

Cooperative Time Window Generation for Cargo Delivery/Pick up with Application to Container Terminals

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Abstract

In this report we study the appointment window system to manage the flow of trucks in traffic networks and at customers' locations. The system introduces the scheduling of transactions into and out of container terminals and requires that freight carriers deliver/pick-up their cargo within a specified time period. We propose a structure and develop an algorithm to generate cooperative time windows. The cooperative time window appointment system is modeled mathematically, and an optimization technique based on insertion method is proposed. Simulation experiments are used to evaluate the efficiency of the algorithm.

In this project we also developed a software package for simulating terminal operations. The Terminal Simulator is used to study the effects of the time window appointment system on various terminal operations. Based on data collected on truck arrivals, several simulation scenarios are created, which compare the current practices to the case when the time window appointment system is applied. It is seen that when the appointment system is used, the queues at the inbound and outbound gates become smaller, and the import and export yards are serviced more efficiently.

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1 Introduction

Over the period of 1990 to 2000, the growth in container traffic in the Los Angeles / Long Beach (LA/LB) port was significant. With an average annual growth of 9.2%, this figure surpasses the forecasted annual growth of 6.2%, which had been the basis of the 2020 Seaport Plan and much of the regional economic and infrastructure planning (Mallon and Magaddino, 2001; The Tioga Group, 2002). Assuming a modest 6.2% annual growth, the estimated container traffic in 2020 will be around 28 million TEUs or almost 15.1 million containers. Thus, by 2020 the volume of containers moving through the combined LA/LB ports will be at least triple the current volume (Mallon and Magaddino, 2001).

The substantial increase in the volume of international cargo arriving at LA/LB ports together with the growth in national freight have already introduced congestion at many regional networks in Los Angeles metropolitan area. In addition, ineffective communications and lack of effective information sharing among parties involved are degrading the reliability and performance of carriers, shippers, and terminal operators (Freight News, 2002). Congestion and lack of good transportation for freight creates delays, increases operating costs and decreases safety, economic competitiveness, and air quality. (California Transportation Plan, 1998). These transportation problems will only get worse, unless careful planning is initiated, system improvements are identified, and goods movement projects are implemented.

In today's trucking industry, there is a lot of discussion about the appointment window system (which will be called time window hereafter) to manage the flow of trucks in traffic networks and at customers' locations (Senecal 2001). The system introduces the scheduling of transactions into and out of container terminals and requires that freight carriers deliver/pick-up their cargo within a specified time period. Recently, some terminals at the port of Los Angeles and Long Beach (LA/LB) have moved to implement the system hoping that the move would eventually reduce the congestion at LA/LB ports and improve air quality within the area.

The time window system is becoming more important for different parties, including:

1. Seaports, airports, intermodal terminals, and warehouses - referred to as service stations (STs) hereafter. STs are currently facing new challenges: volume of cargo at

STs is increasing, the space for storing cargo is often limited, and the congestion and delay at the inbound and outbound gates of the ST are becoming a major problem not only to the ST but also to the adjacent traffic network. STs such as container terminals are considering implementing the time window system to manage the increased flow of trucks at their gates by distributing the flow evenly within their hours of operations.

2. End customers: Nowadays more and more end customers require Just-In-Time (JIT) cargo delivery and pickup. End customers are more willing to do business with reliable companies committed to meet their needs. The implementation of time windows if done properly will eliminate unnecessary delays, provide more predictable schedules and delivery/pick-up times and improve reliability.

It is seen that time window system arises naturally in the trucking industry due to the commitments made to the end customers, and due to the limited availability of certain resources at STs.

The importance of the time window system has drawn the attention of many researchers, as seen from the wide body of recent research dedicated to the Vehicle Routing Problem with Time Windows (VRPTW), and its practical applications (Golden and Assad 1988, Laporte 1992, Desrochers et al. 1992, Ball et al. 1995, Dumas et al. 1995, Kohl et al. 1999, Jula et al., 2005). In VRPTW a number of vehicles, each with a given capacity, are located at a single depot and must serve a number of geographically dispersed customers. Each customer has a given demand and must be served within a specified time window. The objective is to minimize the total cost of travel (Desrochers et al. 1988). An interesting special case of the VRPTW is the Multi-tour Traveling Salesman Problem with Time Windows (m-TSPTW), which emerges in the full-truck-load problem (Savelsbergh and Sol 1995, Jula et al., 2005).

Although the time windows system will solve the problems at the STs, it may seem to create other problems for truckers and end customers. For example, tight time windows may not be met by trucking companies unless they increase the number of vehicles and personnel, which means additional cost and more vehicles on the road. Also, time windows may take away some of the scheduling flexibility that could be viewed as having a negative effect on customer service.

One way to address these problems is to use information, communication and optimization technologies to optimize operations where possible, in order to meet constraints and individual objectives. For instance, once the time windows for a particular set of containers are generated, trucking companies would then run their own routing and dispatching algorithms based on VRPTW or TSPTW optimization techniques that take into account any additional time windows imposed by other customers who are not as cooperative. Despite recent research efforts on the VRPTW and TSPTW problems, efforts on generating time windows in an optimum fashion which in addition to meeting the constraints of the container terminals also take into account the constraints of the trucking companies are scant. The availability of advanced information and communication technologies facilitates the task of generating optimum time windows by considering the constraints and interests of all parties involved. Such cooperative time window generation will enable the trucking companies to manage their fleet in order to meet the end users' requirements with minimum costs.

It is worth mentioning that the transportation industry, like many others, has undergone significant changes in the last few years through the introduction of information technologies such as vehicle tracking using global positioning system (GPS), 2-way communication via wireless communication, point-to-point distance calculation through navigable map databases, etc. Moreover, technological advances such as automatic equipment identification (AEI), electronic data interchange (EDI), automatic vehicle location (AVL), mobile communication devices, electronic clearance systems as well as publicly available traffic information updates brings the industry closer to a wide use of time windows and the implementation of optimization algorithms to improve operations (Ioannou et al., 2001).

The purpose of this study is to investigate methodologies for the generation of optimum or near-optimum time windows for cargo delivery/pickup at service stations (STs) taking into account the objectives and constraints of different parties involved in cargo movement. Moreover, the study considers a typical container terminal as our ST location and investigates the impact of implementing the developed methodologies on the container flows at the gates and within the container terminal using simulation models.

The report is organized as follows. In Section 2, a structure is proposed and an algorithm is developed to generate cooperative time windows. The cooperative time window appointment

system is modeled mathematically, and an optimization technique based on insertion method is proposed. Simulation experiments are used to evaluate the efficiency of the algorithm. In Section 3 we present the development of a software package written to simulate terminal operations. The use of the terminal simulator is described, through several examples and a step by step tutorial. In Section 4 we use the Terminal Simulator to study the effects of the time window appointment system on various terminal operations. Data collected on truck arrivals are presented and analyzed. The terminal simulator parameters are set based on the statistical properties of the data and finally several simulation scenarios are created and presented. The scenarios compare the current practices, without the appointment system, to the case when the time window appointment system is applied. Sections 5 and 6 consider the recommendations for future work and implementation of this study.

2 Part I: Cooperative Time Window Appointment Generation

In this section, we propose a structure and develop an algorithm to generate cooperative time windows. The algorithm takes into account individual inland carriers' as well as container terminals' constraints and objectives. The algorithm is developed in such a way that it let the container terminals generate wide time windows for their cargos. It then communicates the assigned wide time-windows to all involved trucking companies requesting them to come up with narrower windows (of pre-specified width) within the original ones.

To determine the tight time window, each trucking company runs its own optimization algorithm developed based on the Traveling Salesman Problem with Time windows (TSPTW) considering its own constraints that may include travel time, hours of operation, etc. The trucking company will then communicate the results (the narrow time windows) to the corresponding container terminal. The terminal does the final evaluation, makes appropriate modifications in order to avoid conflicts, and to distribute the traffic at gates evenly. The terminal presents the final time windows to be followed.

In the following, the structure and algorithm to generate cooperative time window appointment is discussed in detail. The algorithm is developed based on an insertion-type heuristic method similar to that of (Jula et al. 2005). Our method, however, differs from Jula et al. (2005) in three aspects, which is discussed in-detail in Subsection 2.2.2, Remark 5.

Without loss of generality, hereafter, we consider import container operations. The methodology and findings can easily be extended to export container operations as well.

2.1 Cooperative Time Window Appointment: The Structure

Let's assume that a carrier company receives an order from a customer to pick up an import container from a container terminal. The picked-up container is to deliver at the customer's location. We assume that the container should be picked up from the terminal within a time window, which is assigned by the container terminal to each container. The time window specifies the period of the time that a truck should be appeared at the gates of the terminal to

claim for the container. As discussed earlier, the terminal imposes time windows on all cargos to manage the flow of trucks at its gates.

It is of terminal's advantage to assign tight windows to cargoes. It will distribute the flow of incoming and outgoing traffic more evenly at the gates, and consequently, will utilize the resources within the terminal more efficiently. This practice, however, has many drawbacks. The implementation of tight windows in congested transportation networks such as major metropolitan areas may not be practical. Moreover, although such a policy will be very beneficial for the container terminals, it imposes significant extra costs to inland carriers. It should be noted that, the trucking industry is highly competitive with relatively little differentiation between operators and slim profit margins.

Currently, the relatively tight window policy is being tested and, somewhat, implemented at one of the Los Angeles/Long beach container terminals. The current practice is that the terminal imposes its will on the trucking companies without considering their constraints and limitations. In other words, there is no cooperation (negotiation) between terminal and carriers in order to find a time windows, which could be beneficial to both parties. The local carrier is indeed left with no choice but to accept or reject the tight time window.

In this study, we still aim at generating tight time windows, however, in cooperation with carriers' companies. We develop a framework for negotiation between a terminal and carrier companies; hence, the generated time window will take into account both parties' interests and limitations.

Figure 1 shows the negotiation architecture for generating cooperative time window. In this figure, the horizontal dash lines represent peer-to-peer negotiation between two parties, while vertical solid lines illustrate the flow of information among entities within a party.

A customer initializes the peer-to-peer negotiation by informing the carrier company of its pick-up request. The carrier company, in turn, notifies the container terminal of its intention to pick up the container. We assume that the container terminal, in return, informs the carrier company of availability of the container for pick-up (e.g., if it has already been unloaded from the ship and checked by the customs and other federal and local agencies), and assigns a relatively wide time window to the container to be picked up. This window may be calculated based on the

availability of the container, the availability of the resources at the terminal (e.g., in yard cranes, straddle carriers, etc.), and the flow of traffic at the gates.

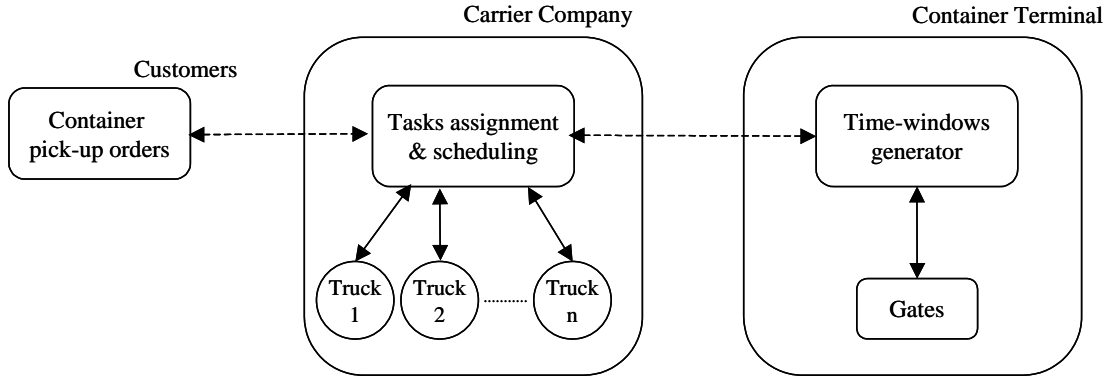


Figure 1: The negotiation architecture among customers, carrier company and container terminal. Horizontal dash lines represent peer-to-peer negotiation. Vertical solid lines show the flow of information.

The container terminal, in turn, requires the carrier company to determine a relatively tight window for container pick-up. The tight window should be determined within the initial wide window and in accordance to some protocols. These protocols basically draw the framework for mutual agreed principals and standards of cooperation between the carrier company and the terminal.

We assume that the container terminal initially assigns a wide time windows, $[a_w, b_w)$, to a container. The carrier company is required to come up with a tight time window $[a_t, b_t)$, where $a_w \leq a_t < b_t \leq b_w$. We assume that the width of the tight window $[a_t, b_t)$ is fixed (i.e., $b_t - a_t$ is a constant). Moreover, we assume that the earliest pick-up time, a_t , cannot be any arbitrary instant of time but has to be chosen among a few pre-determined numbers. In other words, we assume that not only the width of the tight time window is fixed (for instance, 2 hours), but the earliest pick-up time should also be a member of a finite set which is pre-determined by the container terminal (for instance, a_t must be chosen from the following set $\{8:00 a.m., 10:00 a.m., 12:00 p.m., \dots 4:00 p.m.\}$).

One may also assume that the container terminal initially assigns a series of wide time windows for a container pick-up, i.e., $[a_{w1}, b_{w1}) \cup [a_{w2}, b_{w2}) \dots \cup [a_{wm}, b_{wm})$. However, the carrier company is asked to come up with a single tight time window $[a_t, b_t)$ as described above.

Since the latter scenario (assigning a series of time windows) is more general, it is adopted in the rest of this study.

2.2 Cooperative Time Window Appointment: The Algorithm

As soon as the carrier company receives the series of wide time windows for a container pick-up, it examines the feasibility of meeting the assigned time windows and determines the associated cost. It virtually communicates the received information with all trucks within the company. Solid lines in **Figure 1** show the flow of information within the carrier company. The company examines the cost of including the new task within each truck's assigned tasks, and may choose one of the following actions:

1. Accepting the order. The carrier company may accept the order when including the task among current tasks is feasible and handling the task sounds economical. Upon accepting the order, the algorithm assigns the pick-up task to the truck which incurs less operational cost.
2. Pending the order for further negotiation. The carrier company may find handling the order feasible; however, the cost is relatively high. The carrier company will continue negotiating with the terminal in hope to receive another series of large time windows. Another possibility is that the carrier company may consider negotiating with the end-customer to increase the cost of service.
3. Rejecting the order. The carrier company may reject the receiving order when no trucks within the company could handle the new task (i.e., there is no feasible solution), or the cost of handling the task is fairly high.

In the following, we describe the algorithm more precisely.

2.2.1 Problem formulation

Let V be a set of M vehicles labeled v_m , $m=1,2,\dots,M$ working for the carrier company, i.e., $V=\{v_1,v_2,\dots,v_M\}$. We assume that, at any time, a vehicle $v_m \in V$ can transfer at most a single container between its origin and destination. Note that, for import operation, the origin of imported container is the container terminal, while the destination is the customer location. The vehicle v_m , working for the carrier company, will simply transfer an imported container l from its origin to destination. We denote by $O(l)$ and $D(l)$ the origin and destination of container l , respectively.

Let's start by assuming that the pick-up time window for container l at terminal is determined. That is the terminal and the carrier company have negotiated and come up with an agreed time window for container pick-up at gates which is denote by $[a_{O(l)}, b_{O(l)}]$. We also assume that the customer has requested that the container be delivered at its location during a specified time window. Let denote by $[a_{D(l)}, b_{D(l)}]$ the delivery time window at customer location.

With a pick-up/delivery time window $[a_k, b_k]$, we assume that if a vehicle arrives at the pick-up/delivery location at any time $t < a_k$, it waits till time $t = a_k$ to be served (being loaded/unloaded). If it arrives at that location at any time $a_k \leq t < b_k$, it will be immediately served. The vehicle, however, cannot be served if it arrives at that location at any time $t \geq b_k$.

Task l is defined as picking-up (loading) container l from its origin, $O(l)$, transferring it from its origin to destination, $D(l)$, and delivering (unloading) it at its destination. Let assume that to some trucks a set of tasks are assigned. Trucks with assigned tasks are called *active* vehicles, while those without any tasks are called *inactive*.

Let v_m be an active vehicle, and let $|v_m|$ be the total number of tasks scheduled for that vehicle.

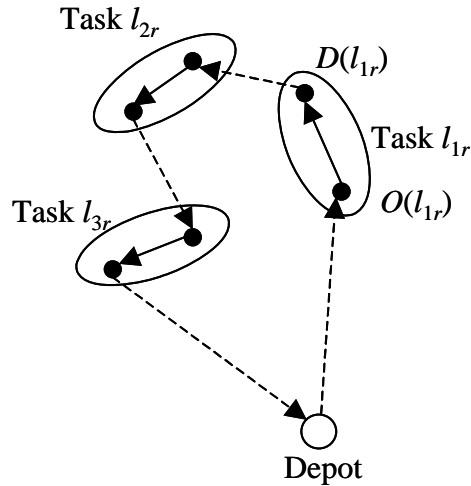
Let $l_{im} \in v_m$ be the i th task assigned to vehicle v_m , i.e. $v_m = \{l_{1m}, l_{2m}, \dots, l_{|v_m|m}\}$. The sequence of the tasks visited (performed) by vehicle v_m is also called route m . Route m denoted by $r_m = \{p_O, l_{1m}, l_{2m}, \dots, l_{|v_m|m}, p_D\}$, starts from the depot, p_O , visits all tasks $l_{im} \in v_m$, and ends at the same depot, p_D . Although the starting and ending depot are physically the same location, the

subscripts are different to differentiate between the starting and ending of the route. Route m is said to be feasible if it satisfies the time window constraints at the origins and destinations of all assigned tasks.

We also require that the total time needed to perform all tasks in any route be less than a certain amount of time called the working shift (time) and denoted by T . That is, it is required that all tasks assigned to a vehicle be done within the time horizon T .

Figure 2 shows a typical routes r starting from the depot of the carrier company and ending at the same depot. Solid lines, in Figure 2, illustrate the traveling between the origin and destination of a container, while dashed lines indicate empty traveling between the destination of the last drop-off and the origin of the next pick-up. The ovals represent the tasks to be performed on route r .

Figure 2: A typical route r consists of three tasks. The route starts from depot and



ends at the same depot. The large empty circle denotes the depot location. Each small black circle denotes the origin (O) or the destination (D) of a container.

We define *service time* of task $l_{im} \in v_m$ as the time needed for carrying container l_{im} from its origin to its destination, (i.e, between $O(l_{im})$ and $D(l_{im})$) together with the loading time at $O(l_{im})$ and unloading time at $D(l_{im})$. The service time includes the waiting time at the destination, if any.

Time window of task l_{im} is defined as the period of time in which task l_{im} should be started. This time window can be expressed in terms of: 1) time window at its origin $[a_{O(l_{im})}, b_{O(l_{im})})$, 2) time

window at destination $[a_{D(l_m)}, b_{D(l_m)}]$, and 3) the traveling time between the origin and destination, $t_{O(l_m)D(l_m)}$. Figure 3 demonstrates a typical relation between these three elements. For the sake of simplicity, we eliminate all subscripts l_m in Figure 3. The time window denoted by $[a'_D, b'_D]$ in Figure 3 is the time window at the destination shifted back in time by $t_{O(l_m)D(l_m)}$.

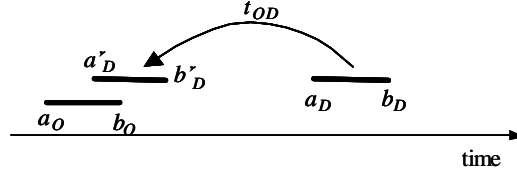


Figure 3: A typical relation between time window at origin $[a_O, b_O]$, destination $[a_D, b_D]$, and time window at destination shifted back in time $[a'_D, b'_D]$.

Figure 4 presents all possible relations between time windows $[a'_D, b'_D]$ and $[a_O, b_O]$. Dashed areas in Figure 4 indicate the time windows at origin node O during which vehicle v_m can be loaded and yet it meets the time window constraint at destination D . For instance, Case I in Figure 4 indicates that if v_m starts task l_m at any time in the interval $[a_O, b_O]$, it would be served at both the origin and destination. Case I also indicates that if the loaded vehicle leaves the origin O at any time $\tau \in [a_O, a'_D]$, it will reach destination D , prior to time a_D . Therefore, the vehicle has to wait at destination D for a period of time equal to $a'_D - \tau = a_D - t_{OD} - \tau$. If the vehicle leaves origin O at any time $\tau \in [a'_D, b_O]$, it will be unloaded at D without any delay. Moreover, if the vehicle reaches the origin O at time $\tau \in (b_O, b'_D]$, it cannot be loaded at the origin even though the vehicle can meet the time constraint (i.e., can be unloaded) at the destination.

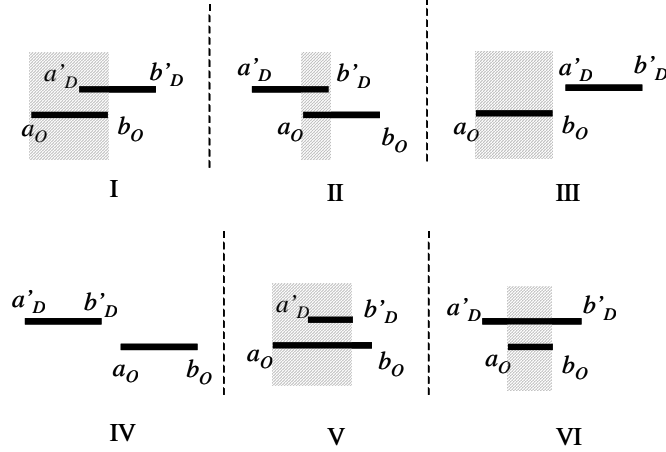


Figure 4: All possible relations between time window at origin, and time window at destination shifted back in time. The dashed area presents the time window at node OD during which a vehicle can be loaded.

Time window of task l_{im} denoted by $[a_{l_{im}}, b_{l_{im}})$ can be computed by (see Figure 4).

$$\begin{aligned}
 a_{l_{im}} &= a_{O(l_{im})} \\
 b_{l_{im}} &= \min (b_{O(l_{im})}, b_{D(l_{im})} - t_{O(l_{im})D(l_{im})})
 \end{aligned} \tag{1}$$

Note that the possibility of $b_{l_{im}} < a_{l_{im}}$ in (1) corresponds to the Case IV in Figure 4 which is an infeasible case and may not occur in a real situation.

In the following we will define the cost associated with each vehicle m . Let $l_{im}, l_{jm} \in v_m$ be the i th and j th scheduled tasks assigned to the vehicle v_m , respectively, and let task j th be performed immediately after task i th. Let denote by $c_{O(l_{im})D(l_{im})}$ the cost of performing task l_{im} . This cost consists of the cost of loading container l_{im} at its origin $O(l_{im})$, carrying the container from its origin to its destination, $D(l_{im})$, and unloading the container at its destination. Let also $c_{D(l_{im})O(l_{jm})}$ be the cost of empty vehicle traveling between the destination of container l_{im} to the origin of container l_{jm} . Let also denote by $c_{P,O(l_{im})}$ and $c_{D(l_{jm}),P}$ the costs of empty traveling from the depot to the first task (origin of the first container) and from the last task (destination of the last task) to the depot, respectively.

Let $F(v_m)$ denote the cost associated with performing all tasks assigned to vehicle v_m in the specified order (according to the route m). The cost $F(v_m)$ is defined as

$$F(v_m) = \sum_{i=1}^{|v_m|} c_{O(l_{im})D(l_{im})} + \sum_{i=1}^{|v_m|-1} c_{D(l_{im})O(l_{i+1,m})} + c_{P,O(l_{1m})} + c_{D(l_{|v_m|m}),P} + f_{act} \quad (2)$$

where $l_{i+1,m}$ is the immediate task on route m after task l_{im} and f_{act} is the vehicle activation cost indicating the cost of bringing an inactivate vehicle into service. In (2), and without loss of generality, we assumed that all containers are located off-depot. Note that containers at the depot can be assigned to a dummy location located very close to the depot.

2.2.2 Truck Selection

In this section we will determine the feasibility and cost of including a new task into the current schedule of tasks assigned to a vehicle. Let route r , $r = \{o, 1, \dots, i, j, \dots, n, d\}$ be an ordered set of tasks assigned to vehicle v_r . The set indicates that the vehicle v_r starts its daily tasks from origin $\{o\}$, visiting all tasks in route r only once, and ending at destination $\{d\}$. Recall that a vehicle is said to be active if route r have at least one scheduled task to visit.

Let A^r be the arc set associated with route (solution) r defined as $A^r = \{(i,j) / i,j \in r, \text{ and task } j \text{ is visited immediately after task } i\}$. Recall that associated to each task $i \in r$ are a service time s_i and a time window $[a_i, b_i]$.

Let time t_{ij} represents the time of traveling between two consecutive tasks i and j , and let t_j^- and t_j^+ be the arrival and departure times from task j , respectively. Assuming, task j is visited immediately after task i , we have,

$$t_j^- = t_i^+ + t_{ij} \quad (3)$$

As discussed earlier, we also require that the total time needed for a vehicle to visit all nodes on its route and return to the depot be less than a certain amount of time, which is called working shift (time) and denoted by T .

Let task j be visited after task i . The *waiting time* at task j denoted by w_j is defined as the duration of time at task j a vehicle has to wait before being served at that location, and is given by

$$w_j = \max(0, a_j - t_j^-) \quad (4)$$

Therefore, the departure time from task j can be calculated by,

$$t_j^+ = t_j^- + w_j + s_j \quad (5)$$

Let also define the *upward excess time* at task i , denoted by Δ_j , as the portion of the time window (at task j) between the latest time to visit task j , b_j , and the time that the service has started at that task, and is given by

$$\Delta_j = b_j - \max(t_j^-, a_j) \quad (6)$$

Likewise, the *downward excess time* at task j denoted by δ_j is defined as the portion of the time window (at task j) between the time the service has started at that task and the earliest time to visit task j , a_j .

$$\delta_j = \max(0, t_j^+ - a_j) \quad (7)$$

Figure 5 illustrates the waiting time and upward and downward excess times for a typical route r , graphically.

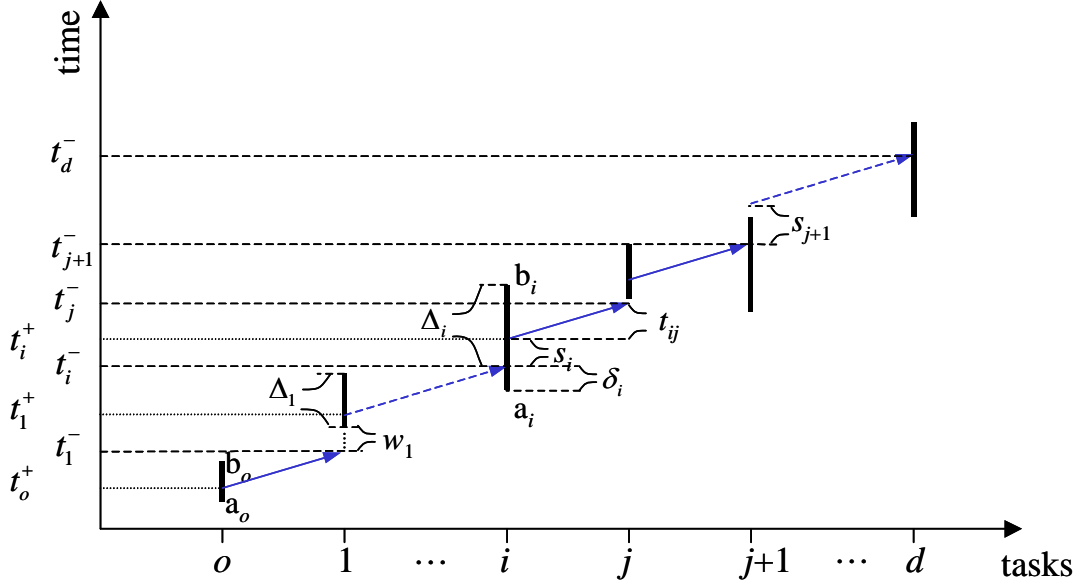


Figure 5: The graphical representation of waiting time, excess time, service time, and time windows at each task in a typical route.

We define the *upward feasibility margin* with respect to the changes in the traveling time on the link (i,j) , denoted by Φ_{ij}^r , as the maximum changes (value of disturbances) in the traveling time on that link toward the end of the route such that the solution r will still be feasible. The feasibility margin Φ_{ij}^r can be computed as follows:

$$\Phi_{ij}^r = \text{Min}_{k \in \{j, j+1, \dots, n, d\}} (\Delta_k + \sum_{p=j}^k w_p) \quad (8)$$

The feasibility margin Φ_{ij}^r implies how robust is the solution r to the changes on the traveling time between tasks i and j . The feasibility margin in (8) can also be calculated recursively as follows:

$$\begin{aligned} \Phi_{ij}^r &= w_j + \text{Min}(\Delta_j, \Phi_{j,j+1}^r) \\ \Phi_{d,n}^r &= M \end{aligned} \quad (9)$$

where $j+1$ is the next task to be visited on route r after task j , and M is a big number. Likewise, we denote by ϕ_{ij}^r the *downward feasibility margin* with respect to the changes in the traveling

time on the link (i,j) of the route r . ϕ_{ij}^r is defined as the maximum changes in the traveling time on that link toward the beginning of the route such that the solution r will still be feasible. The feasibility margin ϕ_{ij}^r can be computed as follows:

$$\begin{aligned}\phi_{ij}^r &= \text{Min}(\delta_i, \phi_{i-1j}^r) \\ \phi_{\alpha,1}^r &= \delta_o\end{aligned}\tag{10}$$

where $i-1$ is the immediate previous task on route r before task i , and δ_o is a the downward excess time at origin. As seen from (10), the downward feasibility margin at each link is bounded by δ_o .

Given route r , a new task l can be inserted (visited) between tasks i and j on that route, if route r remains feasible after inserting task l . In other words, task l can be included in the schedule of tasks if the inclusion of that task doesn't change the feasibility of the route. More precisely, the new order l can be inserted between each two consecutive nodes i and j on route r if the following inequalities are satisfied,

$$t_{il} + w_l + s_l + t_{lj} - t_{ij} \leq \Phi_{ij}^r + \phi_{ij}^r\tag{11}$$

$$t_i^+ + t_{il} < b_l + \phi_{ij}^r\tag{12}$$

and

$$t_d^- - t_o^+ \leq T\tag{13}$$

Equation (11) indicates that the changes in time on route r caused by inserting order l between tasks i and j should be less than or equal to the sum of the downward and upward feasibility margins. Equation (12) ensures that order l is visited before the latest time b_l . Equation (13) guarantees that the total traveling time on route r (including task l) is less than the working shift, T .

It is worth noticing that the downward feasibility margin states that the solution r can still be feasible if the changes in traveling times, on the links of route r , propagated toward the origin o is limited by (10). Note that for real time order insertion in which new order l is to be inserted in the scheduled route after vehicle v_r has departed from the origin, the value of δ_o would be zero as changes cannot propagate back in time. Consequently, according to (10), all values of ϕ_{ij}^r would be zero too. In other words, for real time order inclusion only the upward feasibility margin matters.

Insertion procedure: Let denote by F^{v_m} the cost associated with vehicle v_m given by (2). F^{v_m} is the total cost of visiting all tasks on route r in the specified order. Let's denote by $\Delta F_{ij}^{v_m}(l)$ the changes in the cost of F^{v_m} due to insertion of order l between tasks i and j . Based on the feasibility of inserting task l between tasks i and j (Note, the insertion is feasible if inequalities (11) - (13) are met), $\Delta F_{ij}^{v_m}(l)$ is determined as follows,

1. If vehicle v_m is active and task l can be inserted between tasks i and j on route r , $\Delta F_{ij}^{v_m}(l)$ is given by

$$\Delta F_{ij}^{v_m}(l) = c_{D(i)O(l)} + c_{O(l)D(l)} + c_{D(l)O(j)} - c_{D(i)O(j)} \quad (14)$$

2. If vehicle v_m is active but task l cannot be inserted between tasks i and j on route r (In other words, it is infeasible to handle order l between tasks i and j) $\Delta F_{ij}^{v_m}(l)$ is given by,

$$\Delta F_{ij}^{v_m}(l) = M \quad (15)$$

where M is a big number.

3. If vehicle v_m is inactive, performing task l can be assigned to v_m . In this case, the changes in the cost of F^{v_m} due to performing order l would be,

$$\Delta F_{ij}^{v_m}(l) = c_{p,O(l)} + c_{O(l)D(l)} + c_{D(l),p} + f_{act} \quad (16)$$

where p denote the single origin and destination depot.

