Simulation Test-bed and Evaluation of Truck Movement Concepts on Terminal Efficiency and Traffic Flow

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Abstract

Marine terminals are in need of additional capacity in order to handle increasing demands. In metropolitan areas such as Los Angeles/Long Beach, the scarcity and high cost of land forces the terminals to increase capacity by using advanced technologies rather than expanding in square footage. Higher efficiency within the terminals however could imply more truck traffic in and out of the terminal that will lead to congestion on the roadway network adjacent to the terminals. This traffic congestion will, in turn have a negative effect on the efficiency of the terminals, in addition to increased pollution. It is therefore clear that the efficiency and capacity of the terminals cannot be decoupled from the effect on congestion on the traffic network outside the terminals.

In this study we develop a simulation test bed that allows us to investigate the impact of various technologies and concepts on the terminal capacity and cost as well as on the traffic network outside the terminals in an integrated manner. The test bed is of general use and could be employed to evaluate a wide range of concepts and technologies associated with terminals and ports and the traffic network surrounding them. The test bed is used to evaluate and analyze truck movement concepts that include the use of an inland port with dedicated truck lanes; empty container reuse strategies; and centralized processing and use of chassis.

The test bed consists of three modules: TermSim, TrafficSim and TermCost. The *TermSim* module includes the simulation of operations within the terminal and at the interfaces. The *TrafficSim* module includes the simulation of trucks, vehicles and traffic flow on the roadway network outside the terminals. TermSim interacts with TrafficSim at the interfaces. The *TermCost* module is a cost model developed by the authors for cost evaluation of terminals and is used to evaluate the concepts under consideration. The TermCost module interacts with TermSim. An inland port concept and empty container reuse strategies are evaluated using the test bed in order to investigate and quantify their effect on the terminals and the traffic network outside the terminal. As a specific example, the traffic network surrounding a terminal in the Los Angeles/Long Beach port is used to demonstrate the use of the test bed in evaluating and quantifying benefits associated with the use of an inland port and empty container reuse strategies. In addition the test bed is used to perform a preliminary study of the concept of centralized processing and use of chassis.

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Definitions of Acronyms

ACC	Average Cost per Container
ACT	Automated Container Terminal
ACTIPOT	Automated Container Transport System Between Inland Port and Terminals
AGV	Automated Guided Vehicle
BHL	Berkeley Highway Laboratory
D/S	Demand to Supply ratio for empty containers
E/L	Empty to Loaded ratio for containers
FC	Fixed Cost
HGV	Heavy Goods Vehicle (truck)
ICTF	Intermodal Container Transfer Facility
ITS	International Transportation Services
PeMS	Performance Measurement System
POLA	Port of Los Angeles
POLB	Port of Long Beach
TC	Total Cost
TEU	Twenty Foot Equivalent Unit
VC	Variable Cost

Disclosure

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Introduction

The elimination of international trade barriers, lower tariffs and shifting centers of global manufacturing and consumption has led to new dynamics in intermodal shipping. Worldwide container trade is growing at a 9.5% annual rate, and the U.S. growth rate is around 6%. It is anticipated that the growth in containerized trade will continue as more and more cargo is transferred from break-bulk to containers [1]. By 2010, it is expected that 90 percent of all liner freight will be shipped in containers [2]. Every major port is expected to double and possibly triple its container traffic by 2020.

The situation becomes even more difficult for the three main container port complexes on the West Coast (Long Beach/Los Angeles, Seattle/Tacoma and Oakland), which handle almost 50% of the container traffic in the United States (a combined volume of 17,000,000 TEU for the West Coast out of 35,500,000 TEU total volume for the nation in 2003). In particular the combined ports of Long Beach/Los Angeles, the largest container port in the nation, handles 33% of the total container traffic in the US [3]. This huge volume moving through the local ports has very serious effects not only at the local and regional levels, but on a national scale as well. In 1984 only one weekly eastbound double-stack rail service existed from the whole West Coast (from POLA/POLB to Chicago). Less than ten years later, in 1993 there were 241 train sets of weekly eastbound double-stack rail services from all major ports in the West Coast to several metropolitan centers in the east [4]. The national economy is heavily dependent on the smooth and reliable operation of the POLA/POLB complex, and this fact became quite evident during the longshoremen strike of 2002, which for 11 days crippled the nation and cost $2 billion per day [5].

To handle the huge amount of freight and reduce the cost per TEU container, shipping companies are forced to order faster, larger and deeper ships. The first generation of container ships had an average capacity of 1,700 TEU, and the industry predicted back in 1970 that ship capacity would top at 3,250 TEU. The reality is, that today there are ships such as the “Sovereign Maersk” which carries 6,600 TEU, or Hapag-Lloyd’s “Shanghai Express” which has a capacity of 7,506 TEU, much more than double of what the industry had predicted back in 1970. Given that the newly built “Emma Maersk” has a reported capacity of 11,000 TEU it seems that the prediction of 15,000 TEU mega-ships in the future is a realistic possibility [4].

As a consequence of this unanticipated growth, port generated traffic has emerged as a major contributor to regional congestion. In 1999, in a report to congress, the US Maritime Administration estimated that the LA/LB port handled more than 20,000 truck and 30 train movements per day. The report also predicted that by 2020 these numbers would be 50,000 truck and 100 train movements per day [7]. Other data indicate that the movements predicted by US Maritime Administration are notably conservative. These data estimated that truck trips generated by the combined LA/LB ports are about 34,000 trips per day [6], and that daily truck movements may reach 92,000 by 2020, which is significantly higher than the prediction in [7]. The unanticipated growth in LA/LB port activity suggests that the levels of predicted traffic will be met in 2010, a full 10 years earlier than planned [7]. The geographic configuration of the combined LA/LB port complex is such that only two major freeways (I-710 and I-110) serve almost all fourteen terminals in the complex. The largest share of the truck traffic is currently carried by the I-710, in which the truck traffic volume is currently about 10-15% [6]. This volume of trucks adversely impacts operational capabilities. An analysis of the Southern California freeway collisions by the California Highway Patrol reveals that the I-710 topped the list in two measures: (a) the highest proportion of truck-involved collisions at 31%, and (b) truck-caused collisions at 16% [8]. Other major negative outcomes are [9]:

- Air pollution, especially diesel toxins, generated by idling and slowly moving vehicles,
- Wasted energy, caused by inefficient vehicle movements,
- Wasted time (driver inefficiency), caused by traffic congestion on the road and long queues at the gates of terminals,
- Cost imposed by the volume of trucks on roadway for maintenance, etc.

It is worth mentioning that in the LA/LB port area the driver efficiency is only two to three cycles per day in average. A METRANS-funded survey shows that 40% of trucks visiting LA/LB terminals, are involved in more than two hours waiting time, with almost a quarter of transactions involving a wait in the range of 2 to 3 hours [10].

It is therefore very apparent from the above discussion and data that a high increase in terminal throughput will be accompanied by an increase in truck traffic that could lead to further congestion on the traffic network and in turn have a negative impact on the terminal throughput itself. The problem of maintaining high terminal throughput while at the same time managing congestion and maintaining traffic efficiency in the traffic network outside the terminals should be viewed as an integrated problem.

In previous work, [11-16], [18-24], the authors considered the problem of increasing the terminal throughput separately from the problem of reducing the number of truck trips. In [11] several terminal concepts were introduced and analyzed that showed potential for dramatic improvements in throughput via the use of automation and advanced technologies within the terminal. To achieve such a high throughput, it was assumed that a sufficient number of trucks and trains are available to serve the terminal at steady rates. This assumption implies that the traffic network outside the terminal has sufficient capacity to handle the higher flow of trucks. This is clearly not the case in places like Los Angeles/Long Beach and other major metropolitan areas with adjacent ports, where highway congestion during peak hours reduces traffic flow considerably.

In [12, 13] the authors studied the problem of reducing truck traffic by using optimization and information technologies to develop methods of empty container reuse that will require a smaller number of truck trips to and from the terminal. The analytical models and optimization techniques developed in [12] show that empty container reuse can produce significant reduction in truck miles traveled, which in turn reduces traffic congestion, pollution and the associated negative impact on the surrounding communities. In [14], the authors developed the concept of ACTIPOT (Automated Container Transport System Between Inland Port and Terminals), which involves the use of an inland port to temporarily store containers and move them to the terminal using dedicated lanes at times of low traffic densities in the traffic network.

During these studies [12-14] it became apparent that a simulation test bed is necessary to evaluate the various concepts with respect to terminal performance and cost as well as impact on the traffic network in an integrated manner. The test bed would allow the simulation of container movements within the terminal as well as the truck and vehicle traffic in the adjacent traffic network. Since one system affects the other, both systems have to be considered and simulated together. Feeding the terminal with a high volume of trucks during off-peak hours using an inland port may help reduce congestion outside the terminal during peak traffic hours but it may create congestion and chaos inside the terminal. On the other hand empty container reuse strategies may free capacity within the terminal and at the same time reduce truck trips to and from the terminal leading to a win-win situation. In order to quantify these benefits and better understand the impact of new strategies and concepts on both the terminal and traffic network, a simulation test bed that can simulate the overall system, terminal and traffic network, is therefore essential.

In this project we have developed a simulation test bed that consists of the following three modules: TermSim, TrafficSim and TermCost. The *TermSim* module allows the simulation of container movements inside the terminal by modeling terminal operations. The *TrafficSim* module enables the microscopic simulation of the traffic flow on the traffic road network outside the terminals. The *TermCost* module enables the user to perform a cost analysis of the impact on the terminal of any changes in the terminal characteristics, volume of containers, new approaches etc. The test bed is used to evaluate the impact of different concepts, which have an effect on truck movements and volume of trucks on the terminals and adjacent traffic network. These concepts include the empty container reuse [12,13]; the ACTIPOT inland port approaches [14-16]; and the centralized processing and use of chassis, which is explored at a preliminary level. The central processing of chassis is a concept suggested by several terminal operators as a concept that will free yard space in terminals and reduce traffic.

Simulation Test-bed

This section of the report presents the overall development and description of the simulation test bed. Specifically this section presents the development of the three components of the test bed: The TermSim, TrafficSim, and TermCost modules.

2.1. TermSim

The terminal simulation module referred to as *TermSim* is building upon previous work by the authors, specifically on a previously developed flow-based terminal simulation model. A thorough description of the previous work on the *TermSim* module is provided in reference [46], where the parameters of the module are presented in detail. Additionally, reference [46] provides results of several simulation scenarios, where the *TermSim* module was used to evaluate the effectiveness of measures for the reduction of traffic congestion, such as the appointment system, and extended gate hours. In the previous work no interaction with the adjacent traffic network was possible. The flow of trucks was generated just as the trucks entered the terminal at the inbound gate. The model is balancing the inflows and outflows into and out of the major components of the yard, and produces the flow of trucks at outbound gate, without any further interaction with the outside traffic network.

The current TermSim model is designed to interact with the network outside of the terminal, thus being able to perform realistic simulations of different concepts and evaluate their effect on the performance and efficiency of the terminal under consideration.

2.1.1. Macroscopic terminal model

The flow-based macroscopic terminal model is shown in Figure 0-1. The graph shows the flows of containers from/to inland carriers (trucks and trains) to/from ocean carriers (ships). The diagram shows the possible flows of containers in a terminal. It also shows the direct and indirect (through storage yard) flows between different entities .

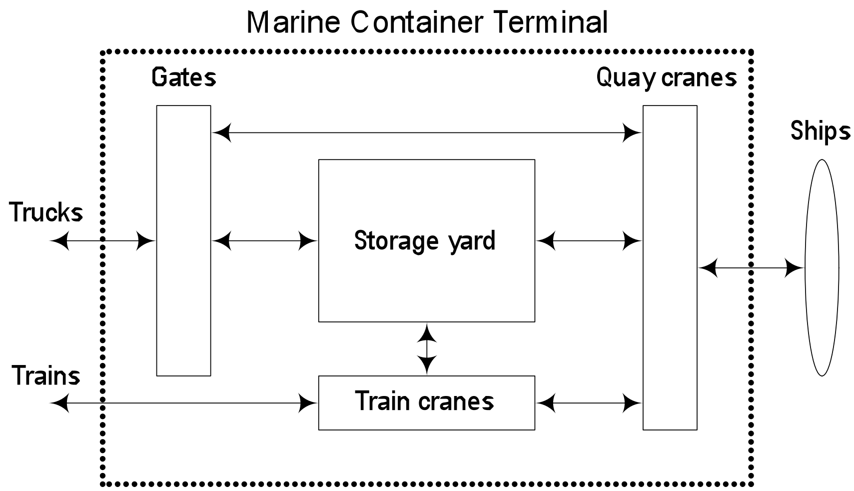

Figure 0-1: Macroscopic terminal model

2.1.2. The *TermSim* module

The TermSim module is an object-oriented, event-based simulation system implemented with the C# programming language and can be executed on a Microsoft .NET platform. The use of C# and object classes makes the model computationally efficient, reconfigurable, and expandable. To analyze the movement of trucks in and out of the terminal, TermSim is keeping track of each individual truck as a separate object. The truck object is being followed around the yard, as it performs its various functions, such as loading a full container from the import yard; unloading a full container at the export yard; picking up an empty container which will be taken out of the terminal and loaded with export goods, etc., thus simulating the movement of trucks inside the terminal at a microscopic level. The overall TermSim module constitutes a complete simulation environment where a number of parameters are set by the user, such as truck arrival rates, gate processing times for inbound and outbound gates, ship and train arrivals, inflows and outflows to the storage yard, yard capacities etc. The simulation environment provides time dependent graphs, and cumulative plots for any variable of interest within the terminal. The simulation environment is developed in C# using object oriented code that allows the macroscopic nature of each subsystem to be converted into a microscopic one without affecting the nature of the other subsystems.

The truck generation mechanism can either be set by the user by specifying a statistical distribution (default is the Poisson distribution, i.e. exponentially distributed inter arrival times), or it can be externally created. The external truck generation mechanism has been used here, since trucks are produced from a microscopic traffic simulation program as will be described later.

2.2. TrafficSim

This module referred to as TrafficSim, models the microscopic traffic flow on the roadway network outside the terminals. The TrafficSim module is based on the traffic simulation suite VISSIM. Since the development of the test bed requires the seamless and continuous interaction between TrafficSim and TermSim, the appropriate software interface was developed for this purpose. Specifically, the TrafficSim outputs are used as inputs to the TermSim environment, and the TermSim outputs serve as inputs to TrafficSim. This provides a high degree of continuous interaction between the simulations of the terminal operations and the surrounding traffic network.

2.2.1. Roadway Network Model

Model and Traffic data

The Los Angeles/Long Beach area is chosen as a specific example of a terminal and roadway network for the purpose of demonstrating our results. In our specific example, the roadway network is chosen as the stretch of the road connecting the ITS (International Transportation Service) terminal at the port of Long Beach, to the ICTF yard (Intermodal Container Transfer Facility). The network roadway consists of a 4.9 km long freeway stretch on Interstate I-710, from ITS to the W. Willow Street exit, and of a 1.8 km long surface street network, west of the I-710, connecting the W. Willow Street exit to the ICTF yard. For the most part, the mainline of the freeway has 3 lanes. The surface street network, covering the W. Willow St. from ICTF to I-710, includes 5 signalized intersections. These intersections are shown in Figure 0-2 , where the layout of the roadway network model is presented. The little block arrows represent the data collection stations. The seven data collection stations were located as following:

- Data collection station 1: About 2 km north of W. Willow Street, collecting the data as the vehicles enter the roadway network.
- Data collection stations 2 and 3: A bit north and a bit south of W. Willow Street, to account for the effects of trucks traveling to/from the ICTF.
- Data collection stations 4, 5, and 6: They are dispersed along the I-710, spaced approximately 1km from each other on the average.
- Data collection station 7: Located slightly north of the ITS terminal. This station provides the data for trucks entering or leaving the particular terminal, in this case ITS.

