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Aaron C. Tan

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THE VIRTUAL INTERMODAL TRANSPORTATION SYSTEM (VITS)

By

Aaron C. Tan

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
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in the Department of Industrial Engineering

Mississippi State, Mississippi

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THE VIRTUAL INTERMODAL TRANSPORTATION SYSTEM (VITS)

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Available tools are insufficient to provide the needed systemwide view for planning freight transportation systems based on the coordinated use of more than one mode of transportation. Many tools are either mode specific or too microscopic in scope. No comprehensive tool exists that considers the performance of the entire system, which is important due to the many interdependencies that exist between the different modes of transportation. Optimizing a particular component of the transportation network could result in sub-optimization of the entire transportation system. Intermodal freight transportation planning tools are needed to optimize future freight transportation systems.

This thesis presents a prototype Virtual Intermodal Transportation System (VITS) that simulates the movement of freight via highways, railways, and waterways on a statewide level. The requirements as well as the processes for building the VITS are researched and identified. Results from hypothetical case studies using the VITS are also discussed.

DEDICATION

I would like to dedicate this research to my family and to the late Jan McIlwain Robinson of Starkville, MS.

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CHAPTER I

INTRODUCTION

Since the advent of ISTEA (Intermodal Surface Transportation Efficiency Act of 1991), and the more recent TEA-21 (Transportation Equity Act for the 21st Century), much effort has been garnered towards better understanding of intermodal systems and the related system modeling issues. For example, Jones et. al. [1] offer a standard definition for intermodal transportation while Graham [2] in his thesis, “Modeling Intermodal Transportation Systems: Establishing a Common Language” lays the foundation for the mathematical modeling of intermodal systems. Jones defines intermodal transportation as “the shipment of cargo and the movement of people involving more than one mode of transportation during a single, seamless journey”.

Many research studies since then have identified a cause for concern in the future of transportation in the United States. Using the southeastern states as an example, the ever-increasing trade with neighboring Latin American countries as well as global trade could overwhelm the transportation network in the near future. A study called “LATTS” (Latin America Trade and Transportation Study) goes into more detail on the existing transportation infrastructure within the LATTS region and the impact of the freight increases due to the LATTS traffic. This study postulates that the Latin American trade gatewaying through the Southeast Transportation Alliance is going to increase by 300% over the next 20 years [3].

It is certain that independent decisions made concerning these transportation issues, whether it is on statewide highway issues or capacity upgrades pertaining to a critical port in a particular region, may not account for the interactions that will occur in the transportation system on a statewide level. Planning more comprehensively by considering the level of performance of the total system will require certain tools. We will call this tool the Virtual Intermodal Transportation System (VITS).

The objective of this thesis is to research and develop the VITS to allow for a large scale, systemwide examination of the freight transportation system with consideration for all major modes of transportation and intermodalism. This thesis will address how discrete-event simulation technology can be used by transportation planners to more effectively:

- Model the random variation inherent in transportation systems as well as the complex interactions of how freight moves over the transportation network and through intermodal connector points.
- Estimate how proposed localized changes will impact the performance of the overall transportation system.
- Conduct statewide level analysis of systemwide design changes to the transportation infrastructure and to effectively communicate the expected performance of the alternatives through powerful visualization/animation presentations.

1.1 Utility of a Virtual Intermodal Transportation Simulation System

While many software tools that incorporate Geographic Information System (GIS) technologies and transportation planning tools help transportation planners

evaluate their transportation network and the related infrastructures, there are deficiencies in most of these tools when it comes to statewide freight transportation planning. For example, a deterministic model for a port is sometimes used to calculate the average throughput and the practical capacity [3]. This deterministic model would treat truck flow into the system as an average figure, with the flow spread out evenly over the entire day, and also the capacities of various resources as average figures based on some samples of typical facilities in the region of study (as reported in the Louisiana Statewide Intermodal Plan study [5]). However, truck movement varies according to the time of day, thus creating high-traffic periods and less-traffic periods, called temporal flow patterns. A particular link in the network (e.g. a highway link) may experience more or less vehicular flow/congestion than typically encountered within periods. This is called within-period temporal flow variation [6]. Temporal highway flow patterns can have a significant effect on the ability of a port to process freight from its facility. A simulation model such as the VITS, accounting for this stochasticity, can bring attention to unanticipated problems arising from changes to policy and/or infrastructures that are not apparent when studying average figures.

Secondly, many transportation planning packages, although some contain a simulation component, lack the capability to effectively analyze means of transportation other than highway systems. In other cases, they are focusing only on some particular highway corridors, and/or arterials for a localized study. In most cases, either the network information for waterways and railways are not readily available, or the software simply does not handle these modes or capabilities to do mode transfers unless some extensive

programming is done. The facilities that are key in intermodal transportation such as ports and transfer terminals are often excluded from traffic analysis software. These shortfalls limit the ability for a comprehensive statewide freight transportation analysis with consideration for intermodalism.