Among all locations (arcs) on route r , the *candidate* arc $(i, j) \in A^{v_m}$ to insert task l is the one which leads to minimum changes in cost $\Delta F_{ij}^{v_m}(l)$ for all possible time windows $\Delta w_k = [a_{wk}, b_{wk})$. In other words, the *candidate* arc is the arc (i, j) leads to

$$\text{Min}_{\Delta w_k} \left\{ \text{Min}_{(i,j) \in A^{v_m}} \Delta F_{ij}^{v_m}(l) \right\} \quad (17)$$

The carrier company examines all vehicles $v_m \in V$ to find the best location among all feasible locations to insert order l . That is, we are interested in finding the best candidate among all candidates with minimum cost of insertion new order l :

$$J = \text{Min}_{v_m} \left\{ \text{Min}_{\Delta w_k} \left\{ \text{Min}_{(i,j) \in A^{v_m}} \Delta F_{ij}^{v_m}(l) \right\} \right\} \quad (18)$$

Finding J in equation (18) results in determining the best arc $(i, j) \in A^{v_m}$, time window $\Delta w_k = [a_{wk}, b_{wk})$, and vehicle $v_m \in V$ to handle order l .

The career company decision (accept or reject order l) will be based on the value of J obtained in (18). The decision can be one the following:

1. If there is no feasible solution, i.e., $J=M$, the order will be rejected. In other words, the carrier company will reject the receiving order when no trucks within the company could handle the new task (i.e., there is no feasible solution or the cost of handling the task is very high).
2. If $J>C$ where C is the marginal profit for the career company, the career company has found handling the order feasible; however, the cost is relatively high. The carrier company will continue negotiating with the terminal in hope of receiving another series of large time windows. The carrier company may also consider negotiating with the end-customer to increase the cost of service.

3. If $J \leq C$, the career company accepts the order and informs the container terminal of its preferred tight time window $[a_t, b_t)$, as follows. Let $(i, j) \in A^{v_m}$, $\Delta w_k = [a_{wk}, b_{wk})$, and $v_m \in V$ be the best arc to insert the order l , the best wide time window to visit the terminal, and the best vehicle to assign the order to, respectively. Let $\Delta w_t = b_t - a_t$ be the fixed width for tight time windows. Recall that, the earliest pick-up time, a_t , should be a member of a finite set, i.e., $A_t = \{a_{t1}, a_{t2}, \dots, a_{ts}\}$, which is pre-determined by the container terminal. Equivalently, it means that b_t should be a member of a finite set, i.e., $B_t = \{b_{t1}, b_{t2}, \dots, b_{ts}\}$, where $b_{ti} = a_{ti} + \Delta w_t$.

Therefore, the preferred tight time window $[a_t, b_t)$ is calculated as follows

$$b_t = \left\lfloor \min \left\{ \max \left(t_l^-, a_t \right) + \Delta w_t, b_t \right\} \right\rfloor_{B_t} \quad (19)$$

where the function $\left\lfloor \cdot \right\rfloor_{B_t}$ returns the largest member in set B_t which is equal to or less than its argument. And

$$a_t = b_t - \Delta w_t \quad (20)$$

Remark 1: Normally in (14) - (16), and due mainly to the vehicle activation cost, f_{act} , the cost of including a new order in an active route is much cheaper than that of an inactive one. Therefore, it might be more desirable for a tracking company to wait till it receives a few orders before running the algorithm. In other words, it is more reasonable to distribute the cost of activating an inactive vehicle among several new tasks.

Remark 2: Recall that the time window appointment system is being considered at the container terminals in order to manage the increased flow of trucks at their gates by distributing the flow evenly within their hours of operations. Thus, it is reasonable to assume that the container terminals would limit the number of available tight time windows at each instant of time to control the inbound and outbound traffic at the gates.

As a result, the container terminal may adopt a policy, such as First Come First Served policy, in order to reserve the limited time window slots. In other words, those carrier companies who get back to the terminal sooner have better chance to keep the preferred time windows.

Remark 3: Considering the above two remarks, on the one hand, it would be of a carrier company's advantage to get back to the terminal as soon as possible to insure better time windows, on the other hand, to distribute the cost of activating a new vehicle, it would be better for the carrier company to wait till it receives a few tasks. Thus, the time to run the developed algorithm to include new tasks is a compromise between these two conflicting criteria.

Remark 4: The problem of routing multi-vehicles, where tasks are to be performed in specified time windows, can be modeled as multi-traveling salesman problem with time windows, m-TSPTW, (Jula et al., 2005). It can be shown that even finding a solution for a single vehicle TSPTW is an NP-complete problem (Savelsbergh, 1985). In other words, the routing problem becomes computationally intractable when the size of the problem increases.

Since in a typical working day hundreds of orders may be received at a carrier company, the developed algorithm for cooperative time window appointment generation should be fast. That is why in this study the developed algorithm is developed based on a heuristic insertion method. The developed heuristic insertion method is capable of finding a sub-optimal solution to the m-TSPTW in a very short amount of time at the cost of missing the optimal solution.

Remark 5: As discussed, the developed optimization algorithm is an insertion-type heuristic optimization method similar to that of Jula et al. (2005). Our method, however, differs from that work in three aspects. First, in Jula et al. (2005) the time windows are fixed and given, while our problem involves finding the best tight time window among a given set of wide time windows. Second, in our developed insertion method, we considered both upward and downward feasibility margins to insert a new task, however in Jula et al. (2005) the only upward feasibility margin was considered. Third, Jula et al. (2005) didn't include the cost of the new vehicle activation.

2.3 Simulation Experiments

In this section, we perform a number of simulation experiments to evaluate the efficiency of the developed algorithm. The algorithm is coded in Matlab 7.0 developed by MathWorks, Inc., and tested on an Intel Pentium 4.

2.3.1 Simulation scenario 1 (a single vehicle)

In this simple scenario, we assume that a particular truck within a carrier company is about to pick-up a container from a terminal and deliver it to an end-customer. We assume that the terminal has already assigned a wide time window for container pick-up, and that the end customer doesn't impose any delivery time constraints. We assume that, in addition to pick-up and delivery of the container, the truck has other jobs (tasks) to perform.

The algorithm developed in Section 2.2 is used to determine the best time to pickup the new container from the terminal. After determining the best time, the carrier company will notify the container terminal of the selected tight time window for container pick-up.

We assume that the container terminal has assigned the time window $[8:00, 12:00)$ to the container, i.e., the container can be picked-up at any time in the morning. We also assume that the terminal, in return, is expecting to receive, from the carrier company, a tight time window with the width of 2 hours. The tight time window must start at the beginning of each hour, e.g., 8:00 a.m., 9:00 a.m., and so on.

Let's also assume that the truck, which is supposed to pick-up the container, has three other tasks to perform. Recall from Section 2.2.1 that a task is defined as picking a container (or any load) from its origin and transferring and delivering it at its destination. Recall also that the time to perform a task - including the time to load a container, transferring it to its destination and unloading it at the destination, is called the service time. In this simulation scenario, we assume that the service time to perform assigned tasks to the truck is given by (21) in minutes in vector form. For instance, the service time for Task 1 is assumed to be 49 minutes and for Task 2 is 39 minutes, and so on.

$$\Sigma = [49 \quad 39 \quad 60] \quad (21)$$

We also assume that the time windows assigned to tasks are given by (22). For instance, the time window assigned to Task 1 is $[9:00,11:00)$ a.m. and for Task 3 is $[1:00,3:00)$ p.m.

$$\Psi = \{[9:00,11:00) \quad [10:00,12:00) \quad [13:00,15:00)\} \quad (22)$$

Likewise we assume that the service time to perform “the new task” (i.e., picking up the new container from the terminal, transferring it to the end customer and unloading it at that location) is 50 minutes. Since we assumed that the end customer doesn’t impose any delivery time constraints, we have $a_d = 7:00$ a.m. and $b_d = 16:00$, in Figure 3, and thus it results in Case VI in Figure 4. Therefore, considering the assigned wide time windows $[8:00,12:00)$ a.m. at the terminal and according to (1), the time window assigned to this task would be $[a,b) = [8:00,12:00)$.

Recall that all tasks assigned to a vehicle should be performed within a working shift, T , which here is assumed to be 10 hours. We assume that the hours of operations at the depot of the carrier company is between 7:00 a.m. till 5:00 p.m. In another words the time window at the depot is $[7:00,17:00)$.

We also assume that the traveling time between depot, the three previously assigned tasks and the new task is given in matrix form by (23), where t_{ij} is the traveling time, in minutes, between the destination of task j and the origin of task i . For the sake of simplicity this matrix is assumed to be symmetric. That is $t_{ij} = t_{ji}$. In (23), the first row and first column show the traveling time from the depot to all other tasks and from all other tasks to the depot, respectively. The fifth row and fifth column indicate the traveling time from the new task and to the new task, respectively.

$$t = \begin{bmatrix} 0 & 33.5 & 15.7 & 30.0 & 34.2 \\ 33.5 & 0 & 39.5 & 25.1 & 60.9 \\ 15.7 & 39.5 & 0 & 43.9 & 21.6 \\ 30.0 & 25.1 & 43.9 & 0 & 64.1 \\ 34.2 & 60.9 & 21.6 & 64.1 & 0 \end{bmatrix} \quad (23)$$

The developed algorithm discussed in Section 2.2 is used to determine the best time, to pickup the new container from the terminal, which results in the minimum cost. Here the cost is equal to the traveling time. The best time is found to be 11:02 a.m. Thus, using (19) and (20), and setting $t_i^- = 11:02$ and $\Delta w_i = 2$, the best tight time window to announce to container terminal is,

$$[a_i, b_i) = [10:00, 12:00) \quad (24)$$

2.3.2 Simulation scenario 2 (a fleet of vehicles)

In this scenario, we assume that the same container, in Simulation 1, is to be picked up by a carrier company. In contrast to the previous scenario, the carrier company has a fleet of vehicles and, therefore, wants to find the *best time*, and *best vehicle* to perform the new task such that the total traveling *costs* of all vehicles is minimized. The developed algorithm is used to find the best truck among all trucks to perform the job. After finding the best time for the best truck to pick up the container, the carrier company will then notify the container terminal of its selection of tight time window.

In this Simulation scenario, we assume that other tasks, to be performed by trucks in the carrier company, are all uniformly distributed in a Euclidean plane. The dimensions of the Euclidian plane and locations of the depot were selected such that any task in the plane can be performed by at least one truck, and the truck can go back to the depot within a working shift (i.e., $T=10$ hours). More precisely, in terms of traveling time, the dimensions were chosen to be between 0 and 5 hours from the origin. The coordinates of the depot were generated randomly between 2:20 and 2:40 hours from the origin using

the uniform distribution function. These numbers ensure that a driver can serve even the farthest customer in the network during a single working shift.

The earliest time to perform a task, a_i , at each node i is generated as a uniform random variable between 9:00 a.m. to 4:00 p.m. The time window interval length is generated as a uniform random variable in the interval $[0,w)$, where $w=4$ hours. The service time at each task, s_i , is assumed to be a uniform random variable generated between 30 to 90 minutes. The time window at the depot is set between 7:00 a.m. to 6:00 p.m. and the service time at the depot is assumed to be zero.

We generated 20 randomly generated tasks as described above. The total number of 8 vehicles is deployed to perform these tasks. After assigning all tasks to vehicles, the new task (i.e., picking the new container from the port and delivering it to its end customer) is generated as follows. Similar to Simulation Scenario 1, we assume that the service time is 50 minutes and that the wide time-window (assigned to the container by the container terminal) is $[8:00,12:00)$. The location of the new task (the OD node in Figure 2) is randomly generated in the same Euclidean plane as described above.

The developed algorithm discussed in Section 2.2 is used to determine the best time and best vehicle to pickup the new container from the terminal. Similar to Simulation Scenario 1, we assume that the cost is equal to the traveling time. For the generated scenario, it took less than a second for the algorithm to find that the best time to pick-up the container is 9:54 in the morning, and thus for $t_i^- = 9:54$ and $\Delta w_i = 2$, and by using (19) and (20), the best tight time window is,

$$[a_i, b_i) = [9:00, 11:00) \quad (25)$$

3 Part II: Container Terminal Simulation Modeling

The surge in number of containers at terminals will not only result in costly delays at the terminal itself but place additional stress on an already overloaded regional transportation system. Many solutions have been proposed to alleviate the terminal's congestion. Each of these solutions requires a significant capital expenditure. Time and money can be saved by determining which proposals will have the greatest impact before the investment is made.

In this project a terminal simulator was constructed. The terminal simulator is a software tool used to study how inbound and outbound trains, ships and trucks carrying shipping containers for import and export affect the flow of containers through a shipping terminal. The simulator is written in a way that a user can create and execute different simulation scenarios, test and evaluate new methodologies, and forecast congestion.

Using a custom graphical user interface, operational scenarios can be constructed by setting the arrival rate of trucks and scheduling ships and trains to arrive for loading and unloading of containers. The user may also adjust over 50 different terminal parameters such as processing time for trucks, trains and ships to control the flow of traffic along approximately 20 different paths. After the simulation is executed, data collected such as truck queue lengths at different junctions and the inventory of containers in the import and export yard can then be plotted on a chart for analysis. The scenario can then be saved, reloaded and executed again in the future.

3.1 Design

The *Terminal Simulator* is an object-oriented, event-based simulation package implemented with the C# programming language and can be executed on a Microsoft .NET platform. To download the simulator package as well as its user manual, please contact the authors via email or visit the METRANS website.

The *Terminal Simulator* is composed of two distinct entities: a simulation executive and a GUI (Graphical User Interface) which are used to control the simulation and plot data (Figure 6).

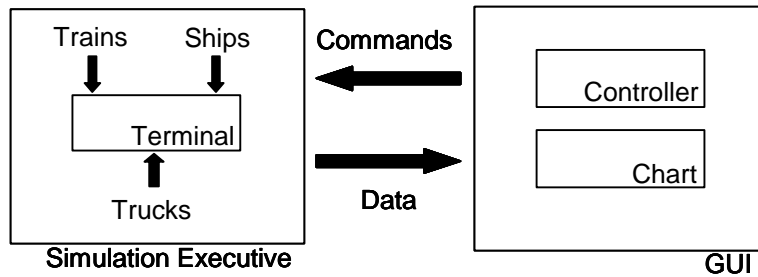


Figure 6: Terminal Simulator Design

The simulation executive is comprised of a terminal object and three other objects used to generate trucks, ships and trains. Other major components such as the import and export yards and inbound and outbound gates are contained within the terminal object. The GUI can be subdivided into a controller used to send commands to the simulation (run, stop, set parameters) and a chart used to graph data sent from the simulation (after execution). The chart object is a 3rd party .NET component obtained from [Dundas Software](#), Ltd.

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

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

3.2 Terminal Operation

The *Terminal Simulator* emulates the actual operation of a shipping terminal. Following is a description of the processes that may occur during the simulation’s execution. The exact

processes that occur are controlled by parameters set by the user. These parameters are described later.

Shipping containers are transported to and from the terminal by truck, train and ship. Trucks and trains bring containers for export and remove containers for import. Conversely, a ship brings containers for import and removes containers for export.

Several structures that exist in a physical terminal are represented in the “virtual” terminal (simulated terminal), including an *import* and *export yard* for storing containers, an *inbound* and *outbound gate* for processing trucks, a *dock* for loading and unloading ships, and a *station* for loading and unloading trains.

- I. **Import and Export Yard:** The import yard is the location where containers that are unloaded by a ship may be stored. These containers are later removed by either a train or a truck (Figure 7). The export yard is the location where containers that are unloaded by either a train or a truck are stored. These containers are later removed and loaded on to a ship for export (Figure 8).

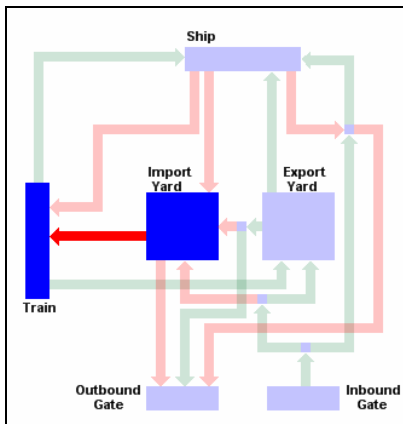


Figure 7: Import Yard to Train

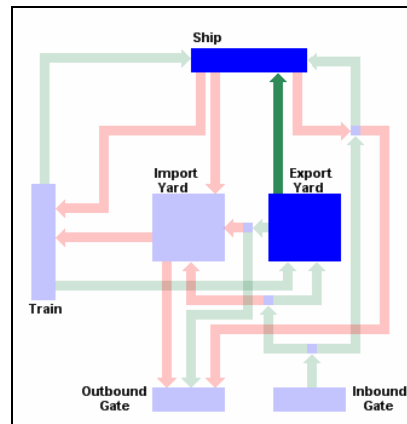


Figure 8: Export Yard to Ship

- II. **Inbound and Outbound Gate:** Trucks arrive at the inbound gate for processing. If there is no ship waiting at the dock, the truck may only proceed to either the import yard or the export yard (Figure 9). Otherwise, the truck may also proceed to the dock (Figure 10).

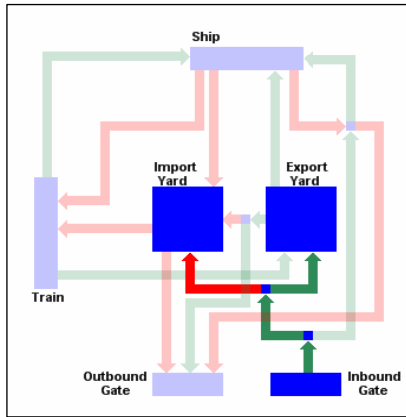


Figure 9: Inbound Gate to Yard

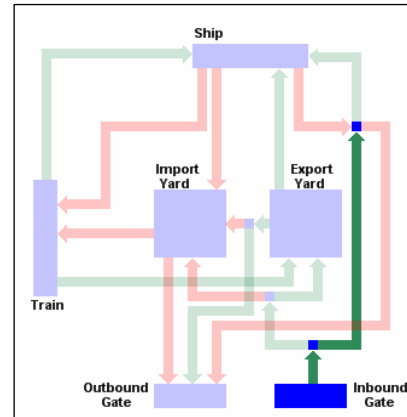


Figure 10: Inbound Gate to Dock

A truck may arrive at the inbound gate either with or without a container. In the terminal simulator, if a truck is destined for the import yard, it is considered to have arrived without a container. When a truck arrives at the import yard, the truck is loaded with a container that has been stored there. Afterwards, the truck departs the import yard for the outbound gate. All trucks arriving at the outbound gate are processed and then leave the terminal.

If a truck is destined for the export yard, the truck is considered to have arrived with a container. In the export yard, the container is unloaded from the truck for storage. At a later time, containers stored in the export yard will be loaded onto a ship. After unloading, the truck may either depart the export yard for the outbound gate or may proceed to the import yard to be loaded with a container for import. In the latter case, after loading, the truck then proceeds to the outbound gate and finally departs the terminal.

As mentioned previously, if a ship is waiting, a truck may proceed to the dock. At the dock, if the truck has no container, it is loaded with a container from the ship and then proceeds to the outbound gate. This procedure is referred to as *live loading*. If a truck has a container upon arrival at the dock, the container is unloaded from the truck and loaded onto the ship. This procedure is referred to as *live unloading*. As in the export yard, after a truck is unloaded, it may then be loaded with a container from the ship. In either case,

after loading or unloading is complete, the truck proceeds to the outbound gate and departs the terminal.

III.Ship Dock: Ships may be scheduled to arrive at the terminal for loading and unloading of shipping containers. Only one ship may be serviced at a time. After a ship arrives at the terminal, loading and unloading begin immediately. The ship may load containers from the export yard and unload containers for storage in the import yard (to be removed later by trucks or trains).

As mentioned earlier, as long as a ship is docked, trucks may arrive at the dock for loading and unloading containers (live loading/unloading processes). In addition, if a train is currently at the terminal, containers from the train may be loaded onto the ship and containers from the ship may be loaded onto the train, directly. If a train is not available (either because there is not one in the terminal or there is one in the terminal but it is currently filled to capacity) all containers destined for the train are diverted to the import yard for storage.

IV. Train Station: Like ships, trains may be scheduled to arrive at the terminal for loading and unloading of shipping containers. Only one train may be serviced at a time. After a train arrives at the terminal, loading and unloading begin immediately. The train will be loaded by containers from the import yard and the unloaded containers will be transferred to the export yard.

Trucks do not arrive at the train station, directly. However, if a ship is currently at the dock, containers from the train may be loaded onto the ship and containers from the ship may be loaded onto the train, directly. If a ship is not available (either because there is not one at the dock or there is one at the dock but it is currently filled to capacity) all containers destined for the ship are diverted to the export yard for storage.

3.3 The Simulator

The *Simulator window*, shown in Figure 11, is the main program window in the *Terminal Simulator*. The Simulator window contains the graph on which terminal data is charted and also provides access to the following main features:

1. Open/Save a simulation scenario,
2. Save a chart as an image file,
3. Start/Reset a simulation scenario,
4. Configure a simulation scenario, and
5. Select data to plot.

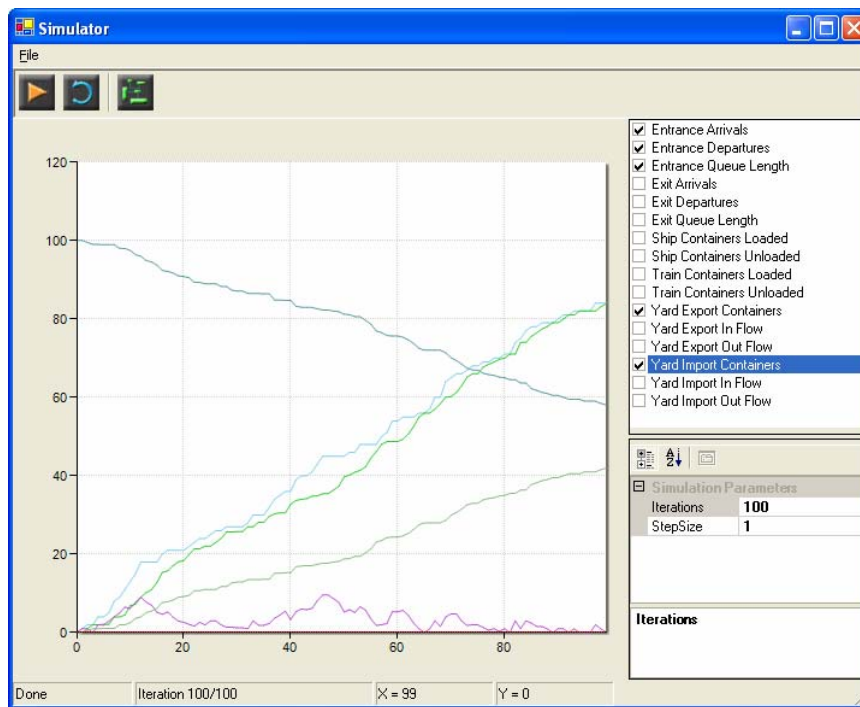


Figure 11: The Simulator window

After a scenario has been created, select “File→Save Simulation” to save the scenario to a data file. To open a previously saved scenario, select “File→Open Simulation.” The graph of the simulation can be saved as an image file by selecting “File→Save Chart.”

Following is a description of the utilities available for creating, executing and analyzing a simulation scenario.

3.3.1 Scenario Editor

Before a simulation can be executed the terminal must be configured. The *Scenario Editor* dialog is accessed by pressing the “Configure Scenario” button from the Simulator window (Figure 13).

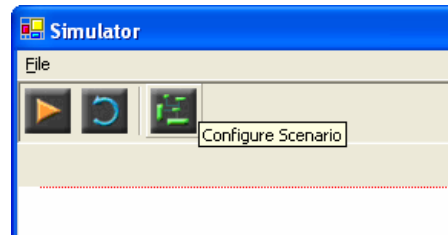


Figure 12: Configure Scenario

In the Scenario Editor dialog, terminal parameters can be set and ship, train, and truck arrivals can be scheduled (Figure 13). In addition, the “initial state” of the import and export yards (i.e., the number of containers in storage) can be set and a profile for ship, train, and truck arrivals can be viewed.

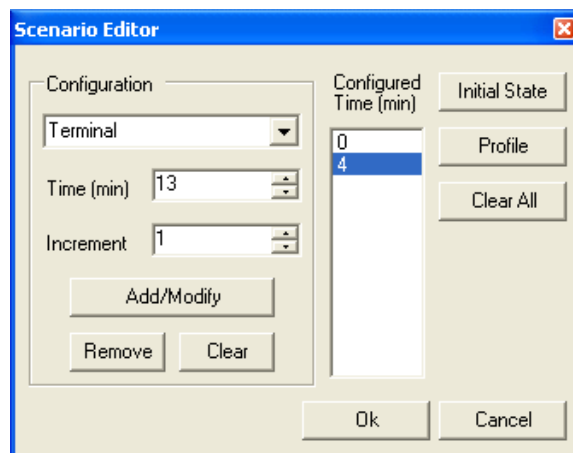


Figure 13: Scenario Editor

In the Scenario Editor dialog, use the combo box on the left to select the terminal, ship, train or truck arrivals for configuration. Next, a number must be entered, for example “13”, in the box labeled “Time”. This is the time (in minutes) at which the configuration will take effect. The value of the “Time” box will be incremented by the amount shown in the “Increment” box.

Pressing the “Add/Modify” button will open the *Configuration* dialog and one of the following three events will occur:

- I. If a configuration for this time does not exist, a new configuration will be created. Existing configurations appear, sorted by the time at which they take effect, in the box labeled “Configured Time.”
- II. If a configuration exists for a time prior to the selected time, the values for that configuration will be copied to the new configuration. For example, based on Figure 3, if “13” is selected for the new time, the values for the new configuration will be copied from time 4.
- III. Finally, if a configuration for the time already exists, it can be modified. For example, if “4” is entered into the “Time” box, the Terminal Configuration dialog will enable the user to modify the values for the configuration at time 4.

The new configuration will take effect beginning at time 13 and will continue until either the simulation ends or a new configuration is specified. Pressing “Remove” will delete the selected time for the selected configuration. Pressing “Clear” will delete all times for the selected configuration. Pressing “Clear All” will delete for *all times for all of the Terminal, Ship Arrivals, Train Arrivals and Truck Arrivals configurations*. In other words, the entire scenario will be deleted.

The Configuration window allows the user to configure the Terminal, Ship, Train, or Truck Arrivals, as follows:

- I. Terminal Configuration.** The *Terminal Configuration* dialog (Figure 15) shows a diagram of the terminal in the box on the right and a list of parameters in the box on the left.

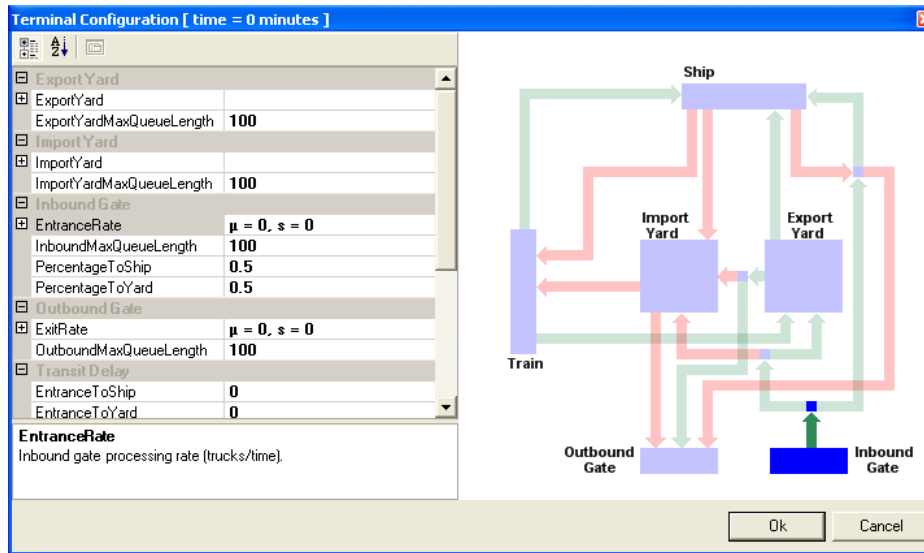


Figure 14: Terminal Configuration

The terminal parameters and definitions are listed in Table 1. When a parameter is selected, the relevant path in the terminal is highlighted.

Table 1: Terminal Parameters

Name	Definition
ExportYard	Storage yard for export containers
OutFlowRate	Flow rate (containers/minute) of containers to ship
TruckRate	Processing rate (trucks/minute) of arriving trucks
ExportYardMaxQueueLength	The maximum queue length of trucks
ImportYard	Storage yard for import containers
OutFlowRate	Flow rate (containers/minute) of containers to train
TruckRate	Processing rate (trucks/minute) of arriving trucks
ImportYardMaxQueueLength	The maximum queue length of trucks
Inbound Gate	Terminal entrance gate for inbound trucks
EntranceRate	Processing rate (trucks/minute) of arriving trucks
PercentageToShip	Percentage of arriving trucks bound for ship
PercentageToYard	Percentage of arriving trucks bound for yard
InboundMaxQueueLength	The maximum queue length of trucks
OutBound Gate	Terminal exit gate for outbound trucks
ExitRate	Processing rate (trucks/minute) of departing trucks
OutboundMaxQueueLength	The maximum queue length of trucks
TransitDelay	Delay (minutes)
EntranceToShip	Delay (minutes) from inbound gate to ship
EntranceToYard	Delay (minutes) from inbound gate to yard
ShipToExit	Delay (minutes) from ship to outbound gate
YardToExit	Delay (minutes) from yard to outbound gate

Truck Arrivals for Ship	
PercentageShipExport	Percentage of trucks bringing containers to be loaded onto the ship
PercentagShipImport	Percentage of trucks going to pick up containers unloaded from the ship
PercentageShipImportAfterExport	Percentage of trucks that pick up containers unloaded from the ship <i>after</i> leaving a container to be loaded onto the ship
Truck Arrivals for Yard	
PercentageYardExport	Percentage of trucks unloading containers for storage in the export yard
PercentageYardImport	Percentage of trucks loading containers from storage in the import yard
PercentageYardImportAfterExport	Percentage of trucks loading containers from storage in the import yard <i>after</i> unloading containers for storage in the export yard

II. Ship Arrivals: The *Ship Configuration* dialog is similar to the Terminal Configuration dialog and shows a diagram of the terminal in the box on the right and a list of parameters in the box on the left. The ship parameters and definitions are listed in Table 2.

Table 2: Ship Parameters

Name	Definition
Container Inventory (imports)	Containers brought by the ship for import
ToTrainInventory	Total containers to unload for the train
ToYardInventory	Total containers to unload for the yard
Container Loading (exports)	Containers the ship will load for export
ContainersToLoad	Number of containers to load before departing
Container Unloading (imports)	Terminal entrance gate for inbound trucks
ToTrainRate	Flow rate of containers to train (containers/minute)
ToYardRate	Flow rate of containers to yard (containers/minute)
Live Loading (exports)	Terminal exit gate for outbound trucks
LoadingRate	Processing rate for live loading operations (containers/minute)
Live Unloading	Delay (minutes)
LiveUnloadingInventory	Total containers to unload from ship to truck
LiveUnloadingRate	Processing rate for live unloading operations (containers/minute) from ship to truck

III. Train Arrivals: The *Train Configuration* dialog shows a diagram of the terminal in the box on the right and a list of parameters in the box on the left. The train parameters and definitions are listed in Table 3.

Table 3: Train Parameters

Name	Definition
Container Loading (imports)	Containers the ship will load for export
ContainersToLoad	Number of containers to load before departing
Container Unloading (exports)	Terminal entrance gate for inbound trucks
ToShipRate	Flow rate of containers to ship (containers/minute)
ToYardRate	Flow rate of containers to yard (containers/minute)
Container Inventory (imports)	Containers brought by the ship for import
ToShipInventory	Total containers to unload for the ship
ToYardInventory	Total containers to unload for the yard

IV. Truck Arrivals: The *Truck Arrival Rate Configuration* dialog shows a diagram of the terminal in the box on the right and a list of parameters in the box on the left. The truck arrival rate parameters and definitions are listed in Table 4.

Table 4: Truck Parameters

Name	Definition
Misc	
ArrivalRate	The arrival rate of the trucks (trucks/minute)

Pressing the “Initial State” button opens the *Initial State* dialog showing a list of parameters used to set the initial state of the import and export yard. The initial state parameters and definitions are listed in Table 5.

Table 5: Initial State

Name	Definition
Yard	
Export Inventory	Number of containers in the export yard
Import Inventory	Number of containers in the import yard

Pressing the “Profile” button creates a new window that shows a profile of truck, train and ship arrivals.

3.3.2 Executing a Simulation

The *Simulation Parameters* box in the Simulator window is used to configure the number of *iterations* (or minutes of “virtual time”) for the simulation to run (Figure 15). The simulation *StepSize* specifies how often to record data. For example, if *StepSize*=1, the simulator will record data after every iteration. If *StepSize*=10, the simulator will record data after every 10 iterations. The simulator’s performance will vary depending on the ratio of *Iterations* to *StepSize* and the configuration of the computer being used.