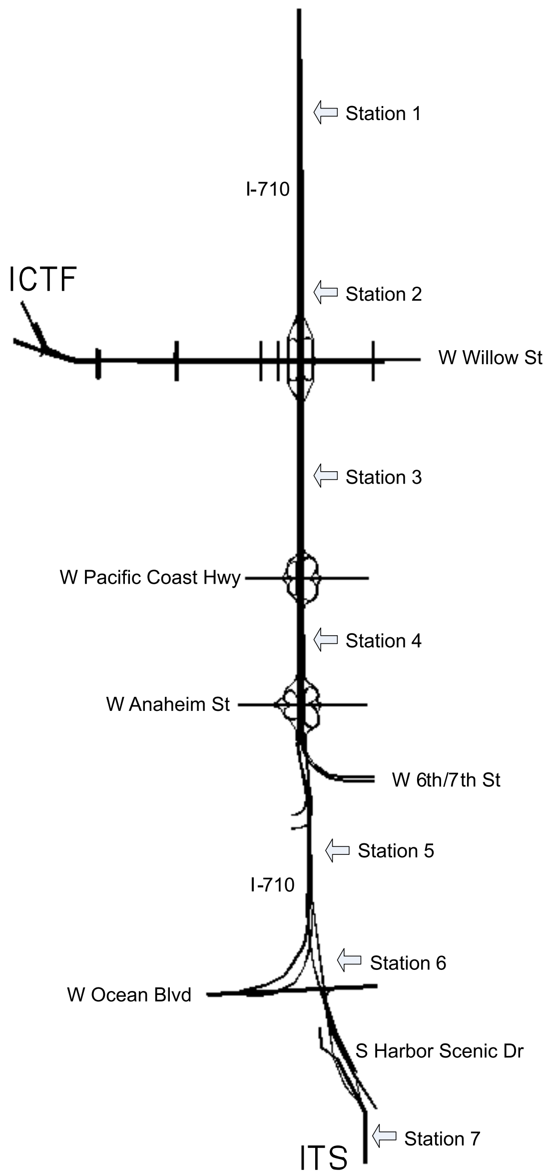

Figure 0-2: Roadway network model

The Freeway Performance Measurement System (PeMS) collects historical and real-time freeway data from freeways in the State of California in order to compute freeway performance measures [25]. Data from the closest PeMS collection station, which is located 2 km north of Station 1 are used, in order to generate the traffic demands.

2.2.2. Design of the VISSIM Simulation Model

Overview of VISSIM model

Microscopic simulation tools have become more sophisticated and are frequently used in traffic analysis. These tools, such as CORSIM [26] and VISSIM [27], are designed to model any combination of surface transportation networks at a high level of detail. They support signal control and other operational strategies and provide various output formats for analysis and comparison. Detailed comparison efforts between several popular microscopic simulation models have been investigated in [28, 29, 30].

In our previous work [31] we used data from the Berkeley Highway Laboratory (BHL) site to compare the simulation models obtained from VISSIM and CORSIM. We demonstrated that both packages have roughly similar capabilities. However, they differ in their network coding structures, signal modeling logic, car-following models, etc. CORSIM uses a link-node representation to build a network, while VISSIM uses link-connector structure which can be constructed over an imported graphical map. This unique network coding structure enables VSSIM to model any kind of intersection or any length of link. Due to its flexibility, VISSIM is selected to simulate various needs in the field of traffic analysis [32, 33, 34]. VISSIM is a discrete, stochastic, time step based microscopic traffic simulation program developed to analyze traffic and transit operations. VISSIM uses the psycho-physical driver behavior model based on the work of Wiedemann [35, 36]. The basic idea of this model is stochastic perceptual thresholds which replicate individual driver characteristics.

Coding of the network

The scaled aerial photographs accessible from Google Maps (http://maps.google.com/) are sources of the geometric information. Over the constructed roadway network based on the sources, several network entities are placed:

- A set of *Detectors* is placed to model a data collection station.
- A set of *Desired Speed Decisions* is also installed on ramp, which makes a transition between freeway and local flows.
- A *Reduced Speed Area* is placed on a curved area of a ramp or an intersection in order to generate more realistic traffic behavior.

Coding of the ramps

Using VISSIM, onramps are configured by adding merging lanes on the mainline and by placing appropriate *Routing Decisions*. However, this generates unrealistic behaviors as the mainline flow approaches its critical density (a large queue on the onramp, fast through traffics on merging area).

Reduced Speed Area and *Lane Change* distance on *Connector* are used to address these unrealistic behaviors. By placing *Reduced Speed Area* right before the merging area and by increasing the *Lane Change* distance on the *Connector* after the merging area, it prevents vehicles on the mainline from using the merge lane as an acceleration lane as well as make sure that the vehicles on the ramp are aware that they do need to merge before this *Connector*.

Similar to the onramp configuration, offramps are modeled by adding splitting lane on the mainline. For both kinds of ramps, the range of *Routing Decision* is defined to be wide enough to capture the behavior of the upstream traffic as long as the geometry allows. Also, *Lane Change* distance is set to greater than the default value to generate a visually acceptable lane changing behaviors.

Coding of the signal control

Ramp metering in VISSIM can be modeled either using the built-in fixed-time control or an optional external signal state generator. The fixed-time control is chosen for the signalized intersections of the surface street.

Coding of the vehicle compositions

VISSIM uses a hierarchical concept to define the vehicle population. *Vehicle Types* defines a group of vehicles that have similar characteristics, such as { *Vehicle Model*, *Length*, *Width*, *Maximum(Desired) Acceleration*, *Maximum (Desired) Deceleration}*, etc. Some of these characteristics are defined probabilistically, using predefined statistical distributions. Also, *Vehicle Class* is used to aggregate one or more *Vehicle Types* which have a similar driving behavior. *Vehicle Compositions* are defined by *Vehicle Types* and *desired speed distribution*.

The roadway network model is assumed to be occupied by four Vehicle Compositions.

- Passenger cars entering a freeway (referred to as CAR_105km in the simulation)
- Passenger cars entering a street (termed CAR_072km in the simulation)
- Container trucks entering a freeway (termed HGV_088km in the simulation)

- Container trucks entering a street (termed HGV_056km in the simulation)

Coding of the traffic demand

As a Windows application, VISSIM provides a window for editing each network entity or decision. However, since the *Vehicle Inputs* are defined by Vehicle Composition, Link, Volume, and time interval, a great deal of operations is needed to edit them. So, an input generator (InpGen) is developed to directly edit the VISSIM network files with its appropriate text structure.

Furthermore, trucks from the outbound gate of TermSim should be fed into TrafficSim. Although the outbound truck volume from TermSim cannot be predetermined, the corresponding *Vehicle Input* object should be predefined. The COM interface, as explained later, allows us to access the *Vehicle Input* object during a simulation run. Therefore, InpGen generates these *Vehicle Inputs* before a simulation run.

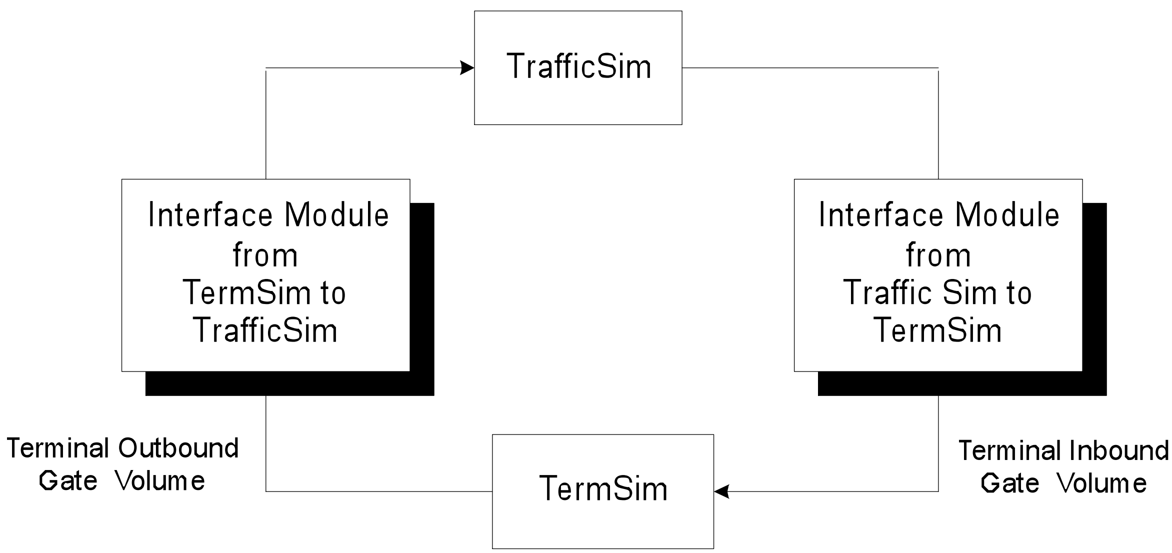

Figure 0-3: Interface between TermSim and TrafficSim

Integrated system architecture

An external program or function which executes COM commands can be used to run a VISSIM model. COM interface provides access to model data, which allows VISSIM to work as an automation server and to export the objects [39].

Figure 0-3 shows the block diagram for the interface between Termsim and TrafficSim.

The interface requires the on-line data collection and on-line traffic volume generation. To create the interface modules, a client function is added to TermSim. It collects data from TrafficSim and converts it into the truck volume for the inbound gate. Also, it receives data from the outbound gate of TermSim and writes it on the corresponding *Vehicle Input* object.

Figure 0-4 shows a flow chart for the client function when each clock event is received. This operation makes the interaction seamless so that the two modules perform together in a completely integrated manner.

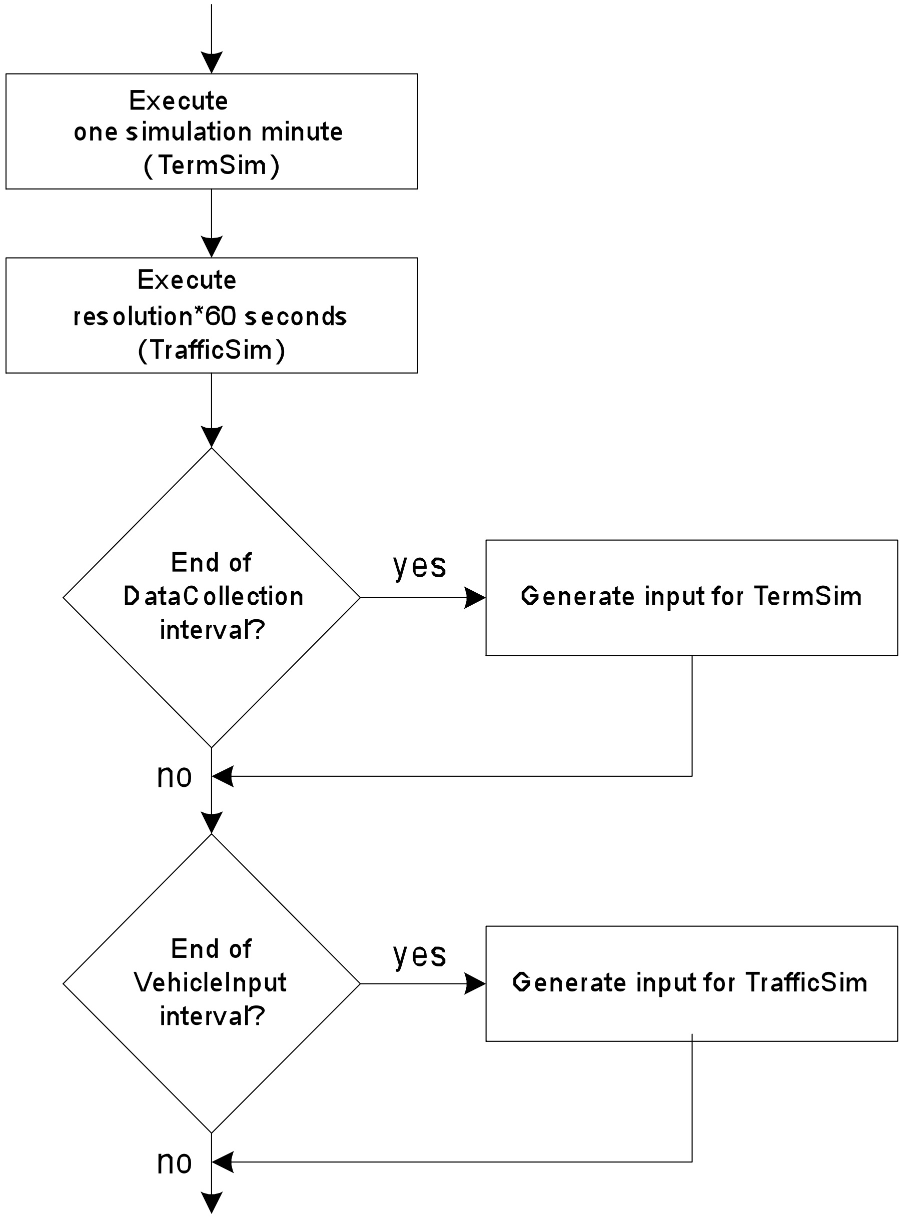

Figure 0-4: Operation per each clock event

TermSim has a chart object which is a 3rd party .NET component obtained from Dundas Software. Using this chart object, TermSim provides cumulative plots for any variable of interest within the terminal.

In the original version of TermSim, truck arrivals at the terminal inbound gate are generated by a non-stationary process based on the Poisson distribution. The non-stationarity of the process is derived form the fact that the mean arrival rates are varying throughout the day. Observations and measurements of truck arrivals have been used in the original version of TermSim to determine the varying means.

In the current version of TermSim the truck arrivals are generated from VISSIM, based on the traffic simulation in the network outside the terminal. Total Arrivals for Inbound Gate are generated by *DataCollection* object of the VISSIM. The truck arrivals are subsequently used as inputs to TermSim through the input interface module.

Similarly, truck departures from the Outbound Gate of TermSim are generated by the terminal simulation model within TermSim. Subsequently Total Departures are fed into *VehicleInput* object of the VISSIM through the output interface module.

Figure 0-5 shows an example graph of the truck volumes at the inbound and outbound gates as produced by the modified TermSim model for a particular simulation scenario.

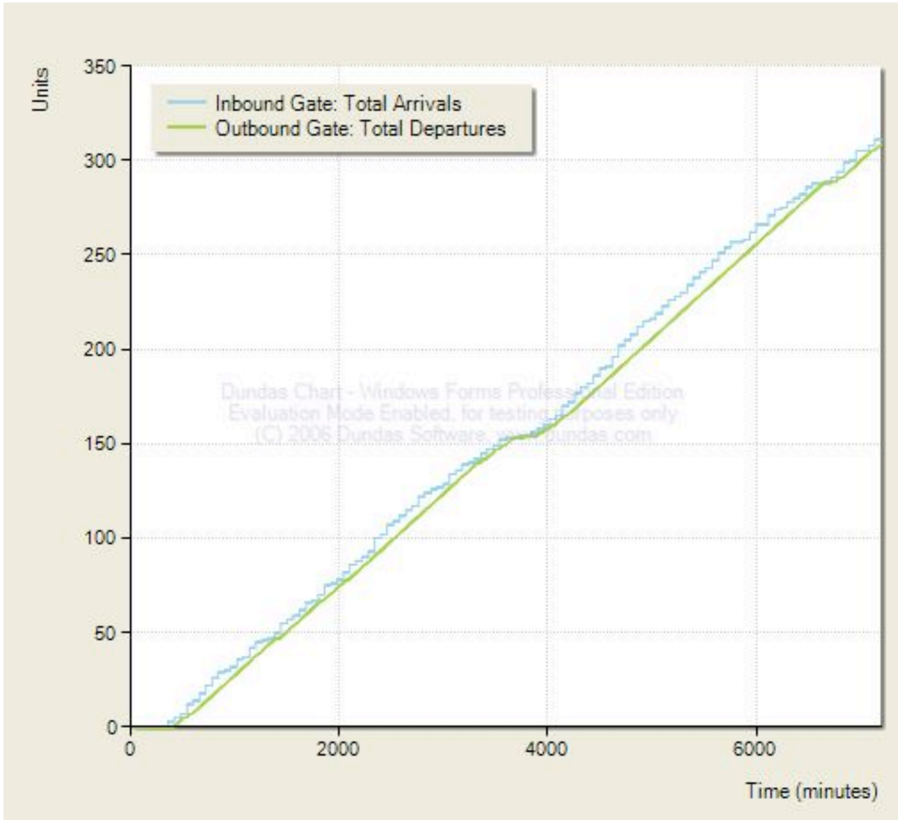

Figure 0-5: Example plots, demonstrating the data transfer between TermSim and TrafficSim

2.3. TermCost

The TermCost module is a cost model developed originally by the authors for the cost evaluation of the Automated Container Terminal (ACT) concepts [11]. This module has been modified to be applicable to the current project, and to interact with TermSim. The TermCost model has been used here to provide cost comparisons between the different concepts under consideration. In order to make such comparisons meaningful, the terminal cost characteristics used here are similar to the ACT cost characteristics. Cost estimates involving other existing or planned terminals will be calculated in exactly the same manner, if the required cost characteristics were available. It is noted however, that the cost characteristics for an existing terminal constitute proprietary information, which is not readily available.