For example, a study conducted by the Texas Public Policy Foundation on freight rail issues revealed that decisions concerning rail freight service could affect the number of trucks operating on highways to a significant degree. The author of the report states that policies that encourage the expansion of commuter rail or inter-city rail service do so at the expense of rail freight service. This can effectively increase truck traffic, which might cause a disproportionate burden on the urban roadway system that is both difficult and expensive to expand [7]. This clearly demonstrates the interaction/relationship between rail and truck modes that should be represented in decision support tools.

The issue of microscopic versus macroscopic level of detail in the simulation is considered within the context of traffic flow. Adolf May, in his widely recognized book in transportation engineering, "Traffic Flow Fundamentals", explains that microscopic flow is one where the "time headway between vehicles" is of concern because of safety, level of service, driver behavior, and capacity issues in the transportation system (time headway is the temporal space between two vehicles). He defines macroscopic flow as one where the flow rate (or volume, expressed as an hourly rate) is the most important characteristic [6]. Ramachandran explains that a microscopic analysis would be appropriate when there is a need to observe the behavior of individual units such as the acceleration and deceleration of truck entities, and a macroscopic analysis to be chosen

when a higher density, large-scale system is to be analyzed (with the behavior of group units being adequate) [8]. Seneviratne states that, “macroscopic simulation models are designed to evaluate levels of service or congestion under stochastic dwell times and demand conditions at selected locations or sections of the network”, whereas in microscopic simulation, “each vehicle is generated and tracked as an individual object moving through the system”. He further explains that at both levels of simulation, vehicle arrival rates, vehicle mix, and dwell times are parameters that can be varied over time to reflect stochasticity [9].

The Virtual Intermodal Transportation System (VITS) would contain elements of both macroscopic and microscopic simulation. The statewide transportation network portion would form the macroscopic portion, while the terminals and ports will form the microscopic portion. The critical element is the interface between the microscopic part of the simulation and the macroscopic part of the simulation. Entity speed on the transportation network for example, would be calculated based on the macroscopic parameters of flow rate and capacity, while the throughput of the port in terms of containers processed, would be dependant upon the arrival times of individual vehicles, among other factors.

Table 1.1 shows examples of some transportation software packages. It is important to recognize that none of these software packages are multimodal by design. Furthermore, most simulation packages are not designed to handle macroscopic simulation.

Table 1.1 Highlights of Transportation Related Software Packages

Product Name	GIS Component	Simulation	Modes Handled	Macroscopic
TransCAD	Yes	No	Mainly Highway	Yes
MultiRail FE	Yes	Yes	Rail only	Yes
CORSIM	No	Yes	Highway only	No
SimTraffic	No	Yes	Highway only	No
VISSIM	No	Yes	Highway only	No
INTEGRATION	Custom*	Yes	Highway only	No
METACOR	No	Yes	Highway only	Yes

* The GIS functionality is available with additional programming by the user

There are numerous researches and knowledge on port simulations [10], highways simulation models [8], intermodal terminal issues [11], traffic flow [12][13], transportation performance measures [14][15], commodity flow studies and trip generation [16], and also vehicle routing models [17]. What is lacking is a concerted research effort to combine the fragmented research results into the building of a statewide intermodal freight transportation simulation model. This thesis will discuss the process of research and development of a VITS prototype, present the results, and identify improvements to the prototype methodology. A port model template is included in the simulation model to demonstrate the VITS's ability to simulate both microscopic (port) and macroscopic details for improved decision support. We will also address some of the important issues that allow the building of a practical and credible intermodal freight transportation simulation model. The prototype VITS model will use the State of Mississippi as an example.

CHAPTER II

LITERATURE REVIEW

2.1 Current Freight Transportation Studies/Agendas

This section reviews the current freight transportation issues with the emphasis on describing future needs as well as the planning process in anticipation of significant future freight increases.

The Latin America Trade and Transportation Study (LATTS) [3] was conducted by the Wilber Smith Associates to determine Latin American trade opportunities, as well as to identify the transportation investments that are necessary to sustain trade growth. The alliance of states impacted by the Latin American trade in this study include Texas, Arkansas, Louisiana, Mississippi, Tennessee, Alabama, Georgia, Kentucky, Wyoming, Virginia, North Carolina, South Carolina, and Florida, which are referred to as “the Alliance” [3]. Studies such as these show the increasing concern about future transportation needs and the need for the evaluation of current transportation capacities to estimate investment costs in anticipation of future congestion.

In order to conduct the analysis, “Port Terminal Planning Modules” were developed for the Alliance states. Described in the Appendix IV of the LATTS report, these modules are used to quantify the throughput/capacity of the ports [3]. With the macro-level characteristics commonly tied to statewide freight transportation planning, these modules can form a good foundation for modeling purposes, especially for a

simulation model where specific parameters can be tweaked to match a particular port instead of generalized regional characteristics. These simplified models of terminals can benefit from including the stochastic nature of the system (such as weather conditions, equipment failures, etc.) as well as interaction between resources (e.g. slowdown of berthing resources will certainly affect the throughput of the storage area and also influences the availability of related resources such as conveyors and forklifts), increasing their analytical value.