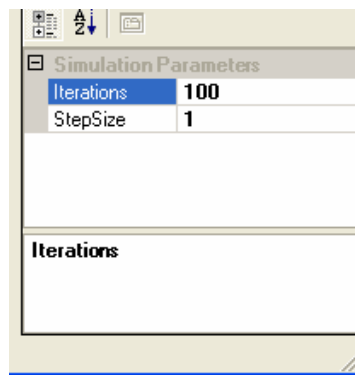


Figure 15: Simulation Parameters

After a scenario has been configured, press the “Start Simulation” button (Figure 16) to start the simulation.

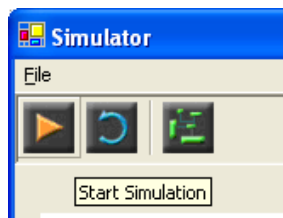


Figure 16: Start Simulation

The status bar shows the state of the simulation and the number of completed simulation iterations (Figure 17). The “status” may be “Ready” (the simulation is ready to run), “Running” (the simulation is currently executing) or “Done” (the simulation is complete).

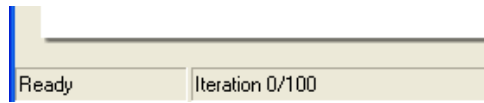


Figure 17: Status Bar

After the simulation has completed, it must be reset before it can be run again. The simulation can be reset by pressing the “Reset Simulation” button (Figure 18).

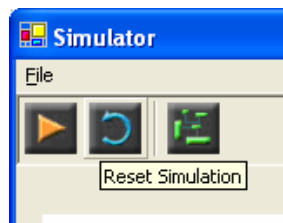


Figure 18: Reset Simulation

3.3.3 Viewing Simulation Data

After the simulation has executed, data may be plotted on the chart in the Simulator window for analysis. Select the data to plot from the list in the box on the right (Figure 19).

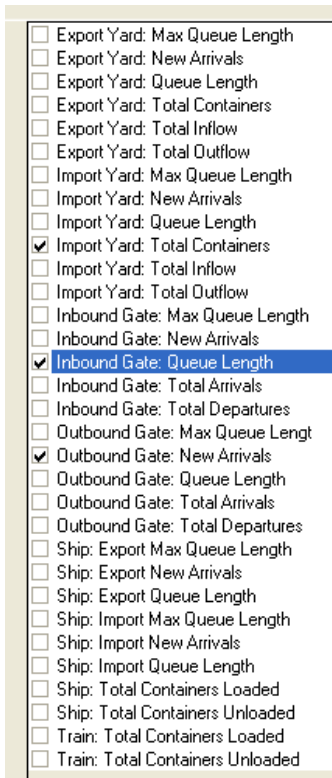


Figure 19: Plotting Data

Table 6 shows the data that is available for plotting.

Table 6: Data Analysis

Name	Definition
ExportYard	Storage yard for export containers
Max Queue Length	Maximum queue length
New Arrivals	Number of new arrivals per minute
Queue Length	Current queue length of trucks
Total Containers	Total containers in storage
Total InFlow	Total number of containers that have flowed into the yard
Total OutFlow	Total number of containers that have flowed out of the yard
ImportYard	Storage yard for import containers
Max Queue Length	Maximum queue length
New Arrivals	Number of new arrivals per minute
Queue Length	Current queue length of trucks
Total Containers	Total containers in storage
Total InFlow	Total number of containers that have flowed into the yard
Total OutFlow	Total number of containers that have flowed out of the yard
Inbound Gate	Terminal entrance gate for inbound trucks
Max Queue Length	Maximum queue length

New Arrivals	Number of new arrivals per minute
Queue Length	Current queue length of trucks
Total Arrivals	Total number of trucks that have arrived
Total Departures	Total number of trucks that have departed
OutBound Gate	Terminal exit gate for outbound trucks
Max Queue Length	Maximum queue length
New Arrivals	Number of new arrivals per minute
Queue Length	Current queue length of trucks
Total Arrivals	Total number of trucks that have arrived
Total Departures	Total number of trucks that have departed
Ship	Current ship
Export Max Queue Length	Maximum queue length of trucks waiting to unload containers to the ship
Export New Arrivals	Number of new arrivals per minute queuing to unload containers to the ship
Export Queue Length	Current queue length of trucks waiting to unload containers to the ship
Import Max Queue Length	Maximum queue length of trucks waiting to load containers from the ship
Import New Arrivals	Number of new arrivals per minute queuing to load containers from the ship
Import Queue Length	Current queue length of trucks waiting to load containers from the ship
Total Containers Loaded	Total number of containers loaded from arriving trucks
Total Containers Unloaded	Total number of containers unloaded to yard, train, and arriving trucks
Train	Current train
Total Containers Loaded	Total containers loaded from import yard
Total Containers Unloaded	Total containers unloaded to export yard and ship

It is possible to “Zoom” into a smaller section of the chart. Press and hold the left mouse button and drag over the desired area (Figure 20). Release the mouse button for a closer view (Figure 21). The status bar shows the X- and Y-coordinate of the mouse. It is possible to zoom in multiple times.

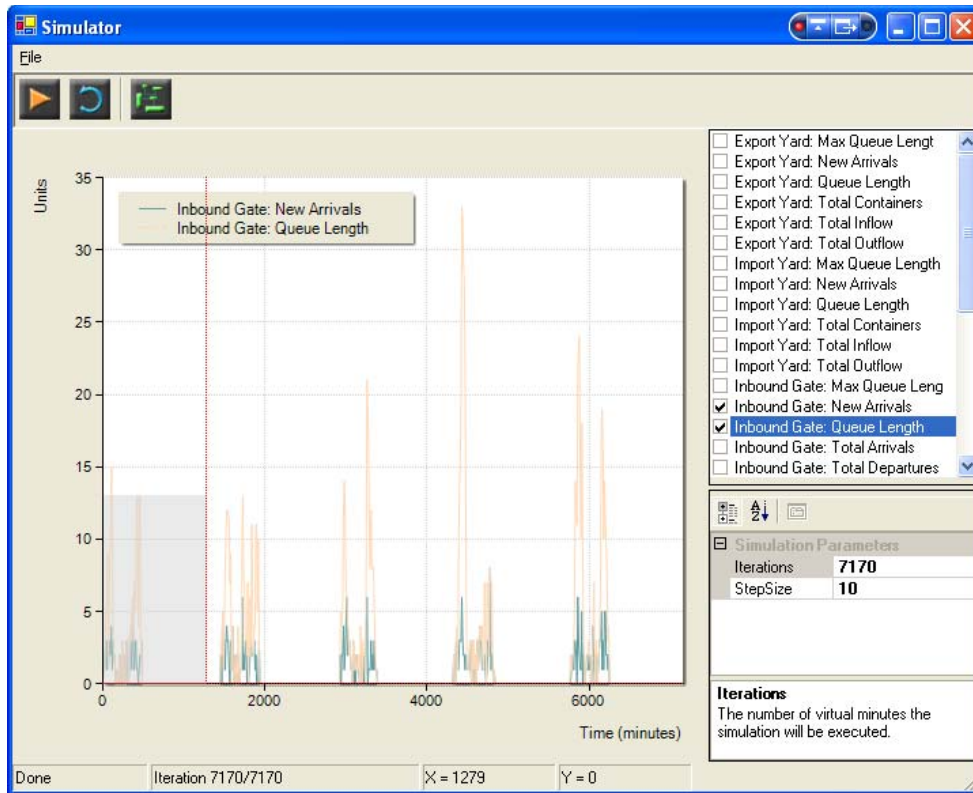


Figure 20: Zoom into the Chart

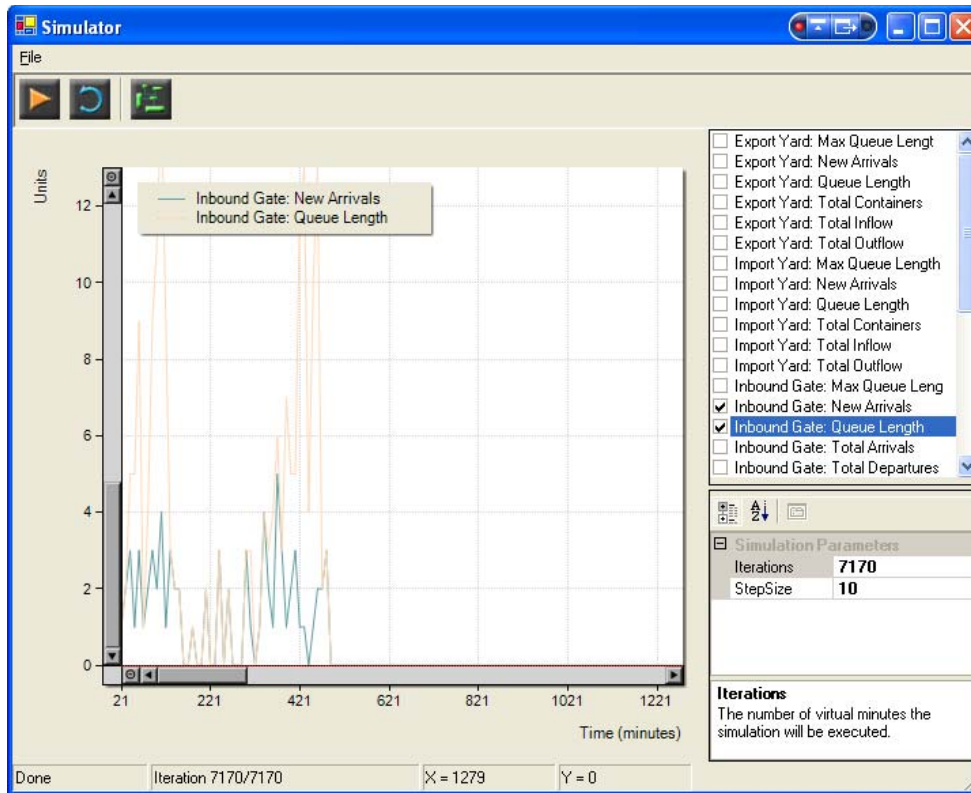


Figure 21: A Closer View

Press and release the right mouse button over the chart area for a context menu (Figure 22). Select “Zoom Out” to zoom out by 1x. Select “Reset Zoom” to zoom out to the default view. “Reset and Start” will reset and execute the simulation. Select “Hide Legend” to hide the legend if it is visible.

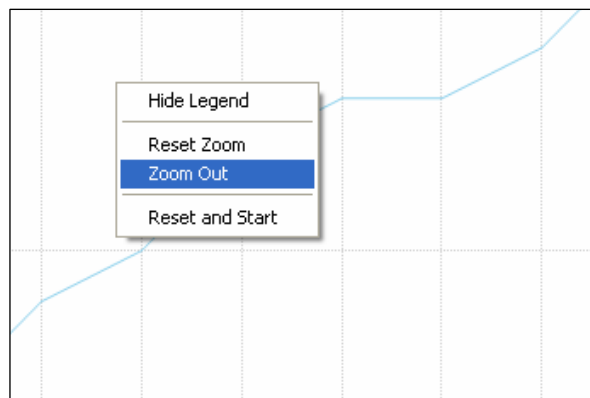


Figure 22: Chart Context Menu

3.4 Examples

3.4.1 Truck Arrivals

In this sample, trucks will arrive at the inbound gate for processing. Afterwards each truck will either go to the import yard or to the export yard. A truck destined for the import yard will unload a container. A truck destined for the export yard will load a container (if one is available).

Configure the Scenario

1. Start the application.
2. Click “Configure Scenario” (Figure 23).

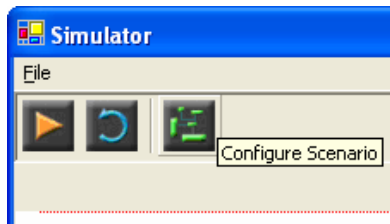


Figure 23: Configure Scenario

3. In the *Scenario Editor*, select “Terminal” in the combo-box and set Time to 0. Click on “Add/Modify” (Figure 24). The *Terminal Configuration* dialog will appear showing a diagram of the terminal and a list of terminal parameters (Figure 25).

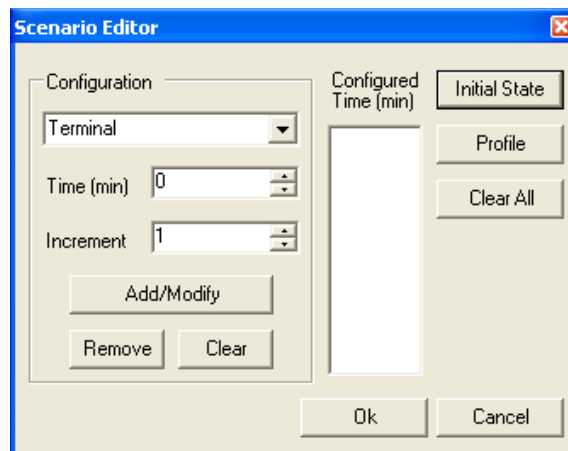


Figure 24: Scenario Editor

- A truck will first enter the terminal at the inbound gate. Select the “EntranceRate” parameter. The “EntranceRate” parameter is the processing rate (trucks/minute) for trucks arriving at the inbound gate. For “Type” select “Gaussian”. In the Parameters section, enter the value of 1 for the “Mean.” Enter 1 for “Variance” as well. The specified parameter means that the amount of time any arriving truck will spend at the entrance gate will have a Gaussian distribution with a mean and a variance of 1.

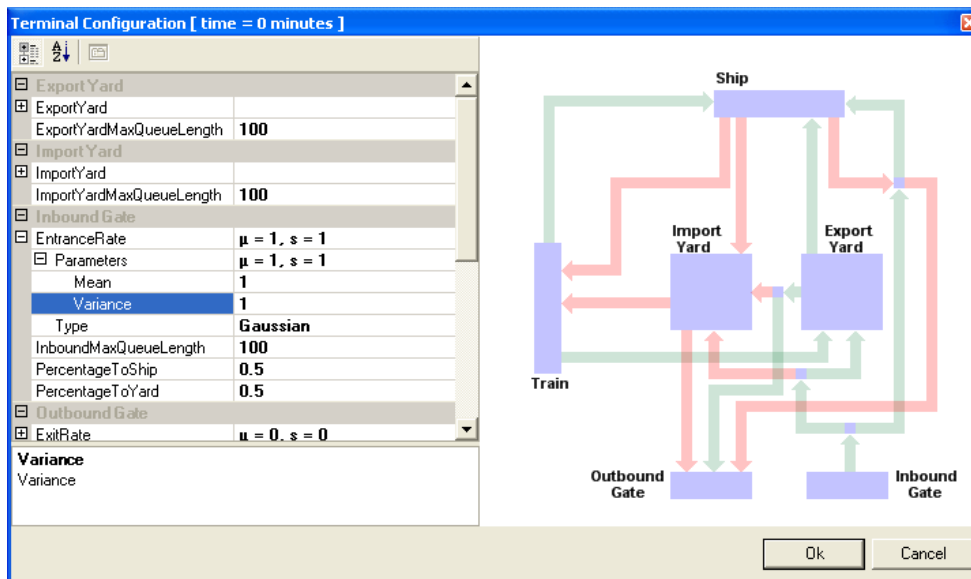


Figure 25: Entrance Rate

- In this example, after a truck has been processed at the inbound gate, it will either go to the export yard or to the inbound yard. In other examples a truck may also go to a ship for live loading and unloading operations. For now, select the “Inbound Gate” category in the *Terminal Configuration* dialog and enter the value of 1 for the “PercentageToYard” parameter. In other words, 100% of arriving trucks will go to the import or export yard. “PercentageToShip” is automatically calculated to be 0.
- In the “Truck Arrivals for Yard” category, select “PercentageYardExport” and enter 0.5. “PercentageYardImport” will be automatically calculated to be 0.5 also. This means that 50% of trucks arriving for the yard will go to the export yard and 50% will go to the import yard. The simulation can also be configured such that a percentage of

trucks that unload a container at the export yard may then load a container at the import yard. This feature will not be used in this example, enter 0 for the “PercentageYardImportAfterExport” parameter.

7. In the “Export Yard” category, select “ExportYard” and then “TruckRate”. The “TruckRate” is the rate (trucks/minute) at which containers are unloaded from arriving trucks. Enter the value of 1 for the “Mean”. Enter 1 for “Variance” and for “Type” select “Gaussian”.
8. In the “Import Yard” category, select “Import Yard” and then “TruckRate”. The “TruckRate” is the rate (trucks/minute) at which arriving trucks are loaded with containers. In Parameters, enter the value of 1 for the “Mean”. Enter 1 for “Variance” and for “Type” select “Gaussian”.
9. After loading or unloading, a truck will leave the terminal at the outbound gate. Click on “ExitRate”, then “Parameters” and enter the value of 1 for the “Mean”. Enter 1 for “Variance” as well. For “Type” select “Gaussian”. Click “Ok.” The “ExitRate” parameter is the processing rate (trucks/minute) for trucks arriving at the outbound gate.
10. In the *Scenario Editor* dialog, under configuration, select “Truck Arrivals” from the combo box (**Figure 26**). Make sure “Time” is set to 0 and then click “Add/Modify”. The *Truck Arrivals* configuration dialog will appear.

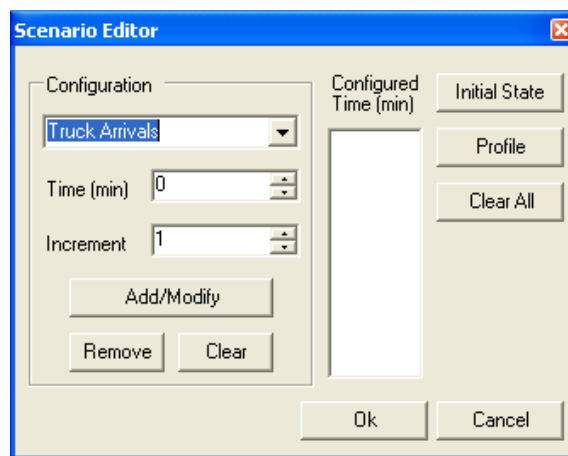


Figure 26: Truck Arrivals

11. For “ArrivalRate” select 1. Click “Ok.”
12. Back to the *Scenario Editor* dialog, click “Initial State” (Figure 27).

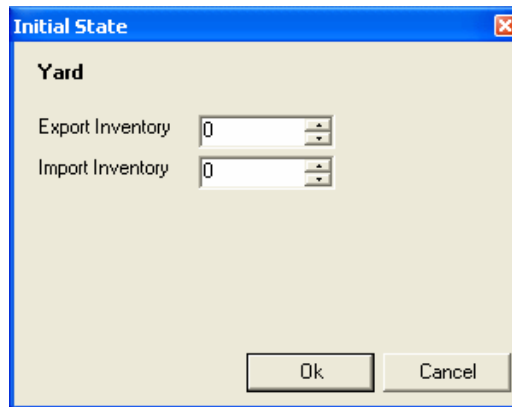


Figure 27: Initial State

13. In the *Initial State* dialog, initial state of the yard can be configured. Enter “100” for the “Import Inventory” parameter. Click “Ok” (Figure 27).
14. In the *Scenario Editor* dialog, click “Ok.” Configuration is complete.

Run the Simulation

1. In the main *Simulator* window, be sure that for the “Simulation Parameters,” Iterations = 100 and StepSize = 1. Click on the “Start simulation” button and the simulation will begin executing.
2. After the simulation has completed, data to plot can be selected from the box on the right. For example, check the “Inbound Gate: Total Arrivals” box. A plot of the total number of arrivals at the inbound gate per minute appears.
3. Check the “Inbound Gate: Total Departures” box. A plot of the total number of trucks departing the inbound gate appears.
4. The numerical difference between the “Entrance Arrivals” and the “Entrance Departures” is the number of trucks waiting to be processed at the inbound gate. Check the “Inbound Gate: Queue Length” box to plot the data.

5. After a truck is processed, it goes to either the import or export yard. According to the configuration specified earlier, the ratio should be 50/50 per 100 trucks. Check on the “Export Yard: Total Containers” box. A plot of the number of containers in the export yard versus time will appear on the chart. The last data point should be close to 50 since approximately 100 trucks arrived at the inbound gate and 50% of those trucks deposited a container in the export yard.
6. The import yard was configured such that it has 100 containers initially in storage. Check the “Import Yard: Total Containers” box to see a plot of the number of containers in the import yard versus time. The last data point should also be close to 50 since approximately 50% of the trucks arriving at the inbound gate removed a container from the import yard. See Figure 28 for an example of what the chart may look like.

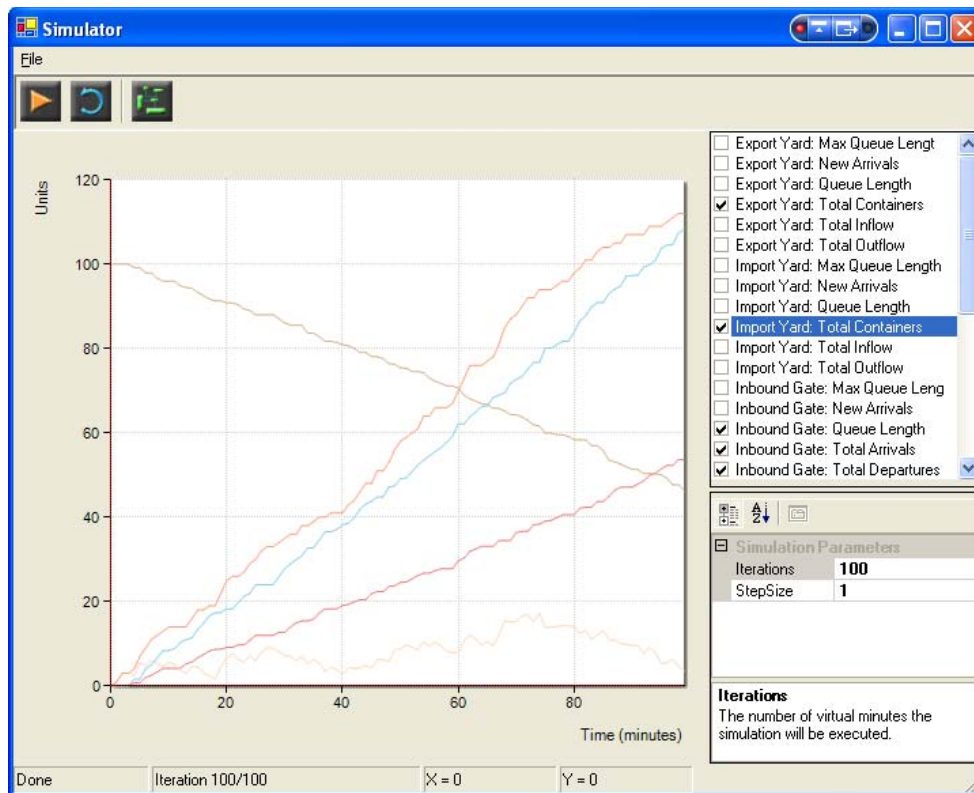


Figure 28: Plotting the Simulation Data

3.4.2 Train Arrivals

In this example, trains will arrive with containers for unloading. Containers may be unloaded to the yard or to a ship. At the same time, containers may be loaded onto the train from either the yard or a ship. In this example, containers from the yard will only be loaded and unloaded.

Configure the Scenario

1. Start the application.
2. Click “Configure Scenario.”
3. In the *Scenario Editor* dialog, select “Train Arrivals” from the combo box. Set “Time” to 25 and then click “Add/Modify” (Figure 29). The train will arrive at time = 25 minutes.

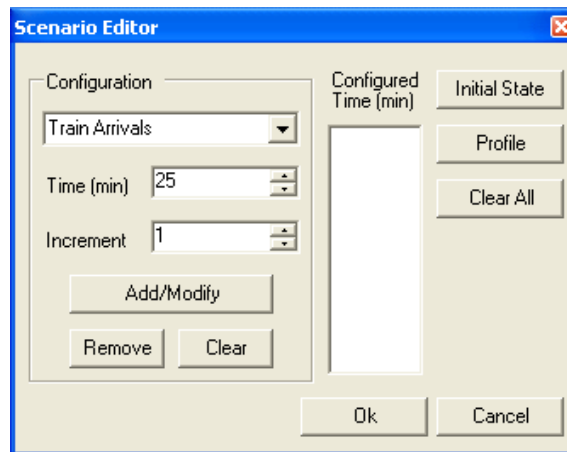


Figure 29: Train Arrivals

4. In the “Container Loading (imports)” category, select “ContainersToLoad” and enter 50. The value specifies the number of containers for the train to load (from both the yard and the ship).
5. In the “Container Inventory (exports)” category, select “ToYardInventory” and enter 25. The value specifies the number of containers for the train to unload to the yard. After all containers have been loaded and unloaded the train will depart.

- In the “Container Unloading (exports)” category, select “ToYardRate”. In “Parameters,” enter the value of 1 for the “Mean.” Enter 1 for “Variance” and for “Type” select “Gaussian.” This value specifies the rate at which containers are unloaded (containers/minute). Figure 30 shows the *Train Configuration* dialog. Click “Ok.”

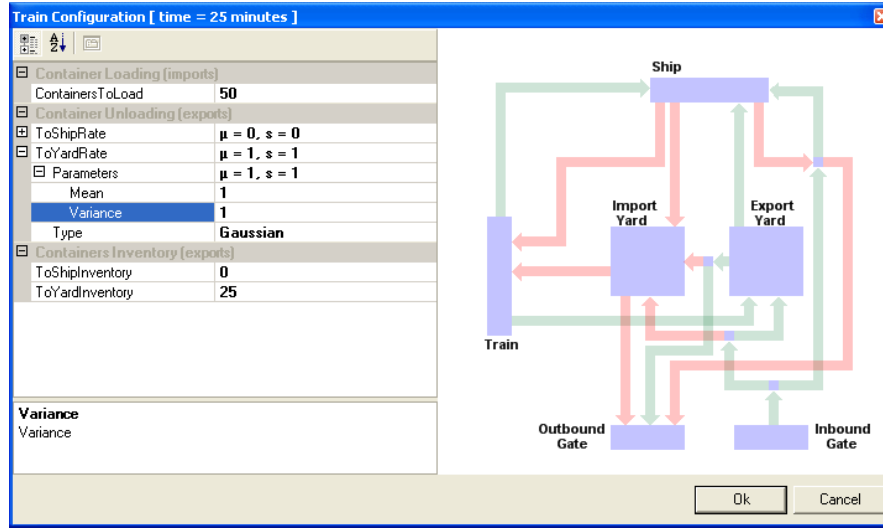


Figure 30: Train Configuration

- In the *Scenario Editor* dialog, select “Terminal” from the combo box. Set “Time” to 0 and then click “Add/Modify.”
- In the “Import Yard” category, select “ImportYard” and then “OutFlowRate”. The “OutFlowRate” is the rate (containers/minute) at which containers are transferred to the train. In “Parameters,” enter the value of 1 for the “Mean”. Enter 1 for “Variance” and for “Type” select “Gaussian.” Click “Ok.”
- In the *Scenario Editor* dialog, click “Initial State.”
- In the *Initial State* dialog, the initial state of the yard can be configured. Enter “100” for the “Import Inventory” parameter.
- Enter “50” for the “Export Inventory” parameter. Click “Ok.”
- In the *Scenario Editor* dialog, click “Ok.” Configuration is complete.

Run the Simulation

1. In the main *Simulator* window, be sure that for the “Simulation Parameters,” Iterations = 100 and StepSize = 1. Click on the “Start simulation” button and the simulation will begin executing.
2. Check the “Train: Total Containers Unloaded” box. A plot of the total number of containers unloaded by the train versus time will appear on the chart. Containers begin accumulating at time = 25 minutes since this is when the train arrived. Approximately 25 containers should be unloaded.
3. The export yard was configured such that it has 50 containers initially in storage. Check the “Export Yard: Total Containers” box to see a plot of the number of containers in the export yard versus time. Approximately 25 containers were transferred to the yard from the train.
4. Check the “Train: Total Containers Loaded” box. A plot of the total number of containers loaded by the train versus time will appear on the chart. Approximately 50 containers should be loaded. After all the containers for import have been loaded and all the containers for export have been unloaded, the train departs.
5. The import yard was configured such that it has 100 containers initially in storage. Check the “Import Yard: Total Containers” box to see a plot of the number of containers in the import yard versus time. Approximately 50 containers were transferred to the train for loading. See Figure 31 for an example of what the chart may look like.

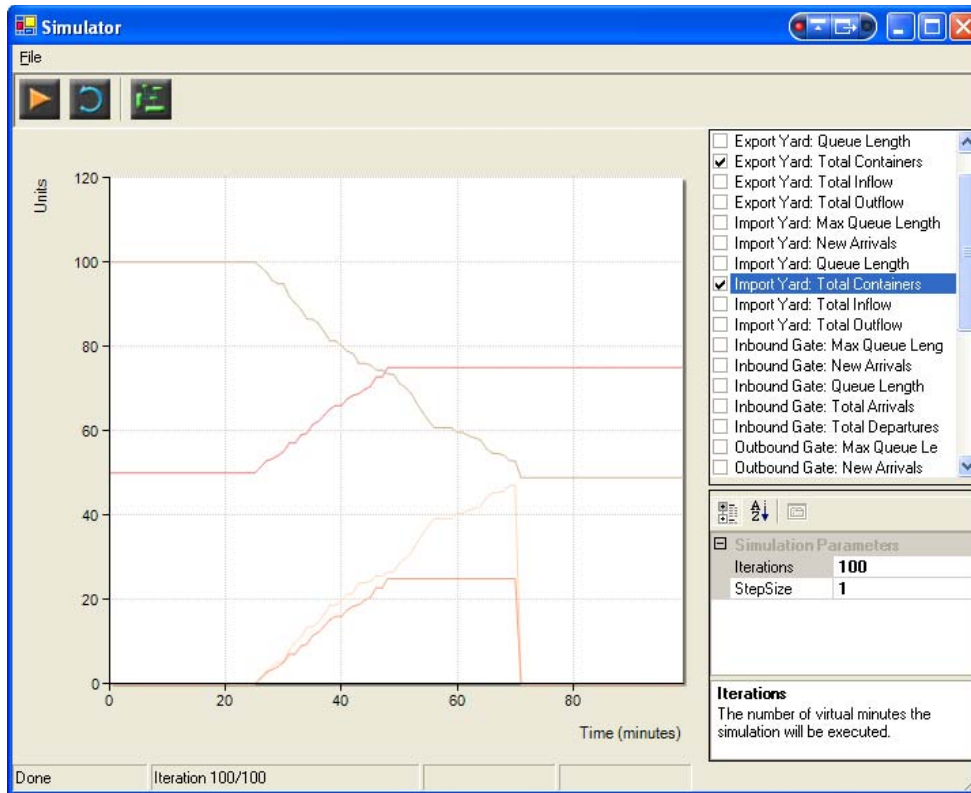


Figure 31: Plotting the Simulation Data

3.4.3 Ship Arrivals

In this example, ships will arrive with containers for unloading. Containers may be unloaded to the yard, a train or trucks. Containers may be loaded onto the ship from the yard, a train or trucks, as well. In this example, only containers from the yard will be loaded and unloaded.

Configure the Scenario

1. Start the application.
2. Click “Configure Scenario.”
3. In the *Scenario Editor* dialog, select “Ship Arrivals” from the combo box. Set “Time” to 25 and then click “Add/Modify” (Figure 32). The ship will arrive at time = 25 minutes.

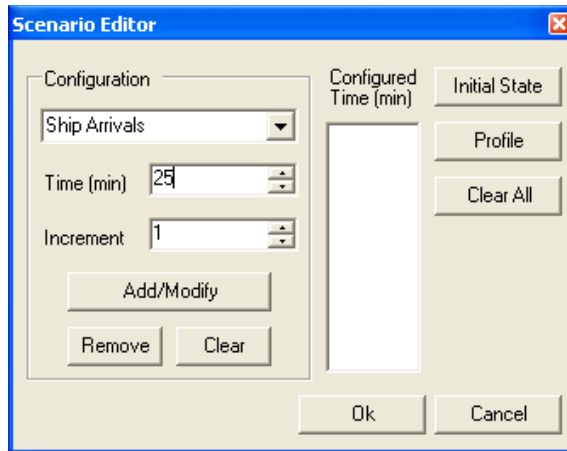


Figure 32: Ship Arrivals

4. In the “Container Loading (exports)” category, select “ContainersToLoad” and enter 50. The value specifies the number of containers for the ship to load (from the yard, train or trucks).
5. In the “Container Inventory (imports)” category, select “ToYardInventory” and enter 25. The value specifies the number of containers for the ship to unload to the yard. After all containers have been loaded and unloaded the ship will depart.
6. In the “Container Unloading (imports)” category, select “ToYardRate”. In “Parameters,” enter the value of 1 for the “Mean.” Enter 1 for “Variance” and for “Type” select “Gaussian.” This value specifies the rate at which containers are unloaded (containers/minute) (Figure 33). Click “Ok.”