A container terminal is a complex system that serves the purpose of storage, processing and movement of containers between different modes of transportation. The goal of every terminal is to perform efficiently and at low cost and at the same time maintain competitiveness by providing low cost and high quality services to customers. Therefore, in order to evaluate the ACT systems, currently in the preliminary design stage, we need to come with models that mimic their behavior in a real situation and performance and cost criteria based on which the evaluation will be carried out.

In this section we present the performance and cost criteria that are used to evaluate the ACT systems. The average cost for a container to go through the terminal is used as the criterion for cost comparisons and analysis. A cost model presented in this section is used to generate the average cost per container. A very similar model is used in several other marine terminal cost studies that include studies for the port of Houston, Barbours Cut terminal [40] and the port of Rio De La Plata, Buenos Aires [17].

2.3.1. Performance Criteria

Measures of physical capacity and productivity in container terminals include gate throughput, truck turnaround time, ship turnaround time, labor productivity, crane productivity, and utilization of berths, cargo handling equipment and yard vehicles, labor, gates, and storage yard (land). However, container ports frequently focus on internal and narrowly construed measures of productivity and efficiency [41]. For example, while the number of containers moved across the quay each hour is often a major focus of marine terminal operators, it is not a measure that is ordinarily of great concern to users of the terminal.

The most often used measure of performance of loading/unloading equipment is the average cycle time expressed in moves/hour. Moves per hour can be used either to evaluate the performance of single loading/unloading equipment or to evaluate the productivity of the terminal. Since the throughput of a terminal cannot exceed the best quay crane performance, a good measure of the terminal throughput is the number of moves per hour per quay crane. By computing the average number of moves per hour per quay crane we get a measure of the number of containers that got loaded or unloaded or both on/from the ship per hour.

A terminal can maintain a high throughput but it could be utilizing a lot of land to avoid stacking. If the cost of land is high that will raise the cost of moving containers through the terminal. Since in our study we consider concepts that require different land coverage for the same container storage and processing capacity, a reasonable measure to use to compare these concepts is the throughput per acre or throughput measured in moves per hour per quay crane per acre. In many ports such as Port of Long Beach, a similar measure defined as the number of processed TEUs per acre per year is often used.

The time a ship spends at the berth for the purpose of loading and/or unloading is referred to as the ship turnaround time. The ship turnaround time is well recognized as an important factor in the overall transportation cost of containers, and its reduction to a minimum possible is one of the main priorities for shippers and terminal operators. This is easy to understand given that modern container ships cost tens of thousands of dollars per day to operate [17]. In our considerations for the ACT systems we chose a desired ship turnaround time of 16 hours. Since in practice the actual ship turnaround time may vary due to randomness in the properties of equipment etc the ship turnaround time may be different from the desired. Therefore the ship turnaround time is another good measure for evaluating the performance of the proposed ACT systems.

The typical external truck variable cost used by the trucking industry is $75 for each hour the truck is in use. This cost includes maintenance and labor costs [40], [42]. The time a truck spends at the terminal for loading and/or unloading cargo is a real cost to the trucking company and affects the overall transportation cost of containers. The ability of the terminal to serve the trucks in short time will translate to cost reduction for the truckers and will make the terminal more attractive to do business with. Therefore, another useful measure of performance is the average time a truck spends in the terminal in order to complete the loading/unloading process and to wait in queues to be processed by the gate. This time is referred to as the truck turnaround time and does not include the actual processing time at the gates. A secondary measure that affects the truck turnaround time is the gate utilization expressed in percentage of time the gate spends serving the incoming and outgoing container traffic. A low gate utilization for a certain arrival and departure container rates shows that the gate is underutilized and it could meet the demand with less number of lanes and people. On the other hand, if the gate utilization is high (close to 100%) that would mean that small changes in the container arrival rates might cause congestion at the gate that may propagate into the traffic network, or small changes in the container departure rates might cause congestion at the gate that may propagate into the terminal.

The time that a container stays in the terminal before being taken away is referred to as the container dwell time. A high container dwell time could affect the transportation cost and the time to reach its destination in an adverse way. In addition, a high dwell time raises the required storage capacity of the yard since containers stay longer in the yard before taken away. An efficient terminal would keep the dwell time as low as possible. We have to add here that in some of today's practices containers are kept in the terminal on purpose in order to reduce cost, because the alternative of storing these containers in warehouses outside the terminal may be higher.

The cost of a terminal depends on many parameters that include the land cost, the equipment cost, infrastructure, etc. The equipment cost that includes the cost for cranes and vehicles could be significant. Therefore a cost effective terminal is the one that keeps the amount of equipment to the minimum possible that is necessary to meet the expected demand. Since demand may vary with time, a good measure as to how effectively the equipment is utilized is the idle rate of the equipment measured as the percentage of time the equipment is idle. Low idle rates indicate an efficient utilization of the equipment where as higher idle rates indicate that the equipment is underutilized. Underutilization may suggest design changes, reduction of the number of machines used, and/or improvement of the management of operations, etc. in order to save costs and improve productivity.

Based on the above discussion, the following Table 0-1 summarizes the performance criteria that are used in this study to evaluate and compare different ACT systems.

Table 0-1: Performance Criteria

Throughput	The number of moves per hour per quay crane
Throughput per acre	The throughput per acre
Annual Throughput per acre	Number of TEUs processed/per acre/per year
Ship turnaround time	The time it takes for the ship to get loaded/unloaded in hours
Truck turnaround time	The average time it takes for the truck to enter the gate, get served, and exit the gate minus the actual processing time at the gate
Gate utilization	Percent of time the gate is serving the incoming and outgoing container traffic
Container dwell time	Average time a container spends in the container terminal before taken away from the terminal
Idle rate of equipment	Percent of time the equipment is idle

2.3.3. Cost Model

The Average Cost per Container (ACC) being processed through a terminal is among the most important cost measures considered by port authorities [17]. Though average-cost-per-container does not express pricing, revenues, or terminal profits, it provides a basis for economic evaluation of container terminal operations. In this study, we adopted this measure in order to evaluate and compare the cost associated with each proposed ACT system.

Costs associated with container handling and storage operations within a terminal can be classified into the following three categories:

- *Cost of activities*: that is the cost of locations where activities (operations) take place i.e. buildings and facilities such as gates, customs, etc.
- *Cost of land:* the capital investment for land in different areas, e.g. berth area, storage area, etc.
- *Cost of equipment*, the cost of yard equipment e.g. yard cranes, quay cranes, AGVs, etc.
- *Labor costs*.

The ACC is equal to the sum of the total annual cost for activities, land, equipment and labor divided by the total annual number of containers that are processed by the terminal.

The total annual cost for activities and equipment can be further classified into *fixed* and *variable* cost. Fixed costs do not vary with the level of activities (operations). For instance, the capital invested on purchasing the equipment is not affected by the working hours. The level of activities affects the variable costs. For example, the energy consumption, such as fuel and electricity, increases with the working hours.

The cost model that generates the ACC is a set of Microsoft Excel Spreadsheets. The first sheet calculates the total Variable Cost (VC), total Fixed Cost (FC) and Total Cost (TC) associated with location activities. The second sheet calculates the land cost, and the third one computes the VC, FC and TC for the equipment. In the fourth sheet the total labor cost is calculated based on the number of people employed, working hours, overtime, salaries etc. The fifth sheet summarizes the total cost for activities, land, equipment, and labor and calculates the ACC value. Appendix I shows the cost model for the AGV-ACT system as an example. In the following subsections, we present some of the main features of the model and the various assumptions made by using the cost model for the AGV-ACT system presented in Appendix I as an example.

Cost of Activities

In the cost model, location activities include various entities that are listed below, together with their design and operating characteristics assumed for each ACT system:

Gates: For all the ACT systems, we designed the number of lanes to be 9 for the inbound gates and 6 for the outbound gates. The operation of the gates is assumed to be 24 hours per day (8,760 hours per year).

Customs: A truck picking up an import container at the maritime container terminal has to pass through the customs before leaving the terminal. At customs both physical and also document-based verification may be performed. Customs is scheduled to work two shifts per day (16hr/day – seven days per week – 5,840 hours/year).

Berth: It is assumed that the berth operates about 16 hours per day (the ship turnaround time assumed), seven days per week (5,840 hours per year).

Storage yard: The storage yard may be divided into the import and export storage area depending on the ACT system that is analyzed. The operation of the storage yard is assumed to be a continuous 24-hour/day operation (8,760 hours per year).

Maintenance area: It is assumed that it operates 80 hours per week (4,160 hours per year).

Central Controller: The central controller governs and monitors all the activities in the terminal around the clock (24 hours per day, 8,760 hours per year).

The variable cost for locations is mainly due to consumption cost of electricity. It is calculated by multiplying 'working hours' by 'electricity consumption per hour' by 'electricity cost'. That is the multiplication of the columns 2, 3 and 4 in sheet I.1 generates the variable cost per year for locations (column 5 in sheet I.1). The electricity cost is assumed to be $0.141 per kWhr.

The life of capital investment (column 6) is assumed to be 25 years (column 7) except for the central controller whose life is assumed to be 10 years. The total investment for a location is depreciated within this period and is calculated based on a straight-line depreciation method [44]. Other fixed costs are assumed to be 3% for repair, 1% for insurance and 10% for interest per year [17]. The fixed cost per year for locations (column 12) is calculated by adding the annual cost of depreciation, insurance, maintenance, and interest i.e.

Location Fixed Cost
='investment'/ ('accounting life')+'investment'('repair'+'insurance'+'interest')*

The total location cost (TC in sheet I.1) is calculated by adding up all fixed costs (FC in sheet I.1) and variable costs (VC in sheet I.1) of all locations.

Cost of Land

The land cost is calculated for different parts of the container terminal: berth, storage, train, and gate area. This amount is considered to be investment only. It is calculated based on the area of each part (in acres) multiplied by the land cost per acre. In Sheet I.2, we assume that the land cost per acre for the area that does not include the berth is $500K (row 10). This is very close to the price paid by the Port of Long Beach for the purchase of land in the Long Beach Port area. For the berth area, we assume a cost of $2.5 million per acre due to the higher cost for land very close to the water. The inflation rate is assumed to be 5% per year (row 12), and the interest rate 10% annually (column 6).

Based on the above assumptions, the annual land cost (column 5) can be calculated as follows [45]:

$$A = P \times R \times \left(\frac{(1+R)^n}{(1+R)^n - 1} \right)$$

where A is the annual land cost, P is the initial land investment, R is the inflation rate, and n is the accounting life, which in sheet I.2 is assumed to be 25 years.

The total annual land cost is then computed as follows:

*Total annual land cost= P*IR+A*

where *IR* is the average (over 25 years) annual interest rate that represents lost investment opportunity. In the cost model, IR is taken to be equal to 10%.

Cost of Equipment

The cost of equipment is calculated in the second spreadsheet of the cost model. The equipment considered depends on the type of the ACT system under consideration. In general, it includes the number of vehicles, yard cranes, quay cranes, management infrastructure (software/hardware system), etc.

The cost associated with energy consumption by each piece of equipment is considered to be the variable cost (column 7 on sheet I.3). 'Working hours per equipment' in a year (column 2) multiplied by 'the price of energy per hour per equipment' (column 5) gives us the price of energy per year per equipment (column 6). The equipment in the yard may not be utilized all the time. The utilization factor (column 4) shows the percentage of time that a specific piece of equipment has been utilized. The performance simulation model generates this factor. Multiplying the number of equipment by its utilization factor by the price of energy per year per equipment generates the equipment variable cost, i.e..

Equipment Variable Cost =
'working hours''price of energy per hour'*'number of equipment'*'utilization factor'*

The way the fixed cost of equipment is calculated is the same as that of locations. The life of capital investment (column 8) is assumed to be 15 years (column 9). The total investment for the equipment is depreciated over the above period and is calculated based on the straight-line depreciation method. Other fixed costs are 10% for repair, 1% for insurance and 10% for interest per equipment per year [17]. The fixed cost per year for equipment (column 15) is calculated by adding up all the annual cost of depreciation, insurance, maintenance, and interests, i.e.

Equipment Fixed Cost=
'investment'/ ('accounting life')+'investment'('repair'+'insurance'+'interest')*

The TC value for equipment is calculated by adding the total FC value with the total VC value of all equipment.

Cost of Labor

The total cost of labor is calculated in the third spreadsheet of the model. It is assumed that all employees at the facility are paid for all the hours they are physically present (scheduled to work) at the terminal no matter what percentage of time they are working (Sheet I.4 column 5). The employee's regular working week is assumed to be 40 hr/week (2,080 hr/year). The employees get paid overtime, if they are scheduled to work more than a shift a day. The overtime pay is 1.5 times the base pay (columns 6 and 7).

Three shifts per day are scheduled for labor at the gate and storage. It is assumed that two checkers and one clerical person can serve two gate lanes. For 9 inbound gate lanes, we need 9 checkers and 5 clerical persons in each shift. Thus, one shift at the inbound gate consists of 14 people; while one shift at the outbound gate (6 lanes) consists of 6 checkers and 3 clerical persons. At customs, two shifts consisting of 2 port employees are scheduled to work per shift (16hr/day – seven days per week – 5,840 hours/year). The gates in the example of Appendix I are assumed to be opened 24 hours a day for 365 days a year i.e. a total of 8,760 hours.

In order to find out how many overtime working hours are needed (column 8), the total scheduled working hours (column 5) must be subtracted from the number of shifts multiplied by 2,080 (regular working hours).

Overtime working hours = 'scheduled working hours' – 2080(number of shifts)*

The total labor cost is calculated as the sum of all the salaries of the people operating the terminal.

Average Cost per Container

The fifth sheet of the model includes the calculation of the ACC value. The total annual cost for the yard is calculated by adding the total cost of location, land, equipment, and labor obtained from the previous sheets of the model. Dividing this number by the total annual container volume, we obtain the ACC value.

2.3.4. Exercise Cost Model for ACT using AGVs

Among four ACT (Automated Container Terminal) concepts that discussed in [11], the AGV (Automated Guided Vehicle) based ACT (AGV-ACT) is chosen for a reference concept. In this concept, the terminal configuration is similar to that of conventional terminals but instead of using manually operating equipment we use AGVs to transfer containers between gate, train, and quay buffers and the storage yards. Table 0-2 summarizes the characteristics of the AGV-ACT system.

A variance of 10% is assumed in all values associated with speeds and time with the exception of the speed of the quay cranes where a variance of 15% is assumed.

Table 0-2: AGV-ACT: Summary of the terminal characteristics

Size of the terminal	1,633*1,875 ft^2 (70.29 acres)
Storage Capacity	22, 464 TEUs
No. of Berths	1
Capacity of quay cranes	42 moves per hour (combined loading and unloading)
No. of quay cranes	5
Gates service time	3 min inbound-gate, 2 min outbound-gate
No. of gate lanes	9 inbound, 6 outbound
Capacity of yard cranes at buffers	Yard crane's speed is 5 mph, takes 15 sec. to line up with the container, and an average time of 65 seconds to unload/load an AGV.
No. of yard cranes at gate buffer	6
No. of yard cranes at Train buffer	2
Capacity of yard cranes at storage yard	Yard crane's speed is 5 mph, takes 15 sec. to line up with the container, and an average time of 45 seconds to unload or load an AGV.
No. of yard cranes at Import and Export storage yard	36
Speed of AGVs	10 mph for empty, 5 mph for loaded AGVs
No. of AGVs	85 (48 for Task 1, 26 for Task 2, 6 for Task 3 plus 5 spare)

The simulation results and the characteristics of the terminal are used to calculate the average cost of moving a container through the terminal, i.e. the ACC value, by exercising the cost model for the AGV-ACT system presented in Appendix I. In addition to these data the model is fed with several other parameters and data that are necessary for the operation of the terminal. These include number of people, salaries and cost data regarding equipment, land, facilities etc. Most of the cost data are collected from the open literature [40], [17] and modified after discussions with experts in the field such as terminal operators and researchers from August Design, Inc.

Table 0-3: AGV-ACT, Cost results

Annual projected volume	2,482,000 TEUs
Annual Variable cost	$28,408,000
Annual Fixed cost	$39,046,000
Annual Land cost	$7,930,000
Annual Labor cost	$20,113,000
Total Annual cost	$95,498,000
Average Cost per Container (ACC)	$77.0

The equipment characteristics used by the model are the same as those listed in Table 0-2**.** Appendix I shows the various inputs and data used to obtain the following calculations shown in Table 0-3.

