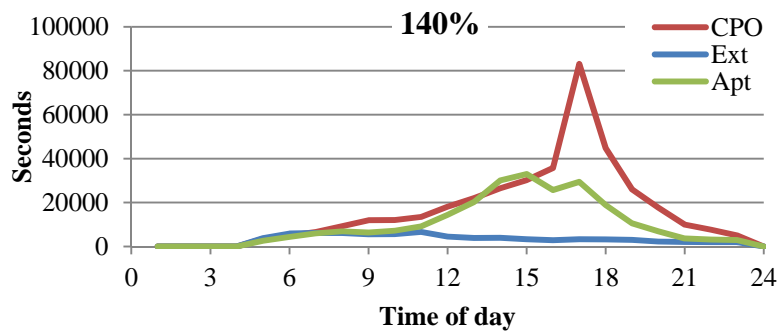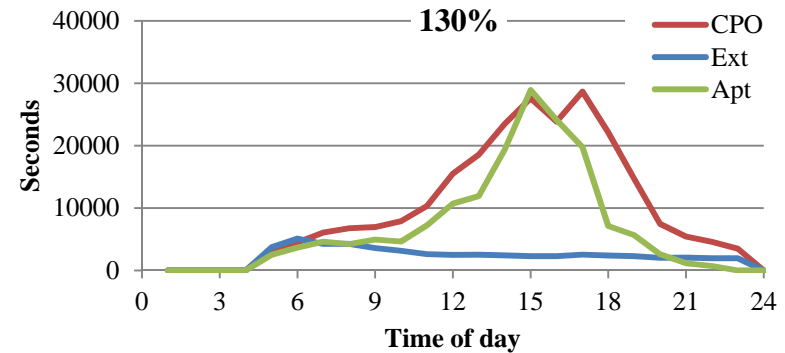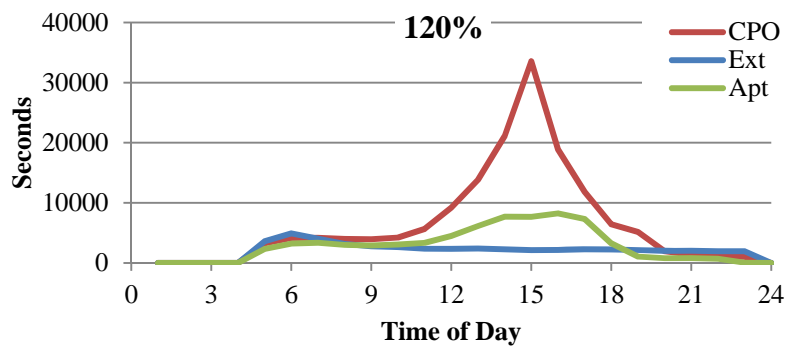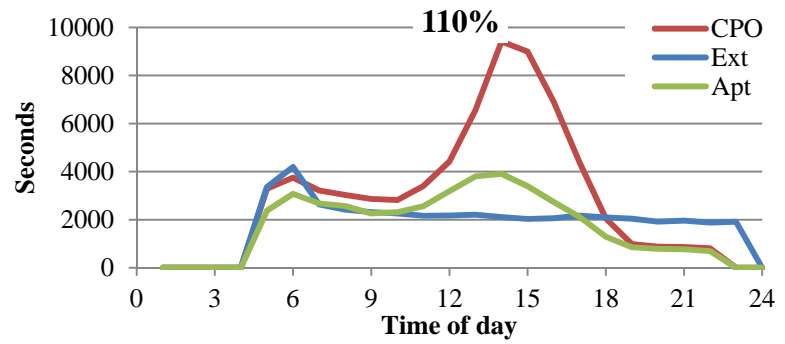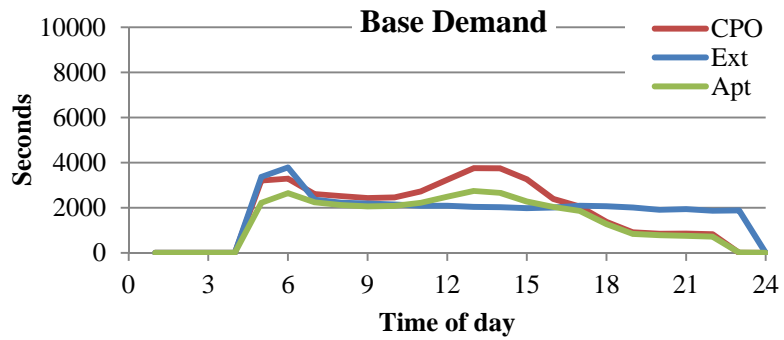
FIGURE 34 HOURLY DELAY

The final increase in demand was 50%. This increase caused both the CPO and appointment scenarios to experience large amounts of congestion over all operational hours of the terminals as well as a large shift of delays to periods extending beyond the original operating hours of the terminals. This indicates that these scenarios are not able to cope with a 50% increase in demand without large amounts of congestion. Delays for the extended hour scenario increased significantly at this level of demand as well. The flat delay pattern for the extended hour scenario indicates that the scenario may be able to accommodate larger increases in demand.

To get a larger picture of the effect that demand increases had on drayage operations, delay was measured over the 24-hour period for each demand level. Total delay was measured against the equivalent value from the CPO scenario. The results of this comparison are shown in Figure 35.

For the base OD, the appointment scenario outperformed the extended hour scenario. The appointment system was more effective at reducing total delay because congestion was minimal for the base OD, therefore the reduction of in-gate processing delays for appointment trucks had a greater impact than shifting demand. For the 10% increase in demand, both the extended gate hour and appointment scenarios reduced delays by approximately 40%.
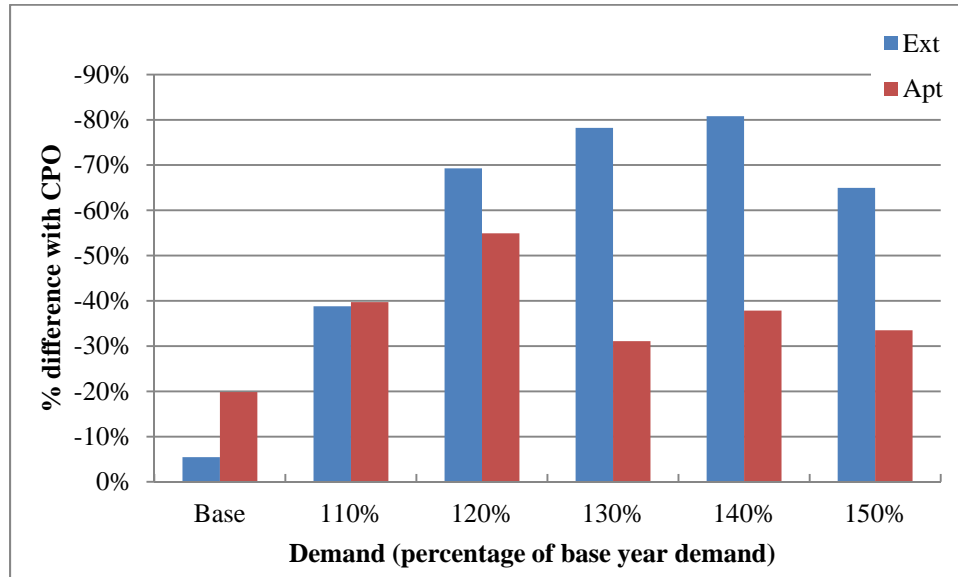
FIGURE 35 TOTAL DELAY

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, indicating that the appointment system was unable to control congestion at the PNE beyond these demand levels.