The MULTIPLAN (Mississippi Unified Long Range Transportation Infrastructure Plan) study [18] is a statewide transportation study that was initiated by the Mississippi Department of Transportation (MDOT) to conduct a comprehensive analysis of transportation infrastructure and needs throughout the state. However, the statistics that are reported on highways include Vehicle Miles Traveled (VMT), Average Daily Traffic, and Volume-Service Flow Ratio. These statistics are being used for comparison across states, but being either cumulative figures or average figures, they cannot provide any details on problematic spikes in traffic that can occur. A particular section of interest is the identification of the Statewide Transportation Framework as an integral component of the MULTIPLAN study. This framework serves to evaluate the transportation network as it currently exists, and can be used to forecast the system's future performance [18]. Inclusive of all significant highways, railroads, waterways, and airports, this network would be a logical choice when determining the level of detail required for a transportation simulation network of the state of Mississippi. However, some additional work may be required to adapt this network for freight transportation simulation.

The State of Virginia has been involved in developing a methodology for statewide freight transportation planning. In this study [16], an advisory committee of public and private stakeholders in freight transportation was formed (FAC). There was no mention of any use of simulation models in the Virginia study. The FAC could certainly use simulation as a tool to help them evaluate alternatives and to quantify the performance measures.

Examining the Louisiana statewide intermodal plan, their report by the National Ports and Waterways Institute of the Louisiana State University submitted in July 1995 [5] emphasized rail, ports, waterways, and intermodal connections between these modes of transportation. The study focuses on developing measures of capacity of the unique transshipment facilities at marine and rail-highway terminals throughout the state. Definitions and categorization of intermodal freight terminals were done and capacity analysis included five generic types of terminals with four involved in water-land transfers and one in land-land transfers. These ideas can certainly benefit the development of the port simulation model by providing an example framework as well as statistics that are typically used to determine capacities. Based on studies such as the examination of Mississippi Industrial Gulf Ports by Couvillion and Allen, information such as commodities handled, berth configurations, storage areas, and cranes available can be obtained for the initial process of model building [19].

The Louisiana research team devised an approach called “Stock & Flow” (or simply S&F) that is based on the analysis of terminal operations and the related facilities. To do this, the terminal facilities are categorized as Flow Processing Components (trains,

trucks, cranes... etc.) or as Stock Holding Components (storage facilities). This approach has three steps where the terminal is represented as a schematic network of S&F components, the capacity of each component is calculated, and lastly, the bottleneck of the entire system is identified. It is important to know that they assume that each of the terminal components is independent of each other to simplify the calculation of capacity [5]. This assumption is unrealistic in many cases and is not required in the case of a simulation. This will be demonstrated by the prototype VITS.

2.2 Aspects in Freight Transportation Simulation

This section focuses on the issues that pertain to transportation simulation and the related transportation science.

2.2.1 Transportation Science

To understand the fundamentals in vehicular flow, we refer to Khisty and Lall in Chapter 5 of their book [12], which talks about traffic flow characteristics that can be applied towards the traffic flow component of the VITS. The authors explain that traffic flow is a complex phenomenon, and requires more than a casual observation to note that an increase in traffic flow generally corresponds to a decrease in speed. Another insight provided is that speed tends to decrease when vehicles bunch together. Adolf May [6] explains that many factors influence speed variations, with many field studies undertaken. He states that the primary factor is traffic flow intensity, which is expressed as flow to capacity ratio, as well as design speed and speed limits.

Khisty and Lall [12] also stress that traffic flow is a stochastic process, but it is common practice to ignore or average out the effects of chance variation when building a model. Using a simulation model, stochastic elements can certainly be preserved as described by Seneviratne [9] where parameters such as vehicle arrival rates, vehicle mix, and dwell times can be varied over time to reflect stochasticity. He also stated that most existing macroscopic models are used for testing signal optimization and emergency vehicle response management, citing examples like METACOR [9]. Khisty and Ball described macroscopic traffic flow as one that is aggregated and analogous to heat flow and fluid flow [12]. In this essence, METACOR can be described as a macroscopic simulator but it is not designed for simulating statewide or regional freight flow.

Highway capacity is another important aspect pertaining to the VITS and is discussed in Chapter 7 of Khisty and Lall's book [12]. Here, basic definitions and concepts relating to capacity and level of service are described. Since most analysis of capacity is done based on the measurements of "passenger cars", the chapter also provided conversion tables for trucks and other vehicles. These conversions depend largely on the geographic characteristics of the roadways. Roess and McShane [20] provide information on the basic uninterrupted flow capacity of highways in passenger cars per hour per lane, or PCPHPL. This capacity depends upon the classification of the highways (Interstates, State Highways, etc.) and also the speed limits. These capacities can be used in the calculation of highway vehicle speed using the Bureau of Public Roads equation (BPR). According to Grady [21], the default α and β values in the BPR equation have been 0.15 and 4, respectively. He reported that these traditional coefficients have

been replaced following more up-to-date research. The values of 0.45 and 7.5, respectively, are recommended.