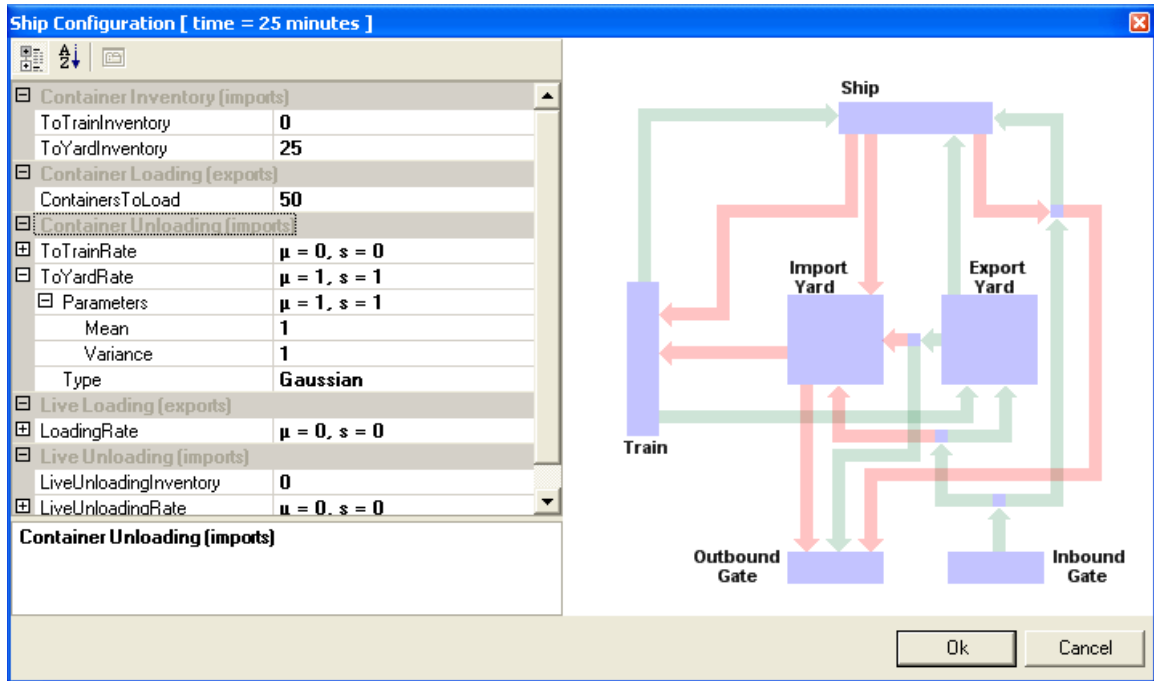


Figure 33: Ship Configuration

7. In the *Scenario Editor* dialog, select “Terminal” from the combo box. Set “Time” to 0 and then click “Add/Modify.”
8. In the “Export Yard” category, select “ExportYard” and then “OutFlowRate”. The “OutFlowRate” is the rate (containers/minute) at which containers are transferred to the ship. In “Parameters,” enter the value of 1 for the “Mean”. Enter 1 for “Variance” and for “Type” select “Gaussian.” Click “Ok.”
9. In the *Scenario Editor* dialog, click “Initial State.” Click “Ok.”
10. In the *Initial State* dialog, the initial state of the yard can be configured. Enter “100” for the “Export Inventory” parameter.
11. Enter “50” for the “Import Inventory” parameter. Click “Ok.”
12. In the *Scenario Editor* dialog, click “Ok.” Configuration is complete.

Run the Simulation

1. In the main *Simulator* window, be sure that for the “Simulation Parameters,” Iterations = 100 and StepSize = 1. Click on the “Start simulation” button and the simulation will begin executing.
2. Check the “Ship: Total Containers Unloaded” box. A plot of the total number of containers unloaded by the ship versus time will appear on the chart. Approximately 25 containers should be unloaded.
3. The import yard was configured such that it has 50 containers initially in storage. Check the “Import Yard: Total Containers” box to see a plot of the number of containers in the import yard versus time. Approximately 25 containers were transferred to the yard from the ship.
4. Check the “Ship: Total Containers Loaded” box. A plot of the total number of containers loaded by the ship versus time will appear on the chart. Approximately 50 containers should be loaded.
5. The export yard was configured such that it has 100 containers initially in storage. Check the “Export Yard: Total Containers” box to see a plot of the number of containers in the export yard versus time. Approximately 50 containers were transferred to the ship for loading. See Figure 34 for an example of what the chart may look like.

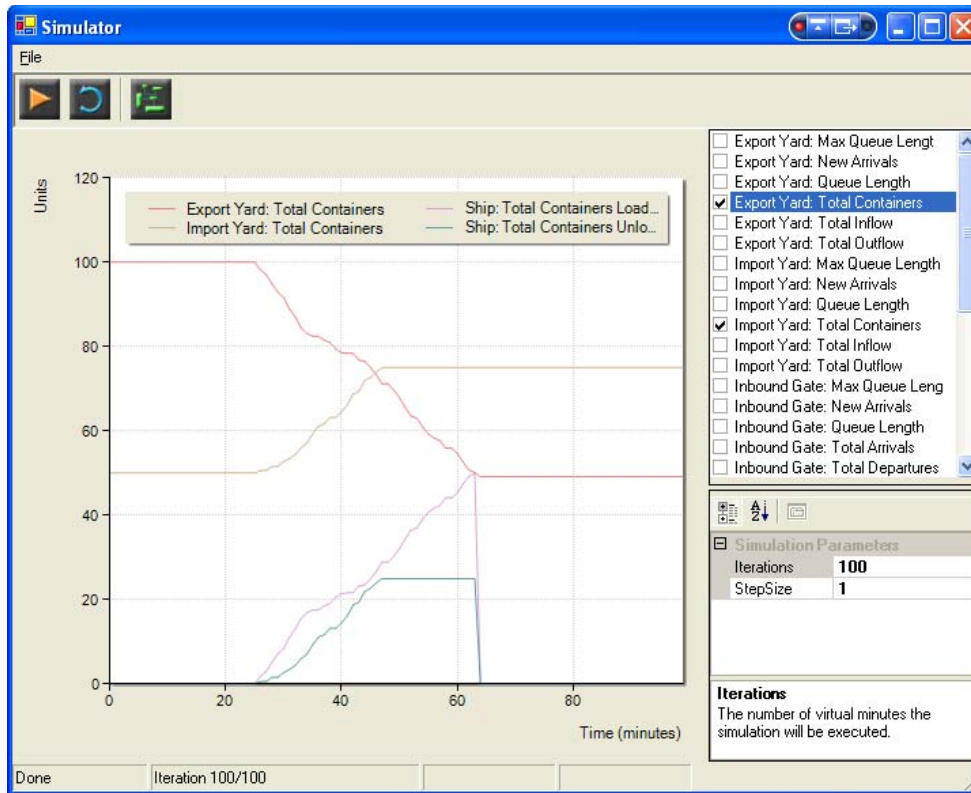


Figure 34: Plotting the Simulation Data

3.4.4 Ship Live Loading and Unloading

In this example, ships will arrive with containers for unloading. Containers may be loaded and unloaded directly from/to arriving trucks. As discussed earlier, this operation is referred to as “Live Loading” or “Live Unloading.”

Configure the Scenario

1. Start the application.
2. Click “Configure Scenario.”
3. In the *Scenario Editor* dialog, select “Ship Arrivals” from the combo box. Set “Time” to 0 and then click “Add/Modify.” The ship will arrive at time = 0 minutes.
4. In the “Container Loading (exports)” category, select “ContainersToLoad” and enter 35. The value specifies the number of containers for the ship to load (from the yard, train or trucks).

5. In the “Live Loading” category, select “LoadingRate.” This value specifies the rate at which containers are loaded (containers/minute) from the trucks. In “Parameters,” enter the value of 1 for the “Mean”. Enter 1 for “Variance” and for “Type” select “Gaussian.”
6. In the “Live Unloading” category, select “LiveUnloadingInventory” and enter 25. The value specifies the number of containers for the ship to unload to the trucks. After all containers have been loaded and unloaded the ship will depart.
7. In the “Live Unloading” category, select “LiveUnloadingRate.” In “Parameters,” enter the value of 1 for the “Mean”. Enter 1 for “Variance” and for “Type” select “Gaussian.” This value specifies the rate at which containers are unloaded (containers/minute) to the trucks (Figure 35). Click “Ok.”

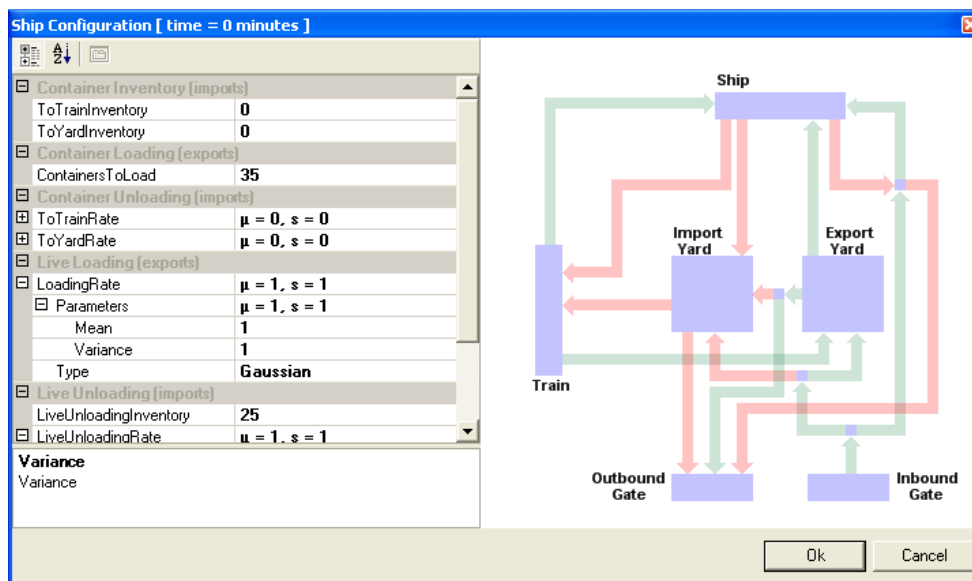


Figure 35: Ship Configuration

8. In the *Scenario Editor* dialog, select “Terminal” from the combo box. Set “Time” to 0 and then click “Add/Modify.”
9. A truck will first enter the terminal at the inbound gate. In the “Inbound Gate” click on the “EntranceRate,” then “Parameters,” and enter the value of 1 for the “Mean.” Enter 1 for “Variance” as well. For “Type” select “Gaussian.” The “EntranceRate”

- parameter is the processing rate (trucks/minute) for trucks arriving at the inbound gate.
10. In this example, after a truck has been processed at the inbound gate, it will go to ship. Select the “Inbound Gate” category in the *Terminal Configuration* dialog and enter the value of 1 for the “PercentageToShip” parameter. In other words, 100% of arriving trucks will go to the ship for live loading or unloading. “PercentageToYard” is automatically calculated to be 0.
 11. In the “Truck Arrivals for Ship” category, select “PercentageShipExport” and enter 0.5. “PercentageShipImport” will be automatically calculated to be 0.5 also. This means that 50% of trucks arriving for the yard will go to the export yard and 50% will go to the import yard. The simulation can also be configured such that a percentage of trucks that unload a container to the ship may then load a container from the ship. This feature will not be used in this example, enter 0 for the “PercentageYardImportAfterExport” parameter.
 12. After loading or unloading, a truck will leave the terminal at the outbound gate. In the “Outbound Gate” click on the “ExitRate,” followed by “Parameters,” and enter the value of 1 for the “Mean.” Enter 1 for “Variance” as well. For “Type” select “Gaussian.” The “ExitRate” parameter is the processing rate (trucks/minute) for trucks arriving at the outbound gate. Click “Ok.”
 13. In the *Scenario Editor* dialog, select “Truck Arrivals” from the combo box. Make sure “Time” is set to 0 and then click “Add/Modify.”
 14. For “ArrivalRate” select 1. Click “Ok.”
 15. In the *Scenario Editor* dialog, click “Ok.”

Run the Simulation

1. In the main *Simulator* window, be sure that for the “Simulation Parameters,” Iterations = 100 and StepSize = 1. Click on the “Start simulation” button and the simulation will begin executing.

2. Check the “Inbound Gate: Total Arrivals” box. A plot of the total number of arrivals at the inbound gate per minute appears.
3. Check the “Inbound Gate: Total Departures” box. A plot of the total number of trucks departing the inbound gate appears. After a truck is processed, it will go to the ship.
4. The numerical difference between the “Entrance Arrivals” and the “Entrance Departures” is the number of trucks waiting to be processed at the inbound gate. Check the “Inbound Gate: Queue Length” box to plot the data.
5. Check the “Ship: Total Containers Loaded” box. A plot of the total number of containers loaded by the ship from a truck versus time will appear on the chart. Approximately 35 containers should be loaded.
6. Check the “Ship: Total Containers Unloaded” box. A plot of the total number of containers unloaded by the ship versus time will appear on the chart. Approximately 25 containers should be unloaded. The ship departs after all containers have been loaded and unloaded. See Figure 36 for an example of what the chart may look like.

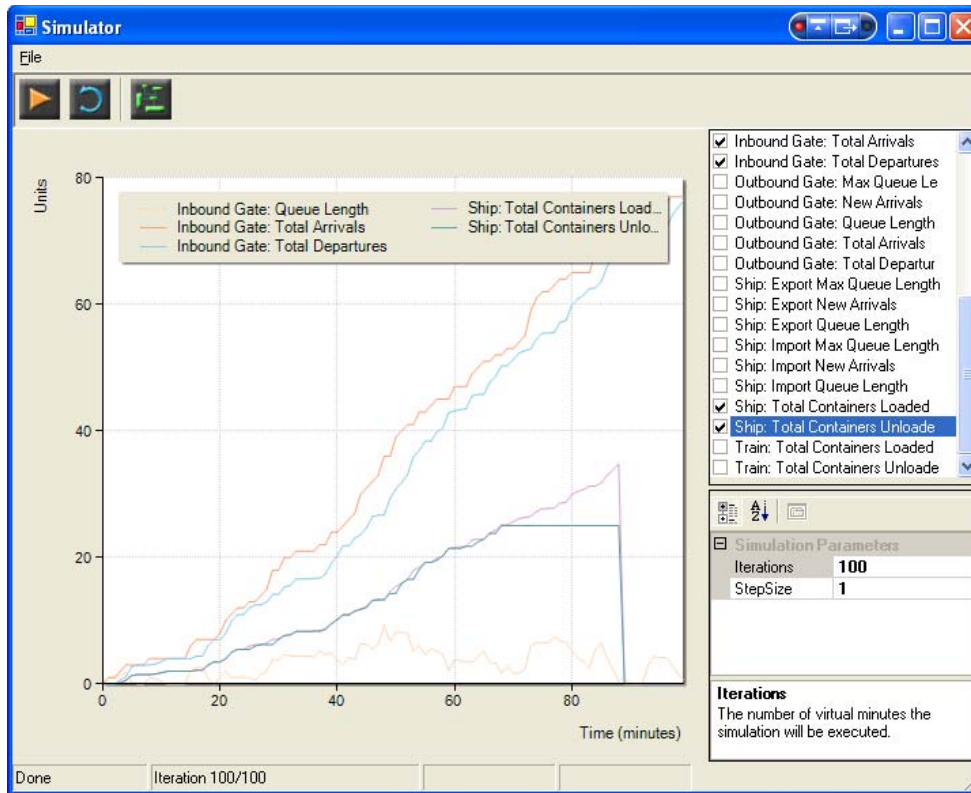


Figure 36: Plotting the Simulation Data

4 Part III: Impact of Time Window System on the Container Flows.

In this section we will use the *Terminal Simulator* software, as described in Section 3, to study the effects of the time window appointment system on various terminal operations. We will run several simulation scenarios, and we will compare the current practices to the appointment system. The parameters of the simulation model are set based on real data collected at certain Port of Long Beach / Port of Los Angeles (POLB/POLA) terminals over several days in July and August of 2004.

The section is organized as follows: First the data collection is discussed and data analysis results are presented; next the model parameters are set based on the statistical properties of the data; finally several simulation scenarios are created and presented. The scenarios compare the current practices, without the appointment system, to the case when the time window appointment system is applied.

4.1 Data Collection

On July 27, 28, 29 and on August 5, 2004 teams of students from the University of Southern California (USC) and California State University at Long Beach (CSULB), under the supervision of Dr. Gen Giuliano and Dr. Tom O'Brien, collected data on truck arrivals and departures at two terminals at the port of Long Beach. At this point the authors would like to acknowledge and thank Dr. Giuliano and Dr. O'Brien for their willingness to share the data with us.

The data collected include:

- Arrival times of trucks at the inbound gate.
- Waiting times from the gate to the pedestal, where a truck is being processed and is allowed to move onto the terminal area to load/unload.
- Departure times from the outbound gate.

Furthermore, the arriving trucks are classified into three categories:

- Bobtail (BT), if they do not have a trailer.

- Container (CT), if they carry a trailer with a container. In this case the container could be loaded or empty, but the data collection method does not differentiate between these two cases.
- Chassis (CA), if they carry a chassis only, without a container.

The data used for this report are the data collected on July 27, 28 and 29 at the first terminal. The data were collected continuously from 8:00 a.m. to 4:00 p.m. The teams at the inbound and outbound gates were recording the arrival and departure times of the trucks, plus additional identification characteristics, such as truck identification numbers, color, etc. For the purposes of this report, the few trucks whose identification was not matched from inbound gate to outbound gate were discarded, and only the matched trucks were used for further analysis.

4.2 Data Analysis

4.2.1 Truck Arrivals

The time profile of truck arrivals is shown in Figure 37, plotted every 10 minutes, from 8:00 a.m. to 4:00 p.m. As one can see, the graph has a deep drop in the morning (around 11 a.m.), which separates it into two parts: the morning and the afternoon sections. The two separate sections can be explained to a degree, by the fact that these are truckers who came to the port in the morning and after completing the morning job returned to the port in the afternoon with a new job to either load or unload.

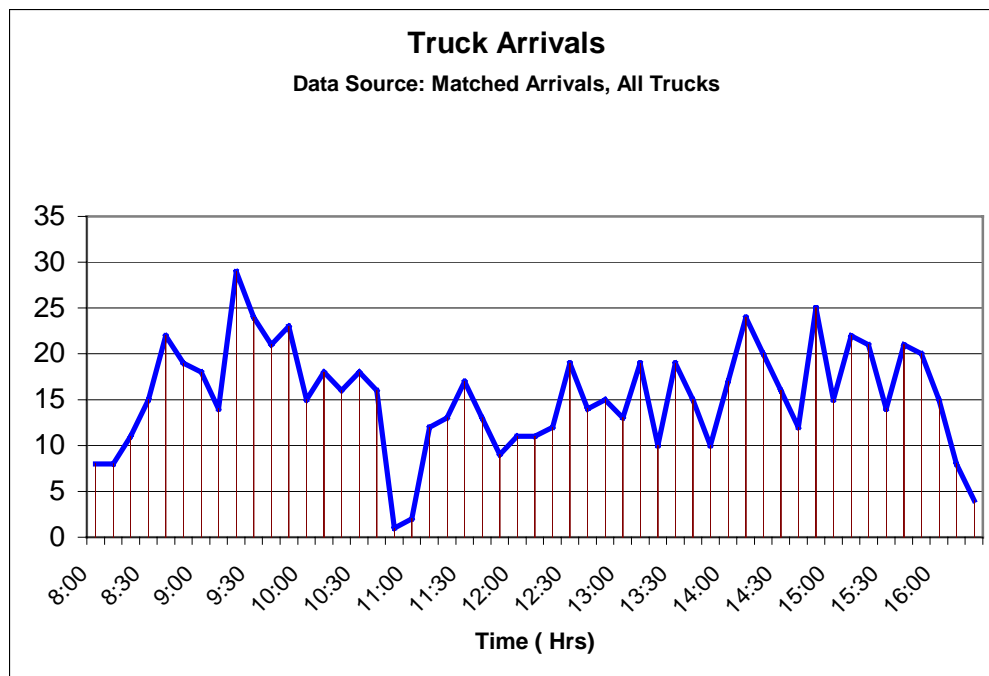
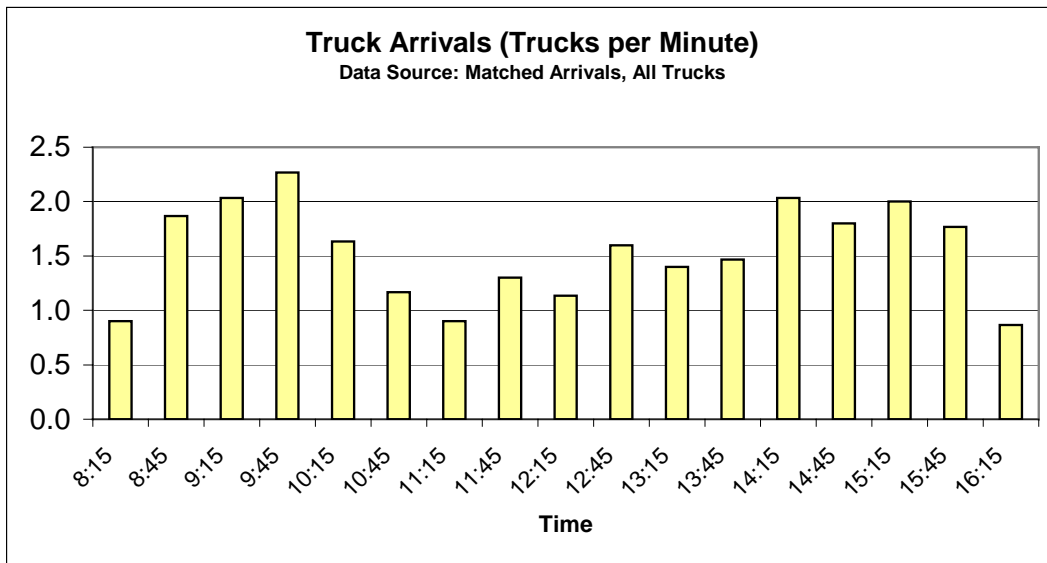


Figure 38 shows a plot of the time profile of truck arrival rates. This graph represents the same data as in Figure 37, plotted at a resolution of 30 minutes, rather than 10 minutes on the horizontal axis. The horizontal axis marks are set at the mid-point of each 30 minute interval (i.e. the bar at 8:15 represents the arrivals in the interval [8:00, 8:30], etc.).

The vertical axis represents the truck arrival rates, in Trucks per Minute, for each 30 minute period. We can see the two sections, clearly separating the morning from the afternoon arrivals. The morning profile shows a more clearly defined peak, and the afternoon profile shows more peaks, more evenly distributed.



because it provides the arrival rates for the basic simulation scenarios.

Figure 38: Time profile of truck arrival rate (Trucks per Minute vs. Time)

Figure 39 shows the total truck arrivals throughout the day, plotted in 30 minute intervals. Here the arrivals are separated in terms of what an arriving truck is carrying (BT for Bobtail; CA for Chassis only; CT for Container). All three categories show a similar pattern in terms of two separate sections (morning and afternoon). The most frequent arrivals are trucks with a container, which could be empty or loaded, followed by bobtails. Finally a small number of arrivals are trucks with chassis only.

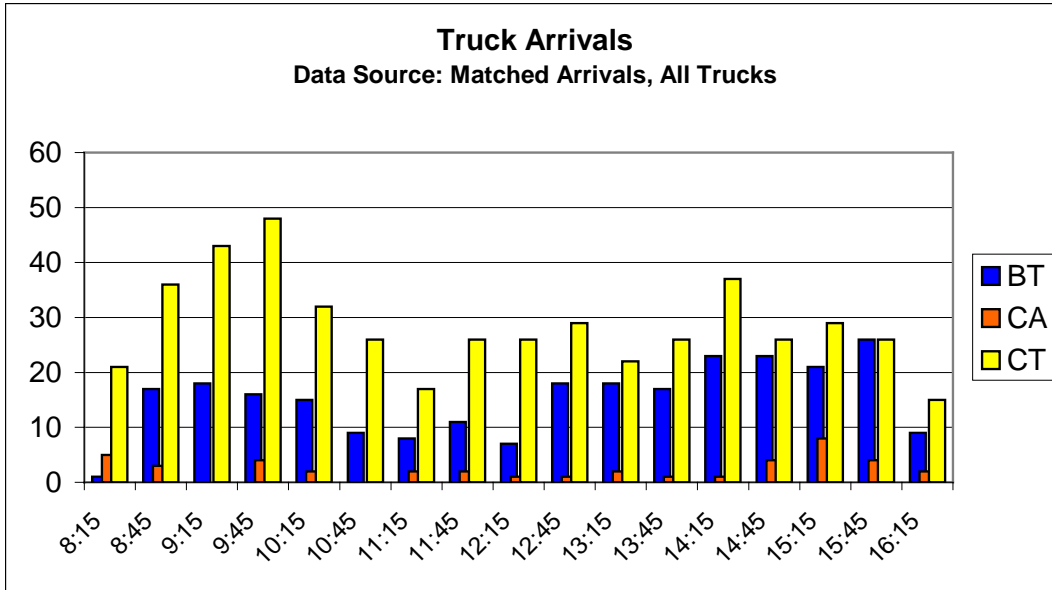


Figure 39: Time profile of truck arrivals by category

4.2.2 Analysis of Data for Truck Arrivals

The basic assumption here is that the truck arrivals follow a Poisson distribution. Since the arrival rates are variable, depending on the time of day, the arrival process will be modeled as a non-stationary Poisson distribution, with varying mean arrival rates. Figure 40 shows the plot of cumulative truck arrivals, which is compared to the cumulative plot if the rate of arrivals was constant. The two separate sections for the morning and afternoon arrivals are clearly seen. The actual morning arrivals are higher than the equivalent constant rate arrivals, whereas the opposite phenomenon is observed in the afternoon. This graph is also an indication that a non-stationary Poisson model should be used, since the actual arrivals show a definite deviation from arrivals with constant rate.

Regarding the parameters of terminal simulation model, the varying means for the non-stationary Poisson process will be taken from the graph of Figure 38. For each 30-minute interval, the simulated arrivals will follow a Poisson distribution, with a mean given from the corresponding time interval of Figure 38. The means will vary throughout the day, following the profile given in Figure 38. For the simulations where a constant arrival rate is used, the simulated arrivals will

follow a stationary Poisson distribution, with a constant mean throughout the day. The constant mean arrival rate will be set at 1.6 Trucks per Minute according to the graph of Figure 40.

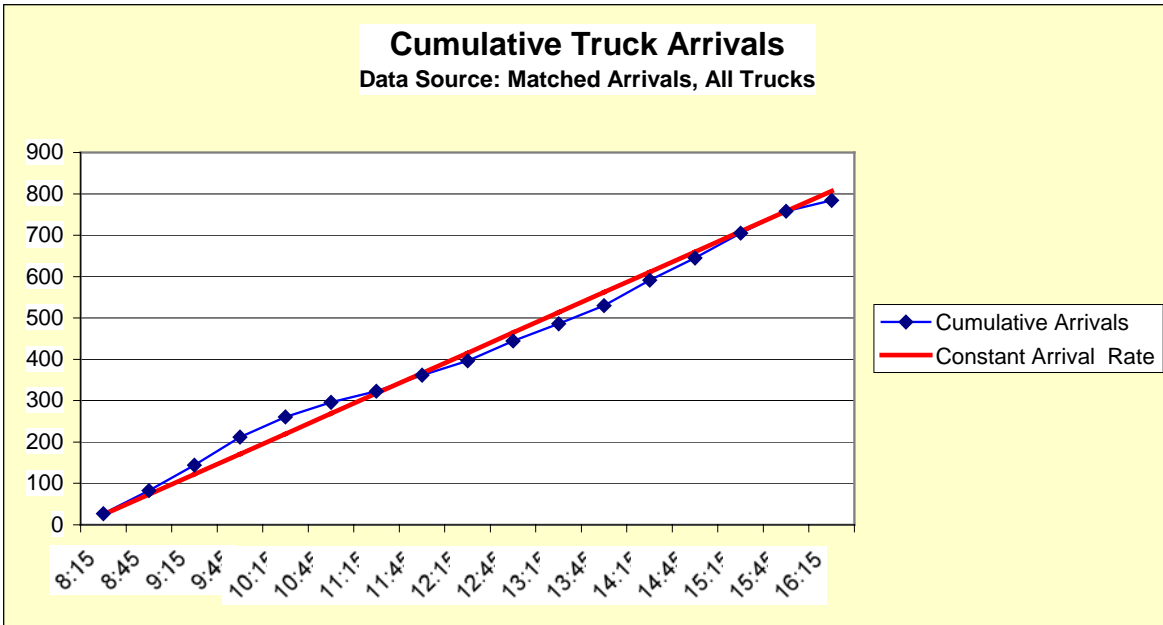


Figure 40: Cumulative truck arrivals

4.2.3 Truck Waiting Times

For the trucks that were identified when entering the queue at the inbound gate, the times of arrival at the gate and at the processing pedestal were recorded. The difference between these times gives the waiting time for each truck within the queue.

The time profile of average waiting times throughout the day is shown in Figure 41. This chart also shows the profile of the mean arrival rates for comparison purposes. It is seen that there is a peak of wait times in the [9:30, 10:00] interval in the morning, which coincides with the day's peak in truck arrival rates. Another peak occurs in the [3:00, 3:30] interval in the afternoon, correlated roughly with peaks of the afternoon arrival rates.

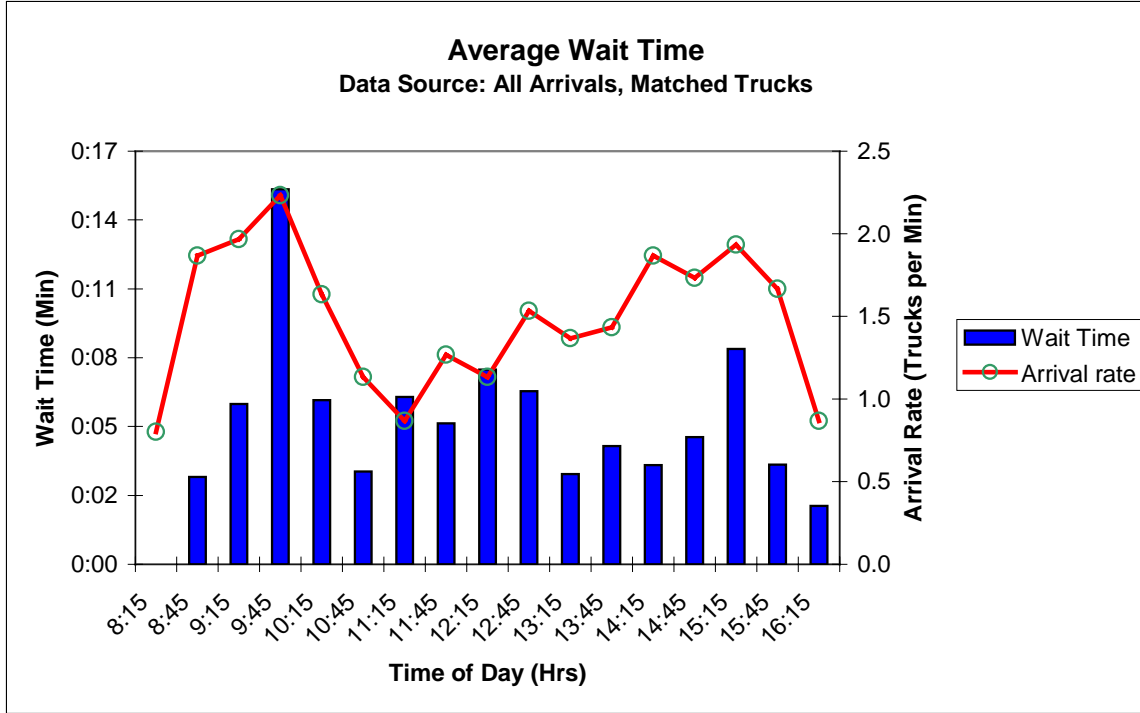


Figure 41: Time profile of average wait time at inbound gate queue

An analysis of the frequency distribution of waiting times at the inbound gates is shown in Figure 42. This is a non-symmetric distribution that has a mode at 6 minutes. For our purposes, a Gamma distribution was fitted to this data set (red line), with the following probability density function:

$$f_X(x) = \frac{\left(\frac{x-\mu}{\beta}\right)^{(\gamma-1)} \exp\left(-\frac{x-\mu}{\beta}\right)}{\beta \Gamma(\gamma)} \quad (26)$$

where $\beta > 0$, $\gamma > 0$, $x \geq \mu$, and $\Gamma(\gamma)$ is the value of the Gamma function at γ .