A key part of this research was to determine the effects of gate strategies on congestion. One of the goals of this research was to determine the delay for drayage vehicles from the time they enter the port to the time the exit. As stated earlier, many of the previous attempts to quantify gate strategy effectiveness lacked either representation of the roadway network or representation of the terminals. Figure 36 shows the percentage of hourly delay that occurred within the terminals.

The comparison of drayage truck delay within the terminal to drayage truck delay on the roadway network shown in Figure 36 shows how increases in demand effect the location where delays occur. For base demand, approximately 70% of the delay for drayage trucks occurs within the terminals. The percentage begins to drop after 5:00 PM when the APM terminal closes, as a larger percentage of delay for the Maher and PNCT terminals occurs on the roadway network due to their external chassis depots.

Figure 36 also illustrates how increases in demand effects congestion on the roadway network. As demand increases, the fluctuations in percentage become greater. The AM peak (where more passenger cars are on the roadway network) and the PM peak (large increase in truck demand) can be clearly seen in the CPO and appointment scenarios when demand in increased to 110%. When demand is increased by 20%, a large spike in delays on the roadway network occurs in the CPO scenario during the PM peak. A 30% increase in demand causes both the appointment and CPO scenarios to experience large percentages of delay on the roadway network. At 40% and 50% increases in demand, less than 50% of drayage truck delays in the gate strategy scenarios occur within the terminals. This data highlights the fact that gate strategies should not be implemented without consideration to the effect that demand increases will have on the roadway network, as well.

To determine the effect that gate strategies had on delay on individual terminals, a comparison of delay on links leading up to and including the entrance gates to the terminals was conducted. Results for the extended hour scenario are shown in Figure 37, which shows that delays at each terminal gate were steadily reduced up to a 30% increase in demand. The results varied when demand was increased by 40% and 50%. The APM terminal entrance gate showed continued improvement in delay reductions. AT the PNCT entrance gate, delays were lower than the CPO scenario but were increasing when compared to the base, 10%, 20%, and 30% demand scenarios. At the Maher terminal entrance, delays were actually larger for 40% and 50% demand increases. Observation of simulation runs where demand was increased by more than 30% and current pattern of operations were used for the terminal gate configurations showed that queues from the PNCT 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. The overall delay increased during peak hours due to queues on the roadway network in the CPO scenario, but delay at the Maher terminal gate was reduced as demand was unable to reach the gates during peak hours.

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.

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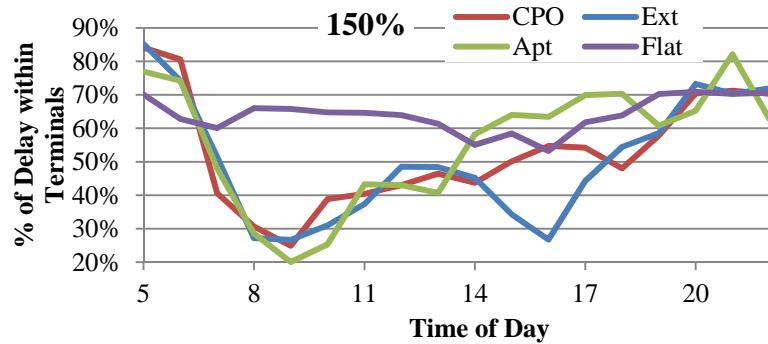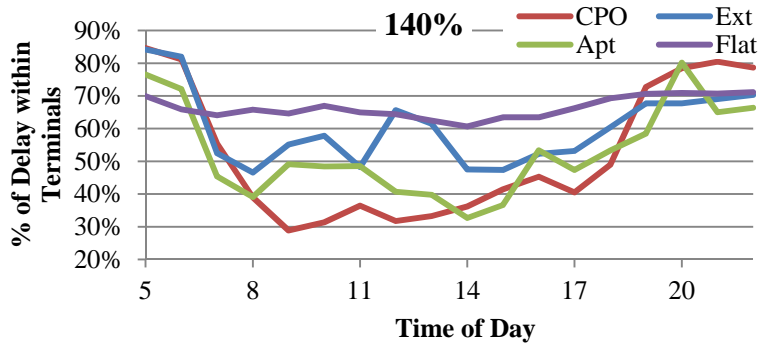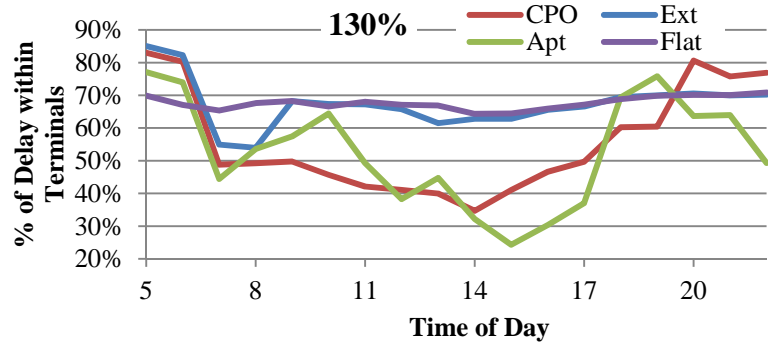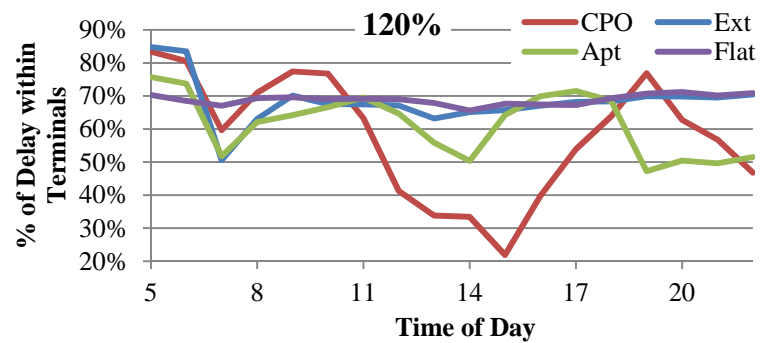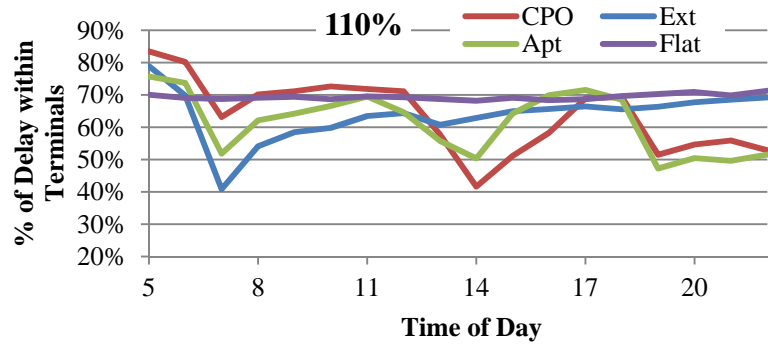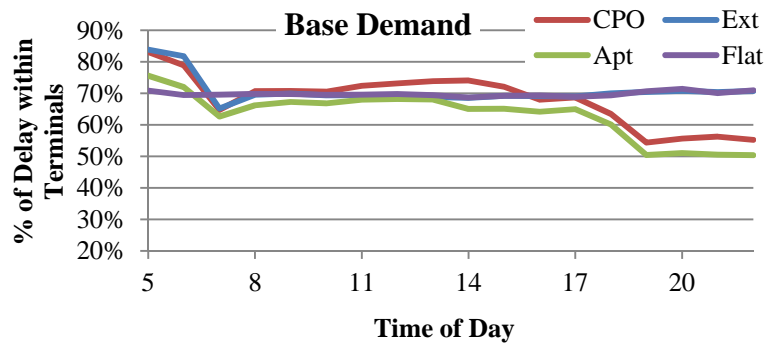
FIGURE 36 PERCENTAGE OF DELAYS OCCURRING WITHIN TERMINALS
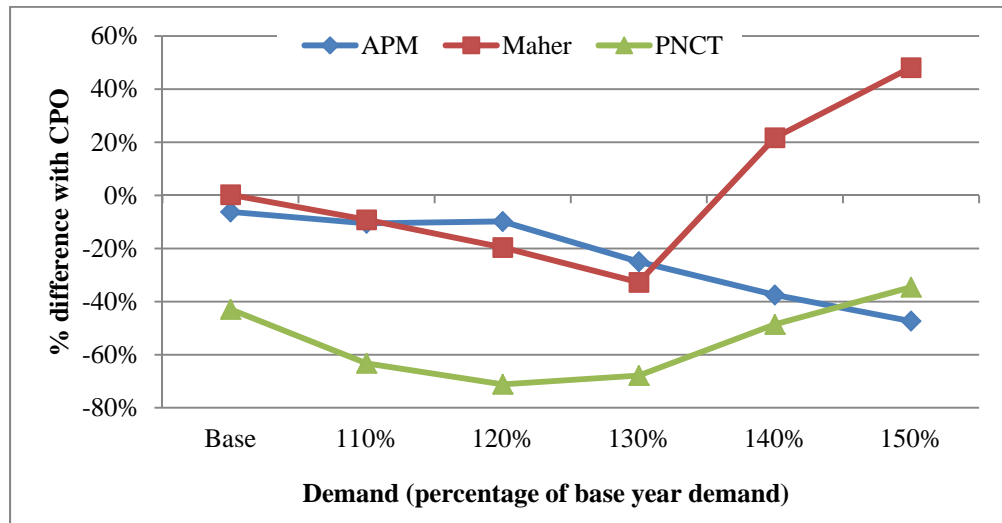
**FIGURE 37 DELAY AT ENTRANCE GATES, EXTENDED HOUR SCENARIO**