An unconventional method for representing vehicular flow on highways is presented by Jain and Smith [13]. Despite the common use of maximum expected flow rate to model roadway capacity (PCPHPL) in the field of traffic science, the authors of this paper adopted another approach where density is used to model the capacity. Density in this case refers to the number of vehicles per mile per lane. As such, the capacity is expressed as the maximum number of vehicles that can lie on a link of roadway (in units of vehicles). The authors explain that this estimated capacity for a given road-link differs from one study to another. Ranges include 185 to 265 veh/mile-lane [13].

One of the processes required in generating the input for the VITS include truck trip generation based on their payload and commodity type. A document on truck size and weight [22] (based on the result of a major study concerning potential changes in Federal policy relating to truck size and weight) was prepared by the Battelle Team in Columbus, Ohio in 1995. This information helps in estimation of the effects of potential policy changes on trucks' transport costs. From a simulation standpoint, truck payloads, maximum allowable weight, and backhaul are important factors in determining the averaged payload on a truck entity traveling on a highway network. Percentages for body types carrying a particular commodity type are also available in this paper. The authors explain that the size of shipments may be limited by three factors that include the legal limits, the cubic capacity of the trailer, and the maximum amount a shipper wishes to send. Christopher Monsere, on the other hand, provided more detail on less-than-

truckload expansion factors in his dissertation [23] that can help when generating truck trips. This factor allows for the inclusion of empty trucks as well as other non-full-load truck traffic in the simulation. Such issues are not a trivial matter and require some thought as to the level of detail in the simulation model, as well as the truck trip generation in the data preparation process. Gerhardt Muller provided general information on truck types, railcars, freight ships, and the related equipments that are involved in intermodalism in his book “Intermodal Freight Transportation” [24].

In exploring vehicle routing issues, Kenyon and Morton [17] considered vehicle routing problems that include stochastic elements on a network with random travel and service times. They defined a route as “...the set of arcs followed by a vehicle and the set of nodes it services.” They reported also that the computed travel times are obtained after all the routes have been planned and the random travel and service times are known. The limitation of their study is that all the vehicles must follow the pre-determined routes, i.e., no route reoptimizations are allowed. They described this as a static model where we select vehicle routes before realizing the random parameters and do not subsequently reoptimize the routes.

2.2.2 *Performance Measures*

On issues of performance measures needed by the VITS, the report entitled “Freight Performance Measures: A Yardstick for Minnesota’s Transportation System” from the State of Minnesota [14] is referenced. It is the result of the recommendations made by the Minnesota Freight Advisory Committee (MFAC). The measures were developed by shippers and transportation companies who make up the MFAC that advise

the Minnesota Department of Transportation. In a broader sense, their performance measures relate to the following five goals [14]:

- Time/Directness
- Safety
- Condition of infrastructure
- Access/basic levels of service
- Socioeconomics

Examining the classical characteristics of material flow, Duma [25] states the basic characteristics of material (freight) flow as the quantity, distance, and time. In the transportation field, a common measure is tonne-kilometres (the equivalent of ton-miles is used in the U.S.). He elaborates further that the classical measures are simple and easy to understand, measurable, and historical data in such form is readily available, although they are lacking in issues such as the value of goods transported, the properties of the goods (perishable, fragile, etc.), quality, and value added by logistical services. Using the available fuel efficiencies by mode, the concept of ton-miles transported per gallon of fuel can be applied as a performance measure. Duma lists mass of goods, transport distance, tariffs, transported units (containers), capacities, operation/haulage time, fuel/energy consumption, utilization indexes, and other artificial indexes as other techniques and measurements that can be used [25].

On economic issues that a simulation model can explore, Yevdokimov [15] explains that the traditional view of the benefits from transportation investment consist of reductions in travel time, reduced vehicle maintenance, and lowered operational costs.

The author classifies the impact of intermodal transportation into four categories that include an increase in volume transported on the existing network, reductions in logistical costs, the economies of scale afforded by the expansion in transportation network, and better accessibility to input and output markets.

2.2.3 *Port and Terminals*

Prianka Seneviratne of Utah State University states that traditional rules-of-thumb and most commercially available software tools do not lend themselves to analyze problems related to intermodal transportation terminals [9]. He points out also that compared to highway and arterial simulation models, intermodal terminal simulation tools are few. As such, he presents a microscopic level simulation tool called Access Traffic Simulation Model (ACTSIM) that was developed to evaluate alternative internal road layouts and traffic management strategies under variable demand conditions and different service area configurations for airport passenger terminals.