The values of the distribution parameters in Figure 42 are given by:

- Location parameter: $\mu = -0.2$
- Shape parameter: $\gamma = 3.0$
- Scale parameter: $\beta = 3.2$

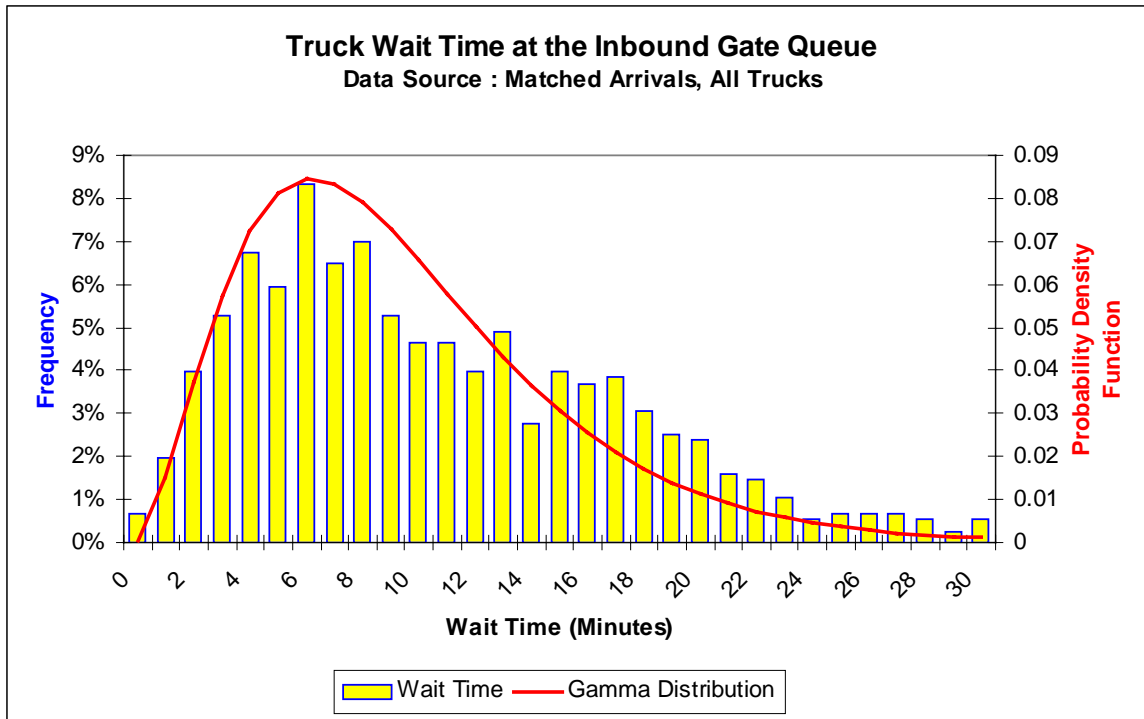


Figure 42: Frequency distribution of wait times for all trucks at the inbound gate queue

The plots in Figure 43 show the frequency distributions for the truck wait times by truck category (Bobtails; Chassis only; and Container carrying). At the terminal under observation the bobtails go through a separate entrance, and as a consequence they move faster through the queue, as it is evident from the graphs of Figure 43.

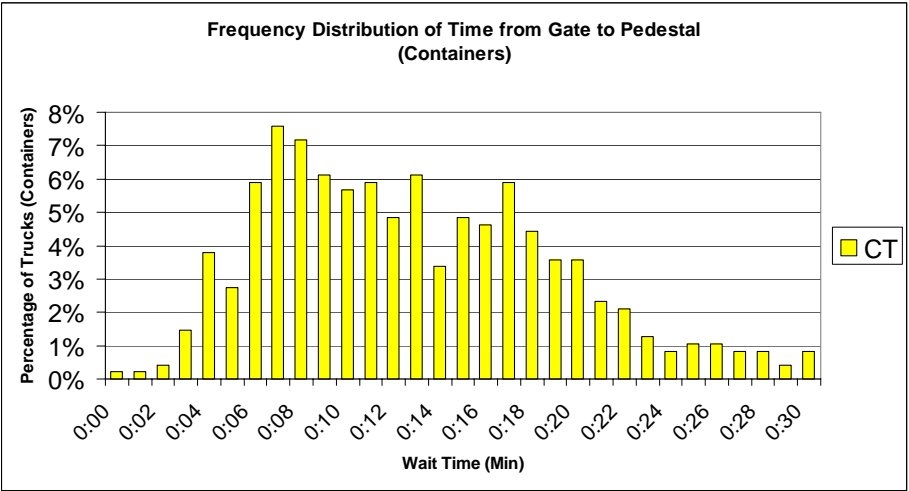
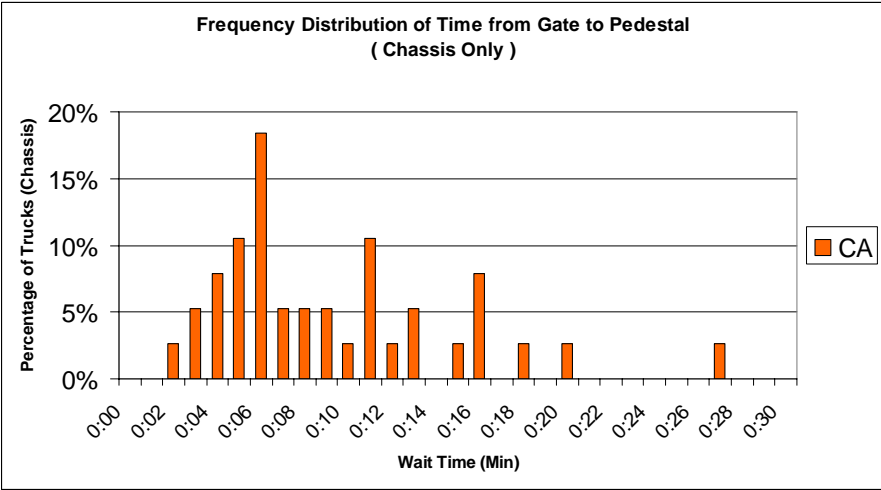
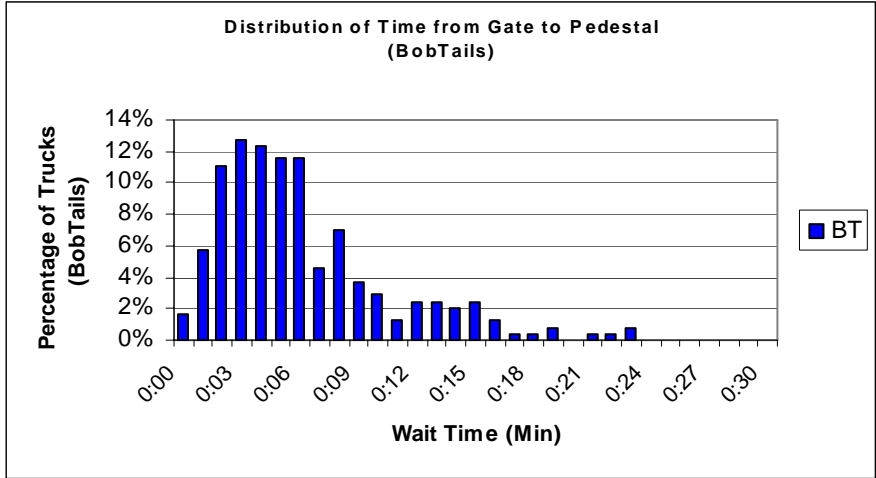


Figure 43: Frequency distribution of wait times for trucks at the inbound gate queue.
Top: Bobtails; Middle: Chassis only; Bottom: Container carrying trucks

4.3 Simulation Experiments of Terminal Operations

In this subsection several simulation scenarios have been created and performed using the terminal simulator described in Section 3.

Each scenario is simulated first under the assumption of current practices for truck arrivals, and next under the appointment system. For the current practices scenarios, the arrivals are random, following a Poisson process with variable mean rates. The truck arrival rates during the day are set according to the profiles discussed in Section 4.2. For the arrivals under the appointment system, the arrivals are random, following a stationary Poisson process with a constant mean, set equal to 1.6 Trucks per Minute, as discussed before.

We start from a simple simulation scenario, where trucks transport containers to/from the port, but there is no ship to be unloaded or loaded at the terminal. Then we proceed to more complex scenarios, involving several ship arrivals over the course of a few days.

For the processing times at the inbound and outbound gate, as well as at other places inside the terminal the user has a choice between four different statistical distributions:

- 1) A normal (Gaussian) distribution, with mean μ and standard deviation σ
- 2) An exponential distribution with parameter μ
- 3) A Gamma distribution with parameters $\beta > 0$, $\gamma > 0$, μ as discussed in Section 4.2
- 4) A truncated normal distribution with mean μ , standard deviation σ and minimum value T_{min} .

The truncated normal is used to overcome the fact that a normal distribution is symmetric and has a left tail. For a small mean and large enough standard deviation the normal distribution may produce negative values of the simulated random variable, which are not acceptable for values of the processing time at the gates. The truncated normal distribution is not symmetric, and it produces values higher than the minimum value T_{min} . The truncated normal is given by the following probability density function:

$$f_X(x) = \frac{1}{1 - \Phi(T_{min})} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x - \mu}{\sigma}\right)^2\right) ; \quad x \geq T_{min} \quad (27)$$

where $\Phi(T_{\min}) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{T_{\min}} \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right) dx$.

The factor $\frac{1}{1-\Phi(T_{\min})}$ is used to normalize the area under the curve to 1.0.

Figure 44 shows the difference between the truncated normal and the normal distributions for $\mu = 1$, $\sigma = 0.5$, and $T_{\min} = 0.3$.

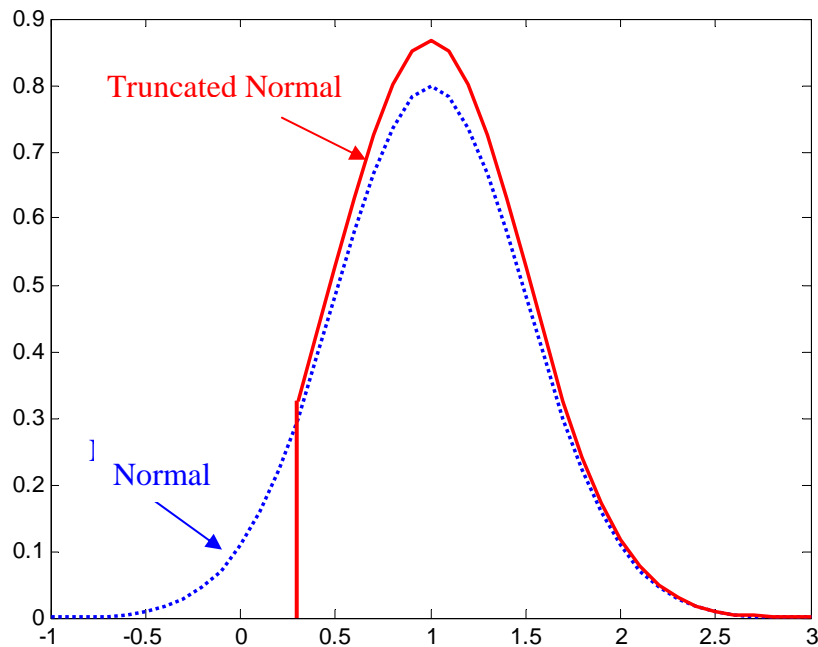


Figure 44: Comparison between normal and truncated normal probability density functions ($\mu = 1$, $\sigma = 0.5$, $T_{\min} = 0.3$).

In the simulation scenarios we are presenting here, the truncated normal distribution is used to simulate the gate processing operations, in order to avoid the problems associated with the use of the normal distribution.

4.3.1 Simulation Experiment 1

This is a very simple simulation experiment. It simulates 8 hours of terminal operations, starting at 8:00 a.m. until 4:00 p.m. The truck arrivals follow the time-varying profile discussed in

Section 4.2. There is some initial inventory in the import yard which needs to be transported away from the terminal. Of the trucks arriving at the inbound gate, 35% carry containers to be unloaded at the export yard, and 65% go to the import to load the stored containers. No ship arrives during the hours of operation, and no train is used to move containers.

The parameters for this simulation experiment are shown in the three tables below. The tables and their contents are self explanatory. The parameters for this simulation are saved in the file “A.OneDayNoShipNoTrain.sim”.

INITIAL STATE		
NAME	VALUE	DEFINITION
Yard		Import or Export Yard
ExportInventory	200	Initial number of containers in the export yard
ImportInventory	500	Initial number of containers in the import yard

TRUCK ARRIVALS		
NAME	VALUE	DEFINITION
Trucks		
ArrivalRate	Variable rate. It follows measured data profile.	The arrival rate of the trucks (trucks/minute)

TERMINAL PARAMETERS		
NAME	VALUE	DEFINITION
ExportYard		Storage yard for export containers
OutFlowRate		Flow rate (containers/minute) of containers to ship
TruckRate: Normal	$\mu=2, \sigma=0$	Processing rate (trucks/minute) of arriving trucks
ExportYardMaxQueueLength	5	The maximum allowable queue length (trucks) for the export yard
ImportYard		Storage yard for import containers
OutFlowRate		Flow rate (cont/minute) of containers to train
TruckRate: Normal	$\mu=2, \sigma=0$	Processing rate (trucks/minute) of arriving trucks
ImportYardMaxQueueLength	5	The maximum allowable queue length (trucks) for the import yard
Inbound Gate		Terminal entrance gate for inbound trucks
EntranceRate: Truncated Normal	$\mu=1.6$ $\sigma=0.5$ $T_{min}=0.5$	Processing rate (trucks/minute) of arriving trucks
InboundMaxQueueLength	30	The maximum allowable queue length (trucks) at

		the inbound gate
PercentageToShip	0%	Percentage of arriving trucks bound for ship (for live loading or unloading)
PercentageToYard	1 (100%)	Percentage of arriving trucks bound for yard (either Import or Export yard)
OutBound Gate		Terminal exit gate for outbound trucks
ExitRate:	$\mu=1.6$ $\sigma=0.4, T_{min}=0.5$	Processing rate (trucks/minute) of departing trucks
OutboundMaxQueueLength	10	The maximum allowable queue length (trucks) at the outbound gate
TransitDelay		Delay (minutes)
EntranceToShip		Delay (minutes) from inbound gate to ship
EntranceToYard	15	Delay (minutes) from inbound gate to yard
ShipToExit		Delay (minutes) from ship to outbound gate
YardToExit	5	Delay (minutes) from yard to outbound gate
Truck Arrivals for Ship		Trucks bound for ship: live loading/unloading
PercentageShipExport		Percentage of trucks bound for ship that bring in containers to be live-loaded onto the ship
PercentageShipImport		Percentage of trucks bound for ship going to pick up containers live-unloaded from the ship
PercentageShipImportAfterExport		Percentage of trucks among "PercentageShipExport" that pick up containers unloaded from the ship <u>after</u> leaving a container to be loaded onto the ship
Truck Arrivals for Yard		Trucks bound for Import/Export Yards
PercentageYardExport	0.35 (35%)	Percentage of trucks bound for yards unloading containers for storage in the export yard
PercentageYardImport	0.65 (65%)	Percentage of trucks bound for the yards loading containers from storage in the import yard
PercentageYardImportAfterExport		Percentage of trucks among "PercentageYardExport" loading containers from storage in the import yard <u>after</u> unloading

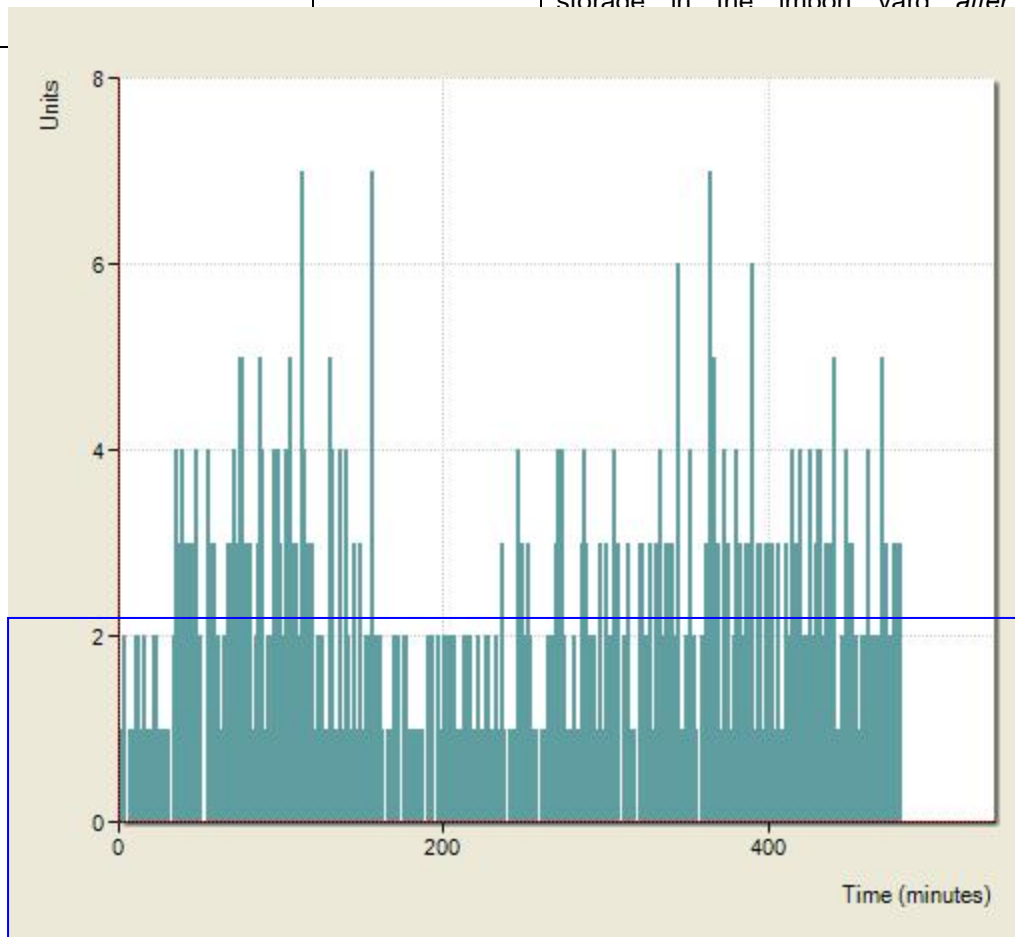


Figure A1 shows the truck arrivals at the inbound gate from 8:00 a.m. to 4:00 p.m. These are generated by a non-stationary Poisson process as discussed in Section 4.2. The pattern of arrivals has similar characteristics to the observed data. The drop in truck arrivals which separates the morning and afternoon sections can be clearly seen.

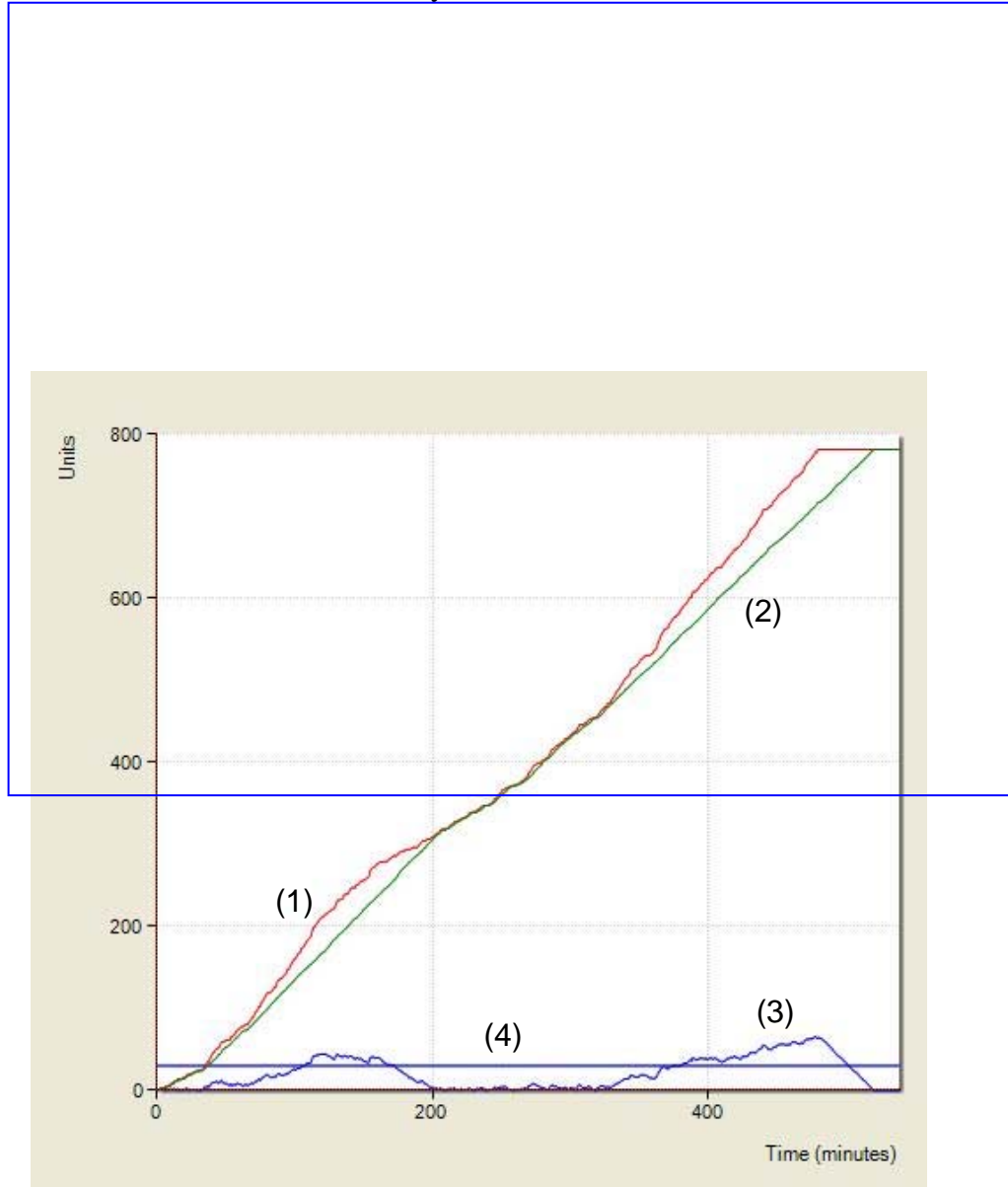


Figure A2: Inbound gate arrivals: (1) Cumulative truck arrivals; (2) Cumulative graph of trucks processed; (3) Queue length; (4) Maximum allowed queue length.

Figure A2 shows the cumulative truck arrivals and the cumulative graph of trucks processed through the inbound gate. The difference of these two graphs is the queue length at the inbound gate, which is compared to the maximum queue length. It is seen that the maximum queue length is exceeded for long periods of time on two occasions in the morning and the afternoon.

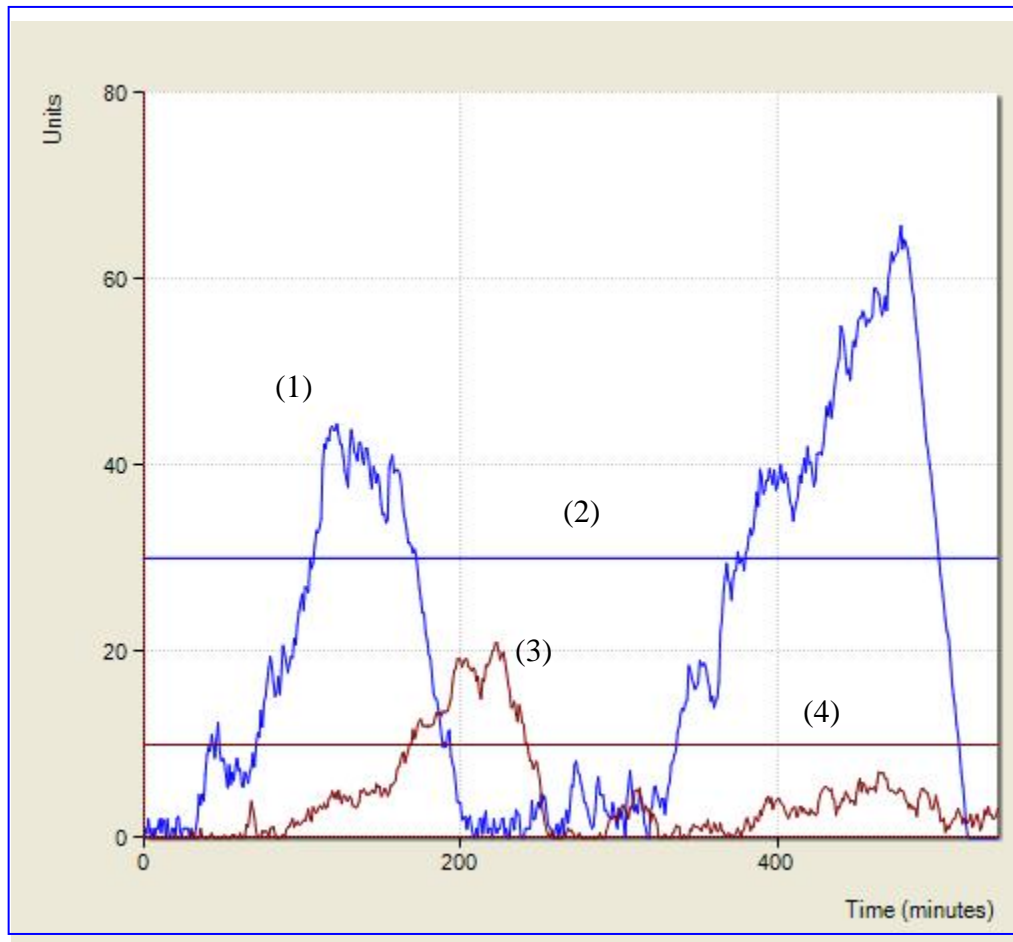


Figure A3: Queues at inbound and outbound gates: (1) Queue length at inbound gate; (2) Maximum allowed queue length at inbound gate; (3) Queue length at outbound gate; (4) Maximum allowed queue length at outbound gate.

Figure A3 compares the queue lengths at the inbound and outbound gates. Both graphs have a clear evidence of two separate sections for the morning and afternoon arrivals, due to the variable arrival rates. These characteristics are similar to those of the observed data. The inbound gate queue length is clearly exceeding the maximum queue length. The outbound gate queue length is also exceeding the maximum queue length during some time intervals.

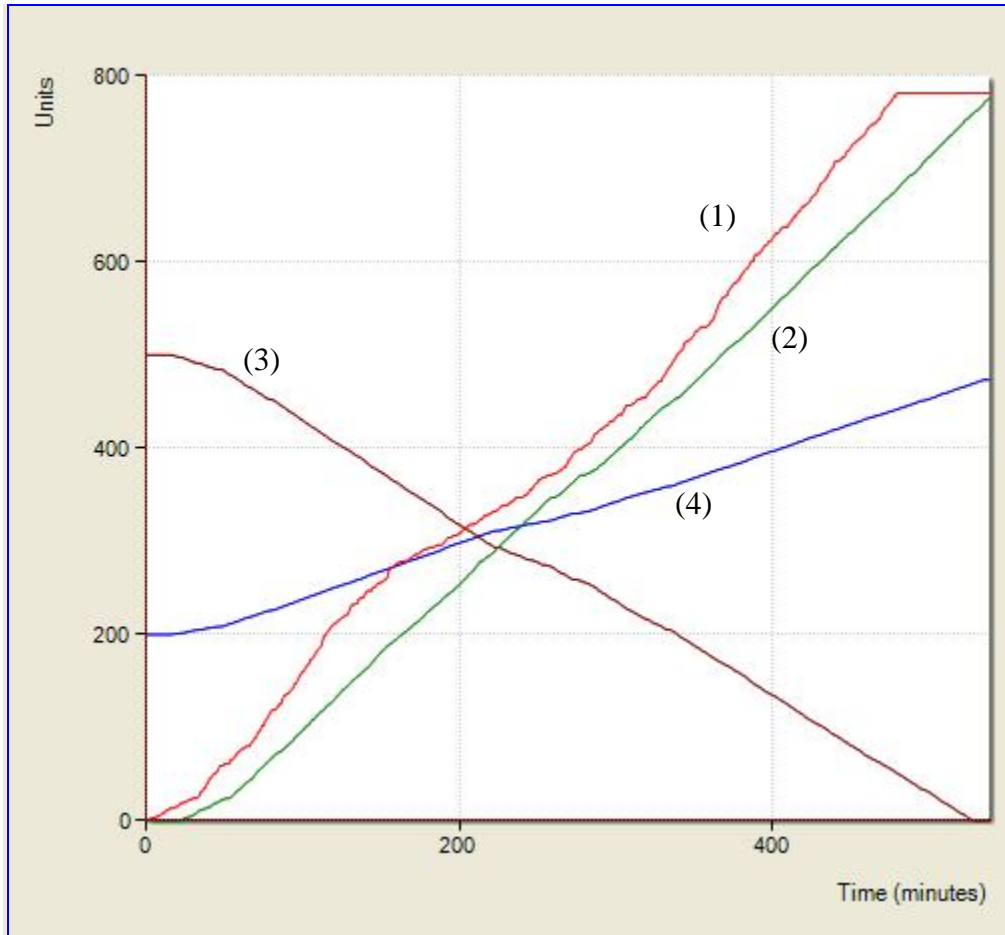


Figure A4: Arrivals, departures and yard inventories: (1) Cumulative truck arrivals at inbound gate; (2) Cumulative truck departures from outbound gate; (3) Number of containers in import yard; (4) Number of containers in export yard.

Figure A4 shows the cumulative truck arrivals at the inbound gate; the cumulative truck departures from the outbound gate; the number of containers in the import yard, and the number of containers in the export yard. In this very simple experiment the number of containers in the import yard is continuously decreasing, since there are no ship arrivals during this time period. Similarly the number of containers in the export yard is continuously increasing.

4.3.2 Simulation Experiment 2 (Appointment System)

This is the same as Simulation Experiment 1, with the appointment system in place. The terminal will be able to set the appointments cooperatively with the trucking companies as described previously. In this case the truck arrivals will be uniformly distributed throughout the day. The

simulation for this experiment generates truck arrivals from a stationary Poisson process with a constant mean arrival rate, which is set equal to 1.6 Trucks per Minute as discussed before.

The parameters for this simulation experiment are not shown here since they are the same as in the case of Simulation Experiment 1. The simulation parameters for this experiment are saved in the file “A.OneDayNoShipNoTrainWithAppt.sim”.

TRUCK ARRIVALS		
NAME	VALUE	DEFINITION
Trucks		
ArrivalRate	Constant = 1.6	The arrival rate of the trucks (trucks/minute)

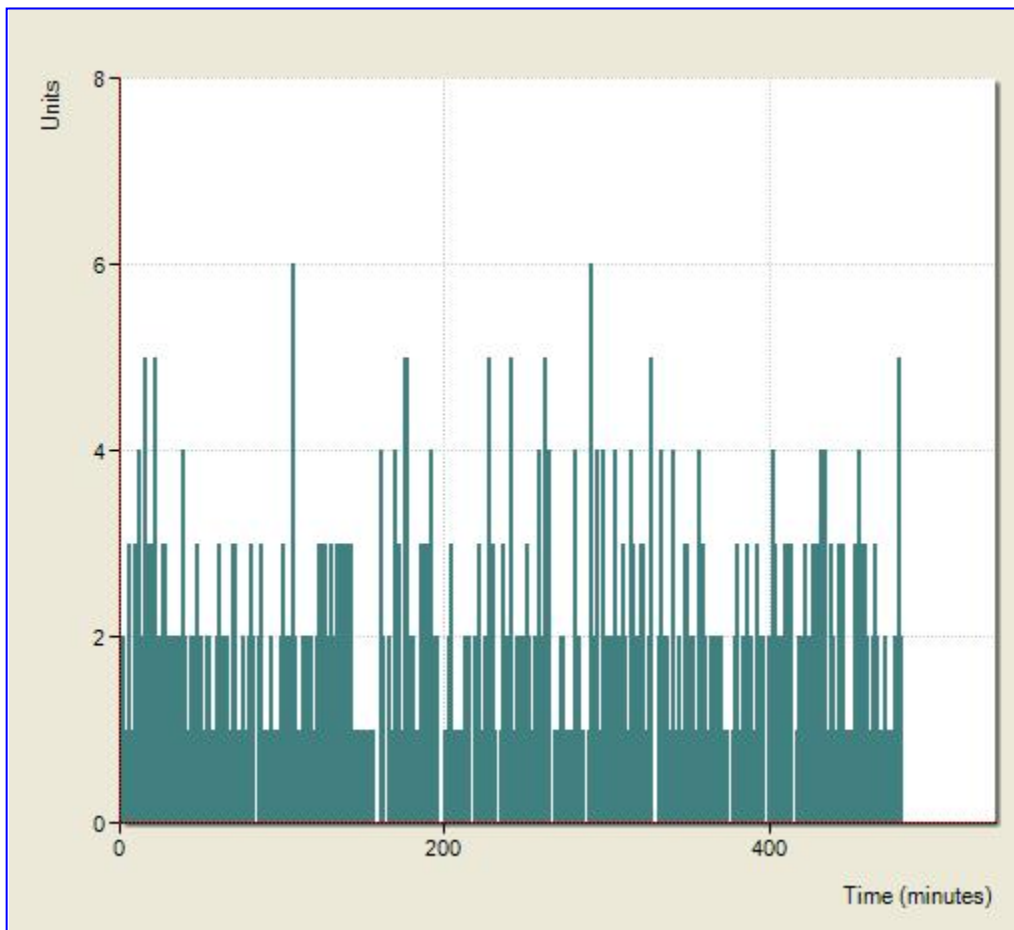


Figure A5: Inbound gate arrivals with appointment system: Truck arrivals at the inbound gate – constant arrival rate

Figure A5 shows the truck arrivals at the inbound gate from 8:00 a.m. to 4:00 p.m. These are generated by a stationary Poisson process as discussed in Section 4.2, with a constant mean. The mean arrival rate set to 1.6 Trucks per Minute. This graph does not exhibit characteristics similar to the observed data, since it represents the case where the appointment system is in place.