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 show that the appointment scenario was less effective for demand increases greater than 20%. Delays at the APM terminal entrance gate showed that the benefits of the appointment scenario decreased as demand increased.
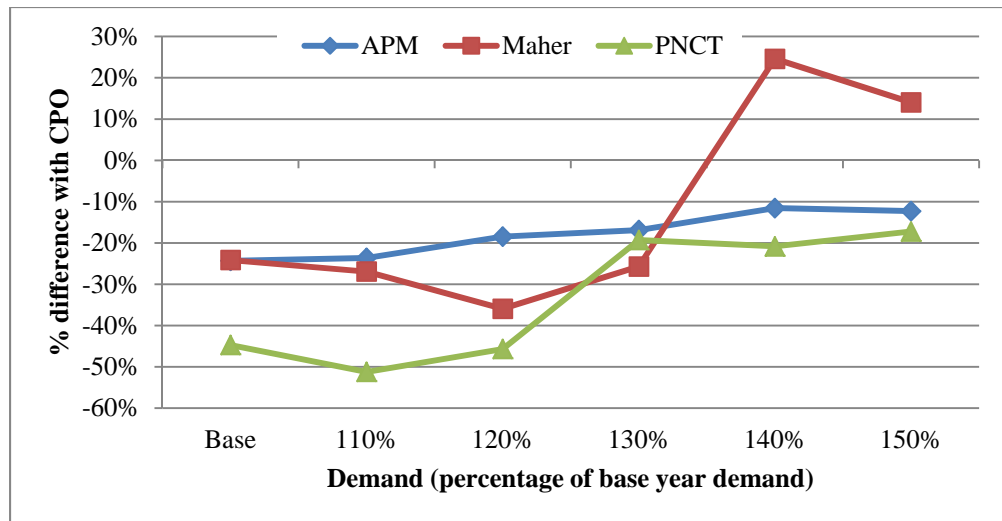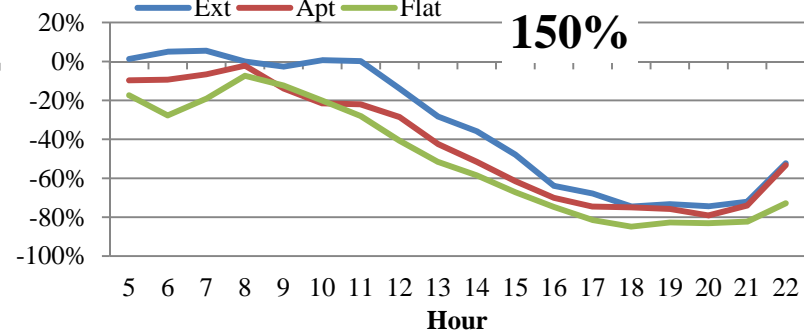