The paper by Gambardella et al. [10] discusses another microscopic level simulation tool for a decision support system for the management of an intermodal container terminal. The researchers define an intermodal terminal as a place where containers enter by means of transport such as trucks, trains, and vessels. Problems stated include the spatial allocation of containers in the terminal yard, the allocation of resources, and the scheduling of operations in order to maximize performance measures based on some economic indicators (which include the costs associated with resource usage). In this particular paper, emphasis was placed on the resource allocation problem,

with the application of mixed integer linear programming (MILP) and the use of simulation to validate the solution obtained.

A survey conducted in a study on truck trip generation at container terminals by Holguin-Veras and Lopez-Genao [26] identified the following general characteristics to help determine the physical attributes of the container terminals as well as the main features of the port activities:

- Number of Twenty-foot Equivalent Units (TEUs) handled per year at the terminal
- Percentage of boxes of 20', 35', 40', and 45'
- Working days per week
- Number of people working at the container terminal
- Size of terminal (in acres)
- Operating hours of the truck gates
- Number of lanes at the truck gates
- For inbound and outbound truck traffic: number of loaded containers, empty containers, bare chassis, and number of truck only
- Number of berths
- Number of gantry cranes
- Percentages of containers carried by rail, trucks, and barges
- Slowest and busiest months
- Number of ships per week.

Kulick and Sawyer [27] report that simulation modeling has been successfully used to analyze intermodal capacity issues for a wide variety of facilities. Due to the fact that many interactions between variables can occur within a facility, other methods are usually difficult to employ. This is confirmed by part of the study done by the State of Louisiana [5] where very rough assumptions had to be applied in calculating the capacity of an intermodal port without the aid of a simulation model (using their “Stock and Flow” methodology). Kulick and Sawyer [27] describe some of these interacting variables as equipment and resource types (cranes, etc.), infrastructure (storage locations, etc.), forecasted demands (peak conditions, etc.), arrival and departure schedules (vessels, etc.), tactical operation rules (FIFO, etc.), and strategic options (simultaneous load/discharge).

The National Ports and Waterways Institute presented a dynamic simulation of ports and the related intermodal system [28] that is used to evaluate responses to emergency disruptions of commercial operations in view of current national security concerns. Called the Disruption Model or REDS (Response to Emergency Disruption Simulation), they bring attention to the problem of access time and delays, which are of primary concern to port operators. Service parameters into this model include cargo types, volumes, and dwell times (these are inputs supplied by terminal operators). The building of the VITS port model can benefit from a lot of the insights presented in this report.

The researchers of the REDS model [28] emphasize that marine terminal capacity utilization is affected by the vessels and cargo flows at the terminal itself, as well as the capacity of the related local access roads and rail links. In studying the constraints of a

marine terminal, the report describes vehicle access to these terminals as being limited by the working schedule for terminal gates rather than terminal operations. They believe that the future of access research will be the development of a systemwide examination of the interrelationships between the terminal operations and highway access [28]. We believe that the VITS is taking a first step in that direction.

Robert Leilich [11] discusses the use of simulation models in solving problems concerning constrained rail traffic corridors. The paper specifically addresses issues which simulation can help, where quantitative results cannot be derived by any other method. Specific examples are provided in the paper, such as the Raleigh-Durham-Charlotte corridor, where the seemingly endless highway construction has not resolved traffic congestion due to rapid growth in population. Meinert et al. [29] presented a unique discrete event, microscopic level simulation of railway terminal component. Unlike other studies that are limited in scope to the terminal of interest, this particular study links the terminal simulation with a regional level truck distribution network. Their simulation model also allows concurrent modeling of multiple terminals. Unlike the VITS simulation model, waterway modes as well as non-rail related truck traffic are not included in the study. However, such detailed rail terminal models would be of huge potential if linked with a simulation model like the VITS.

CHAPTER III

VITS METHODOLOGY

This section outlines the methodology for building the prototype VITS. Creating a new tool such as the VITS requires a combination of research and creativity. The VITS prototype was developed using ProModel [30] by PROMODEL Corporation. ProModel was selected because it is a flexible general purpose discrete event simulation language that can be user-coded to develop specific functions/capabilities required in statewide freight transportation simulation models. It is capable of handling both macroscopic and microscopic elements required for the simulation.

It is important to note that the VITS simulates only the flow of vehicles based on data derived from a preceding study and does not forecast travel demand. Although the software package TransCAD was used for determining travel demand, other software could also be used. The four-step travel demand modeling methodology that is usually used by transportation engineers in virtually all metropolitan areas of the United States [4] was employed but details on the methodology is beyond the scope of this thesis.

The State of Mississippi was used as the proving ground for the VITS concept in this thesis although the methodology can be applied towards other states or a region of states. Figure 3.1 shows a screenshot of the VITS's animation.