The results obtained from the cost model presented in Appendix I, like all models, depend on the validity of the input variables. For instance, one may argue that the price of the land differs based on the geographical location, which will affect the cost results presented above. Figure 0-6 illustrates the sensitivity of the average cost per container (ACC) with respect to land cost per acre. In Appendix I, the initial cost of land per acre depreciated over 25 years is considered to be $0.5 million, which leads to the ACC value of $77.0.

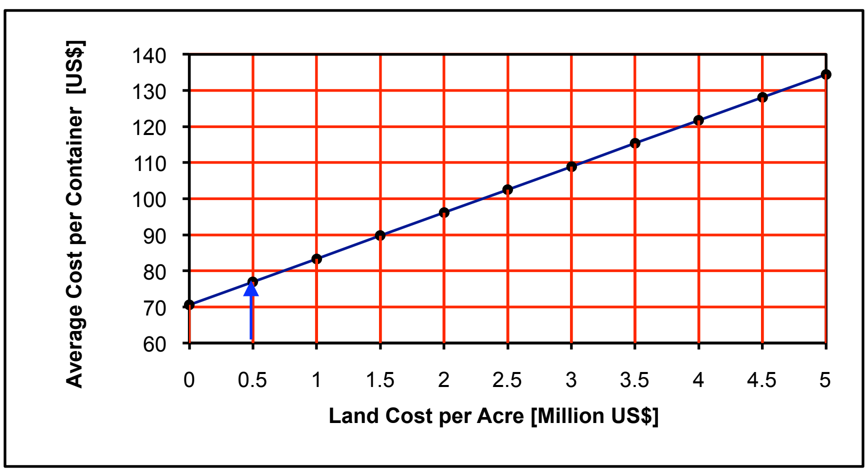

Figure 0-6: AGV-ACT: Average Cost per Container

(arrow indicates the value assumed in the results of Table 2.3)

Figure 0-6 shows how the ACC value varies with the initial land cost per acre. The arrow indicates the value used in the calculations of Table 0-3 . The Figure shows that changes in the land price have a smaller effect on the ACC value. For instance, increasing the value of the land price per acre by 50% (a $0.5 Million increase) causes less than 9% increase in the ACC value, i.e. the ACC value becomes $83.3. Since we are dealing with many containers that may be an important factor, it translates to an annual cost increase of $7.9 million for the AGV-ACT terminal.

Figure 0-7 Figure 0-1illustrates the effect of the changes in the price of AGVs and its infrastructure on the ACC value. In our analysis in Table 0-3, the price of AGVs together with its infrastructure was assumed to be $200k per unit (column 8, row 2 of sheet I.3). The sensitivity analysis in Figure 0-7 shows that a 50% increase in the price of AGVs leads to less than 2.5% increase in the value of ACC.

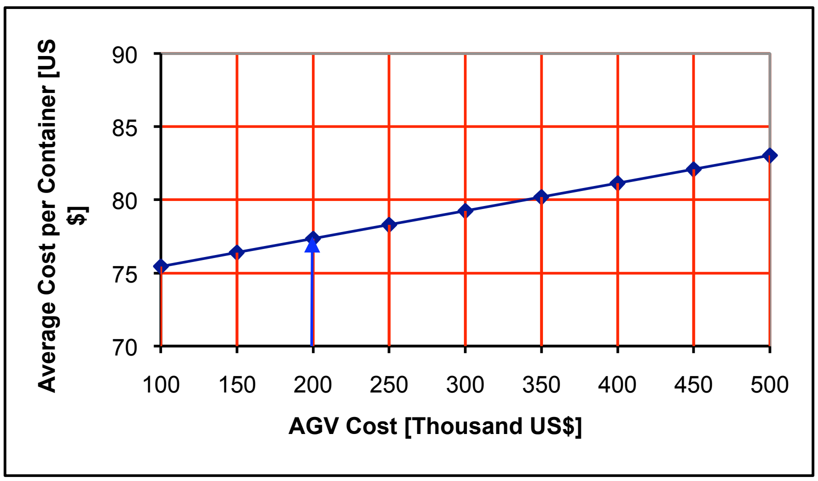

Figure **0-7**: AGV-ACT: Average Cost per Container vs. AGV cost

(arrow indicates the value assumed in the results of Table 2.3)

The AGV-ACT cost model is modified to fit to the particular scenario and the ACC value is evaluated. For comparison purposes, TermSim follows the design considerations of the ACT. Furthermore, it is assumed that the different truck movement concepts under consideration, do not affect the costs of land activities and labor of the cost model.

Simulation of truck movement concepts

3.1. Empty container reuse

As stated before, for the year 2003 the combined ports POLA/POLB handled 33% of the nation's container traffic, i.e. 11.5 million TEU. Given that the vast majority of containers are forty feet in length, it is estimated that an average container corresponds to 1.85 TEU. This figure implies that almost 6.24 million full containers were handled during 2003 in the LA/LB port complex. Each container is typically handled twice, once as a loaded container, and the second time recycled as an empty. This translates into 12.48 million containers moved one way annually by road or rail within the region in 2003. The loaded containers arriving at the port are picked up and transported by trucks to their destinations. After having been unloaded, they must be picked up as empty containers. The empties are typically moved back to the port (or in some cases to another depot - inland port). The exporters, who need empty containers that will be filled with exportable goods, will hire another trucking company to pick up the empties from the port, and transport them to their locations. After empties have been loaded at the export firm, the truckers will transport them back to the port where they will be loaded on the ship for export. Figure 0-1 shows the general flows of containers in and out of the port, where the empty container flows have been specifically pointed out.

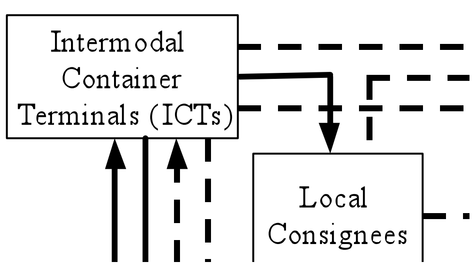

Figure 0-1: Container flows in LA/LB port area.

Solid lines: loaded container flows; dashed lines: empty container flows.

Based on the above description, it is clear that a system which facilitates the interchange of empties outside the ports is highly desirable. The authors have been working on the concept of empty container "reuse", which consists of using empty import containers for export loads without first returning them to the marine terminal. The author's previous work focused on modeling and optimizing empty container reuse [12], [13]. In the optimization studies the cost function was defined in terms of miles traveled. The simulation studies compared the current practices for empty container interchange to the proposed optimized reuse. It was shown that optimized empty reuse can have significant effects on miles traveled, up to 79% reduction as compared to current practices, i.e. significantly reduced truck miles, which means reduced pollution and reduced traffic congestion. In addition, interchange of containers outside the port will free up scarce and expensive land inside the terminal.

3.1.1. Impact on the roadway network

The empty container reuse strategy is simulated using the test bed, in order to quantify its effects on the terminal and on the roadway network. The TermSim simulation environment has the ability to differentiate between empty and loaded containers and the ability to simulate different handling strategies of empty containers. The TermCost is be used to evaluate the impact on cost of these strategies, whereas the TrafficSim is used to generate the traffic simulation data, and to analyze the effects of reduced truck trips that arise from empty container reuse, on the traffic network adjacent to the terminals.

In order to investigate the benefits of the empty container reuse, containers should be differentiated into full and empty ones. To do so, trucks in and out of the terminals are assumed to be divided into three classes.

- Loaded truck with a full container
- Loaded truck with an empty container
- Empty truck (chassis only or bobtail)

In creating the simulation scenarios, we consider a set of possibilities, regarding the incoming and outgoing truck status. These possibilities differentiate between trucks carrying loaded or empty containers, and also between trucks carrying an unloaded chassis vs. container carrying trucks. The following Table 0-1 provides a description of these possible cases, and the corresponding truck flows as will be used later on, when setting up the simulation scenarios.

Table 0-1: Task descriptions for empty container reuse

Flow symbol	Inbound truck load	Task description	Outbound truck load
f1	Chassis only or bobtail	Pickup full container	Full container
f2	Empty container	Drop off empty container Pickup full container	Full container
f3	Full container	Drop off full container	Chassis only or bobtail
f4	Full container	Drop off full container Pickup empty container	Empty container
f5	Empty container	Drop off empty container	Chassis only or bobtail
f6	Chassis only or bobtail	Pickup empty container	Empty container

The simulation scenarios are based on estimates of the container flows to the terminals used previously by the authors, including estimates of full and empty containers [12]. In order to make comparisons on an equal basis, all scenarios assume the following flows of total number of trucks to the terminal (including trucks loaded with full or empty containers, and trucks coming in with only a chassis or as bobtails):

(1) Total number of inbound containers per day: 2040 containers arrive by trucks. All these containers are assumed to be 40-foot long.
(2) Total number of inbound trucks coming in with chassis only, or as bobtails: 816 empty trucks arrive at the gate to pick up import containers.

Furthermore, the demands and supplies of empty containers are converted into the corresponding truck flows at the gates. The following two parameters are used to generate the different case scenarios. These parameters have been used previously by the authors, when evaluating the benefits of empty container reuse strategies [12]

- **E/L ratio**: the ratio of empty containers to full containers at the inbound gate
- **D/S ratio**: the ratio of demand for empty containers to the supply of empty containers.

Table 0-2: Case scenarios for empty container reuse strategy

	Case I	Case II	Case III
Empty Truck (Chassis only or bobtail) [vehicles/day]	816	816	816
Loaded Truck [vehicles/day]	2040	2040	2040
E/L ratio	0.25	0.50	0.50
D/S ratio	0.40	0.40	0.60

Table 0-2 defines three cases according to the different E/L and D/S ratios. Although the total truck volumes at the gates stay the same over the three cases, the reuse strategy will result in different outcomes for each case. For each case, the outbound truck volume is set equal to the inbound volume, for equilibrium. Based on the above assumptions and Table 0-2, the sets of detailed truck flows for both the base and reuse scenarios are defined for the TermSim module, and they are represented graphically in Figure 0-2, Figure 0-2 and Figure 0-3.