FIGURE 38 DELAY AT ENTRANCE GATES, APPOINTMENT SCENARIO
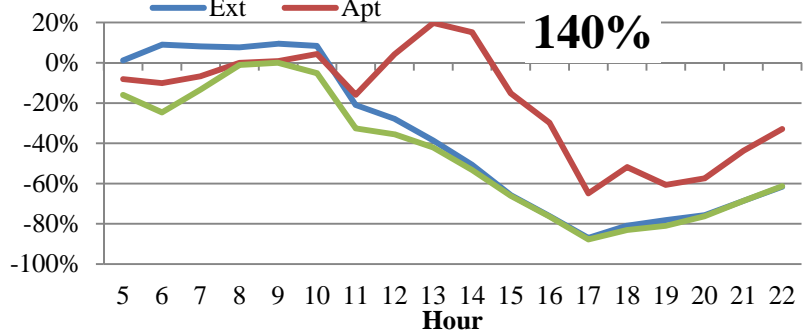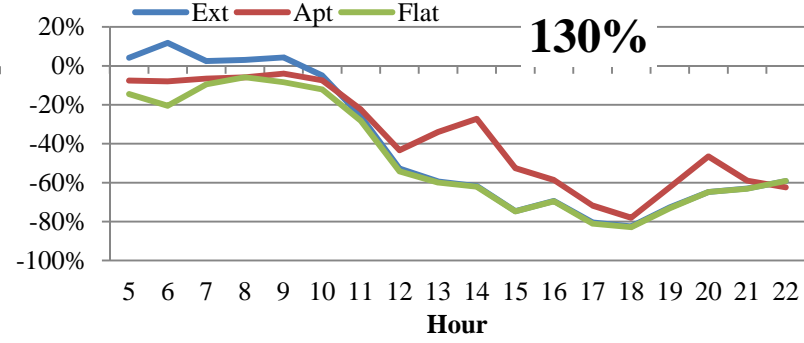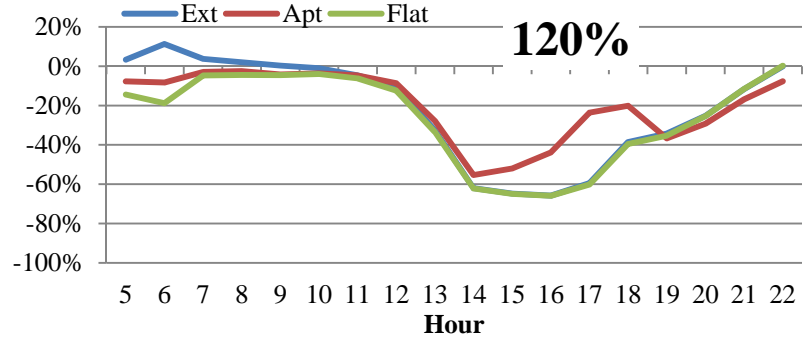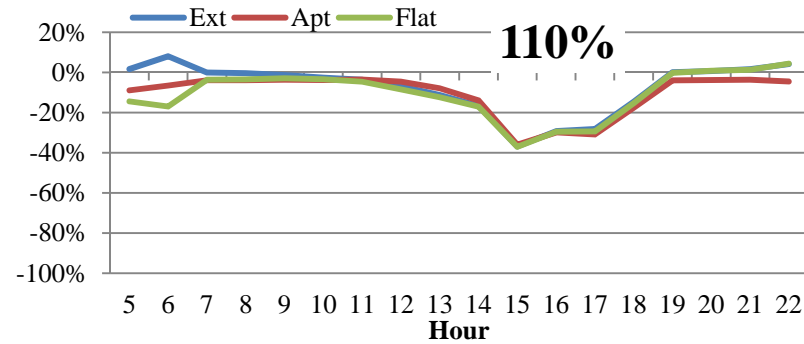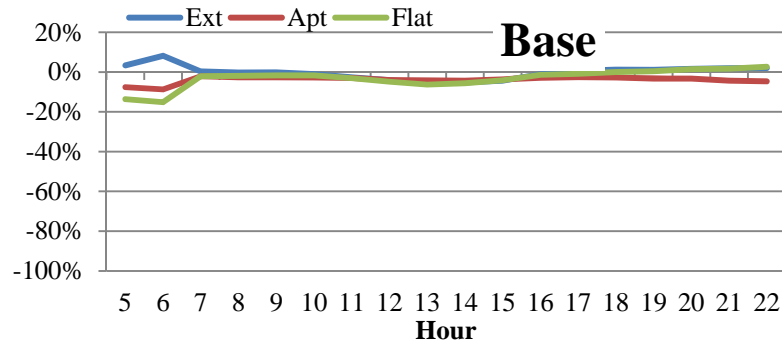
A direct comparison of travel time within the IMCTs is shown in Figures 39, 40, and 41. This comparison shows differences between terminal travel times in the gate strategy scenarios when compared to the CPO scenario.
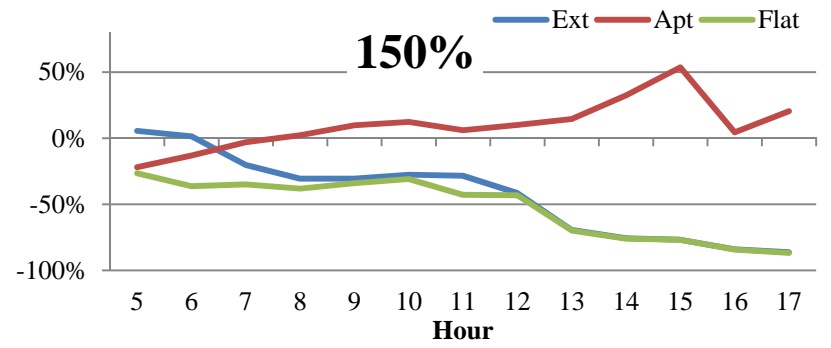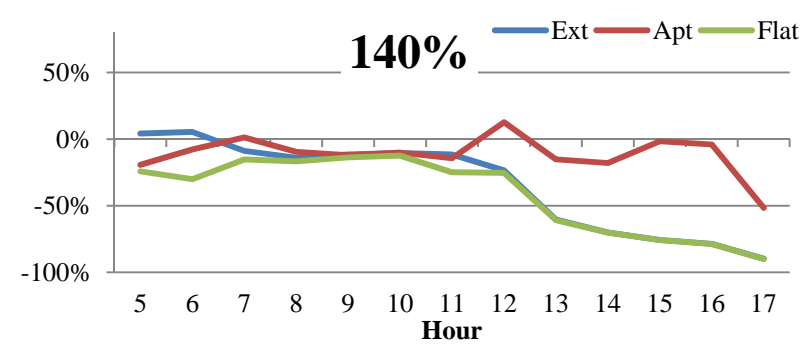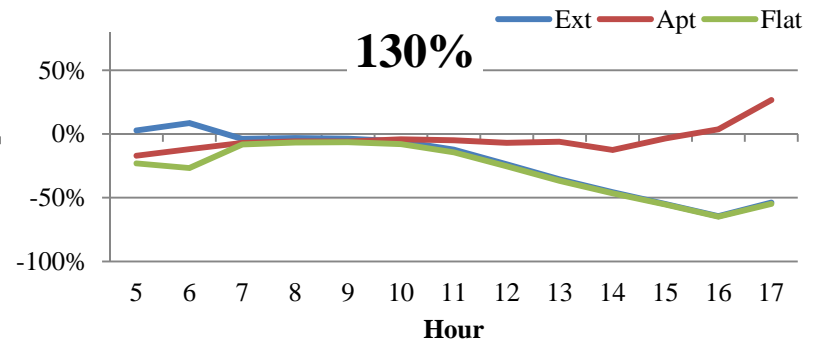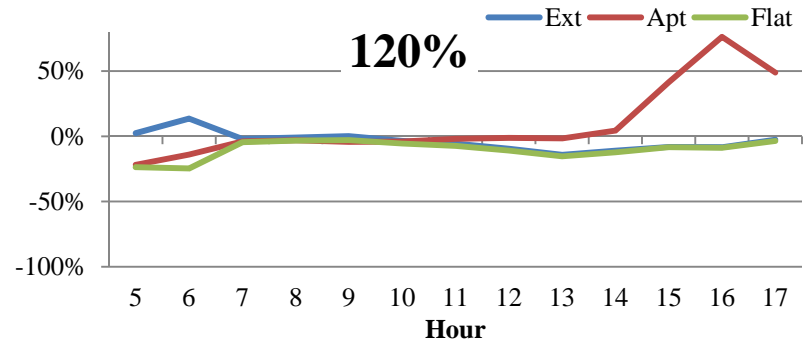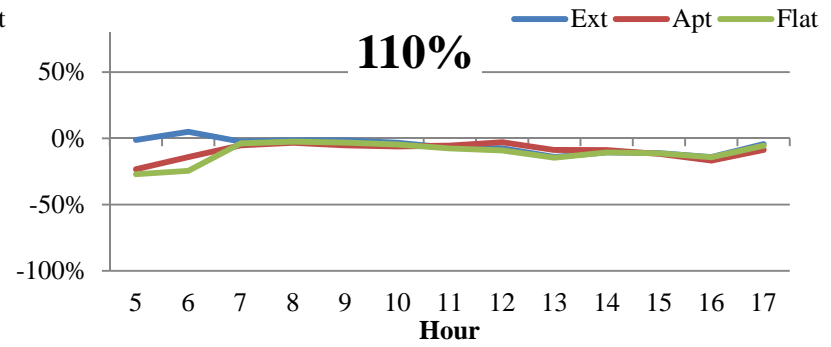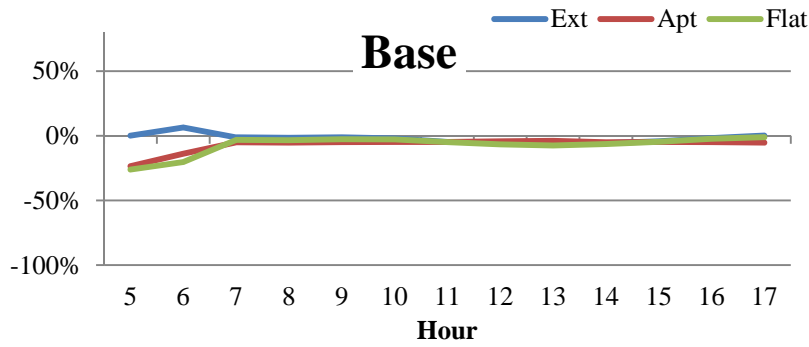
FIGURE 39 APM TRAVEL TIMES