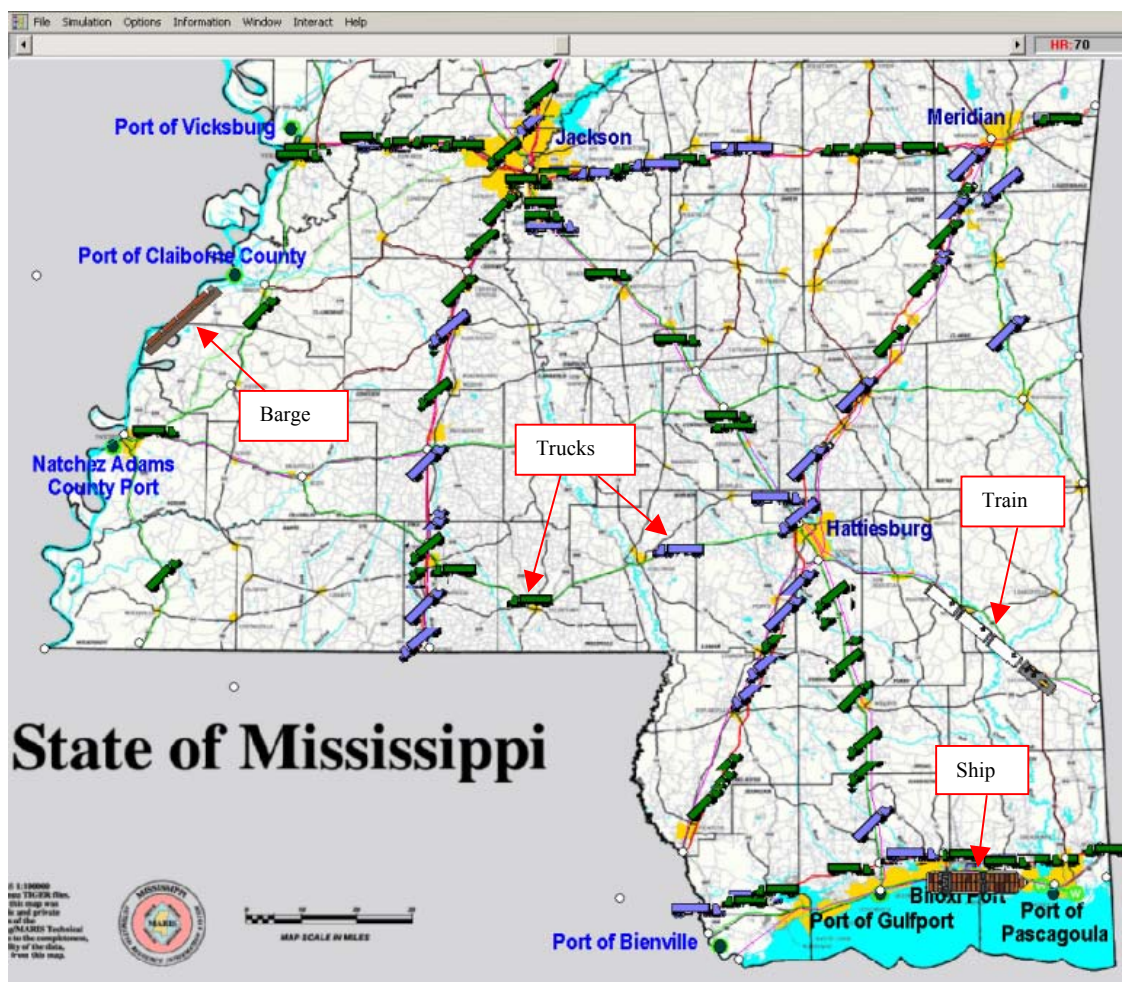


Figure 3.1 Animation Screenshot of the Prototype VITS Showing the Movements of Barges, Trucks, Trains, and Ships over the Transportation Network.

Figure 3.2 gives an overview of the major components of the VITS and how they relate to one another. From the figure, observe that data is fed into three components (Model & Vehicle Settings, Transportation Network, and Vehicle Routing). The Model & Vehicle Settings component provides the necessary information for the Transportation Network to handle traffic flow and freight transfers while the Vehicle Routing component routes the vehicles on the network. The Transportation Network provides information for

the Performance Measures component during the simulation run. The Performance Measures component handles the simulation statistics for systemwide performance measures as well as local performance measures (relating to terminals and ports) not automatically calculated by ProModel. At the end of the simulation, statistical results are summarized in the ProModel output report and in Excel spreadsheets.