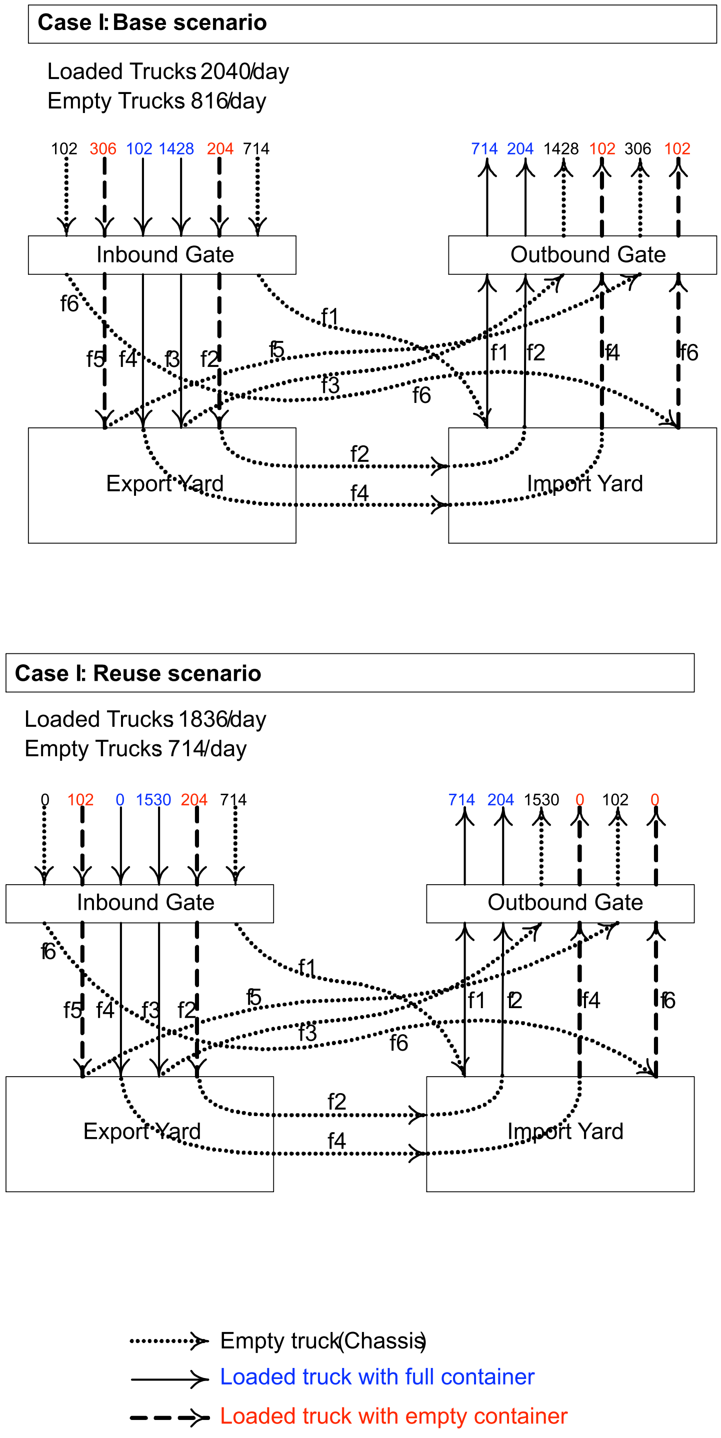

Figure 0-2: Details of truck flows for case I

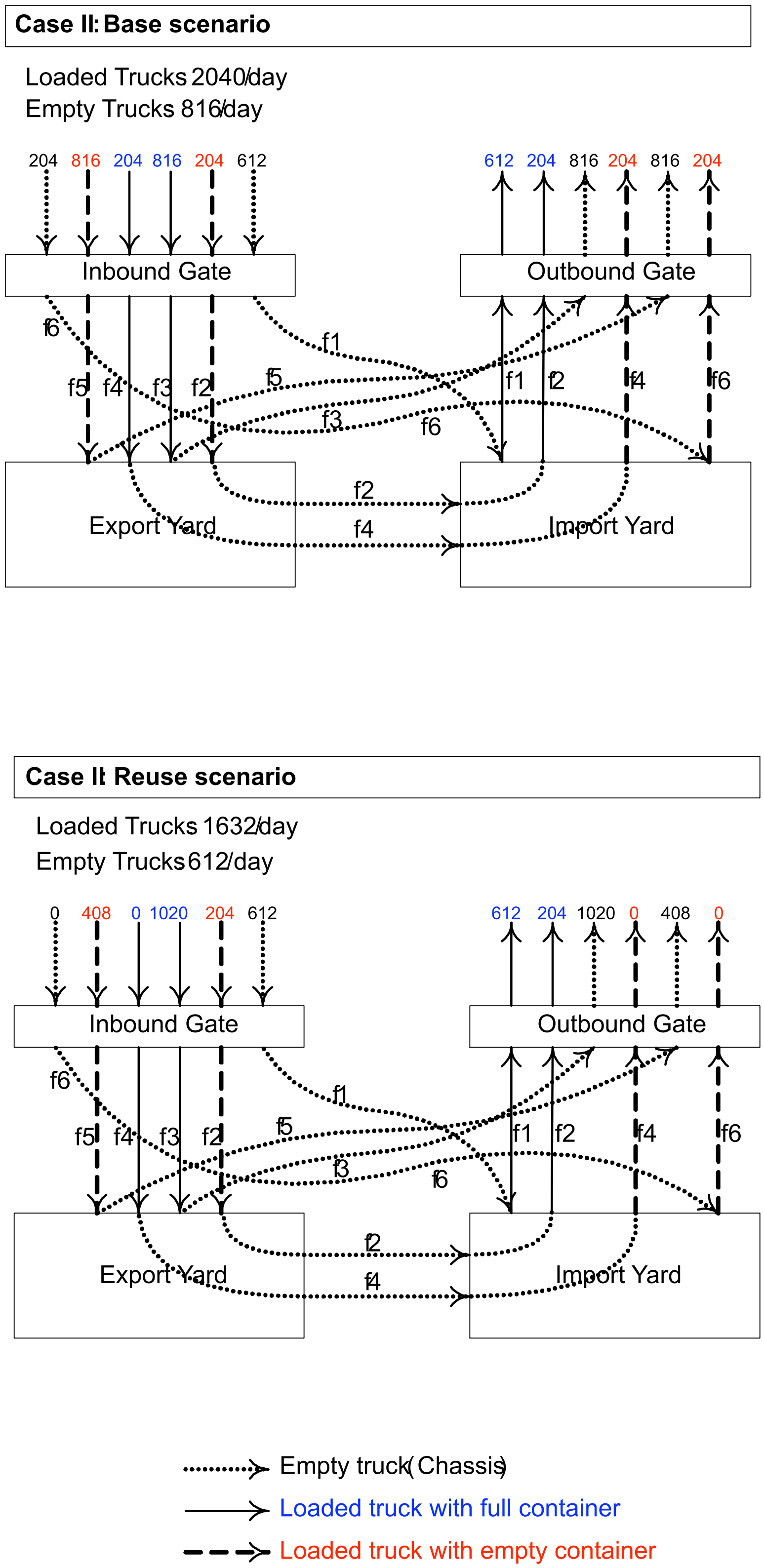

Figure 0-3: Details of truck flows for case II

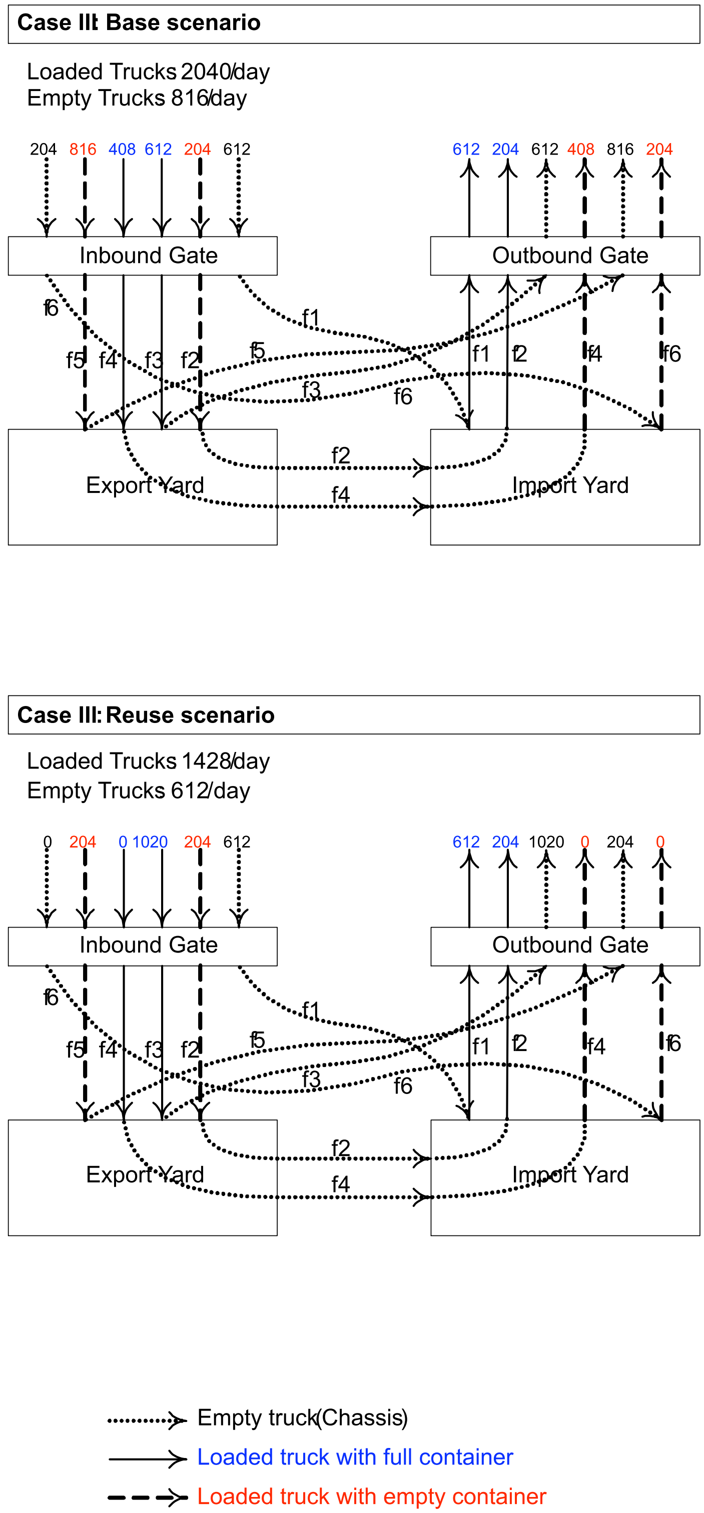

Figure 0-4: Details of truck flows for case III

Table 0-3: Volume reduction achieved by empty container reuse

Case I E/L = 0.25; D/S =0.40			
	Base Scenario	Empty Reuse Scenario	Volume Reduction
Volume [vehicles/hr]	119	106.25	10.71%

Case II E/L = 0.50; D/S =0.40			
	Base Scenario	Empty Reuse Scenario	Volume Reduction
Volume [vehicles/hr]	119	93.5	21.43%

Case III E/L = 0.50; D/S =0.60			
	Base Scenario	Empty Reuse Scenario	Volume Reduction
Volume [vehicles/hr]	119	85	28.57%

For each case, Table 0-3 shows the truck volume at the inbound gate for the base and the reuse scenarios. Note that the truck volume includes all the loaded trucks and empty trucks (chassis only and bobtails). A higher E/L ratio yields a higher reduction in the truck volumes at the gate. The scenario corresponding to Case III is chosen to be used for the investigation of the impact of empty reuse on the traffic network, since this case shows the most observable truck volume reduction.

In order to perform a simulation with the test bed, the demanding traffic is set to be close to the critical density of a general freeway in the US. Assuming traffic conditions close to the critical density on the freeway is important, since these are the conditions when small increases in traffic volume can create significant congestion, and slight decreases in traffic volume can avoid congestion. For the simulation scenarios, the following additional parameters are being used.

(3) The incoming Southbound HGV flow (for the base scenario) is 700 vehicles/hour.
(4) The incoming Southbound CAR flow is more than 5000 vehicles/hour.
(5) Ramp flow rates account for about 5% to 10% of the mainline flow rate.
(6) The Northbound flow is set to be almost balanced with the Southbound flow.
(7) The processing rate of the gates is set to be enough to handle trucks without waiting. This particular assumption is used in order for the simulation to focus on the effects of empty container reuse rather than on a combination of other effects, which might have included the waiting time at the gates. For other simulation purposes, the waiting time at the gate could be included.

Figure 0-5 and Figure 0-6 show the average speed at each station when the incoming CAR flow rate is set at 5400 vehicles/hour. The figures indicate the typical benefit achieved by the reuse scenario, which results in the reduction of the truck volume. At station 4, the Southbound speeds have improved by 36% when empty reuse is implemented. Similarly, the Northbound speeds at station 4 improve by 18% with empty reuse.

In order to evaluate the speed-flow relationship, the incoming CAR flows vary from 5000 vehicles/hour to 5700 vehicles/hour. The range of [5000-5700] vehicles/hour was chosen for examination, since the value of critical flow rate of the freeway is included within this range.

Figure 0-7 through Figure 0-10 show that speeds at four Northbound data collection stations are slightly improved by the reuse scenario. The improvement is more noticeable at station 4, which is vulnerable to recurrent congestion due to the presence of ramps. It is seen that station 4 becomes congested under the base scenario when CAR flow is a little higher than 5500 vehicles/hour. At 5500 vehicles/hour the improvement in speed under the reuse scenario is about 6%, whereas at 5700 vehicles/hour the improvement in speed under the reuse scenario is about 16% as compared to the base scenario.

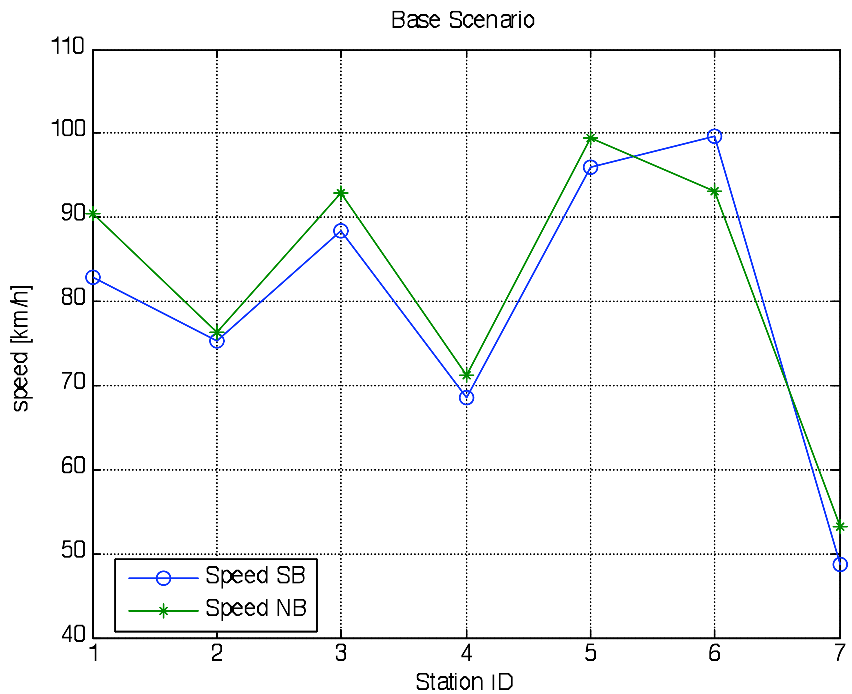

Figure 0-5: Average speeds at data collection stations (base scenario)

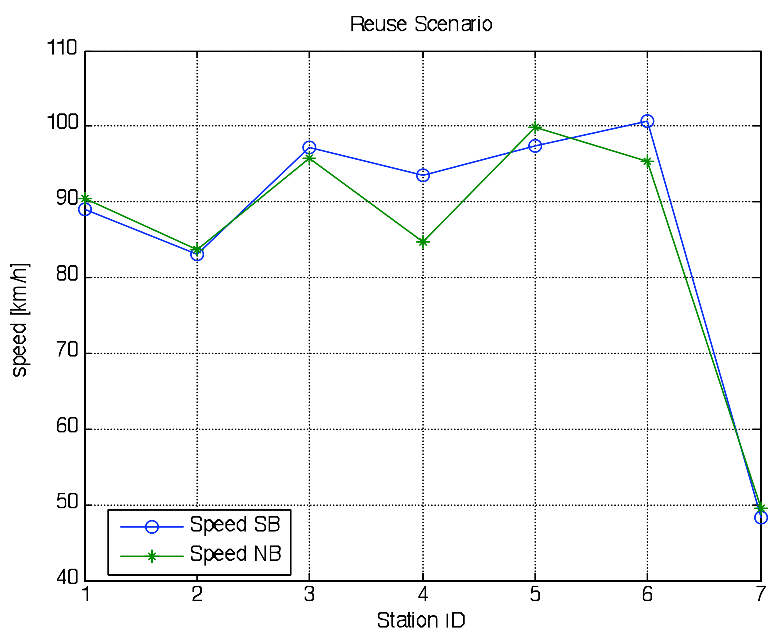

Figure 0-6: Average speeds at data collection stations (reuse scenario)

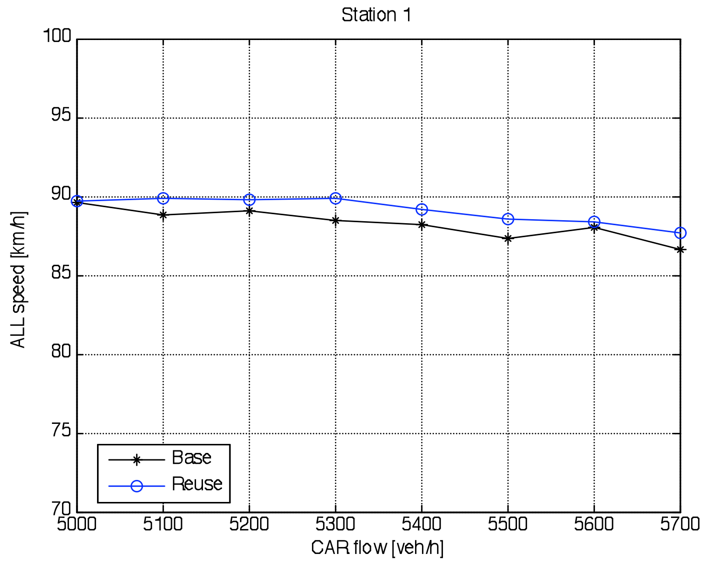

Figure 0-7: Speed-Flow relationship at Station 1

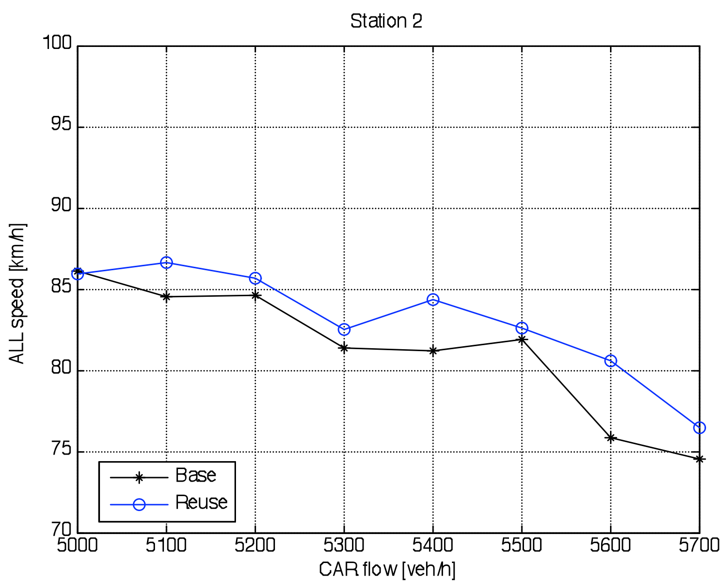

Figure 0-8: Speed-Flow relationship at Station 2

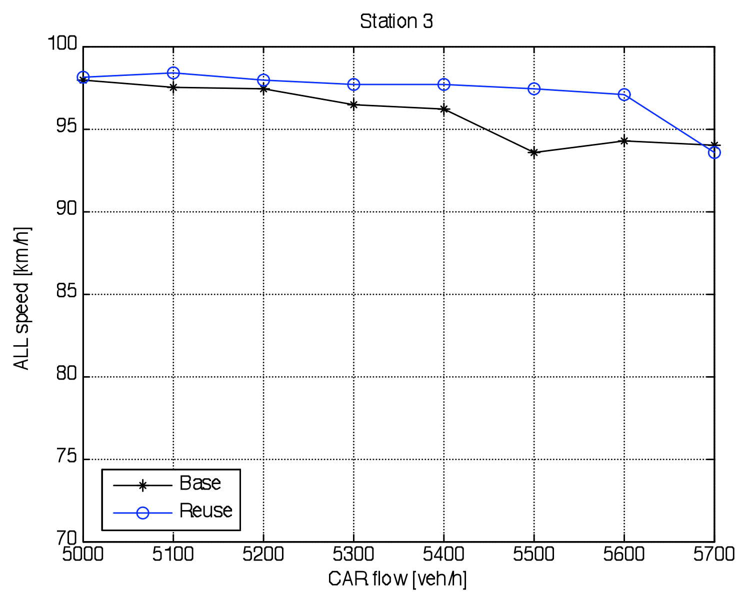

Figure 0-9: Speed-Flow relationship at Station 3

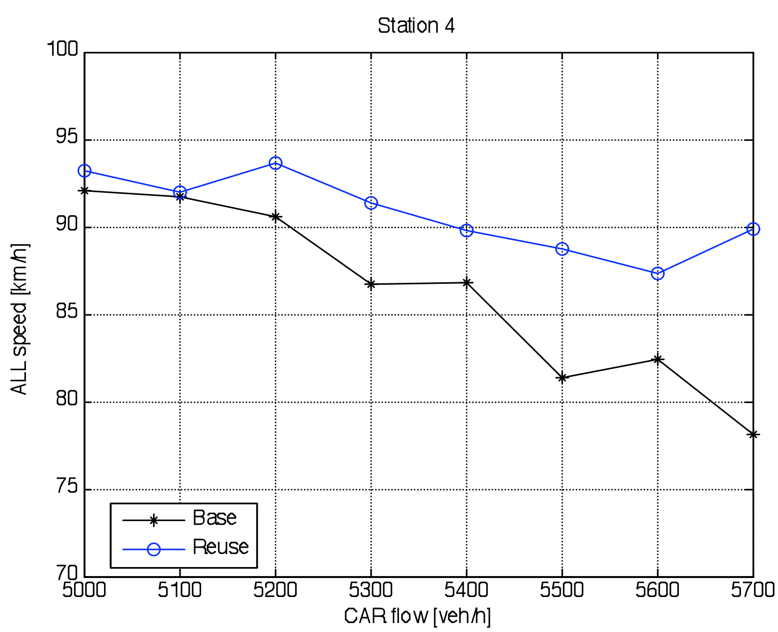

Figure 0-10: Speed-Flow relationship at Station 4

3.1.2. Impact on the terminal cost model

Regarding the impact on cost, the base scenarios were compared to the reuse scenarios in terms of reduction in the miles traveled. The parameters used for these calculations are the same as the parameters used by the authors in [12], in order to have a comparable evaluation set. These parameters include the spatial distribution of shippers and consignees, the demands and supplies of empties during a given day, and the distances between pickup and drop off points for the empties. The cost of transporting containers was calculated on the basis of miles traveled for the base and the reuse scenarios. Table 0-4 shows the final cost in miles traveled for both the base and the reuse scenarios. It is shown that higher E/L and D/S ratios yield a higher reduction in the empty container allocation cost.