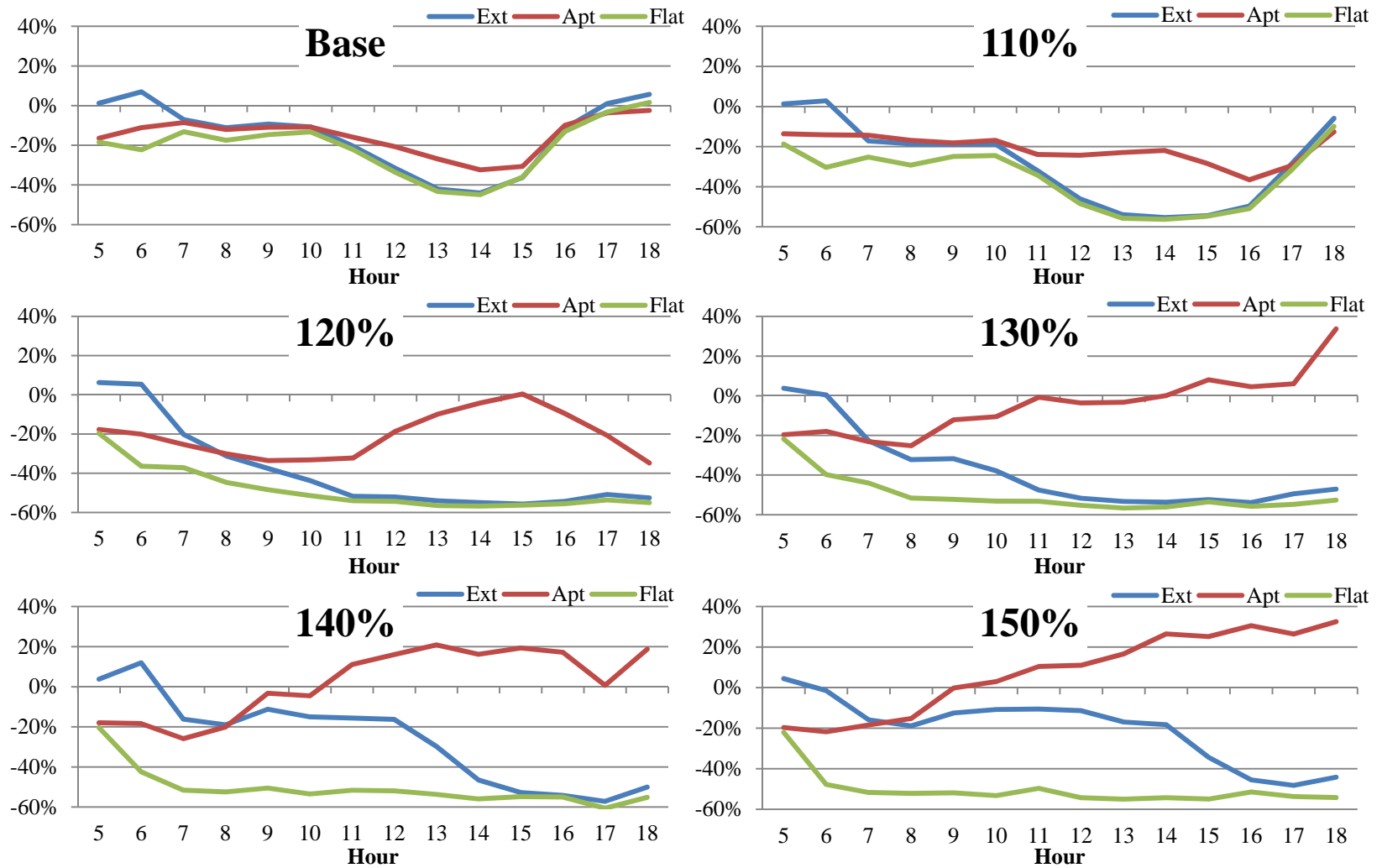**FIGURE 40 MAHER TRAVEL TIMES**

FIGURE 41 PNCT TRAVEL TIMES

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Travel times for the APM terminal are shown in Figure 39. For the base and 110% demand scenarios, travel times remain close to the values recorded in the CPO scenario. At demand increases greater than 20%, travel times in the appointment scenario became higher than the CPO scenario during the PM peak. The extended gate hour scenario continued to reduce travel times at the terminal in a manner consistent with that found in the results from the flat demand scenario until the demand level was increased by 40%.

Figure 40 shows the travel times recorded in the Maher terminal and chassis depot. The base and 110% demand show patterns similar to that of the APM terminal, where all three gate strategies show similar reductions compared to the CPO. The travel times for the extended hour scenario began to separate from the flat demand scenario in the AM peak, with the travel times increasing as demand increased. Travel times for the appointment scenario also began increasing when demand was raised by 20%, but the increase occurred during the midday and PM periods.

Travel times for the PNCT are shown in Figure 41. Fluctuation between the appointment scenario and the flat demand scenario began with the base OD. This sensitivity is a result of the difficulty of implementing an appointment system at the PNCT due to its geometry. When demand was increased by more than 30%, travel times for the appointment scenario were actually higher than that of the CPO scenario. The extended hour scenario also showed greater fluctuation in travel times at the PNCT. The travel times for the extended hours scenario start to separate from the flat demand travel times when demand is increased by 10%, with travel times getting further separated from the flat demand scenario as demand is increased.

The final 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 41.

The hourly emission patterns shown in Figure 41 resemble hourly delay patterns shown in Figure 34. 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.

The hourly emissions patterns shown in Figure 41 show that at the base demand level, the hourly emissions produced by the CPO, extended hour, and appointment scenarios are all relatively similar. As demand increases, the emissions produced by the extended hour scenario are significantly reduced when compared to the CPO and appointment scenarios.
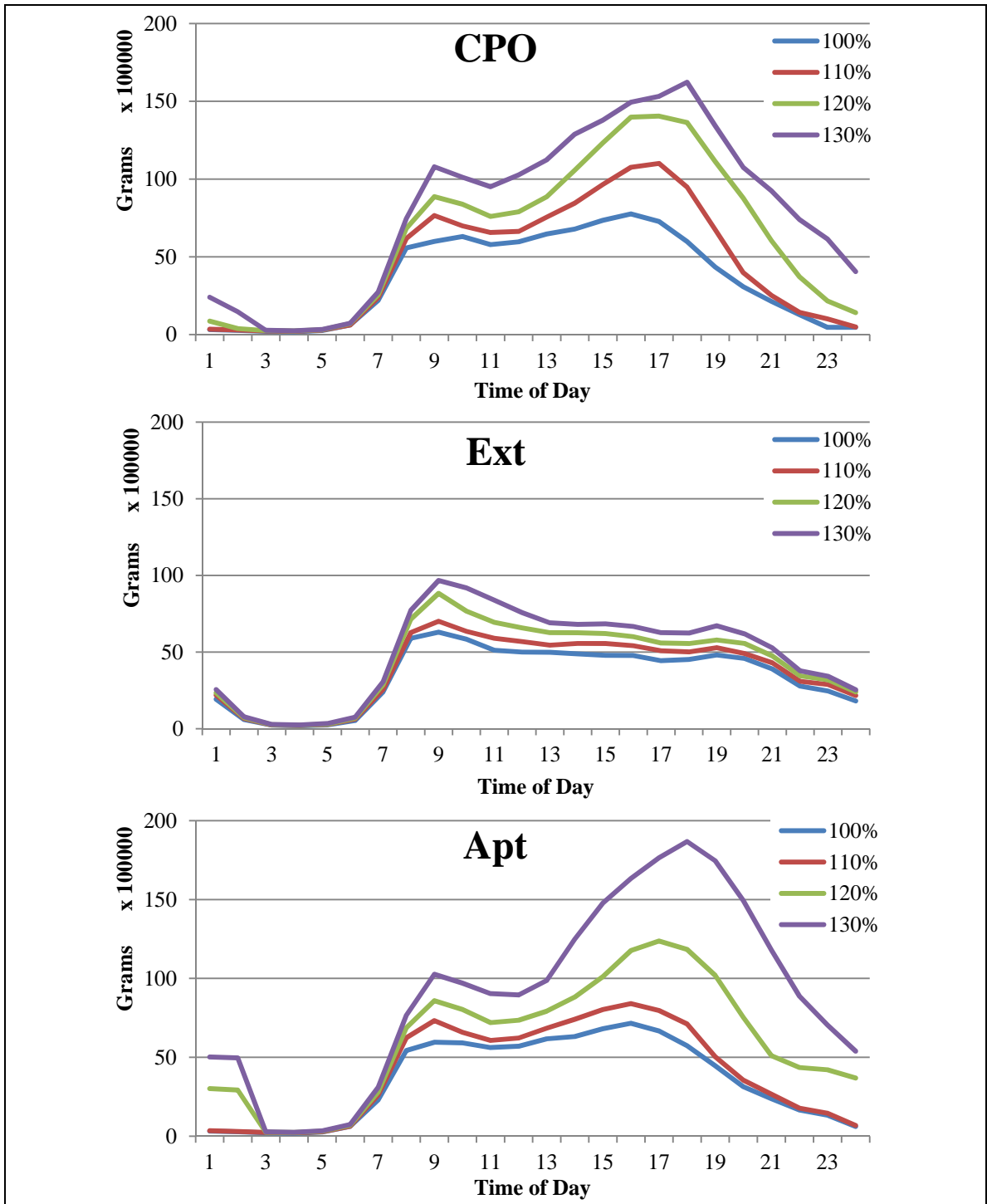
FIGURE 41 HOURLY CARBON MONOXIDE EMISSIONS