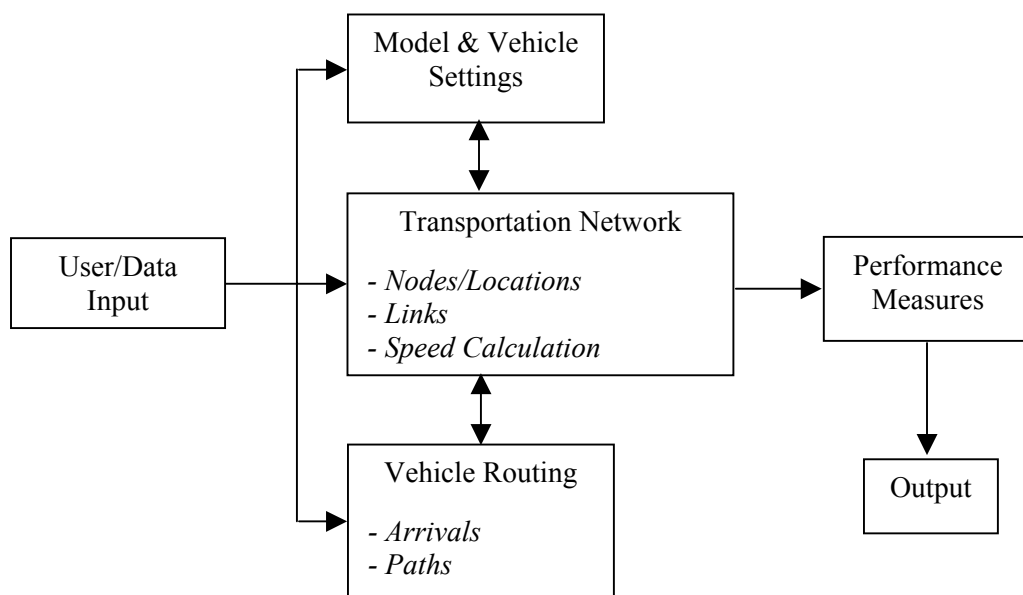


Figure 3.2 Relationship Between Major Components of the VITS

The User/Data Input component includes user input that governs the behavior/operation of the system, as well as data input that generates traffic and dictates routing. The data input is in the form of Excel spreadsheet and ProModel Run-Time Interface (RTI), which is accessed before the simulation starts. This is where the scenarios for the simulation are defined.

The Transportation Network component contains the nodes/location where transfers of freight can happen (e.g. ports or intersection points for the transportation networks), the links for the different modes of transportation (water, rail, and highway), and the logic for the determination of speeds. The terms “nodes” and “locations” in the VITS will be used interchangeably throughout this thesis.

The Vehicle Routing component disseminates the Origin and Destination (OD) pairs into vehicle arrivals into the network. These vehicle arrivals are varied according to the time in the day. Routing is handled by reading in routing information from an Excel spreadsheet that tells the vehicles where to go.

The Performance Measures component calculates the values of each of the systemwide performance measures such as Ton-Miles per Gallon (for all three modes), zonal congestion percentages, link congestion indices, and highway links average speeds based on inputs received from the Transportation Network component. The Output component includes dynamic screen displays of key variables as well as statistics of all systemwide statistics collected to allow further analysis of the system.

The Simulation User Guide can be obtained from the National Center for Intermodal Transportation by contacting Dr. Royce Bowden, Professor of Industrial Engineering at Post Office Box 9542, Mississippi State, MS 39762 (phone: 662-325-7623; email: bowden@engr.msstate.edu). It will help enhance the understanding of the reader concerning the various VITS constructs introduced in the thesis.

3.1 Building of the Simulation Transportation Network

Alternatives in ProModel were evaluated to determine the best way of representing highway, railway, and waterway networks. In ProModel, these networks could be represented as ProModel queues, ProModel routing links between locations, or as ProModel path networks. The problem with ProModel queues and ProModel routing links between locations is that two queues or links are needed to implement two-directional flow for a single network path. It also lacks the flexibility in having multiple branches on a single network. Many path networks in ProModel are combined to form the statewide transportation network. Note that path network is a means in the ProModel software to define the path of travel for entities between locations, where a model can have multiple path networks. We will use the terms links and path networks interchangeably in this thesis. Using path networks in ProModel, we simulated entities moving in both directions, passing, as well as speeding up and slowing down.

The networks implemented in the model are based on information obtained from a GIS software called ArcView (refer to Figure 3.3 for a screenshot of ArcView), and covers all Interstate Highways, all US Highways, and key State Highways. Also included are active railroads (includes both Class I and regional short lines) as well as the Mississippi River, Tenn-Tom waterway, and the Gulf Coast waterway. The GIS data was obtained from the Mississippi Automated Resource Information System (MARIS) [31].