Table 0-4: Cost reduction achieved by the empty container reuse strategy

Case I E/L = 0.25; D/S =0.40			
	Base Scenario	Empty Reuse Scenario	Cost Reduction
Cost [miles traveled]	12191.4	6294.58	48.37%

Case II E/L = 0.50; D/S =0.40			
	Base Scenario	Empty Reuse Scenario	Cost Reduction
Cost [miles traveled]	24342.4	12553.4	48.43%

Case III E/L = 0.50; D/S =0.60			
	Base Scenario	Empty Reuse Scenario	Cost Reduction
Cost [miles traveled]	27378.4	9859.7	63.99%

In Case III, the empty container reuse strategy yields 64% reduction in the empty container allocation cost in terms of miles traveled. It was also shown that empty container reuse reduces the truck volume at the inbound terminal gates by 28.6%. This reduction in volume (i.e. number of containers and trucks at the gates) has a significant impact on the terminal cost model. For a simple comparison, characteristics related to the gates and the AGVs are assumed to be unchanged. Then, the reuse scenarios are shown to produce the following reductions in yard equipment, yard acres and average cost per container (ACC).

Table 0-5: Changes in terminal characteristics and cost per container resulting from empty container reuse

Characteristics	Base Scenario	Empty Reuse Case I	Empty Reuse Case II	Empty Reuse Case III
No. of yard cranes at train buffer	2	2	2	2
No. of yard cranes at gate buffer	6	6	6	5
No. of yard cranes at storage yards	36	34	32	30
Storage area [acres]	44.62	42.14	39.66	37.19
Average Cost per Container ACC [$]	76.95	76.01	75.08	73.75

Among four ACT concepts discussed in [11], the AGV based ACT (AGV-ACT) is chosen as the reference concept. Based on this cost model, it is found that the ACC value of Case III is reduced to $73.75 from $76.95 if the empty container reuse strategy is fully implemented. It is also seen that required yard equipment is reduced as compared to the base scenario, and that the required yard storage area is reduced when empty reuse is implemented, as compared to the base scenario (this reduction in required yard acreage is at 16% for Case III of the reuse scenario). .

Additional cost benefits related to the reduction in miles traveled include environmental effects. These benefits are not captured by the TermCost module, since the model is not set up to calculate environmental cost, but it is clear that reductions in miles traveled will reduce emissions of pollutants and noise in the areas around the terminal. Models developed for this purpose (e.g. by EPA) would be able to quantify the environmental benefits of empty container reuse.

3.2. Inland port and dedicated truck lanes

One additional possibility to reduce the pressure of increased storage capacity demand at terminals is the use of an inland port, which will act as an intermediate storage area before the cargo is processed for export/import. Such a facility could have a significant impact through efficient processing, scheduling, storing, and transferring of containers between the inland port and the container terminals. In a previous METRANS project, the authors worked on the concept of employing fully automated trucks to transfer cargo between the inland port and the terminals [14] on dedicated lanes. Automated trucks are studied to analyze the automated cargo transportation between the inland port or intermodal yard and the terminals as shown in Figure 0-11.

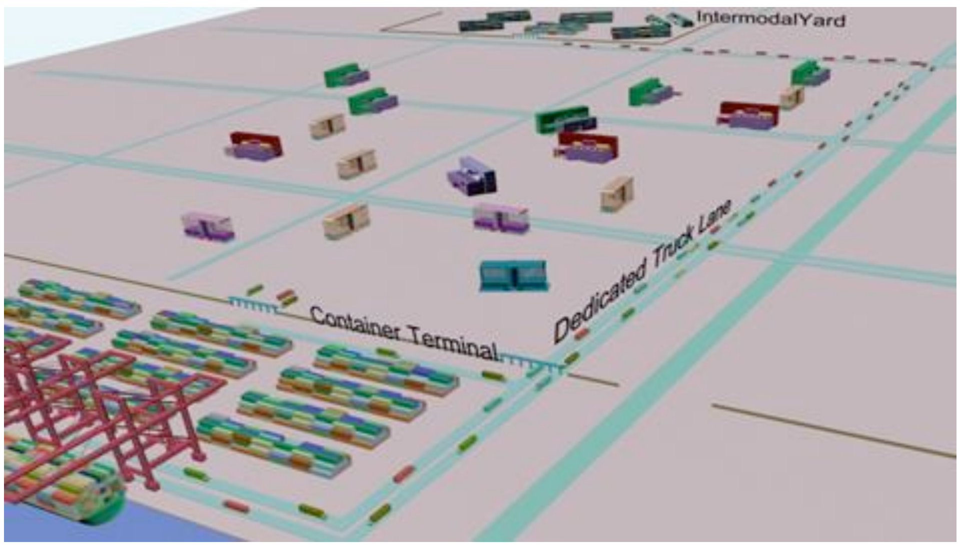

Figure 0-11: The ACTIPOT concept

The particular location of the inland port was chosen as the Intermodal Container Transfer Facility (ICTF) located approx. 4.7 miles from the port, as described before. The operation of the ACTIPOT system is performed at three levels:

- Control at the individual vehicle level: Variables such as location and speed of the individual vehicle were controlled by a controller local to the vehicle.
- Control at the platoon level: Platoons of 5 vehicles were formed and controlled through inter-vehicle communication and exchange of data. It was shown that forming platoons is more efficient as compared to moving each vehicle individually.
- Control at the system level: A supervisory controller was designed for the overall system. The controller was designed to avoid collisions, and to coordinate the interface of vehicles and platoons of vehicles with the yard equipment, and ships.

Simulation studies of the overall system showed that the system is stable, with no collision occurring between the automated trucks, and that the system efficiency can be guaranteed by properly choosing the numbers of cranes and trucks.

The objective of the overall system simulation was to study the performance of the ACTIPOT system in serving ships with a capacity of 8,000 TEUs, with the service time strictly limited to 24 hours or less. In our design, we further assumed that the ship carries import containers up to 85% of its capacity and it would be reloaded with the same number of export containers. The turnaround time for a ship with an 85% load was restricted to 20 hours, so that the system is able to serve any ship within 24 hours even if the ship is fully loaded and some unexpected events take place. The simulation studies also showed that the ACTIPOT system was able to meet the performance requirements, and that it was able to recover from unexpected events. The studies also showed that there is a limit on the amount of yard equipment that can be used effectively. Any additional equipment above this limit does not increase which efficiency in the terminal.

In the current project we study the ACTIPOT concept not from the control viewpoint, but in terms of the effect such a system may have on the surrounding traffic network. For example, dedicating lanes to the automated trucks during off peak traffic hours may help the traffic network but may create congestion inside the terminal if the terminal does not have the extra capacity for storage of the containers that are not destined for live loading to the ship. In addition redirecting truck traffic to the inland port may shift truck traffic to another part of the traffic network, leading to congestion in a different area. These trade-offs and issues are studied under this project.

3.2.1. Impact on the roadway network

In this section we use the simulation test bed to model the inland port and analyze and evaluate its effect on the terminal efficiency and on the traffic network.

Figure 0-12 shows the simplified flows of the ACTIPOT system. The data collection stations on the highway are clearly shown. It is assumed that the automated trucks operating on dedicated lanes do not generate traffic on the existing roadway network. Also, since the dedicated lanes do not constitute part of the roadway network, the corresponding flow (f1) is not considered in the impact analysis. Redirecting truck traffic to the inland port transfer truck traffic to another part of the roadway network. The redirection reduces the flow around the terminal and, consequently, increases the flow between the inland port and customers (f2).

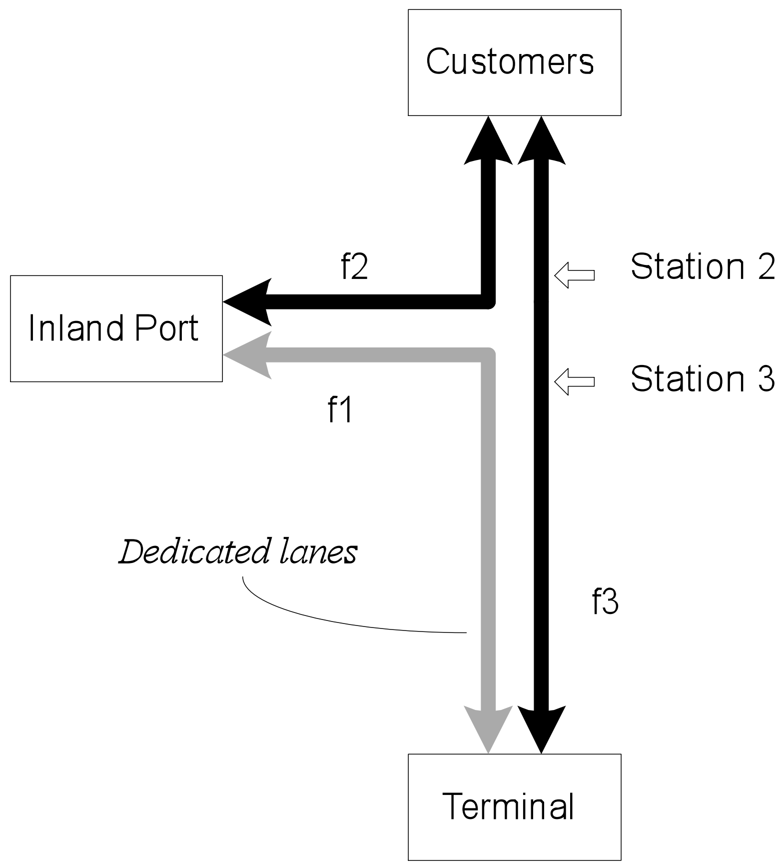

Figure 0-12: S implified flows in the ACTIPOT system

In order to perform a simulation with the test bed, two cases are considered under different traffic demands. The traffic densities for the two simulation scenarios are in the same range as the ones used for the empty container reuse simulations.

- **Case I:** The incoming Southbound CAR flow is 5000 vehicles/hour
- **Case II:** The incoming Southbound CAR flow is 5400 vehicles/hour

In case II, the traffic demand is set close to the critical density of a general freeway in the US. Assuming traffic conditions close to the critical density on the freeway is important, since these are the conditions when small increases in traffic volume can create significant congestion, and slight decreases in traffic volume can avoid congestion.

In addition, the following considerations are used for the simulations, for both Case I and Case II situations:

1. The incoming Southbound HGV flow is 700 vehicles/hour.

2. Ramp flow rates account for about 5% to 10% of the mainline flow rate.
3. The Northbound flow is set to be almost balanced with the Southbound flow.
4. The processing rate of the gates is set to be enough to handle trucks without waiting. This particular assumption is the same as in the simulation of the empty container reuse concept. It is used in order to create the focus on the effects of the use of the inland port, rather than on a combination of other effects, which might have included the waiting time at the gates. For other simulation purposes, the waiting time at the gate could be included.

In order to investigate the impact on the roadway network, a parameter of interest is the *utilization percentage* of the inland port, which is defined as the portion of HGV vehicles routed to the inland port, expressed as a percentage of the total vehicle volume destined for the terminal. The utilization percentage starts from 0% (when there is no inland port available) and it is gradually increased to 100% (when all HGV vehicles are routed to the inland port).

The HGV volume routed to the terminal gate is 170 vehicles/hour when the inland port is not used. In the Southbound direction, data collection stations 2 and 3 are located immediately upstream and immediately downstream of the W. Willow St. exit, which connects I-710 to the ICTF. Similarly, in the Northbound direction, data collection stations 2 and 3 are located immediately downstream and immediately upstream of the W. Willow St. exit. The volume and speed measurements around these two data collection stations are the variables of interest for the simulations.

Figure 0-13 and Figure 0-14 show the impact of the inland port concept on the freeway traffic for Case I.

In Case I, the Southbound traffic at station 2 shows signs of congestion when the utilization percentage of the inland port is increased. At utilization percentage of about 80% the Southbound speed at station 2 has dropped by 10% as compared to the speeds when the utilization percentage is 0%. On the contrary, Southbound speeds at station 3, downstream of the inland port, are unaffected by the utilization percentage. Northbound speeds at station 3 however, are more sensitive to the inland port utilization.

Northbound speeds at station 3 for utilization of 0% are 96 km/h, whereas Northbound speeds for utilization of 80% are down to 59 km/h, a decrease in speed by 38%. This Northbound congestion right before the inland port, reflects the phenomenon of a large number of trucks coming out of the inland port (loaded or unloaded) and traveling north, to a customer, a warehouse or a distribution center. As this large number of trucks enters the freeway, traffic before station 3 becomes congested. A curious phenomenon is the sudden drop in Northbound speed at station 3 for the relatively small utilization percentage of 20%. The speed drops to 78 km/h, but then it recovers back to 96 km/h when the utilization percentage is 30%. This phenomenon, which is also observed at a smaller scale at station 2, is probably due to the specific parameter values used for this particular simulation.

In Case II the traffic demand is set close to the critical value. As seen from Figure 0-15 and Figure 0-16, in this case the freeway speeds are more sensitive to the utilization percentage of the inland port, as expected. At utilization percentage of about 80% the Southbound speed at station 2 has dropped by 17% as compared to the speeds when the utilization percentage is 0%. This drop in speed is higher than the corresponding drop for case I.

Similarly to case I, Southbound speeds at station 3, are unaffected by the utilization percentage. Northbound speeds at station 3 however, are more sensitive to the inland port utilization. Northbound speeds at station 3 for utilization of 0% are 96 km/h, whereas Northbound speeds for utilization of 80% are down to 60 km/h, a decrease in speed by 38%, similar to the drop in speed for Case I. The reasons for Northbound congestion are the same as in Case I.

The congestion phenomena observed here, mean that enhancement at the infrastructure level is necessary, for the network to be able to handle the increased volumes. Besides the ramps and the merging/splitting area on the freeway, the intersection in front of the ICTF gates turns out to be vulnerable to congestion.