A 24-hour emission output for four levels of demand (i.e. base (100%), 110%, 120%, and 130%) was compared with the CPO scenario and is 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 which caused congestion within the port, the appointment system did not reduce emissions. In fact, converting lanes to "appointment only" appears to have a negative impact when 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 40% and 50% increases in demand were omitted from Table 8 because it was believed that the high levels of congestion in these scenarios prevented a significant percentage of vehicles from being released into the simulation, thereby distorting the emissions levels.

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 will best utilize the selected lane configuration. Failure to reach this balance will increase delays and emissions, rather than reduce them. In contrast, an extended gate hour program that successfully shifts demand will allow IMCTs to 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 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 these 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 on the landside coupled with capacity issues can degrade reliability and performance of the terminal. In addition to these issues, environmental effects stemming from idling trucks has further emerged as a serious problem, as truck emissions have been linked to negative 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, applying 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 gate strategies either through simulation modeling or through before-and-after case studies of terminals which have implemented gate strategies.

This research presents the development of a traffic simulation model capable of measuring the impact that gate strategies will have on the levels of congestion at IMCT terminal gates. The traffic model was used to quantify travel time, delay, and emission levels within the terminals 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 70% 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 (as well as emissions) was extending the terminal gate hours to divert 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 of the model, particularly data that details 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 emission levels. 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 the chassis depots due to drayage operators picking up or dropping off a chassis.