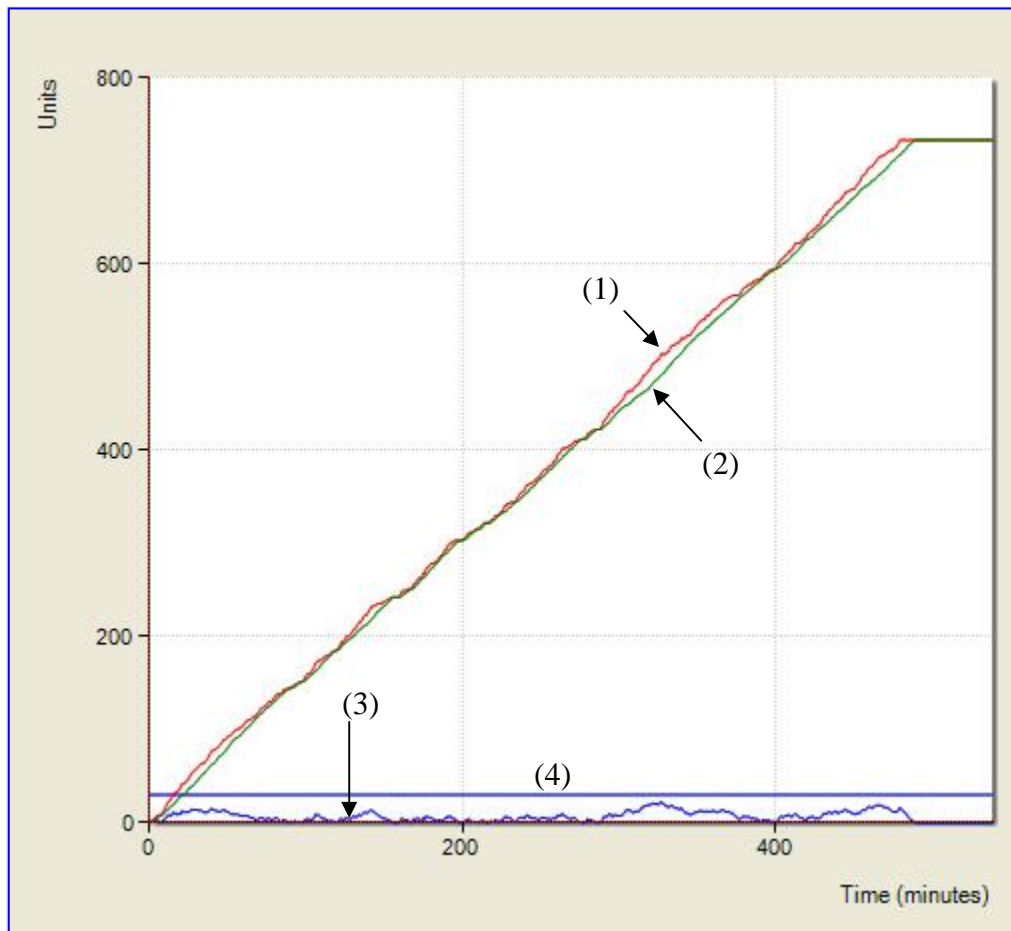


Figure A6: Inbound gate arrivals with appointment system. (1) Cumulative truck arrivals; (2) Cumulative graph of trucks processed; (3) Queue length; (4) Maximum allowed queue length.

Figure A6 shows the cumulative truck arrivals and the cumulative graph of trucks processed through the inbound gate. The difference of these two graphs is the queue length at the inbound gate which is compared to the maximum queue length. The queue length at the inbound gate has different characteristics to those of the measured data and those of Simulation Experiment 1, since here the appointment system is in place. The cumulative departures from the inbound gate

follow the cumulative arrivals very closely, hence the queue length never exceeds the maximum allowed queue length.

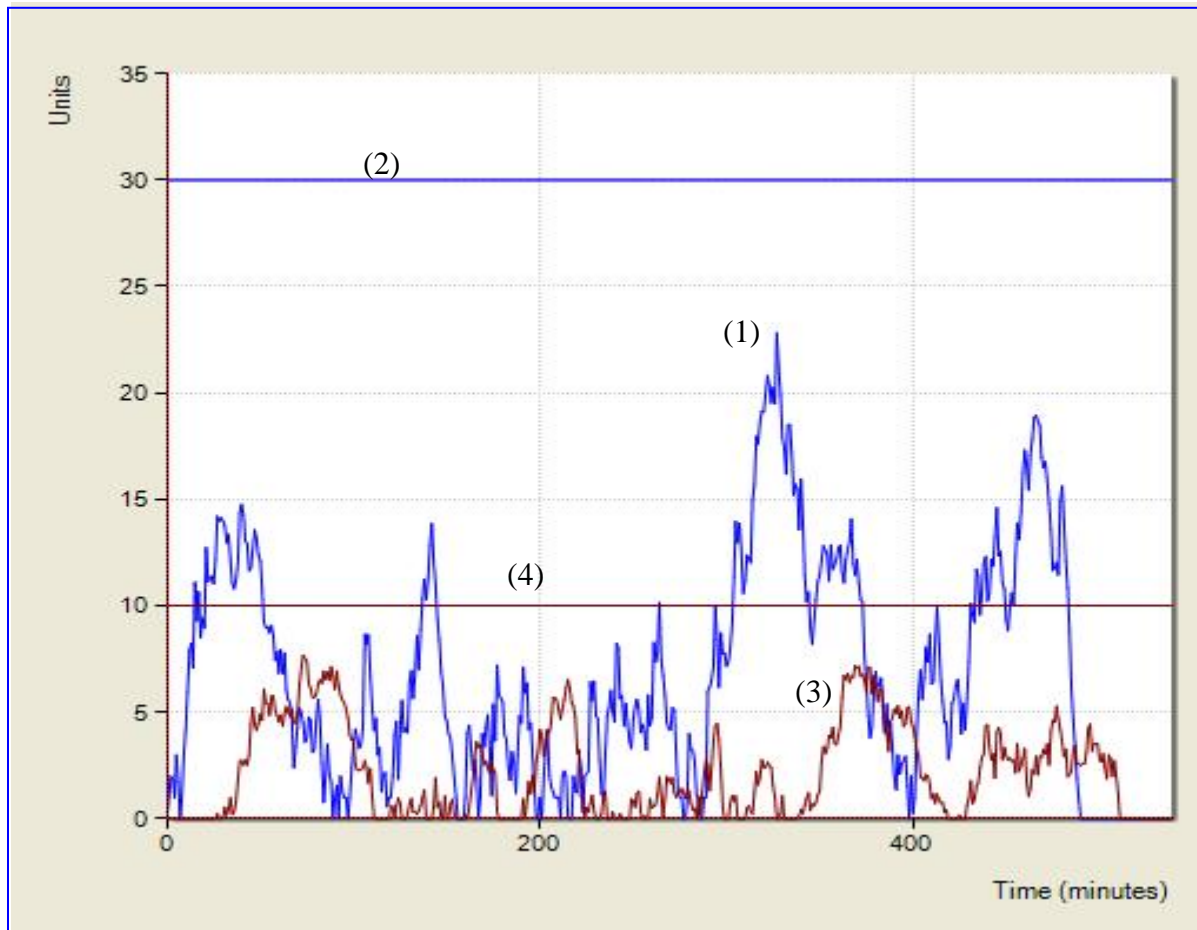


Figure A7: Queues at inbound & outbound gates with appointment system: (1) Queue length at inbound gate; (2) Maximum allowed queue length at inbound gate; (3) Queue length at outbound gate; (4) Maximum allowed queue length at outbound gate.

Figure A7 compares the queue lengths at the inbound and outbound gates. Here there is no evidence of the two separate sections for the morning and afternoon arrivals which were prominent in Simulation Experiment 1. The inbound gate queue length never exceeds the maximum queue length. The outbound gate queue length also never exceeds the maximum queue length.

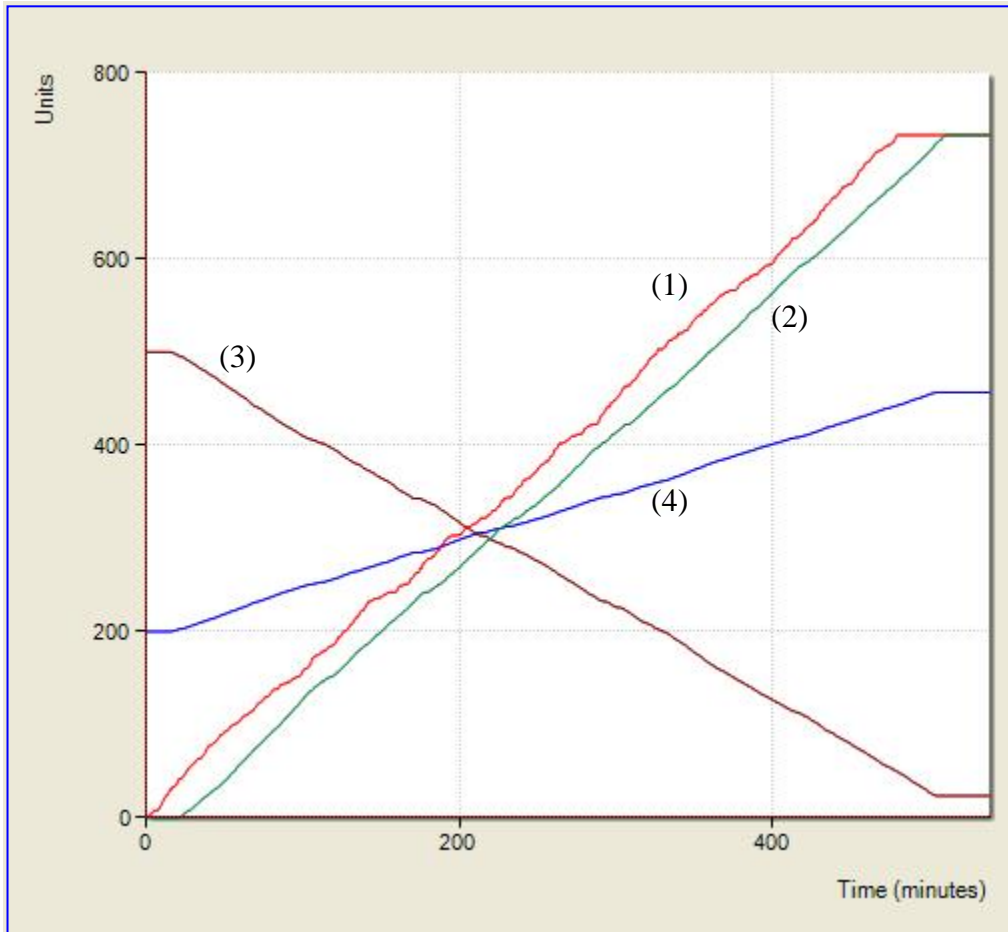


Figure A8: Arrivals, departures and yard inventories with appointment system: (1) Cumulative truck arrivals at inbound gate; (2) Cumulative truck departures from outbound gate; (3) Number of containers in import yard; (4) Number of containers in export yard.

Figure A8 shows the cumulative truck arrivals at the inbound gate; the cumulative truck departures from the outbound gate; the number of containers in the import yard and the number of containers in the export yard. It is seen that the departures from the outbound gate parallel the arrivals at the inbound gate.

4.3.3 Simulation Experiment 3

This is a more complex scenario as compared to simulation experiments 1 and 2. It simulates 8 hours of terminal operations, starting at 8:00 a.m. until 4:00 p.m. The truck arrivals follow the time-varying profile discussed in Section 4.2. There is some initial inventory in the import yard

which needs to be transported away from the terminal, and some inventory in the export yard which needs to be loaded to a ship.

Of the trucks arriving at the inbound gate, 35% carry containers to be unloaded at the export yard, and 65% go to the import yard to load the stored containers. Of the trucks that go to the export yard and unload a container, 40% will continue on, to the import yard to pickup another container to be transported out of the terminal. This operation will help in reducing the import yard inventory faster.

At time $t=120$ min a ship arrives. The ship carries 1500 containers to be unloaded and stored at the import yard. The ship will be loaded with 500 containers from the export yard. No live loading/unloading directly from trucks to ship or vice versa is taking place in this scenario.

At time $t=240$ min a train arrives. The train carries 40 containers to be unloaded to the export yard. The train will be loaded with 100 containers from the import yard before it departs. The train is expected to help in reducing the import yard inventory faster. No direct loading/unloading from train to ship or vice versa (on-dock rail) is taking place in this scenario.

The parameters for this simulation experiment are shown in the five tables below. The tables and their contents are self explanatory. The parameters for this simulation are saved in the file “B.OneDayWithShipWithTrain.sim”.

INITIAL STATE		
NAME	VALUE	DEFINITION
Yard		Import or Export Yard
ExportInventory	200	Initial number of containers in the export yard
ImportInventory	500	Initial number of containers in the import yard

TRUCK ARRIVALS		
NAME	VALUE	DEFINITION
Trucks		
ArrivalRate	Variable rate. It follows measured data profile.	The arrival rate of the trucks (trucks/minute)

TERMINAL PARAMETERS

NAME	VALUE	DEFINITION
ExportYard		Storage yard for export containers
OutFlowRate: Normal Distrib.	$\mu=1, \sigma=0.2$	Flow rate (containers/minute) of containers to ship
TruckRate: Normal Distribution	$\mu=2, \sigma=0$	Processing rate (trucks/minute) of arriving trucks
ExportYardMaxQueueLength	5	The maximum allowable queue length (trucks) for the export yard
ImportYard		Storage yard for import containers
OutFlowRate	$\mu=0.5, \sigma=0.1$	Flow rate (cont/minute) of containers to train
TruckRate: Normal Distribution	$\mu=2, \sigma=0$	Processing rate (trucks/minute) of arriving trucks
ImportYardMaxQueueLength	5	The maximum allowable queue length (trucks) for the import yard
Inbound Gate		Terminal entrance gate for inbound trucks
EntranceRate: Truncated Normal Distrib.	$\mu=1.6$ $\sigma=0.3, T_{min}=0$	Processing rate (trucks/minute) of arriving trucks
InboundMaxQueueLength	30	The maximum allowable queue length (trucks) at the inbound gate
PercentageToShip	0%	Percentage of arriving trucks bound for ship (for live loading or unloading)
PercentageToYard	100%	Percentage of arriving trucks bound for yard (either Import or Export yard)
OutBound Gate		Terminal exit gate for outbound trucks
ExitRate: Truncated Normal Distrib.	$\mu=1.6$ $\sigma=0.3, T_{min}=0$	Processing rate (trucks/minute) of departing trucks
OutboundMaxQueueLength	5	The maximum allowable queue length (trucks) at the outbound gate
TransitDelay		Delay (minutes)
EntranceToShip		Delay (minutes) from inbound gate to ship
EntranceToYard	15	Delay (minutes) from inbound gate to yard
ShipToExit		Delay (minutes) from ship to outbound gate
YardToExit	5	Delay (minutes) from yard to outbound gate
Truck Arrivals for Ship		Trucks bound for ship: live loading/unloading
PercentageShipExport		Percentage of trucks bound for ship that bring in containers to be live-loaded onto the ship
PercentageShipImport		Percentage of trucks bound for ship going to pick up containers live-unloaded from the ship
PercentageShipImportAfterExport		Percentage of trucks among "PercentageShipExport" that pick up containers unloaded from the ship <i>after</i> leaving a container to be loaded onto the ship
Truck Arrivals for Yard		Trucks bound for Import/Export Yards
PercentageYardExport	35%	Percentage of trucks bound for yards unloading containers for storage in the export yard
PercentageYardImport	65%	Percentage of trucks bound for the yards loading containers from storage in the import yard
PercentageYardImportAfterExport	40%	Percentage of trucks among "PercentageYardExport" loading containers from storage in the import yard <i>after</i> unloading containers for storage in the export yard

SHIP PARAMETERS

NAME	VALUE	DEFINITION
Container Inventory (imports)		Containers brought by the ship for import
ToTrainInventory	0	Total containers to unload for the train (on-dock rail)
ToYardInventory	1500	Total containers to unload for the yard
Container Loading (exports)		Containers the ship will load for export
ContainersToLoad	500	Number of containers to load before departing
Container Unloading (imports)		Unloading rates
ToTrainRate	$\mu=0, \sigma=0$	Flow rate of containers to train (containers/minute)
ToYardRate	$\mu=1, \sigma=0.2$	Flow rate of containers to yard (containers/minute)
Live Loading (exports)		
LoadingRate	$\mu=0, \sigma=0$	Processing rate for live loading operations (containers/minute)
Live Unloading		
LiveUnloadingInventory	0	Total containers to unload from ship to truck
LiveUnloadingRate	$\mu=0, \sigma=0$	Processing rate for live unloading operations (containers/minute) from ship to truck

TRAIN PARAMETERS		
NAME	VALUE	DEFINITION
Container Loading (imports)		Containers the ship will load for export
ContainersToLoad	100	Number of containers to load before departing
Container Unloading (exports)		Terminal entrance gate for inbound trucks
ToShipRate	$\mu=0, \sigma=0$	Flow rate of containers to ship (containers/minute)
ToYardRate	$\mu=0.3$	Flow rate of containers to yard (containers/minute)
Truncated Normal Distrib.	$\sigma=0.1$ $T_{min}=0$	
Container Inventory (imports)		Containers brought by the ship for import
ToShipInventory		Total containers to unload for the ship
ToYardInventory	40	Total containers to unload for the yard

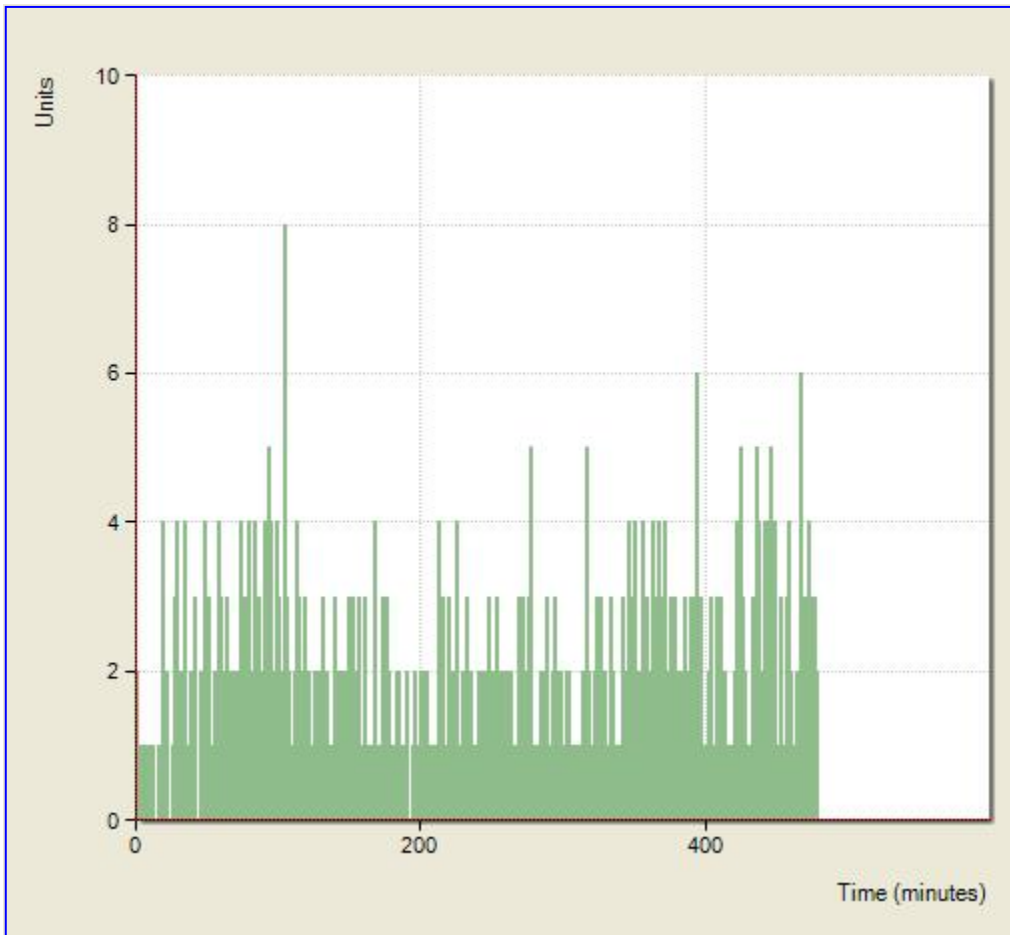


Figure B1: Inbound gate arrivals: Truck arrivals at the inbound gate – variable arrival rates

Figure B1 shows the truck arrivals at the inbound gate from 8:00 a.m. to 4:00 p.m. These are generated by a non-stationary Poisson process as discussed in Section 4.2. The pattern of arrivals has similar characteristics to the observed data.

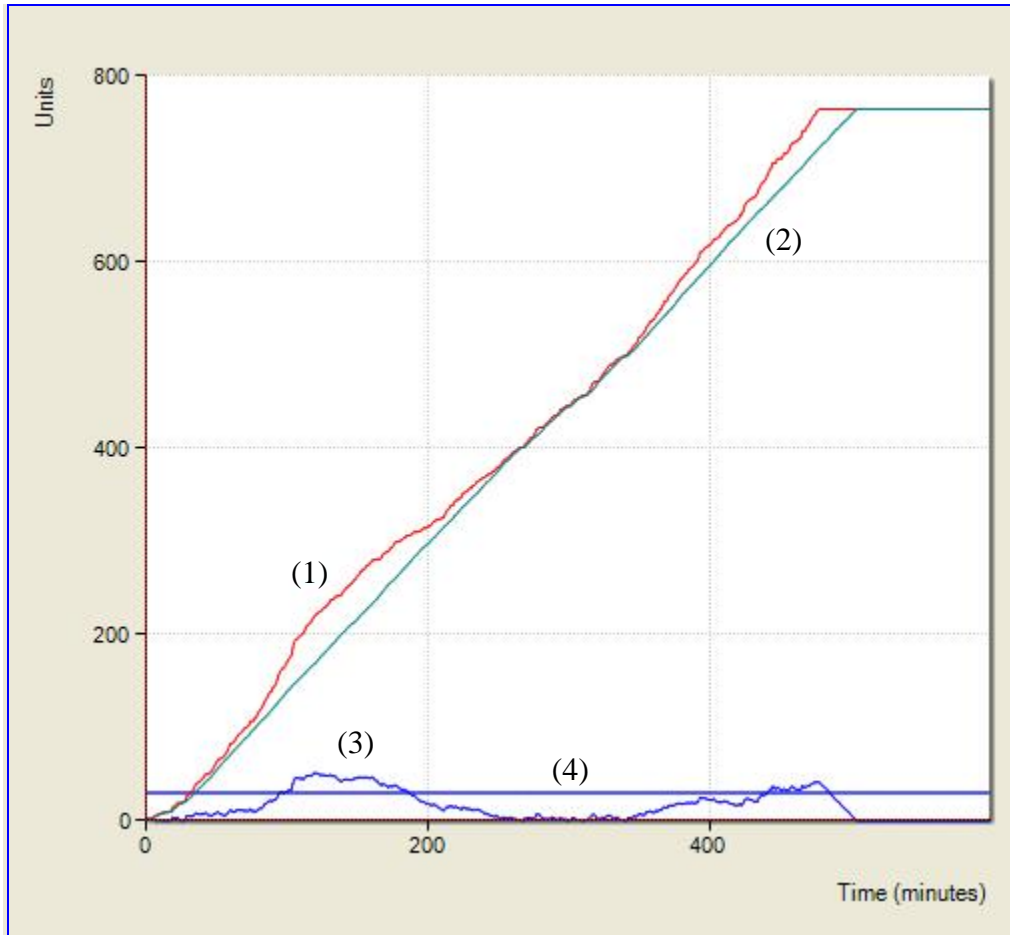


Figure B2: Inbound gate arrivals: (1) Cumulative truck arrivals; (2) Cumulative graph of trucks processed; (3) Queue length; (4) Maximum allowed queue length.

Figure B2 shows the cumulative truck arrivals and the cumulative graph of trucks processed through the inbound gate. The difference of these two graphs is the queue length at the inbound gate, which is compared to the maximum queue length. The queue length at the inbound gate has similar characteristics to those of the measured data. It is seen that the maximum queue length is exceeded for long periods of time on two occasions in the morning and the afternoon.

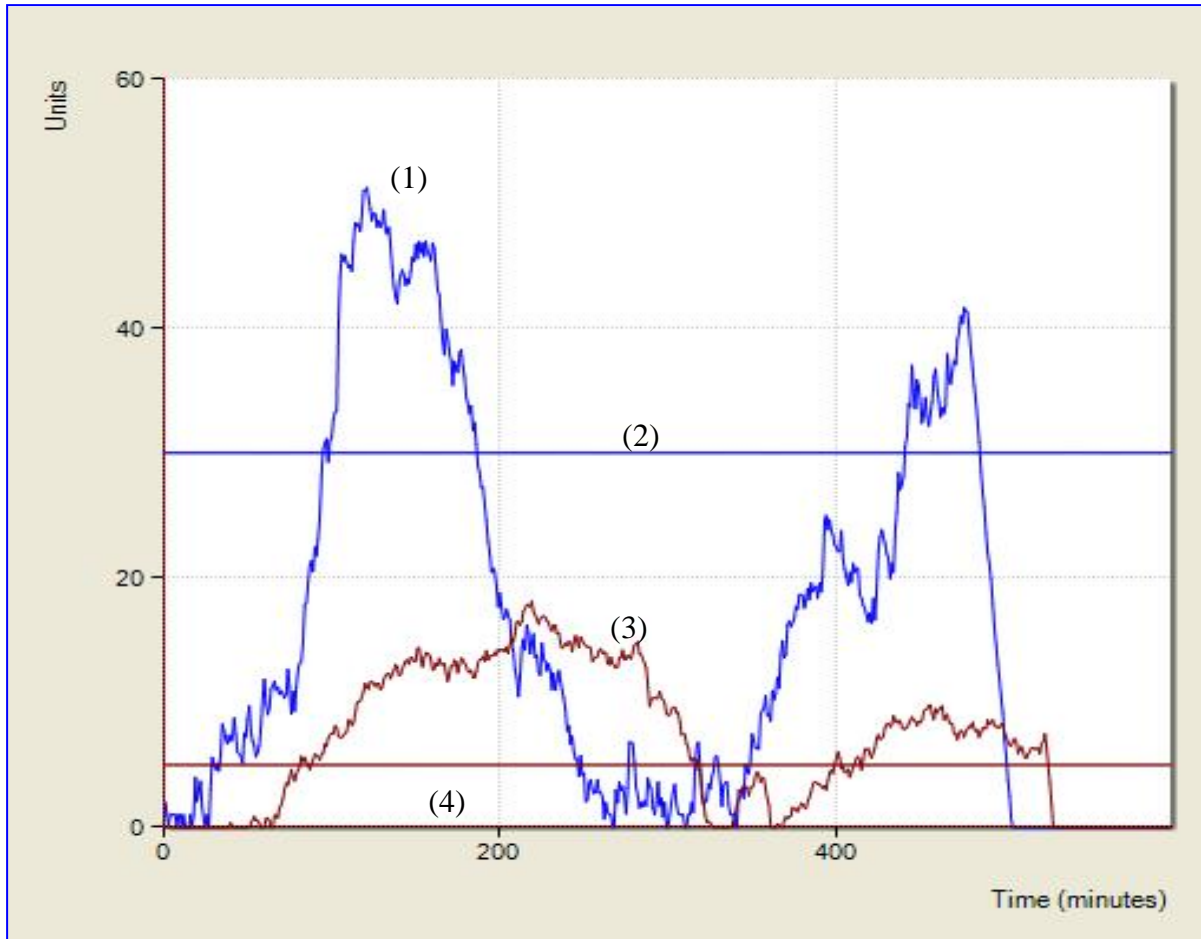


Figure B3: Queues at inbound and outbound gates: (1) Queue length at inbound gate; (2) Maximum allowed queue length at inbound gate; (3) Queue length at outbound gate; (4) Maximum allowed queue length at outbound gate.

Figure B3 compares the queue lengths at the inbound and outbound gates. Both graphs have a clear evidence of two separate sections for the morning and afternoon arrivals, due to the variable arrival rates. These characteristics are similar to those of the observed data. The inbound gate queue length is clearly exceeding the maximum queue length. The outbound gate queue length is also exceeding the maximum queue length during some time intervals. The train arrival, although it will help reduce the time to empty the import yard, does not have any noticeable effect on reducing the outbound gate queue.

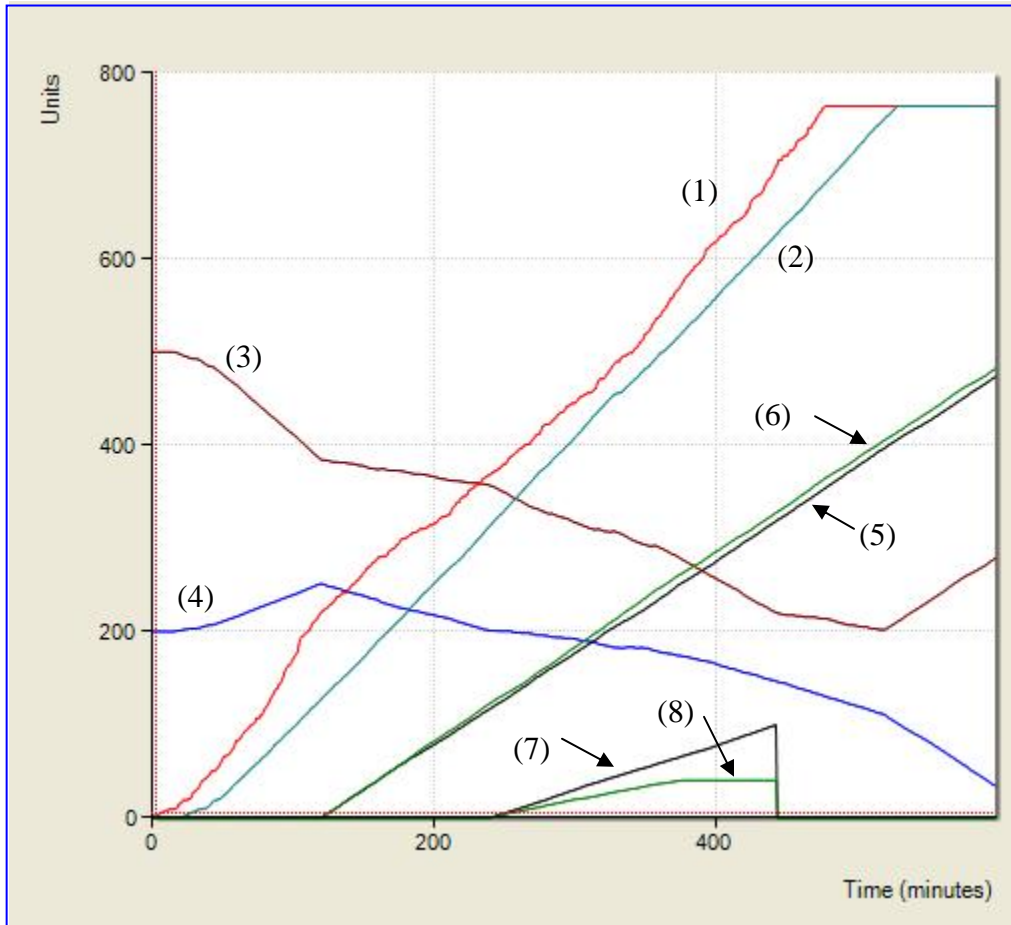


Figure B4: Arrivals, departures and yard inventories: (1) Cumulative truck arrivals at inbound gate; (2) Cumulative truck departures from outbound gate; (3) Number of containers in import yard; (4) Number of containers in export yard; (5) Cumulative containers loaded onto ship; (6) Cumulative containers unloaded from ship; (7) Cumulative containers loaded onto train; (8) Cumulative containers unloaded from train.