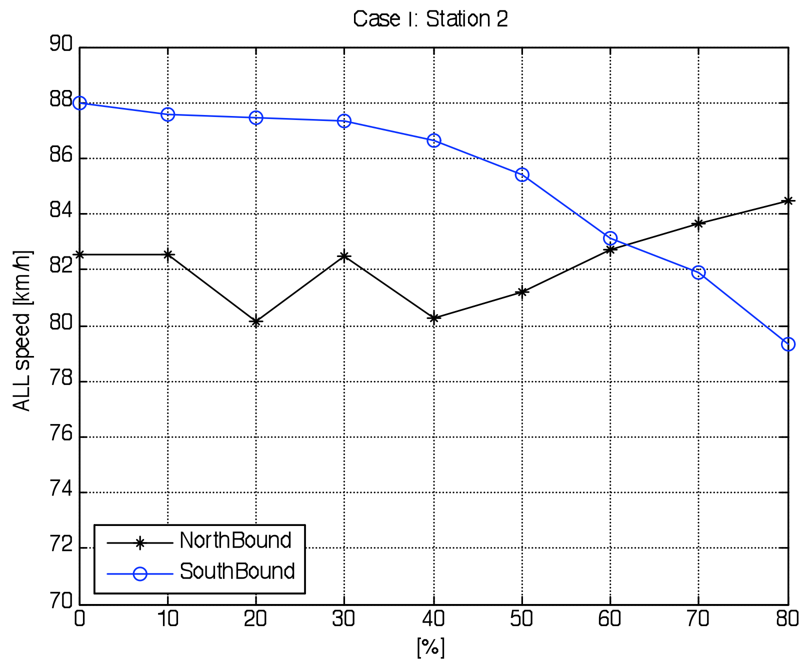

Figure 0-13: Speed at Station 2 (Case I)

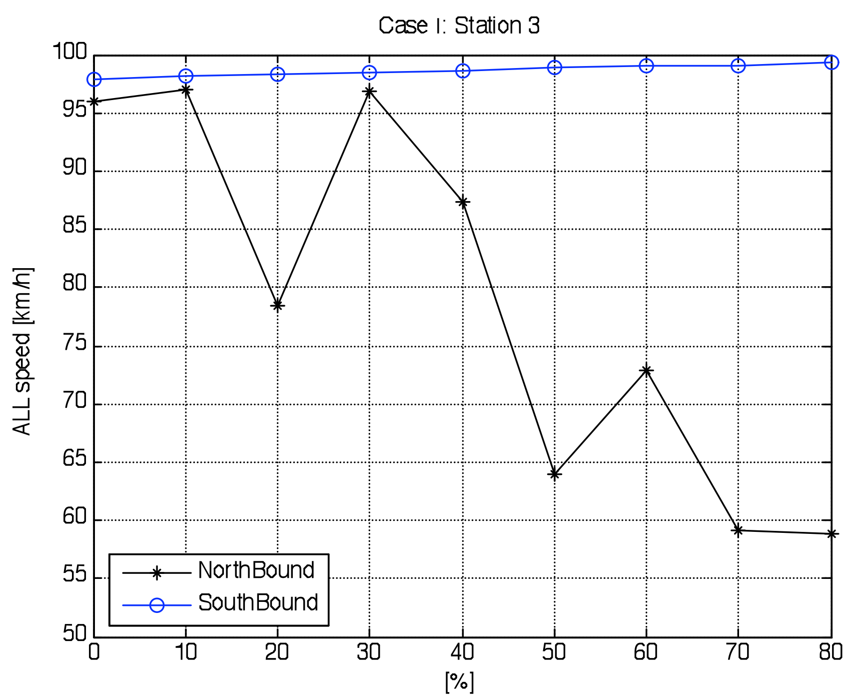

Figure 0-14: Speed at Station 3 (Case I)

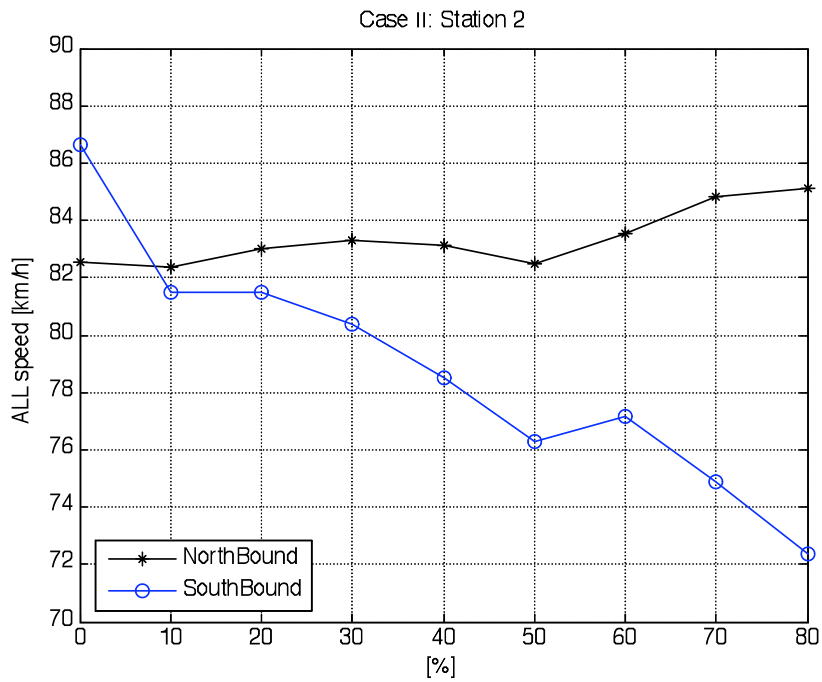

Figure 0-15: Speed at Station 2 (Case II)

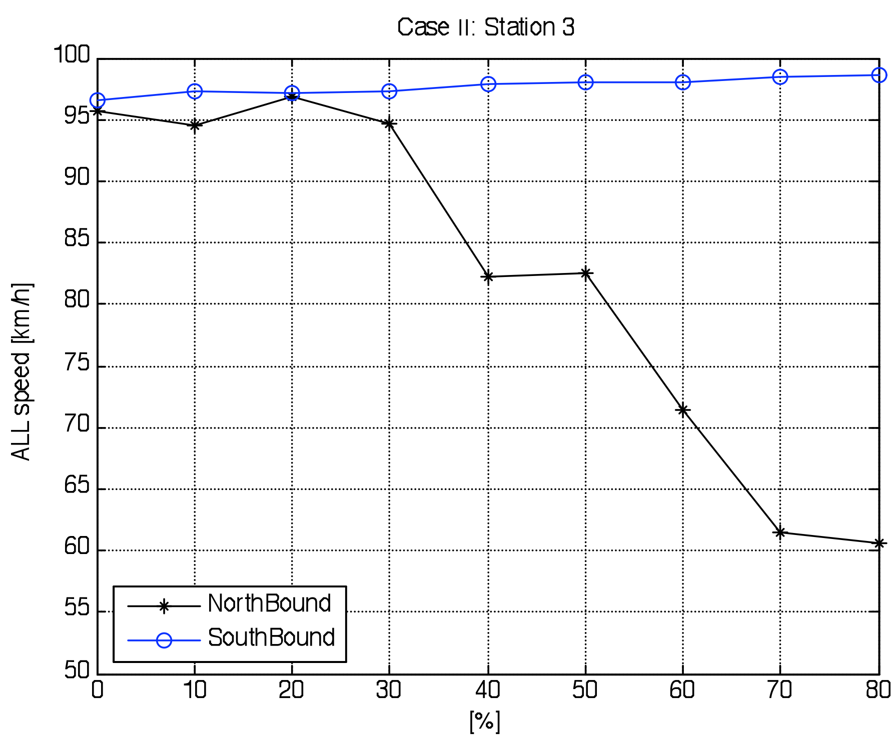

Figure 0-16: Speed at Station 3 (Case II)

3.2.2. Impact on the terminal cost model

In order to keep the cost calculations independent of the utilization percentage of the inland port, the cost is computed under the assumption that all the import containers will be transported to the inland port before they are distributed to different destinations and all the export cargoes will be stored in the inland port before they are transferred to the terminal.

To evaluate the cost of the inland port, the following assumptions are added to the design considerations described in [11].

1. A set of 5 yard cranes is installed in each buffer of the inland port.
2. The fixed costs required to build and maintain the infrastructure necessary for the operation of the dedicated lanes are not considered in the cost model.
3. The number of AGVs employed in the ACTIPOT system is 80. This consideration is a result of our previous work on the ACTIPOT system [14, 15], where it was found that the most efficient operating point of the automated system was when we employed around 80 AGVs. This number of AGVs is sufficient to service a ship within 18-24 hours according to the performance specifications. It was also seen that increasing the number of AGVs beyond 80, does not contribute to improving the efficiency of the system.

In the AGV-ACT system, the transfer between different transportation modes and the storage area to be carried out by the AGV can be divided into three tasks.

Task 1: Transfer of containers between the quay crane and the gate buffers, the storage area, or train buffers
Task 2: Transfer of containers between the gate buffers and the storage area
Task 3: Transfer of containers between the train buffers and the storage area

In the original AGV-ACT system, Task 1 is done by AGVs operating within the terminal area. For the concept under study, the inland port AGV-ACTIPOT system, the AGVs for Task 1 are operating from the terminal to the inland port through the dedicated lanes. Including an additional 5 spares for the long range AGVs, the total number of AGVs to be used for Tasks 1, 2 and 3 is increased to 122 as shown in Table 0-6.

Table 0-6: Comparison of AGVs for the ACT and ACTIPOT systems

Number of AGVs	AGV-ACT	AGV-ACTIPOT
Task 1	48	80
Task 2	26	26
Task 3	6	6
Spare	5	10
Total	85	122

Table 0-7 shows the physical characteristics of the ACT and the ACTIPOT systems. The inland port consists of the storage area along with the import and export buffers. Each buffer is comprised of 5 cranes, respectively, according to the design considerations for the ACTIPOT system. Based on these characteristics, the cost model described in previous sections was applied and calculated the Average Cost per Container (ACC). It is seen that in the ACTIPOT system the ACC is $88.82 as compared to $76.95 without the inland port concept, an increase of 15.4%.

Table 0-7: Average Cost per Container for the ACT and ACTIPOT systems

Characteristics	ACT	ACTIPOT
No. of yard cranes at train buffer	2	2
No. of yard cranes at gate buffer	6	6
No. of yard cranes at storage yards	36	36
No. of yard cranes at inland buffer	0	10
Import/Export buffer area [acre]	0	11.2
Berth area [acre]	5.6	5.6
Average Cost per Container ACC [$]	76.95	88.82

3.3. Centralized Processing and Use of Chassis

Currently terminals store unused chassis in the yard, occupying considerable yard space. Trucks often waste considerable time dealing with operations involving these chassis, especially in cases where the allocated chassis is not acceptable to the truck driver due to damage etc. Terminals have to maintain these chassis and keep track of them, something that it requires additional labor and resources. Trucks searching for chassis in the yard add to congestion, influencing other operations with negative effects on the overall performance. Here we explore the concept suggested to us by terminal operators in the past, on the centralized processing and use of chassis that may also have an effect on truck movements. This study is preliminary, and an in-depth analysis could be the subject of another project.

3.3.1. Impact on the roadway network

The concept of central processing of chassis aims at increasing the capacity of terminals and reducing truck traffic within the terminal. In order to evaluate the impact of this concept on the roadway network, we select a location near the port where the centralized storage of chassis will take place. For ease of the simulation, this location is chosen to be close to the inland port, since the roadway network and traffic conditions have already been coded for this part of the network. The centralized processing of chassis can work in conjunction with the inland port concept, or independently. It can also work in conjunction with the empty container reuse. In this study, which is exploratory, and in order to keep the effects of each concept separate, we investigate the centralized processing of chassis on its own, using the base scenario we employed before, which does not include either the empty container reuse or the inland port / ACTIPOT concept.

The selected location for the central chassis depot is on W. Willow St., which will only require minor modifications to the existing roadway network. For simplicity's sake we are only focusing on the Southbound truck traffic. All Southbound trucks have a destination at a terminal, but only a certain percentage of the Southbound trucks will be involved in chassis-related operations. Figure 0-17 shows the simplified flow diagram for the centralized chassis processing. Table 0-8 describes the Southbound truck tasks corresponding to the Southbound flows (f1, f2 and f3). Since for this preliminary study we are focusing on the Southbound trucks, the Northbound chassis-related tasks (such as dropping off a chassis at the chassis depot after having dropped off a container at the terminal) are not included in the simulation.

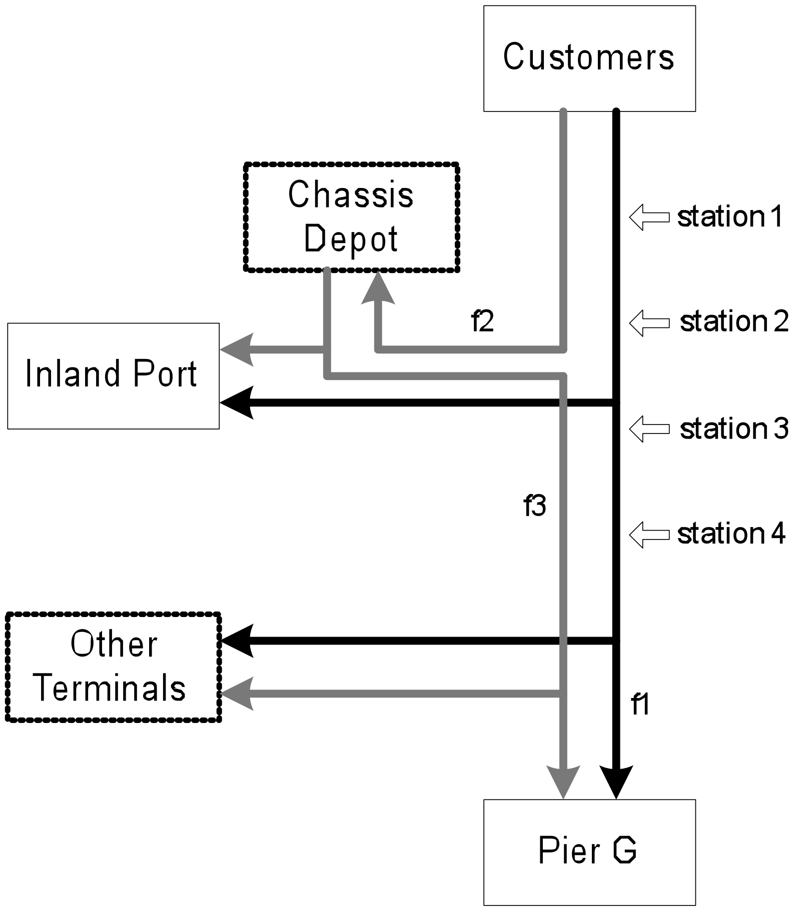

Figure **0**-**17**: Simplified flows for centralized chassis processing

Table 0-8: Task descriptions for centralized processing of chassis

Flow symbol	Inbound truck	Task description
f1	Truck with container	Drop off container at the destination terminal
f2	Bobtail	Pick up chassis from chassis depot
f3	Chassis only	Pickup container from destination terminal

The following considerations are used to create the simulation scenarios. These determine the road conditions, and are similar to the conditions used for the empty container reuse and inland port concepts.

1. The incoming Southbound CAR flow is 5000 vehicles/hour.
2. The incoming Southbound HGV flow is 700 vehicles/hour.
3. Ramp flow rates account for about 5% to 10% of the mainline flow rate.
4. The Northbound flow is set to be almost balanced with the Southbound flow.
5. The processing rate of the gates is set to be enough to handle trucks without waiting. This particular assumption is used in order for the simulation to focus on the effects of centralized processing of chassis, rather than on a combination of other effects, which might have included the waiting time at the gates. For other simulation purposes, the waiting time at the gate could be included.

In order to investigate the impacts on the roadway network, the *utilization percentage* is used, which is defined as *utilization percentage* of the inland port, which is defined as the portion of HGV vehicles routed to the chassis depot, expressed as a percentage of the total vehicle volume destined for the terminal. The utilization percentage starts from 0% (when there is no chassis depot available) and it is gradually increased to 40%.

In the Southbound direction, data collection stations 2 and 3 are located immediately upstream and immediately downstream of the W. Willow St. exit, which connects I-710 to the chassis depot. Two more data collection stations (station 1 and station 4) are added upstream and downstream of stations 2 and 3 respectively, to provide data on the propagation of traffic congestion around the W. Willow street exit. The speed measurements around these four data collection stations are the variables of interest for the simulations.

Figure 0-18 through Figure 0-21 show the average speed at the 4 data collection stations as a function of utilization percentage. The average speed at station 2 starts to fall when the utilization percentage is between 20% to 30%. At 30% utilization percentage, the capacity of the local surface street reaches saturation, and it cannot keep up with the flow discharged from the freeway through the off-ramp. Figure 0-18 shows that this congestion is propagated back on the freeway. Figure 0-19 through Figure 0-21 show that the concept of centralized processing of chassis does not have an effect on the traffic South of the chassis depot. This is due to the fact that trucks leaving the chassis depot, travel on the local street which is equipped with signalized intersections, and they do not generate abrupt speed reductions before the freeway entrance.

The simulation results show that the existing roadway network can accommodate the concept of centralized processing of chassis without a significant modification of its infrastructure, if the percentage of trucks which involves chassis operations is less than 30%. The concept of central processing can be used to increase the capacity of terminals and reduce truck traffic within the terminal without any deteriorating effects on the traffic on the roadway network.