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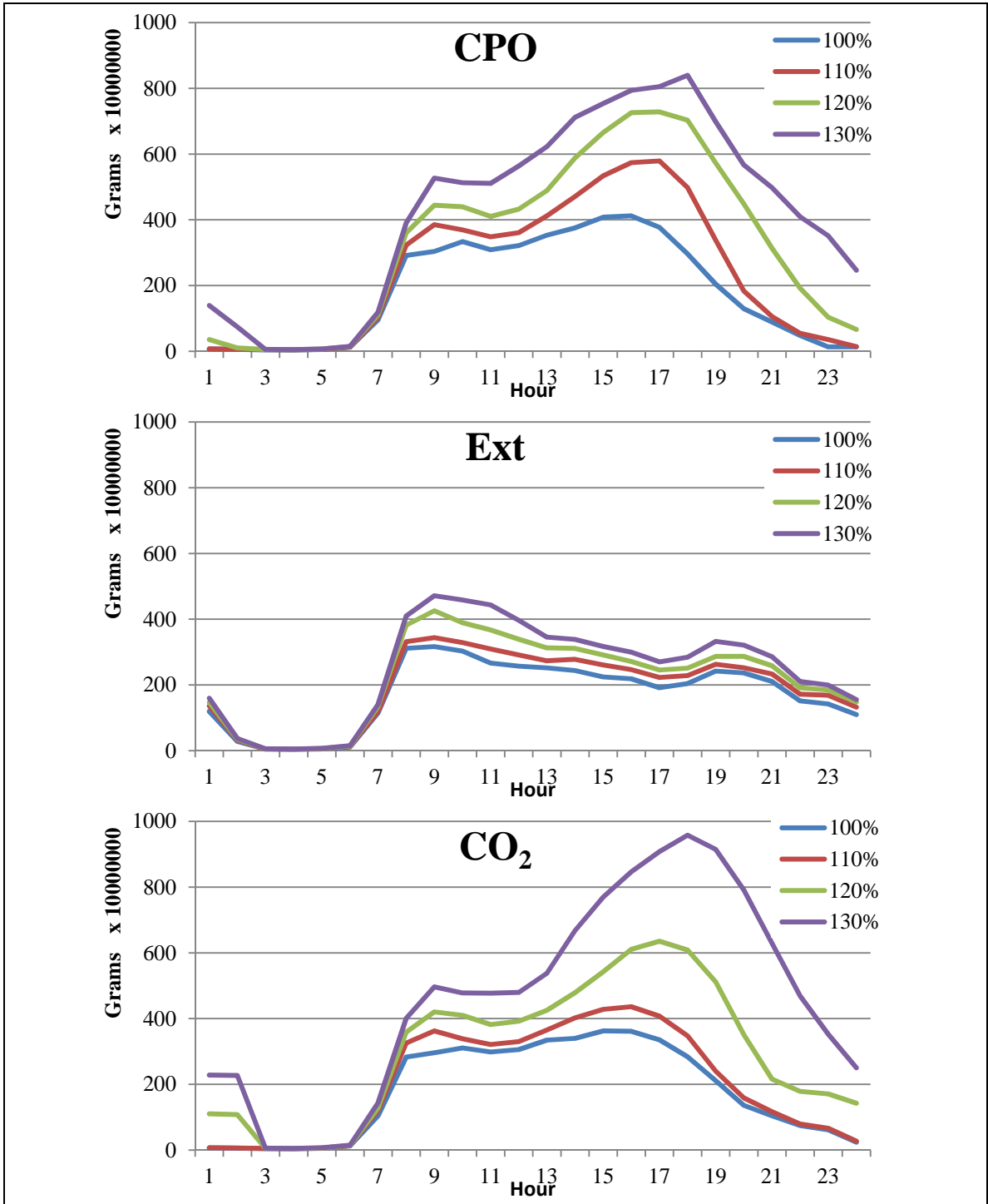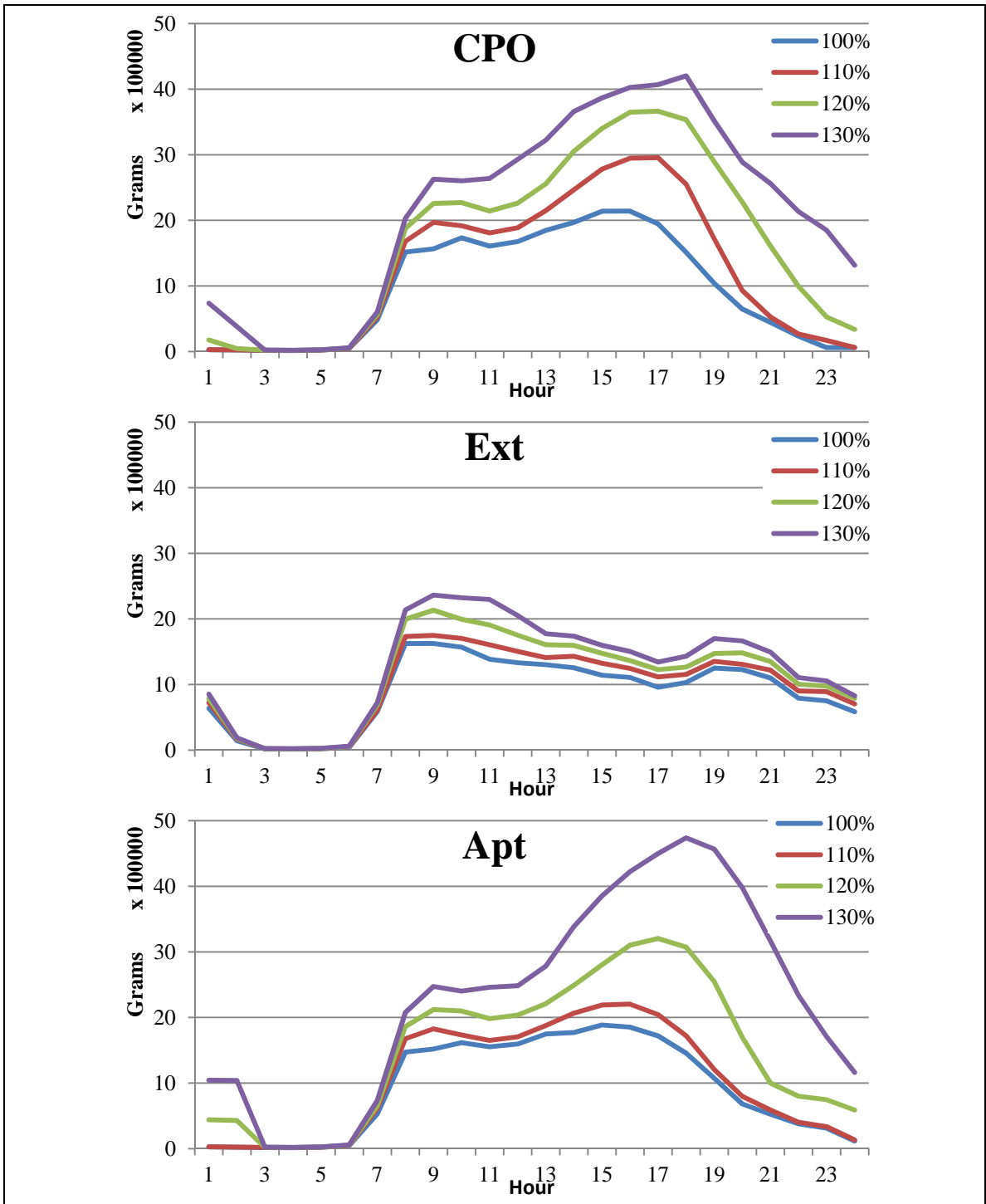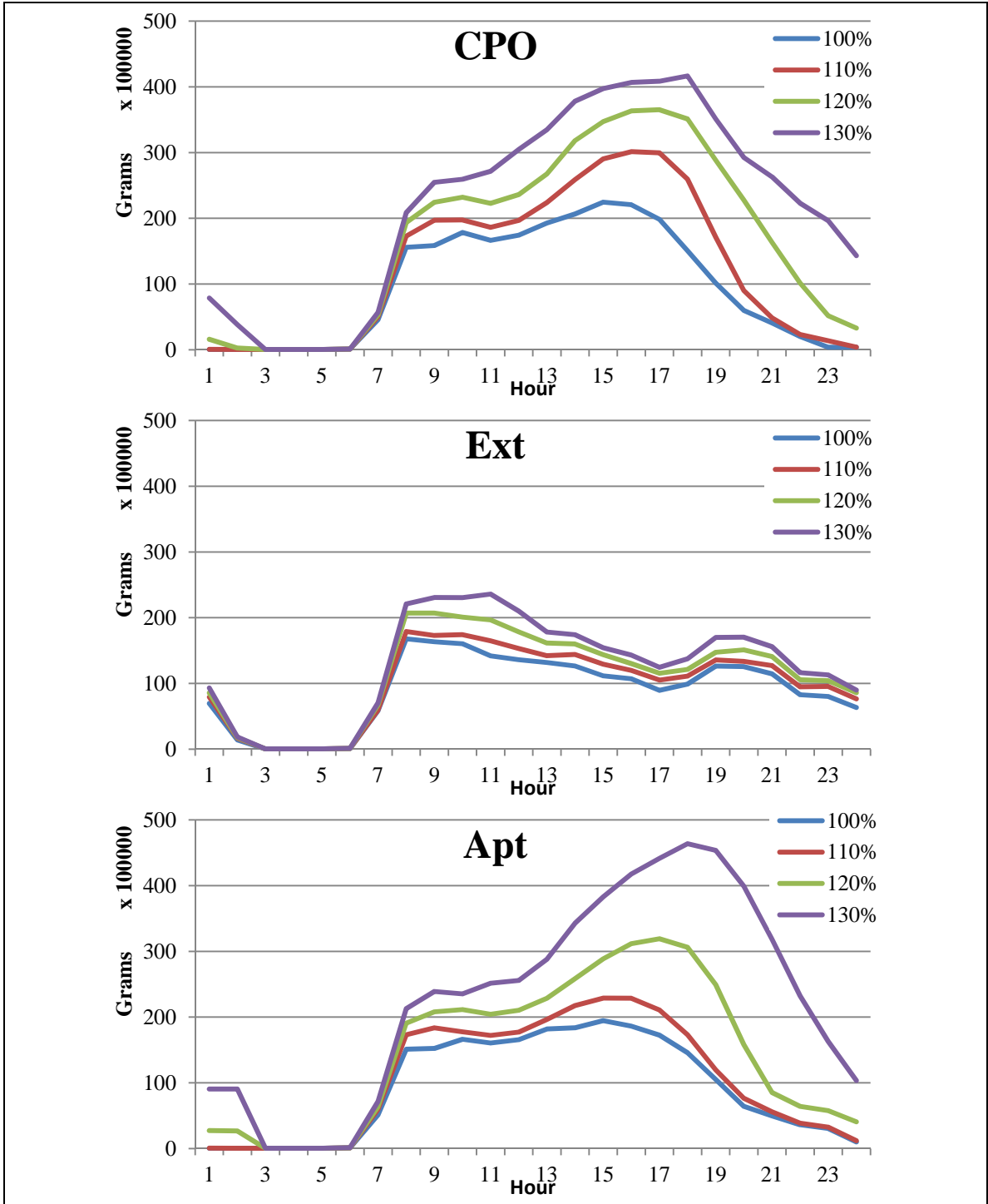**FIGURE A-1 HOURLY CARBON DIOXIDE EMISSIONS**