Figure B4 shows the cumulative truck arrivals at the inbound gate and the cumulative truck departures from the outbound gate. The difference between these graphs is the number of trucks being inside the terminal at any given time. The loading/unloading of the ship is done at almost a constant rate, since very little variation was including when setting the simulation parameters. The same is true for the loading/unloading of the train. The import and export yard inventories show definite changes in slope after the ship arrival ($t=120$ min), since additional containers are moving into the import yard or out of the export yard. They also exhibit changes in slope after the train arrives ($t=240$ min) and after the train departs.

4.3.4 Simulation Experiment 4 (Appointment System)

This is the same as Simulation Experiment 3, but with the appointment system in place. The terminal will be able to set the appointments cooperatively with the trucking companies as described previously. In this case the truck arrivals will be uniformly distributed throughout the day. The simulation for this experiment generates truck arrivals from a stationary Poisson process with a constant mean arrival rate, which is set equal to 1.6 Trucks per Minute as discussed before.

The parameters for this simulation experiment are not shown here since they are the same as in the case of Simulation Experiment 3. The simulation parameters for this experiment are saved in the file “B.OneDayWithShipWithTrainWithAppt.sim”.

TRUCK ARRIVALS		
NAME	VALUE	DEFINITION
Trucks		
ArrivalRate	Constant = 1.6	The arrival rate of the trucks (trucks/minute)

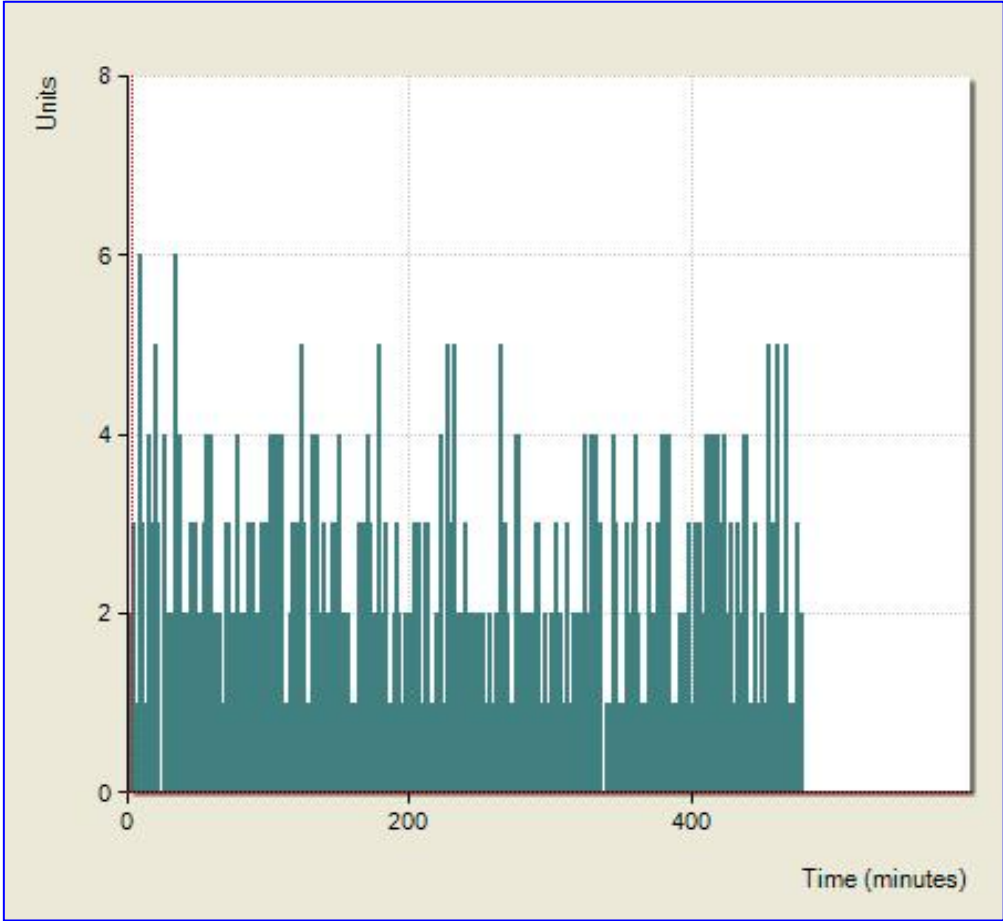


Figure B5: Inbound gate arrivals with appointment system: Truck arrivals at the inbound gate – constant arrival rate.

Figure B5 shows the truck arrivals at the inbound gate from 8:00 a.m. to 4:00 p.m. These are generated by a stationary Poisson process as discussed in Section 3, with a constant mean. The mean arrival rate set to 1.6 Trucks per Minute.

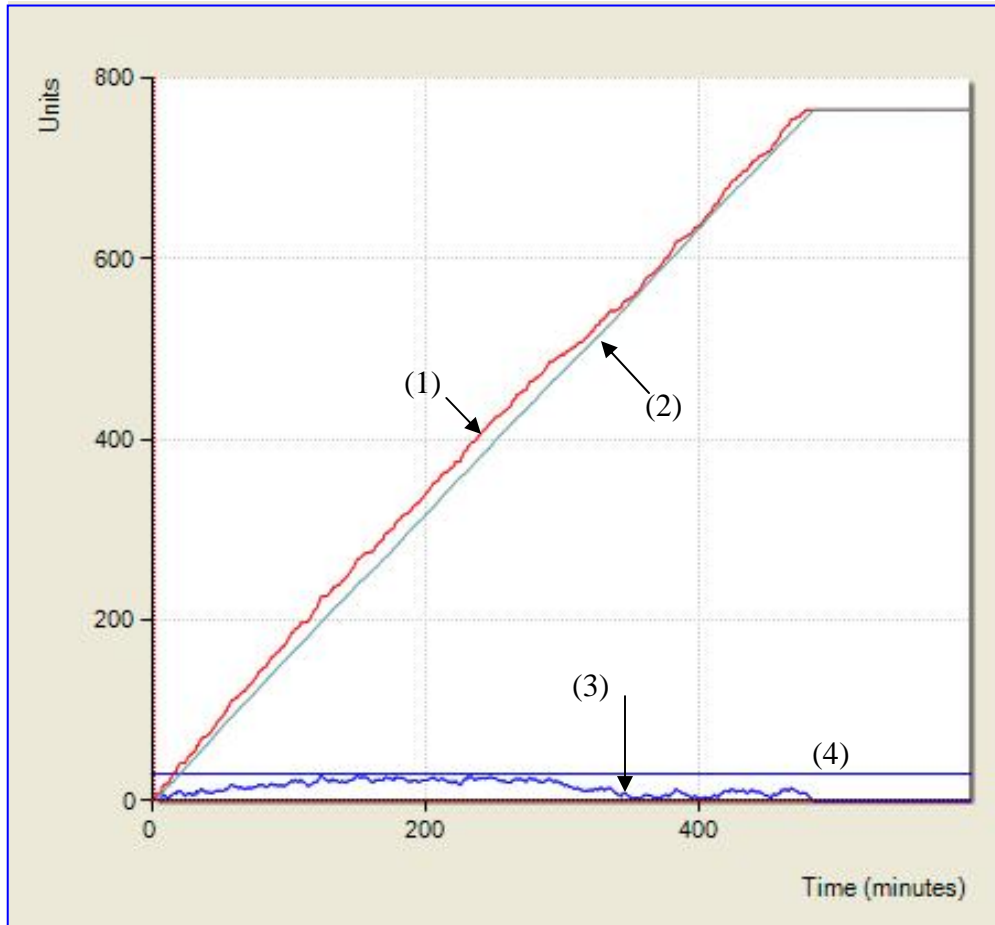


Figure B6: Inbound gate arrivals with appointment system: (1) Cumulative truck arrivals; (2) Cumulative graph of trucks processed through inbound gate; (3) Queue length; (4) Maximum allowed queue length.

Figure B6 shows the cumulative truck arrivals and the cumulative graph of trucks processed through the inbound gate. The difference of these two graphs is the queue length at the inbound gate which is compared to the maximum queue length. The queue length at the inbound gate has different characteristics to those of the measured data and those of Simulation Experiment 3, since here the appointment system is in place. The cumulative departures from the inbound gate follow the cumulative arrivals very closely, hence the queue never exceeds the maximum allowed queue length.

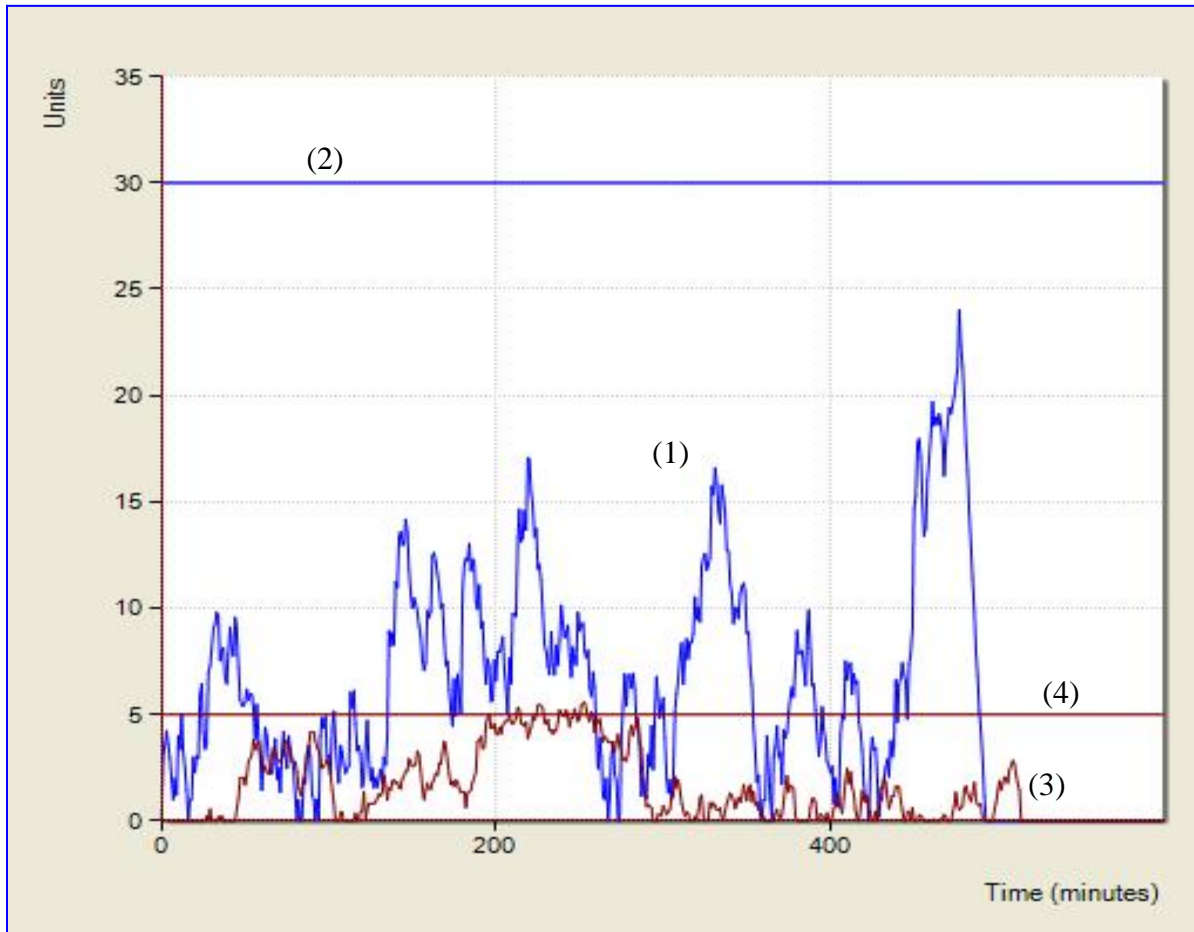


Figure B7: Queues at inbound & outbound gates with appointment system: (1) Queue length at inbound gate; (2) Maximum allowed queue length at inbound gate; (3) Queue length at outbound gate; (4) Maximum allowed queue length at outbound gate.

Figure B7 compares the queue lengths at the inbound and outbound gates. Here, because of the appointment systems, there is no evidence of the two separate sections for the morning and afternoon arrivals which were prominent in Simulation Experiment 3. The inbound gate queue length never exceeds the maximum queue length. The outbound gate queue length also, never exceeds the maximum queue length.

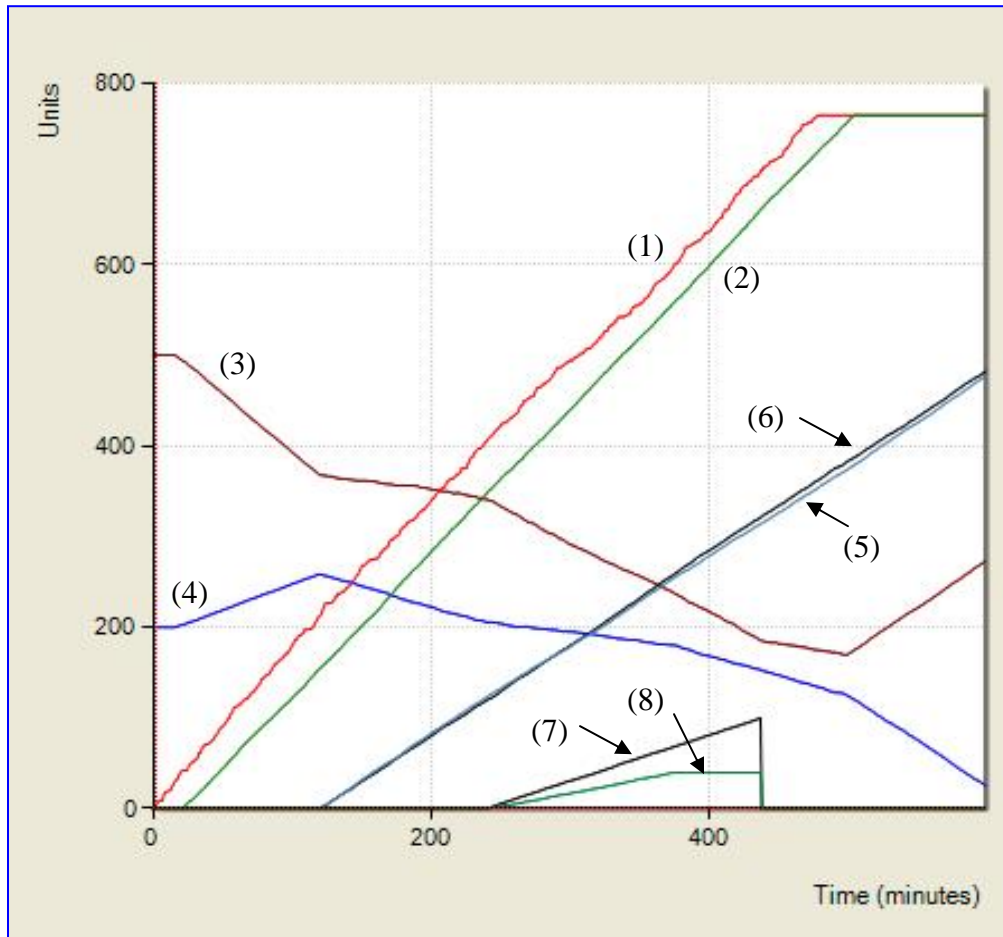


Figure B8: Arrivals, departures and yard inventories with appointment system: (1) Cumulative truck arrivals at inbound gate; (2) Cumulative truck departures from outbound gate; (3) Number of containers in import yard; (4) Number of containers in export yard; (5) Cumulative containers loaded onto ship; (6) Cumulative containers unloaded from ship; (7) Cumulative containers loaded onto train; (8) Cumulative containers unloaded from train.

Figure B8 shows the cumulative truck arrivals at the inbound gate and the cumulative truck departures from the outbound gate. The difference between these graphs is the number of trucks being inside the terminal at any given time. The loading/unloading of the ship is done at almost a constant rate, since very little variation was set in the simulation. The same is true for the loading/unloading of the train. The import and export yard inventories show definite changes in slope after the ship arrival ($t=120$ min), since additional containers are moving into the import yard or out of the export yard. They also exhibit changes in slope after the train arrives ($t=240$ min) and after the train departs.

4.3.5 Simulation Experiment 5

This is a complex scenario involving the arrivals of several trains and ships over the course of several days. It simulates 5 days of terminal operations. The trucks arrive each day between 8:00 a.m. and 4:00 p.m. The truck arrivals follow the time-varying profile discussed in Section 4.2. There is some initial inventory in the import yard which needs to be transported away from the terminal, and some initial inventory in the export yard which needs to be loaded to a ship.

Of the trucks arriving at the inbound gate, 35% carry containers to be unloaded at the export yard, and 65% go to the import to load the stored containers. Of the trucks that go to the export yard and unload a container, 40% will continue to the import yard to pickup another container to be transported out of the terminal. This operation will help in reducing the import yard inventory faster.

At time $t=120$ min a ship arrives. The ship carries 3150 containers to be unloaded and stored at the import yard. The ship will be loaded with 1300 containers from the export yard. Another ship arrives at $t=4000$ min, which carries 1750 containers to be unloaded and which will be loaded with 1500 export containers. The loading/unloading of the ship is modeled as a continuous operation (24 hours). No live loading/unloading directly from trucks to ship or vice versa is taking place in this scenario.

Several train arrivals occur during the course of the 5 days. No direct loading/unloading from train to ship or vice versa (on-dock rail) is taking place in this scenario.

The values of the train and ship loads are shown in the profile graph of Figure C1. For a ship or a train a positive value denotes the number of containers to be loaded onto the ship/train. A negative value denotes the number of containers to be unloaded from the ship/train.

The parameters for this simulation experiment are shown in the five tables below. The tables and their contents are self explanatory. The parameters for this simulation are saved in the file “C.FiveDayWithShipWithTrain.sim”.

INITIAL STATE		
NAME	VALUE	DEFINITION
Yard		Import or Export Yard
ExportInventory	500	Initial number of containers in the export yard

ImportInventory	2000	Initial number of containers in the import yard
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TRUCK ARRIVALS		
NAME	VALUE	DEFINITION
Trucks		
ArrivalRate	Variable rate. It follows measured data profile.	The arrival rate of the trucks (trucks/minute)

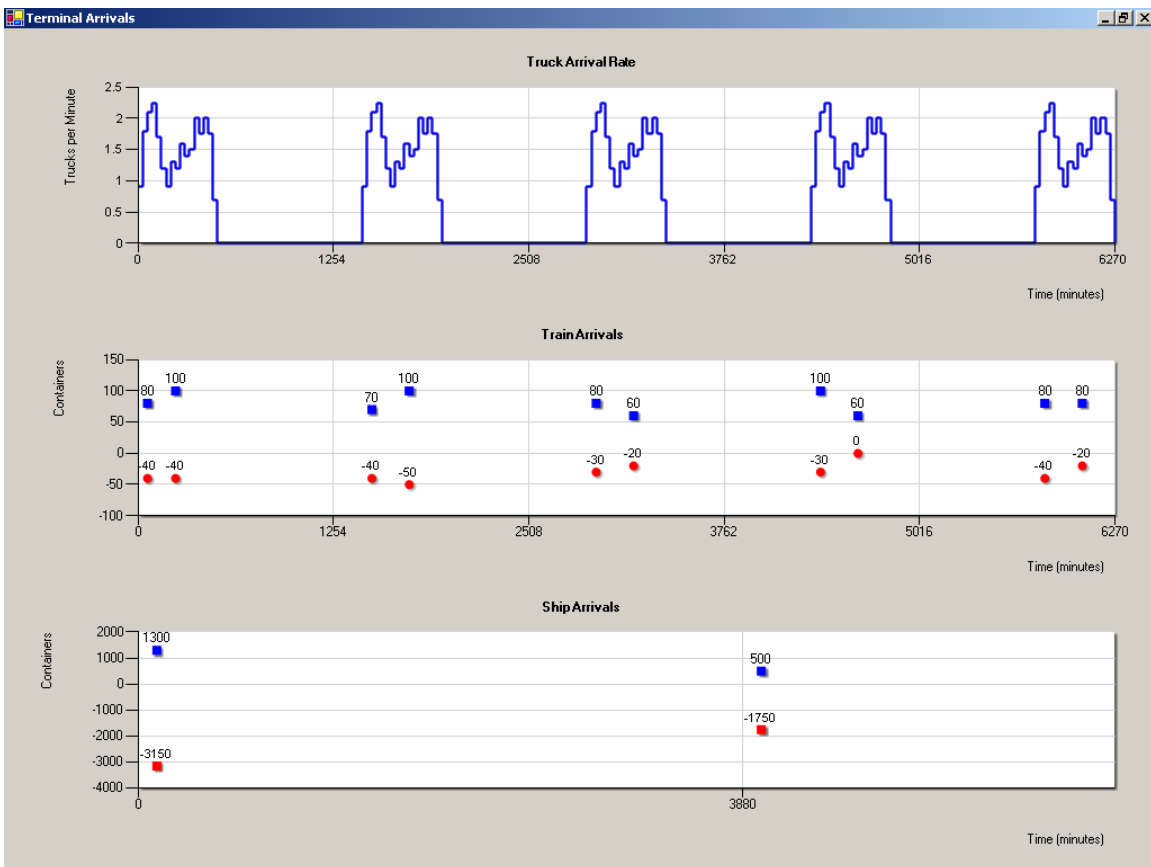


Figure C1: Profiles for truck, ship and train arrivals (5-day simulation). Variable truck arrival rates positive values: Containers to load onto ships/trains. Negative values: Containers to unload from ships/trains.

TERMINAL PARAMETERS		
NAME	VALUE	DEFINITION
ExportYard		Storage yard for export containers
OutFlowRate	$\mu=1, \sigma=0.4, T_{min}=0$	Flow rate (containers/minute) of containers to ship
TruckRate	$\mu=1, \sigma=0.3, T_{min}=0$	Processing rate (trucks/minute) of arriving trucks
ExportYardMaxQueueLength	5	The maximum allowable queue length (trucks) for the export yard
ImportYard		Storage yard for import containers
OutFlowRate	$\mu=1, \sigma=0.3, T_{min}=0$	Flow rate (cont/minute) of containers to train
TruckRate	$\mu=1, \sigma=0.3, T_{min}=0$	Processing rate (trucks/minute) of arriving trucks
ImportYardMaxQueueLength	5	The maximum allowable queue length (trucks) for the import yard
Inbound Gate		Terminal entrance gate for inbound trucks
EntranceRate	$\mu=1.6, \sigma=0.3, T_{min}=0$	Processing rate (trucks/minute) of arriving trucks
InboundMaxQueueLength	30	The maximum allowable queue length (trucks) at the inbound gate
PercentageToShip	0 (0%)	Percentage of arriving trucks bound for ship (for live loading or unloading)
PercentageToYard	1 (100%)	Percentage of arriving trucks bound for yard (either Import or Export yard)
OutBound Gate		Terminal exit gate for outbound trucks
ExitRate	$\mu=1.6, \sigma=0.3, T_{min}=0$	Processing rate (trucks/min) of departing trucks
OutboundMaxQueueLength	5	The maximum allowable queue length (trucks) at the outbound gate
TransitDelay		Delay (minutes)
EntranceToShip	10	Delay (minutes) from inbound gate to ship
EntranceToYard	15	Delay (minutes) from inbound gate to yard
ShipToExit	15	Delay (minutes) from ship to outbound gate
YardToExit	10	Delay (minutes) from yard to outbound gate
Truck Arrivals for Ship		Trucks bound for ship: live loading/unloading
PercentageShipExport		Percentage of trucks bound for ship that bring in containers to be live-loaded onto the ship
PercentageShipImport		Percentage of trucks bound for ship going to pick up containers live-unloaded from the ship
PercentageShipImportAfterExport		Percentage of trucks among "PercentageShipExport" that pick up containers unloaded from the ship <i>after</i> leaving a container to be loaded onto the ship
Truck Arrivals for Yard		Trucks bound for Import/Export Yards
PercentageYardExport	0.35 (35%)	Percentage of trucks bound for yards unloading containers for storage in the export yard
PercentageYardImport	0.65 (65%)	Percentage of trucks bound for the yards loading containers from storage in the import yard
PercentageYardImportAfterExport	0.40 (40%)	Percentage of trucks among "PercentageYardExport" loading containers from storage in the import yard <i>after</i> unloading containers for storage in the export yard

SHIP PARAMETERS (t = 120 Minutes)		
NAME	VALUE	DEFINITION
Container Inventory (imports)		
ToTrainInventory	0	Total containers to unload for the train (on-dock rail)
ToYardInventory	3150	Total containers to unload for the yard
Container Loading (exports)		
ContainersToLoad	1300	Number of containers to load before departing
Container Unloading (imports)		
Unloading rates		
ToTrainRate	$\mu=1, \sigma=0.3, T_{min}=0$	Flow rate of containers to train (containers/minute)
ToYardRate	$\mu=1.2, \sigma=0.4, T_{min}=0$	Flow rate of containers to yard (containers/minute)
Live Loading (exports)		
LoadingRate	$\mu=1.2, \sigma=0.4, T_{min}=0$	Processing rate for live loading operations (containers/minute)
Live Unloading		
LiveUnloadingInventory	0	Total containers to unload from ship to truck
LiveUnloadingRate	$\mu=0, \sigma=0.2, T_{min}=0$	Processing rate for live unloading operations (containers/minute) from ship to truck

SHIP PARAMETERS (t = 4000 Minutes)		
NAME	VALUE	DEFINITION
Container Inventory (imports)		
ToTrainInventory	0	Total containers to unload for the train (on-dock rail)
ToYardInventory	1750	Total containers to unload for the yard
Container Loading (exports)		
ContainersToLoad	1500	Number of containers to load before departing
Container Unloading (imports)		
Unloading rates		
ToTrainRate	$\mu=1, \sigma=0.3, T_{min}=0$	Flow rate of containers to train (containers/minute)
ToYardRate	$\mu=1.2, \sigma=0.4, T_{min}=0$	Flow rate of containers to yard (containers/minute)
Live Loading (exports)		
LoadingRate	$\mu=1.2, \sigma=0.4, T_{min}=0$	Processing rate for live loading operations (containers/minute)
Live Unloading		
LiveUnloadingInventory	0	Total containers to unload from ship to truck
LiveUnloadingRate	$\mu=0, \sigma=0.2, T_{min}=0$	Processing rate for live unloading operations (containers/minute) from ship to truck

TRAIN PARAMETERS (t = 60 Minutes)		
NAME	VALUE	DEFINITION
Container Loading (imports)		Containers the ship will load for export
ContainersToLoad	80	Number of containers to load before departing
Container Unloading (exports)		Terminal entrance gate for inbound trucks
ToShipRate	$\mu=0.3$ $\sigma=0.1, T_{min}=0$	Flow rate of containers to ship (containers/minute)
ToYardRate	$\mu=0.3$ $\sigma=0.1, T_{min}=0$	Flow rate of containers to yard (containers/minute)
Container Inventory (imports)		Containers brought by the ship for import
ToShipInventory		Total containers to unload for the ship
ToYardInventory	40	Total containers to unload for the yard

PARAMETERS for ALL TRAINS		
Arrival Time (Min)	Cont to Load	Cont to Unload
60	80	40
240	100	40
1500	70	40
1740	100	50
2940	80	30
3180	60	20
4380	100	30
4620	60	0
5820	80	40
6060	80	20

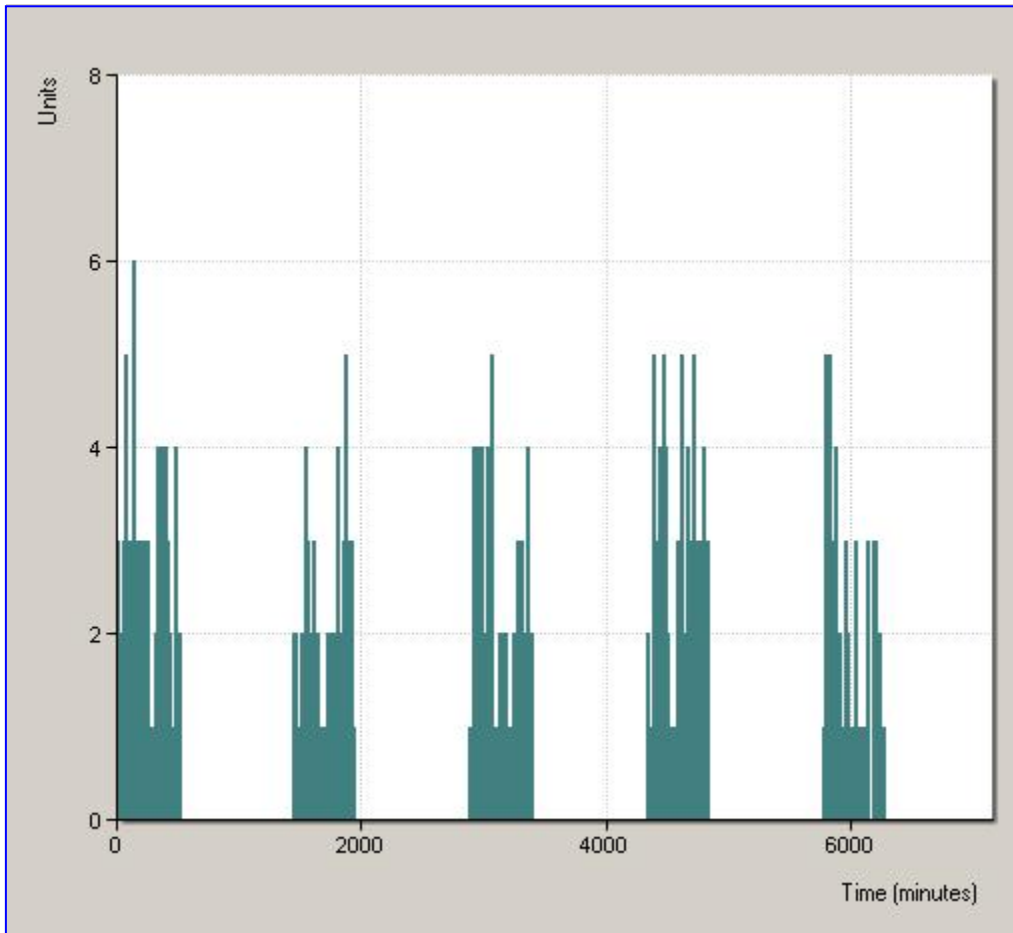


Figure C2: Inbound gate arrivals (5-day simulation): Truck arrivals at the inbound gate – variable arrival rates.

Figure C2 shows the truck arrivals at the inbound gate for the 5-day period. These are generated by a non-stationary Poisson process as discussed in Section 4.2. The pattern of arrivals for each day has similar characteristics to the observed data. The two separate sections for morning and afternoon can be clearly seen for each day.