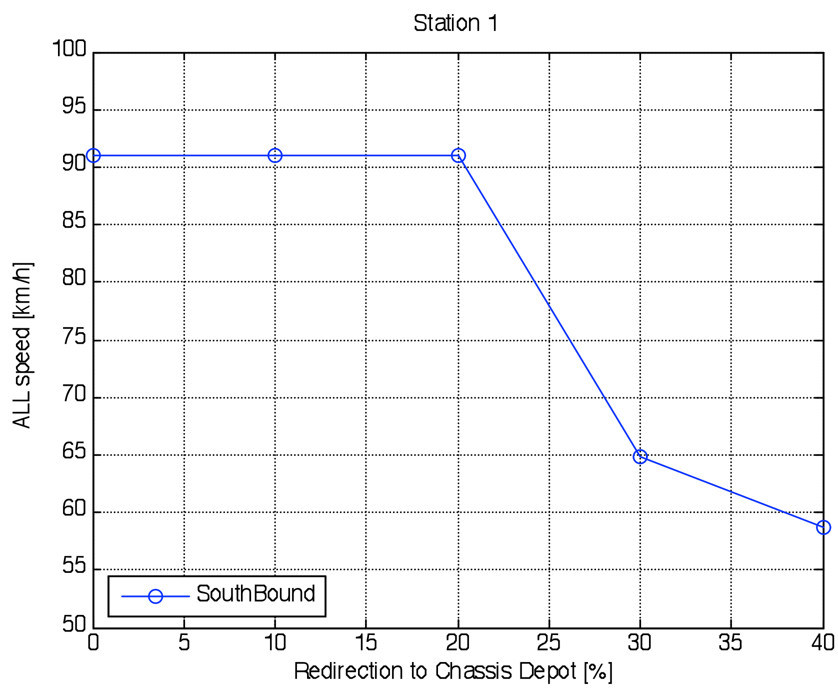

Figure 0-18: Impact of centralized chassis processing (station 1)

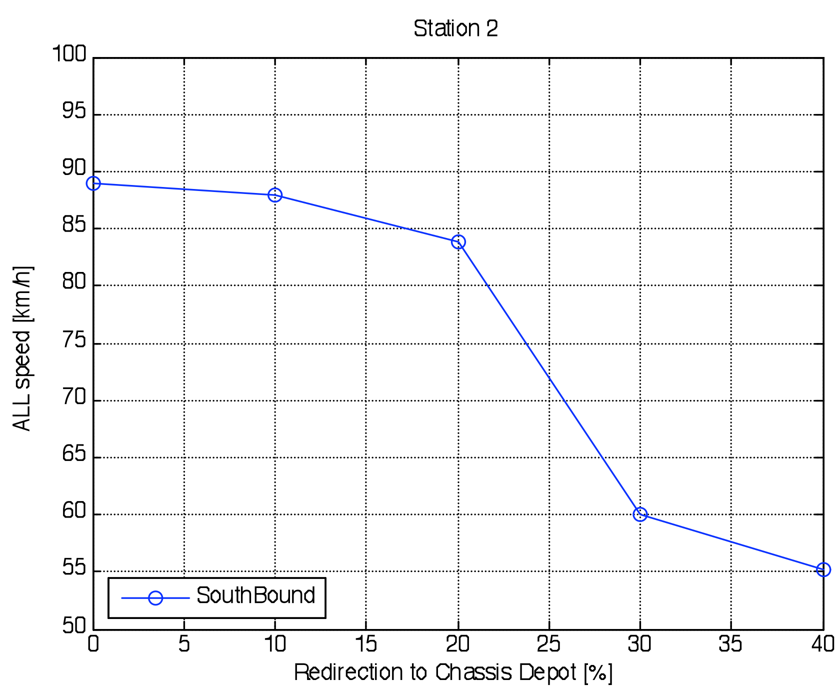

Figure 0-19: Impact of centralized chassis processing (station 2)

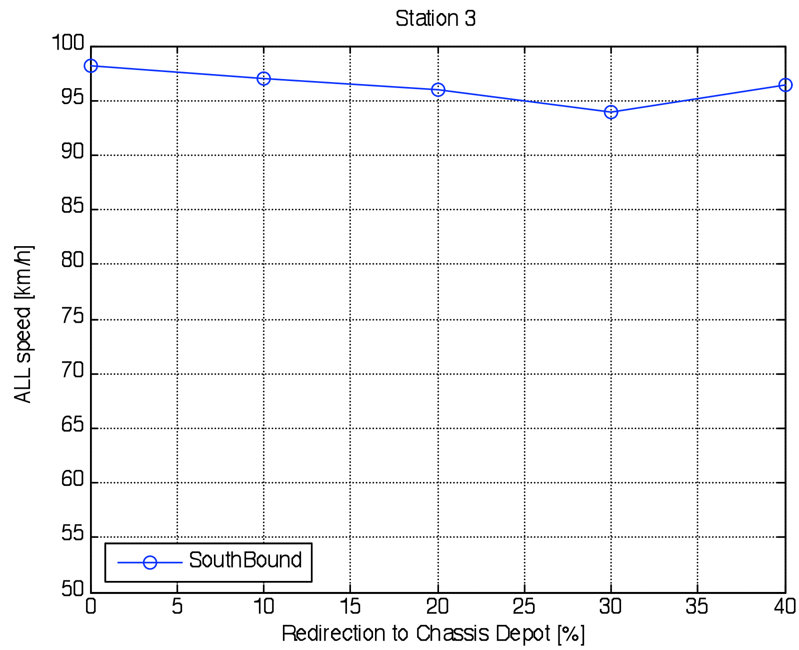

Figure 0-20: Impact of centralized chassis processing (station 3)

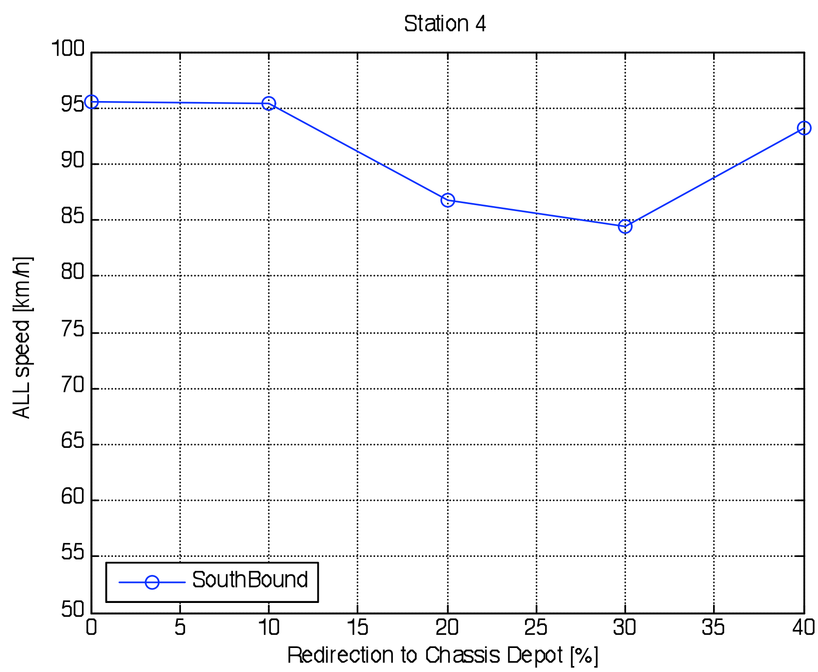

Figure 0-21: Impact of centralized chassis processing (station 4)

Conclusions

In this study we develop a microscopic simulation test bed that allows us to investigate the impact of various technologies and concepts on the terminal capacity and cost as well as on the traffic network outside the terminals in an integrated manner. The test bed is of general use and could be employed to evaluate a wide range of concepts, technologies and geometric configurations associated with terminals and ports and the traffic network outside the terminals.

The test bed is used to evaluate and analyze two truck movement concepts that include the use of an inland port with dedicated truck lanes and empty container reuse strategies. It is also used to study the concept of centralized processing and use of chassis. As an example, a particular terminal from the Los Angeles/Long Beach port complex with associated traffic network outside the terminal is used to demonstrate the use of the test bed in evaluating and quantifying benefits associated with the proposed truck movement concepts.

The results of using the test bed to evaluate the empty container reuse strategies show that empty reuse can improve terminal capacity and traffic conditions on the roadway network. Simulation results from the evaluation of the inland port concept suggest that this concept should be considered very carefully, in conjunction with modifications to the existing roadway network, which will be necessary to accommodate the resulting traffic conditions. This is because the inland port concept redirects traffic to other part of the network, and it could generate unexpected traffic congestion. The preliminary results from the evaluation of the centralized processing of chassis are promising, and show reduction of traffic congestion around the terminals, without significant adverse effects if the utilization percentage of the chassis depot remains under certain limits.

Implementation

In this project developed a microscopic simulation test bed that allows us to investigate the impact of various technologies and concepts on the terminal capacity and cost as well as on the traffic network outside the terminals in an integrated manner. The test bed is of general use and could be employed to evaluate a wide range of concepts, technologies, and geometric configurations associated with terminals and ports and the traffic network outside the terminals. As an example a terminal from the LA/LB port with associated traffic network outside the terminal was used to demonstrate the use of test bed in evaluation and quantifying benefits associated the two proposed truck concepts.

The software module *TrafficSim* could be based on any commercial microscopic traffic simulation tool which supports some required run time expansion features. However, since the data interface is hard-coded in *TermSim*, any change in the structure of the data collection and vehicle input functions of *TrafficSim* will require *TermSim* to be recoded. Therefore, the functional characteristics related to the interface of the two modules should be carefully determined during the phase of constructing the roadway network model using *TrafficSim*.

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Appendix I: Cost tables for AGV-ACT SYSTEM

I.1) Activity

Activity Center	Working Hours	Electricity consumption Whirs per hour	electricity cost per KWHR	**Total electricity cost per activity**	Investment	Accounting life	Depreciation per year	Repair per year 3%	Insurance 1%	Interest 10%	**Total Fixed Costs**	**Total Costs**
								0.030	0.010	0.100		
Inbound gate	8,760	1,500	0.1410	1,852,740	1,000,000	25	40,000	30,000	10,000	100,000	180,000	2,032,740
Customs	5,840	1,500	0.1410	1,235,160	1,000,000	25	40,000	30,000	10,000	100,000	180,000	1,415,160
Outbound gate	8,760	1,500	0.1410	1,852,740	1,000,000	25	40,000	30,000	10,000	100,000	180,000	2,032,740
Gate buffer	8,760	1,500	0.1410	1,852,740	500,000	25	20,000	15,000	5,000	50,000	90,000	1,942,740
EXPORT Storage Area	8,760	1,500	0.1410	1,852,740	500,000	25	20,000	15,000	5,000	50,000	90,000	1,942,740
IMPORT Storage Area	8,760	1,500	0.1410	1,852,740	500,000	25	20,000	15,000	5,000	50,000	90,000	1,942,740
Train/AGV buffer	8,760	1,500	0.1410	1,852,740	500,000	25	20,000	15,000	5,000	50,000	90,000	1,942,740
Berth	5,840	3,000	0.1410	2,470,320	2,000,000	25	80,000	60,000	20,000	200,000	360,000	2,830,320
Maintenance area	4,160	1,500	0.1410	879,840	1,500,000	25	60,000	45,000	15,000	150,000	270,000	1,149,840
Central controller	8,760	1,500	0.1410	1,852,740	3,000,000	10	300,000	90,000	30,000	300,000	720,000	2,572,740

VC	FC	TC
17,554,500	2,250,000	19,804,500

I.2) Land

0.100

Land	Area (Acre)	Investment(U.S.$)	Accounting life(year)	Annual Land Cost (considering Inflation rate)	Interest 10%	**Total Costs(U.S.$)**
Storage Area	44.6284	22,314,200	25	1,583,247.32	2,231,420	3,814,667
Berth	5.6222	14,055,500	25	997,272.26	1,405,550	2,402,822
Train Area	6.9728	3,486,400	25	247,368.65	348,640	596,009
Gate Area	13.0667	6,533,350	25	463,557.24	653,335	1,116,892

Cost per Acre	500,000

Land Inflation Rate	0.05

Total Annual Land Cost
7,930,390

I.3) Equipment

										0.100	0.010	0.100			
	Working hours	Number of Equipment	Utilization Factor	Fuel, electricity, ..per equipment per hour($)	Fuel, electricity, …per equipment per year($)	**Fuel, electricity, … per year($)**	Investment	Accounting life	Depreciation per year	Repair per year 10% of investment cost	Insurance 1%	Interest 10%	Total Fixed Costs per equipment	**Total Fixed Cost**	**Total Co**
AGV/AGV Infrastructure	8,760	85	0.640	15.00	84,096	7,148,160	200,000	15	13,333	20,000	2,000	20,000	55,333	4,703,333	11,851,49
Yard crane	8,760	44	0.350	20.00	61,320	2,698,080	1,500,000	15	100,000	150,000	15,000	150,000	415,000	18,260,000	20,958,08
Quay crane	5,840	5	0.690	50.00	201,480	1,007,400	10,000,000	15	666,667	1,000,000	100,000	1,000,000	2,766,667	13,833,333	14,840,73

VC	FC	TC
10,853,640	36,796,667	47,650,307

I.4) Labor Costs

GATES			# of people	sch. hours	$ per hour	$ per hour overtime	overtime	salary	salary overtime	salary Total
5,084,400.00	Inbound gate	checkers	27	8,760.00	30.00	45.00	2,520.00	1,684,800.00	113,400.00	1,798,200.00
		supervisor	0	8,760.00	61.00	91.50	0.00	0.00	0.00	0.00
		clerical	15	8,760.00	30.00	45.00	2,520.00	936,000.00	113,400.00	1,049,400.00
		custodial	0	8,760.00	24.00	36.00	0.00	0.00	0.00	0.00
	Customs	checkers	0	5,840.00	45.00	67.50	0.00	0.00	0.00	0.00
		supervisor	0	5,840.00	61.00	91.50	0.00	0.00	0.00	0.00
		clerical	4	5,840.00	30.00	45.00	1,680.00	249,600.00	75,600.00	325,200.00
		custodial	0	5,840.00	24.00	36.00	0.00	0.00	0.00	0.00
	Outbound gate	checkers	18	8,760.00	30.00	45.00	2,520.00	1,123,200.00	113,400.00	1,236,600.00
		supervisor	0	8,760.00	61.00	91.50	0.00	0.00	0.00	0.00
		clerical	9	8,760.00	30.00	45.00	2,520.00	561,600.00	113,400.00	675,000.00
		custodial	0	8,760.00	24.00	36.00	0.00	0.00	0.00	0.00
YARD			# of people	sch. hours	$ per hour	$ per hour overtime	overtime	salary	salary overtime	salary Total
5,282,460.00	Gate-buffer	supervisor	3	8,760.00	61.00	91.50	2,520.00	380,640.00	230,580.00	611,220.00
		yard worker	12	8,760.00	30.00	45.00	2,520.00	748,800.00	113,400.00	862,200.00
	EXPORT Storage Area	supervisor	3	8,760.00	61.00	91.50	2,520.00	380,640.00	230,580.00	611,220.00
		yard worker	12	8,760.00	30.00	45.00	2,520.00	748,800.00	113,400.00	862,200.00
	IMPORT Storage Area	supervisor	0	8,760.00	61.00	91.50	0.00	0.00	0.00	0.00
		yard worker	12	8,760.00	30.00	45.00	2,520.00	748,800.00	113,400.00	862,200.00
	Train/AGV interface	supervisor	3	8,760.00	61.00	91.50	2,520.00	380,640.00	230,580.00	611,220.00
		yard worker	12	8,760.00	30.00	45.00	2,520.00	748,800.00	113,400.00	862,200.00
BERTH			# of people	sch. hours	$ per hour	$ per hour overtime	overtime	salary	salary overtime	salary Total
5,414,280.00	Berth	dock foremen	2	5,840	83.00	124.50	1,680.00	345,280.00	209,160.00	554,440.00

		marine planner	4	5,840	83.00	124.50	1,680.00	690,560.00	209,160.00	899,720.00
		operator	30	5,840	61.00	91.50	1,680.00	3,806,400.00	153,720.00	3,960,120.00
MAINTENANCE			# of people	sch. hours	$ per hour	$ per hour overtime	overtime	salary	salary overtime	salary Total
2,408,640.00	Maintenance Area	repairmen	16	4,160.00	58.00	87.00	0.00	1,930,240.00	0.00	1,930,240.00
		supervisor	2	4,160.00	61.00	91.50	0.00	253,760.00	0.00	253,760.00
		clerical	2	4,160.00	30.00	45.00	0.00	124,800.00	0.00	124,800.00
		custodial	2	4,160.00	24.00	36.00	0.00	99,840.00	0.00	99,840.00
CONTROLLER			# of people	sch. hours	$ per hour	$ per hour overtime	overtime	salary	salary overtime	salary Total
1,923,840.00	Central controller	programmer	3	8,760.00	72.00	108.00	2,520.00	449,280.00	272,160.00	721,440.00
		manager	3	8,760.00	120.00	180.00	2,520.00	748,800.00	453,600.00	1,202,400.00

Total Labor Cost
20,113,620.00

I.5) Summary

Activity					
	Variable Costs	Fixed Costs	**Total Costs**		
	17,554,500	2,250,000	**19,804,500**		
Equipment					
	Variable Costs	Fixed Costs	**Total Costs**		
	10,853,640	36,796,667	**47,650,307**		
Total					
	Variable Costs	**Fixed Costs**	**Land Costs**	**Labor Costs**	**Total Costs**
	28,408,140	**39,046,667**	**7,930,390**	**20,113,620**	**95,498,817**

Projected annual TEUs handling	2,482,000
Average Cost per Container	76.95