FIGURE A-2 HOURLY HYDROCARBON EMISSIONS

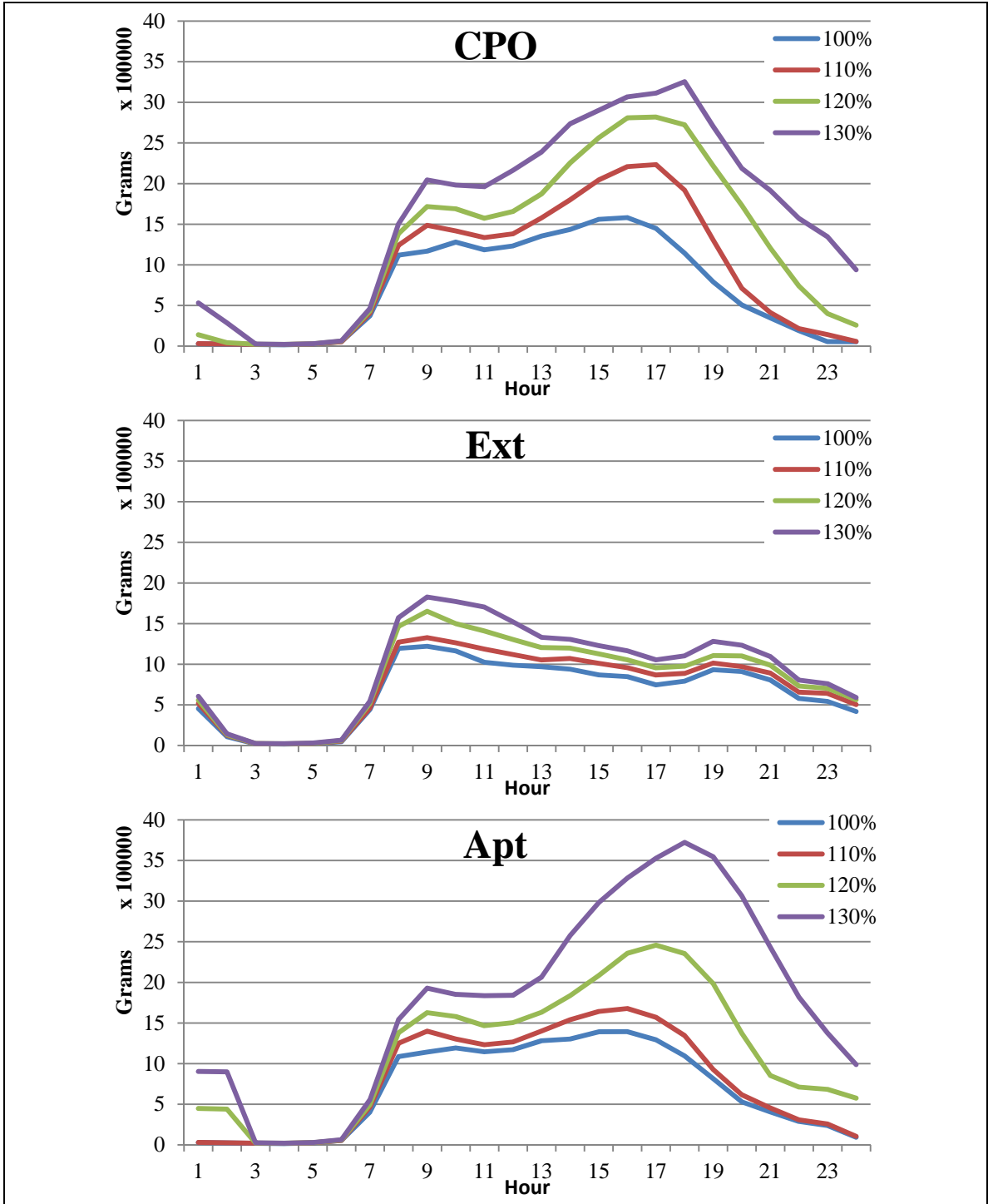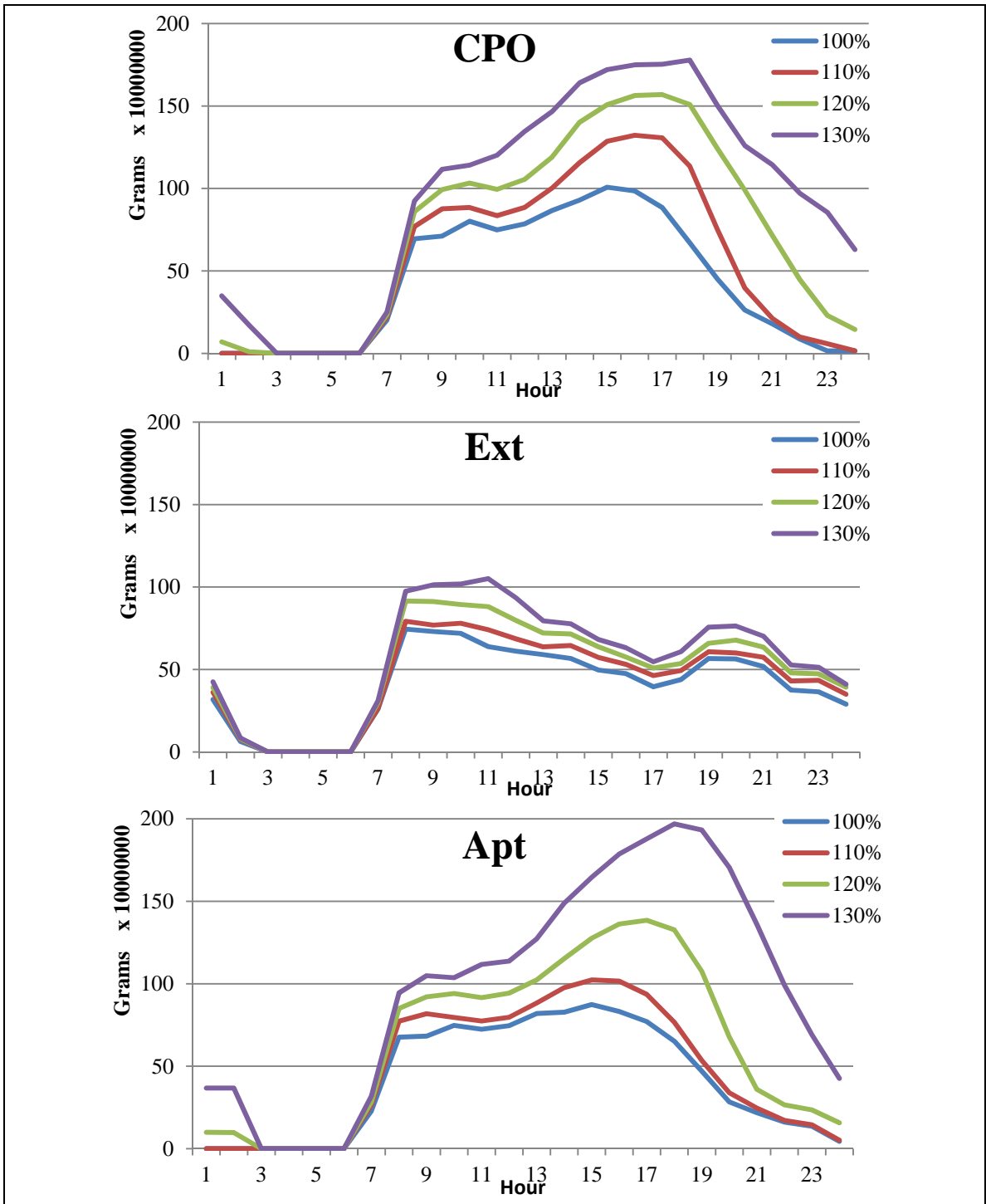**FIGURE A-3 HOURLY NITROGEN OXIDE EMISSIONS**

FIGURE A-4 HOURLY FUEL CONSUMPTION

FIGURE A-5 HOURLY DIESEL PARTICULATE EMISSIONS

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