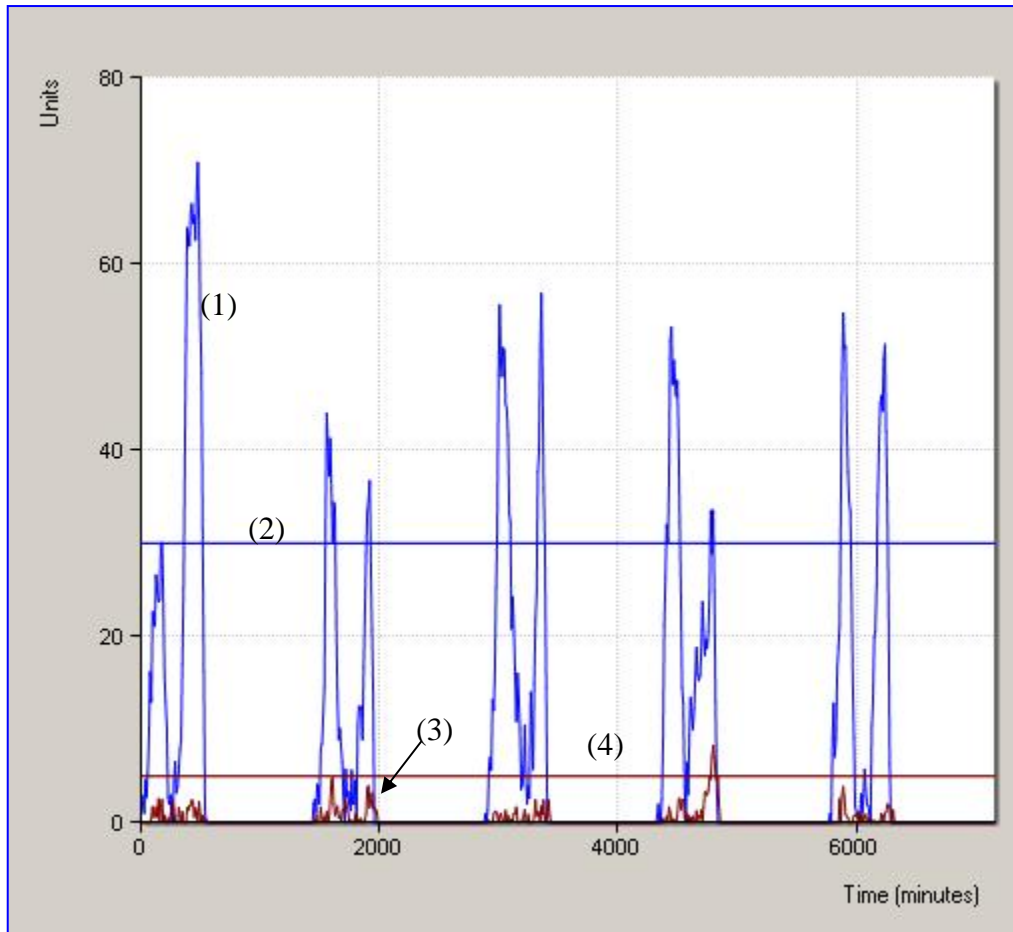


Figure C3: Queues at inbound and outbound gates (5-day simulation): (1) Queue length at inbound gate; (2) Maximum allowed queue length at inbound gate; (3) Queue length at outbound gate; (4) Maximum allowed queue length at outbound gate.

Figure C3 compares the queue lengths at the inbound and outbound gates. Both graphs have a clear evidence of two separate sections for the morning and afternoon arrivals, due to the variable arrival rates. These characteristics are similar to those of the observed data. The inbound gate queue length is clearly exceeding the maximum queue length. The outbound gate queue length is also exceeding the maximum queue length during some time intervals.

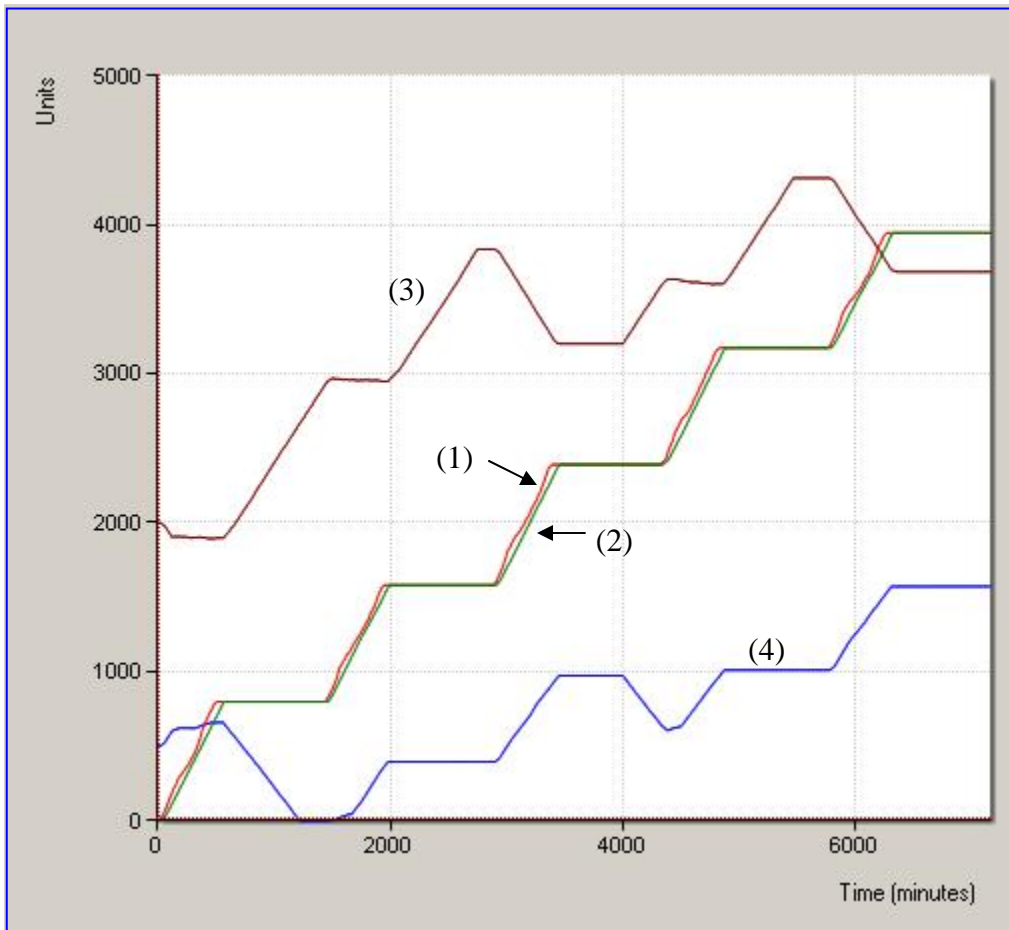


Figure C4: Cumulative graphs (5-day simulation): (1) Cumulative graph of arrivals at inbound gate; (2) Cumulative graph of departures from outbound gate; (3) Number of containers (inventory) in import yard; (4) Number of containers (inventory) in export yard.

Figure C4 shows the cumulative truck arrivals at the inbound gate and the cumulative truck departure from the outbound gate. It also shows the container inventories at the import and export yards. Since we assumed a continuous operation for the ship loading/unloading process, the inventories in the export/import yards are changing continuously, even when the gates are closed.

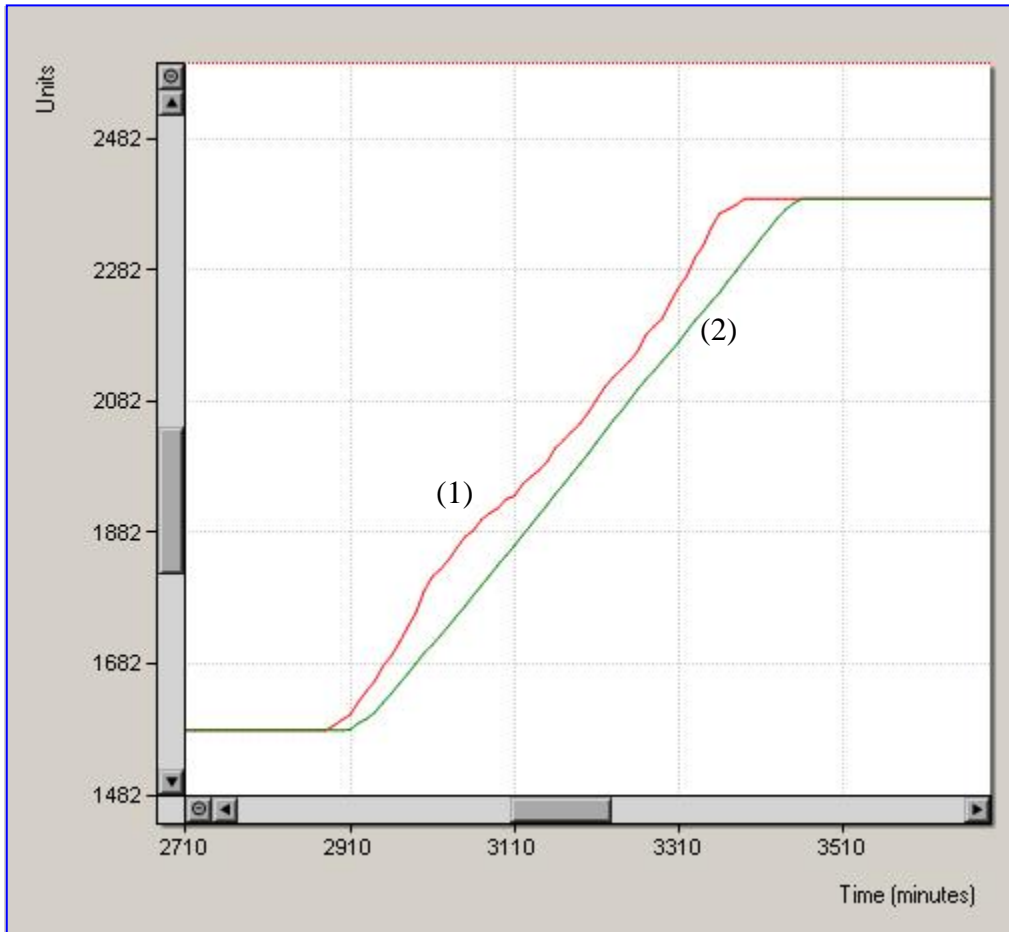


Figure C5: Truck arrivals and departures and yard inventories (5-day simulation):
(1) Cumulative truck arrivals at inbound gate; (2) Cumulative truck departures from
outbound gate.

Figure C5 is a zoom-in of the cumulative truck arrivals at the inbound gate and the cumulative truck departures from the outbound gate during the times between 2700 and 3800 minutes. The difference between these graphs is the number of trucks being inside the terminal at any given time. This has the same characteristics as the graphs shown previously in Simulation Experiment 1.

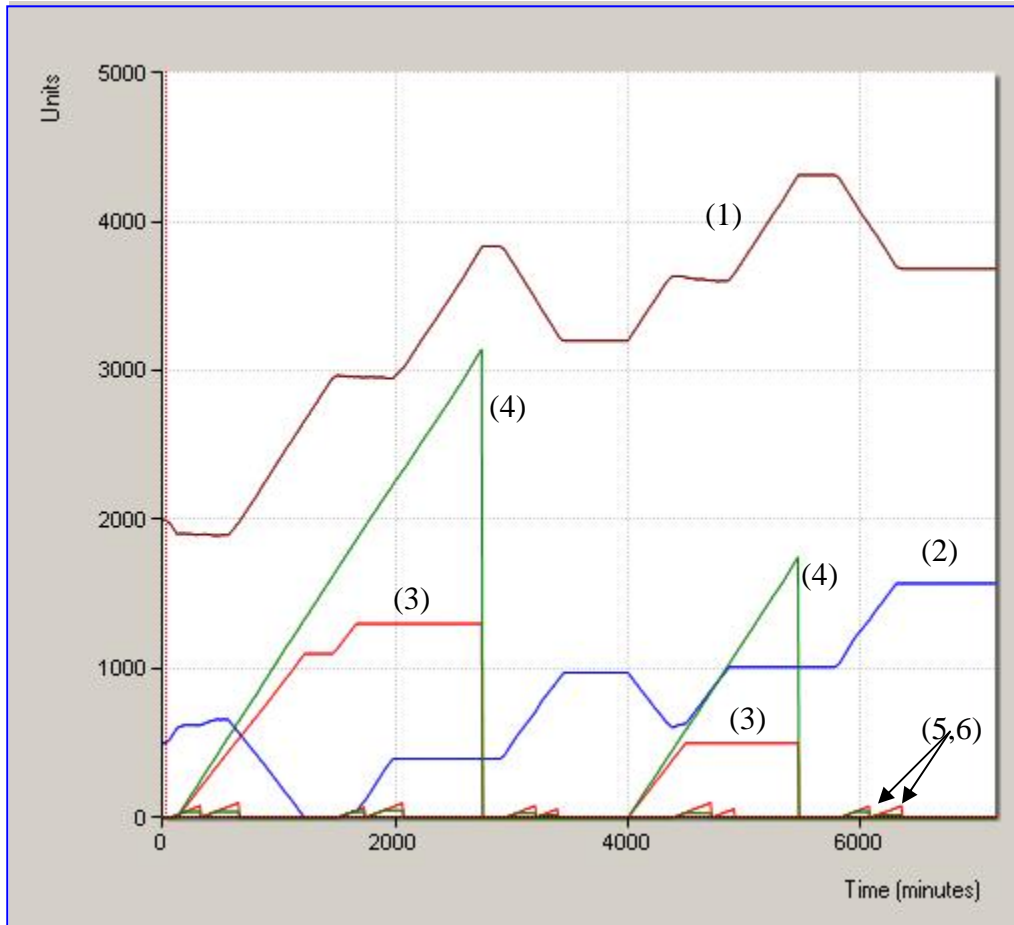


Figure C6: Arrivals, departures and yard inventories (5-day simulation): (1) Number of containers in import yard; (2) Number of containers in export yard; (3) Cumulative containers loaded onto ship; (4) Cumulative containers unloaded from ship; (5) Cumulative containers loaded onto train; (6) Cumulative containers unloaded from train.

Figure C6 shows the container inventory at the import and export yards, and how they vary with ship and train arrivals. We assume a continuous operation for ship loading/unloading. Loading of the ship is completed a lot faster than unloading, since fewer containers need to be loaded. The train arrivals have an imperceptible effect on the yard inventory, since trains carry a lot fewer containers as compared to a ship.

4.3.6 Simulation Experiment 6 (Appointment System)

This is the same as the complex scenario of Simulation Experiment 5, involving the arrivals of several trains and ships over the course of several days. It simulates 5 days of terminal operations. The trucks arrive each day between 8:00 a.m. and 4:00 p.m. In this scenario, because of the time window appointment system, truck arrivals follow a stationary Poisson process with constant mean, equal to 1.6 Trucks per Minute. All the other parameters are equal to the parameters of Simulation Experiment 5.

The parameters for this simulation are saved in the file
“C.FiveDayWithShipWithTrainWithAppt.sim”.

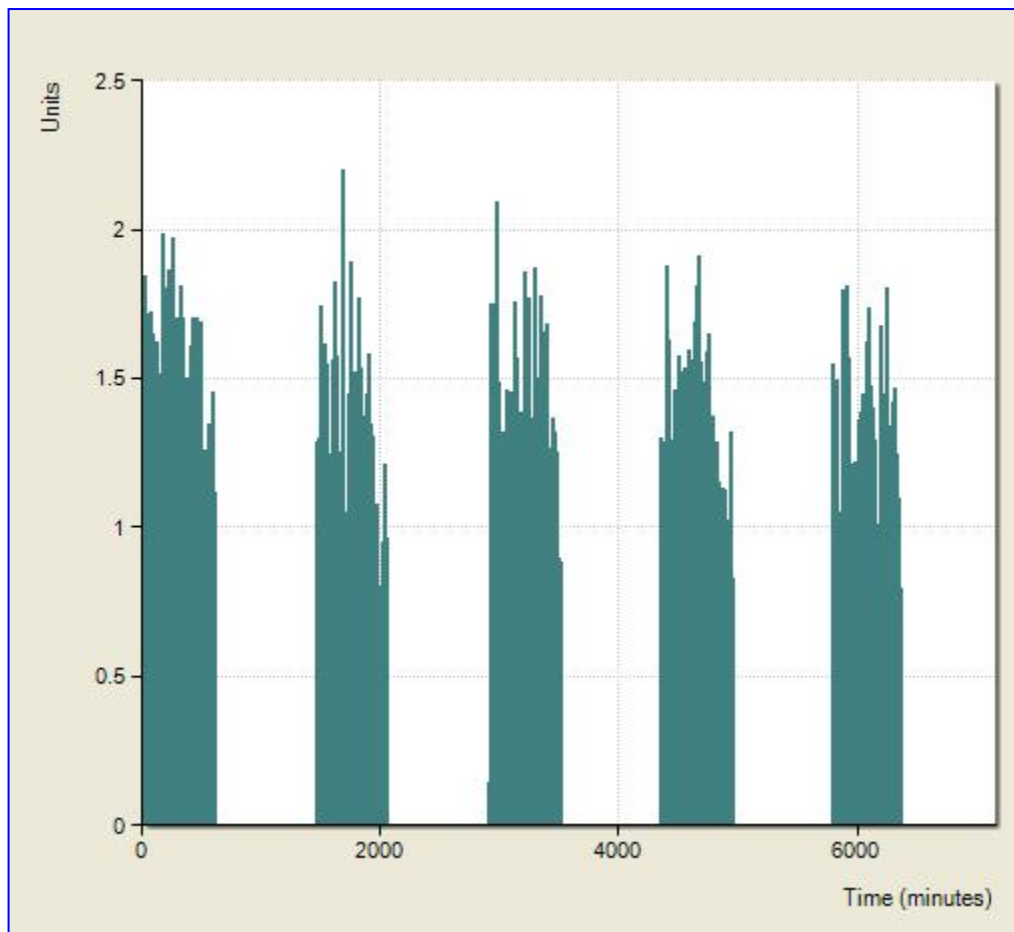


Figure C7: Inbound gate arrivals with appointment system (5-day simulation): Truck arrivals at the inbound gate – constant arrival rate.

The truck arrivals at the inbound gate for the 5-day period are generated by a stationary Poisson process with mean equal to 1.6 Trucks per Minute.

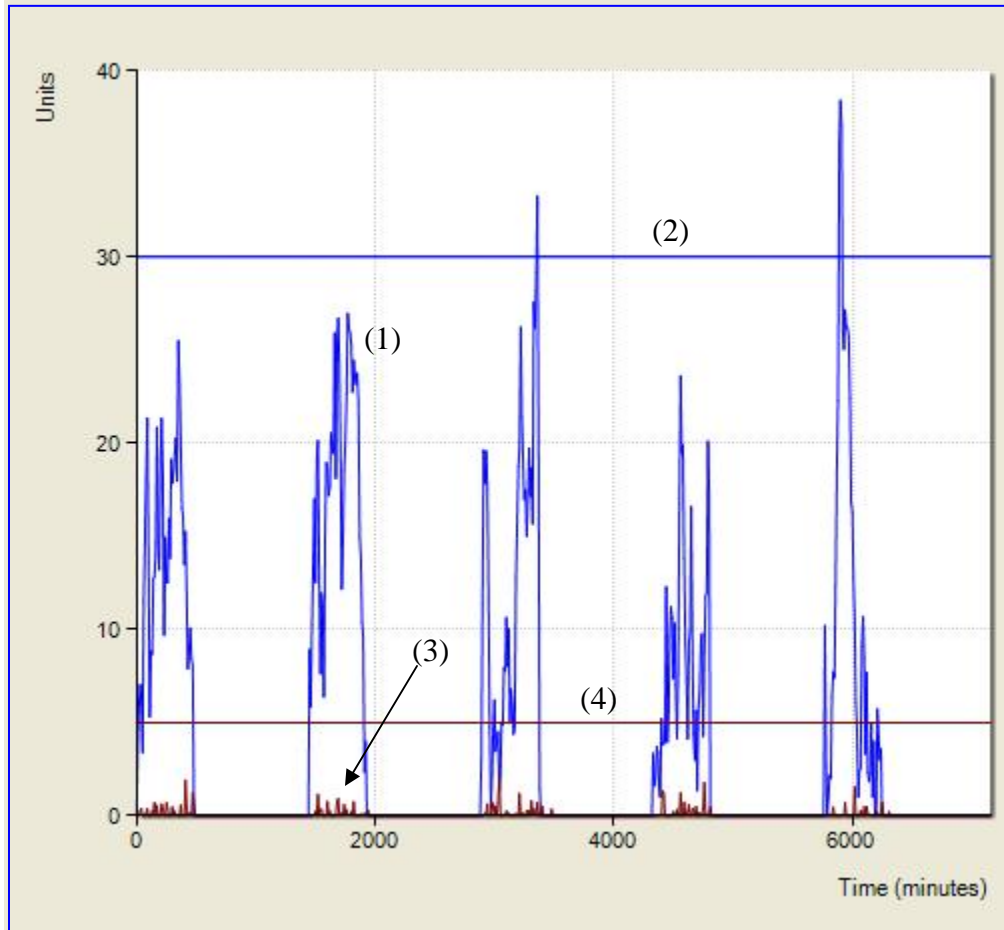


Figure C8: Queues at inbound and outbound gates with appointment system (5-day simulation): (1) Queue length at inbound gate; (2) Maximum allowed queue length at inbound gate; (3) Queue length at outbound gate; (4) Maximum allowed queue length at outbound gate.

Figure C8 compares the queue lengths at the inbound and outbound gates. The inbound gate queue length is very rarely exceeding the maximum queue length for a very short period of time. The outbound gate queue length is never exceeding the maximum queue length.

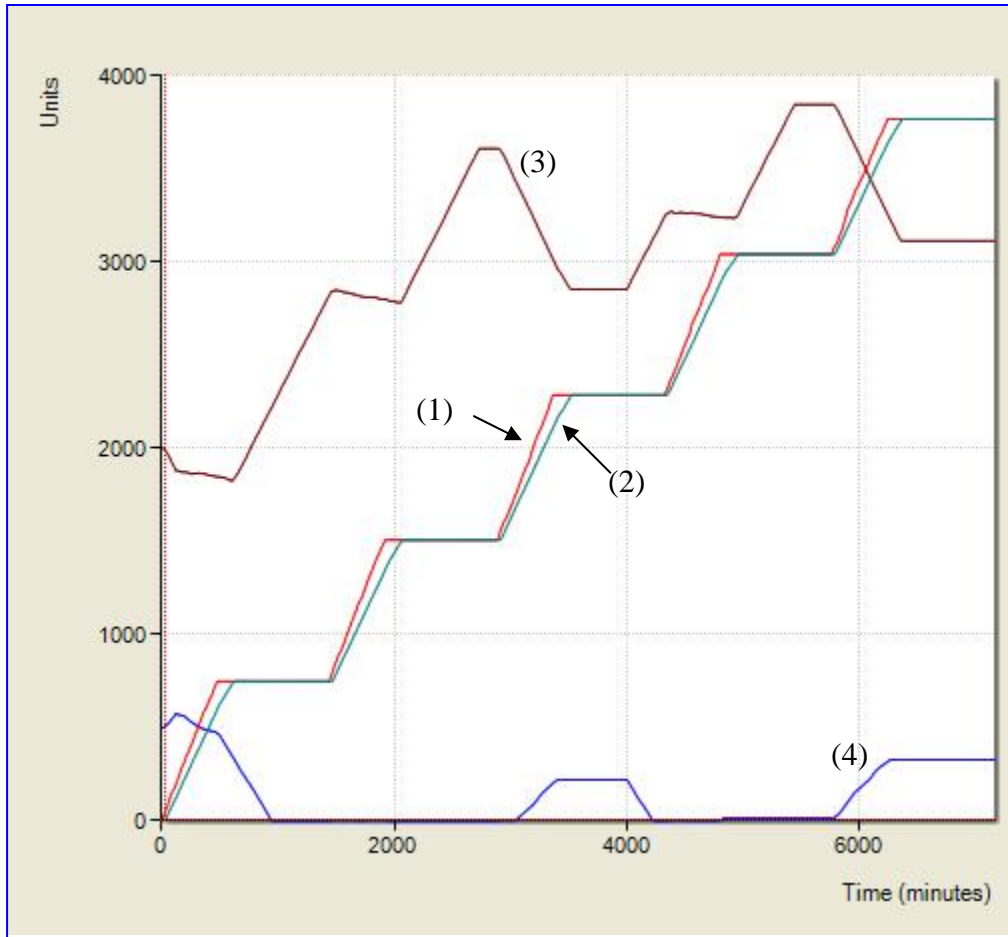


Figure C9: Cumulative graphs with appointment system (5-day simulation). (1) Cumulative graph of arrivals at inbound gate; (2) Cumulative graph of departures from outbound gate; (3) Number of containers (inventory) in import yard; (4) Number of containers (inventory) in export yard.

Figure C9 shows the cumulative truck arrivals at the inbound gate and the cumulative truck departures from the outbound gate. It also shows the container inventories at the import and export yards.

It is seen that the export yard inventory at the end of the simulation is about 300 containers. This is compared to the case of arrivals without appointments, where the inventory at the end of the 5-day simulation is 1600 containers. The appointment system gives reduction of 81% in the number of containers stored in the export yard.

Similarly, it is seen that the import yard inventory at the end of the simulation is about 3100 containers. This is compared to the case of arrivals without appointments, where the inventory at

the end of the 5-day simulation is 3600 containers. The appointment system gives reduction of 14% in the number of containers stored in the import yard.

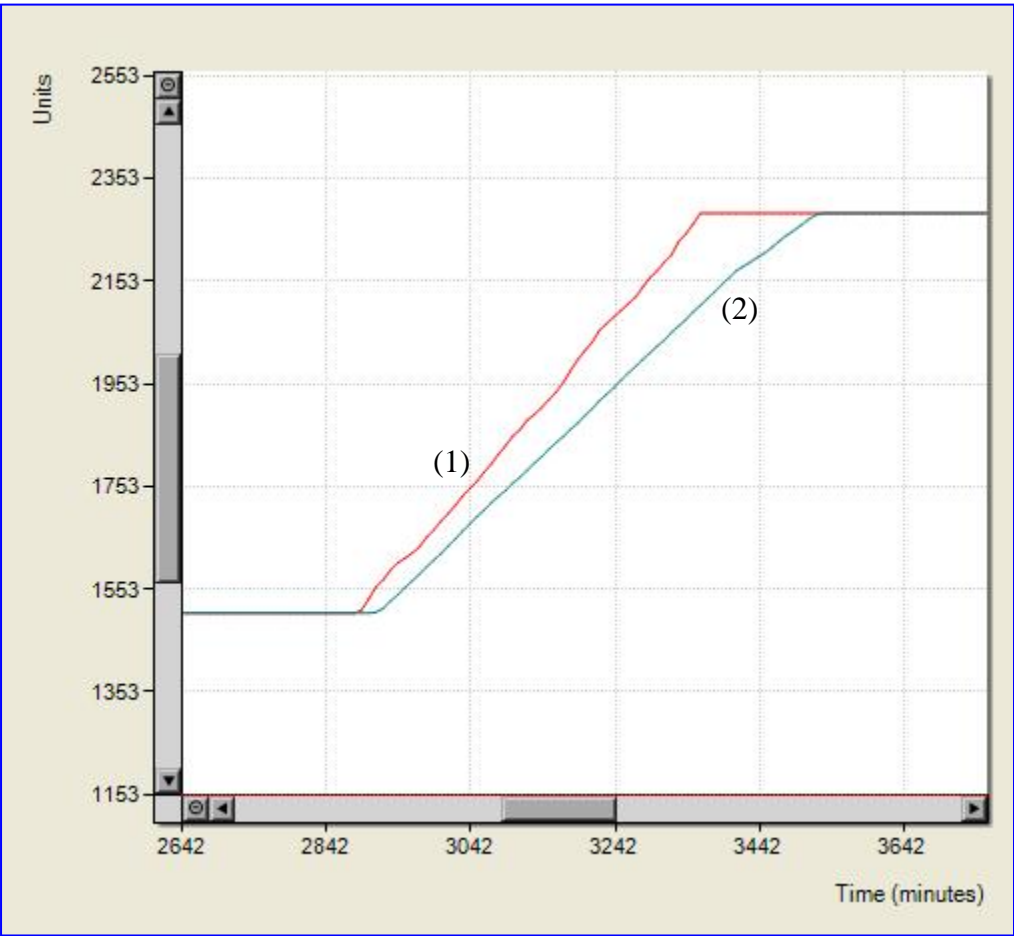


Figure C10: Truck arrivals and departures and yard inventories with appointment system (5-day simulation): (1) Cumulative truck arrivals at inbound gate; (2) Cumulative truck departures from outbound gate.

Figure C10 is a zoom-in of the cumulative truck arrivals at the inbound gate and the cumulative truck departures from the outbound gate during the times between 2600 and 3700 minutes. The difference between these graphs is the number of trucks being inside the terminal at any given time. This has the same characteristics as the graphs shown previously in Simulation Experiment 2.

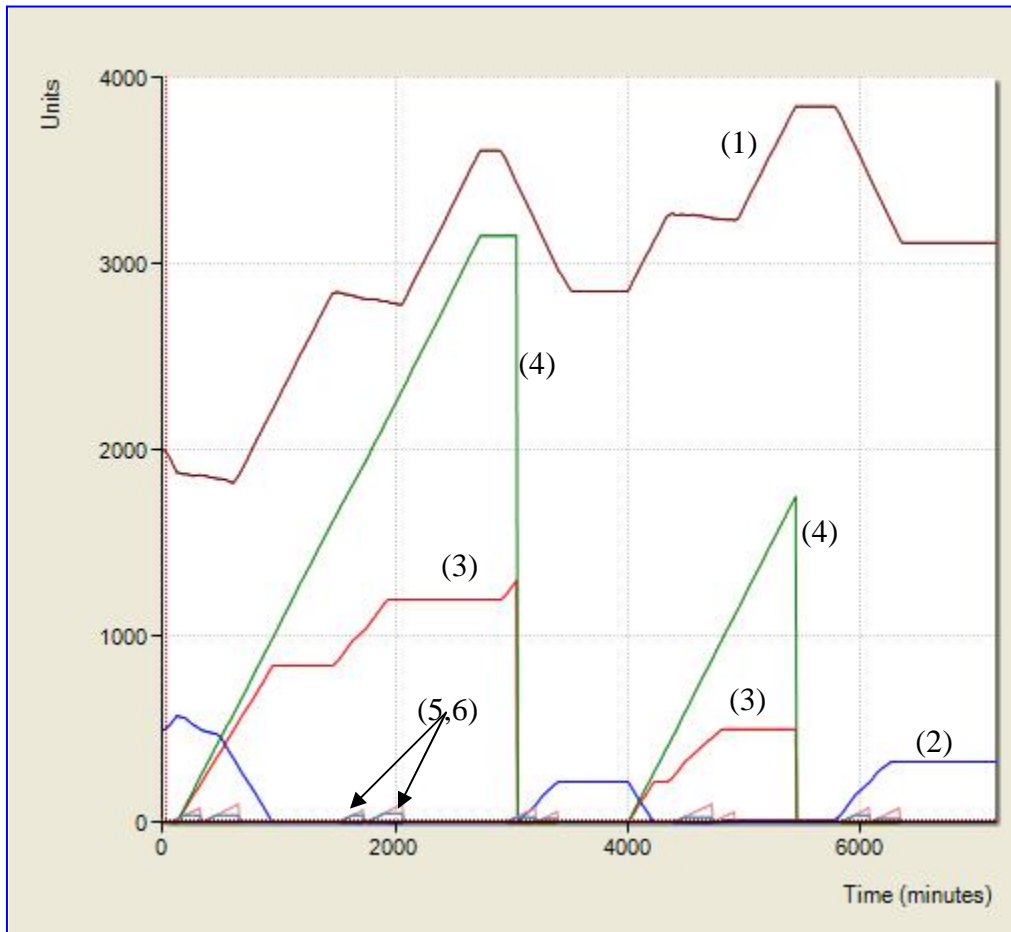


Figure C11: Arrivals, departures and yard inventories with appointment system (5-day simulation): (1) Number of containers in import yard; (2) Number of containers in export yard; (3) Cumulative containers loaded onto ship; (4) Cumulative containers unloaded from ship; (5) Cumulative containers loaded onto train; (6) Cumulative containers unloaded from train.

Figure C11 shows the container inventory at the import and export yards, and how they vary with ship and train arrivals. The appointment system provides a reduction of 81% in the number of containers in export yard. It is seen that the number of containers in the export yard goes down to zero during some time intervals. A consequence of this, for this particular situation, is that it takes a long time to load the ship, since no containers are available in the export yard during certain periods of time. The train arrivals have an imperceptible effect on the yard inventory, since trains carry a lot fewer containers as compared to a ship.

5 Conclusions and Recommendations

In this report, a structure is proposed and an algorithm is developed to generate cooperative time windows. The cooperative time window appointment system is modeled mathematically, and an optimization technique based on insertion method is proposed. Simulation experiments are used to evaluate the efficiency of the algorithm.

We also developed a software package for simulating terminal operations. The Terminal Simulator was used to study the effects of the time window appointment system on various terminal operations. Based on data collected on truck arrivals, several simulation scenarios were created and presented. The scenarios compare the current practices, without the appointment system, to the case when the time window appointment system is applied. It is seen that when the appointment system is used, the queues at the inbound and outbound gates become smaller, and the import and export yards are serviced more efficiently.

Future work should focus on refining the terminal simulator software and on obtaining more data on truck arrivals and turnaround times. Each of the model components, such as yards, ship, train, gates, can be refined and simulated at the microscopic level. The outputs of the microscopic models from one component will be used as inputs to other components within the terminal. Moreover the model can contain additional features such as movement of empty containers, separate bobtail and chassis only sections etc. At this point more data are necessary, especially on the transport of empty containers, to be able to set up the refined simulation models with realistic parameters.

6 Implementation

One aspect of the project's implementation will be to collect data on truck arrivals at the terminals when the appointment system is set in place. The model will be recalibrated with actual arrival times with the appointed system in operation. The distributions will be compared to the current data, collected before the appointment system is set. What will be of particular interest is data on the inbound and outbound gate queues, and truck turnaround times. According to our current model, the queues should be considerably shorter for longer periods of time, and the container transport operations from the import and export yards should be more efficient.

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