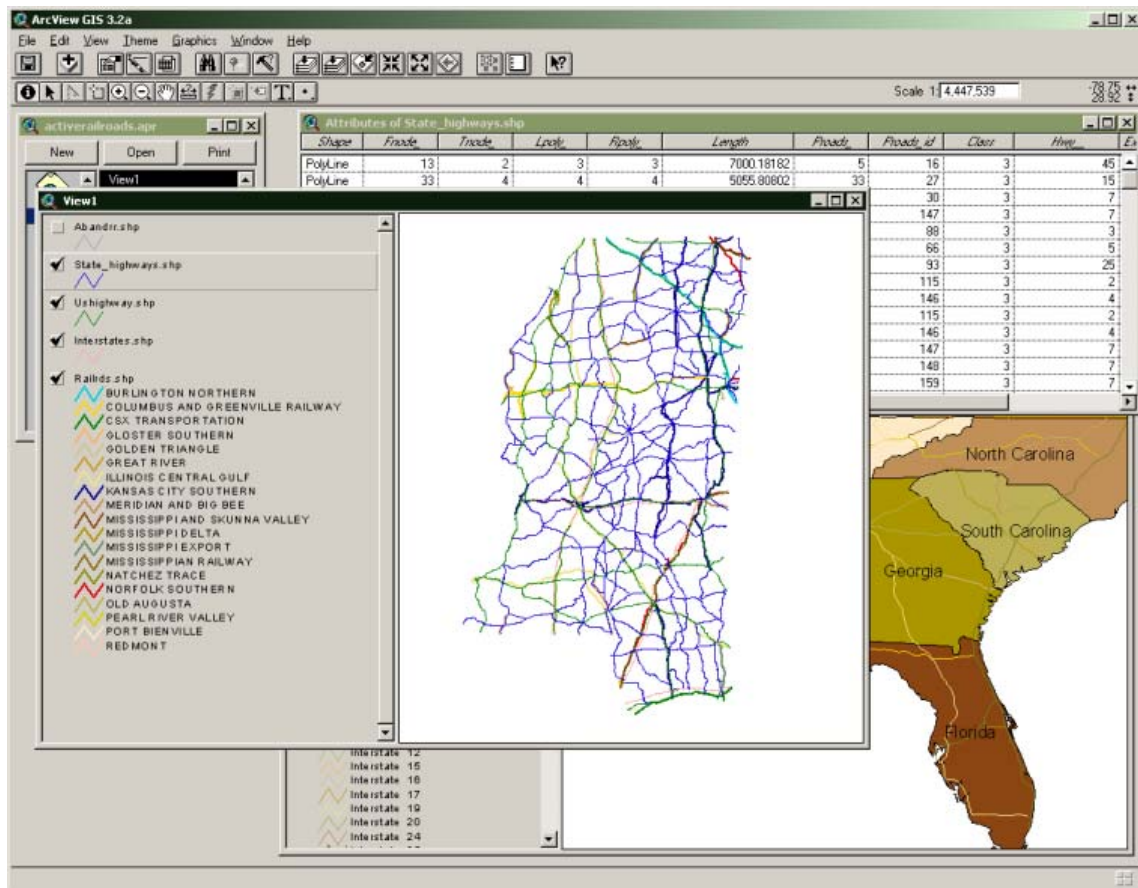


Figure 3.3 ArcView GIS with Data Views on Highways, Waterways, and Railways.

Intersections between links, which are often major towns or cities, are modeled as ProModel locations where speed calculations are made and various statistics are collected. Key locations that include major cities and ports along the waterways are also connected to the transportation network.

Information concerning the capacity (number of lanes) and speed limits for the highways are obtained via ArcView (using data obtained MARIS) and contained in an Excel spreadsheet to initialize the simulation (refer to the Simulation User Guide for more details). This spreadsheet is defined within ProModel as an array. It allows for

convenient changes to the capacity as well as speed limits to observe the impact on the transportation system.

The networks are color coded for easier reference (to represent the different classes). Refer to Table 3.1 below for more detail. The following pages show diagrams of the networks used in the simulation model (Figure 3.4, 3.5, 3.6, and 3.7).

Table 3.1 Color Code for Network Links

Link Color Code	Type/Classification
Red	Interstate Highways
Green	US Highways
Brown	State Highways
Pink	Rail
Blue	Waterways

The bright blue dots in those diagrams represent locations in the model that are connected to the entire network (that consists of multiple modes). They may not be shown as being connected in some figures depending upon the mode being displayed. The highways are labeled as R1, R2, R7.2, etc. The numbers correspond to the name of the highways and the decimals, if applicable, refer to the different branches of that highway link. For more detail on the names used in the model for representing a highway segment, please refer to the Simulation User Guide. Note that names for key arrays used to store information on traffic flow and speed calculations contain “SB” and “BS” notations. These are used to denote the direction of traffic flow.

Active Class 1 railroads as well as key short lines were identified using ArcView. The following lists the corresponding rail Class 1 companies and major short line company with railroads in the State of Mississippi.

- Burlington Northern
- Illinois Central Gulf
- Columbus and Greenville Railway (short line)
- CSX Transportation
- Kansas City Southern
- Norfolk Southern

The locations in the model are usually named after highway intersections they reside on, followed by a unique number. The highway names are used as references or descriptors for the simulation users but the last number uniquely identifies the location throughout the model and the accompanying input spreadsheets (detail on these spreadsheets are available from the Simulation User Guide). As an example, locations I55_US82_LOC5, I55_M27_LOC8, and US90_LOC73 are simply known as locations 5, 8, and 73, respectively. In the input spreadsheet for example, the notation of O5-D73 will denote an origin at location 5 to a destination at location 73. The numbers are used by the simulation to carry out any computation that might involve locations, such as determining routing choices at origin locations.

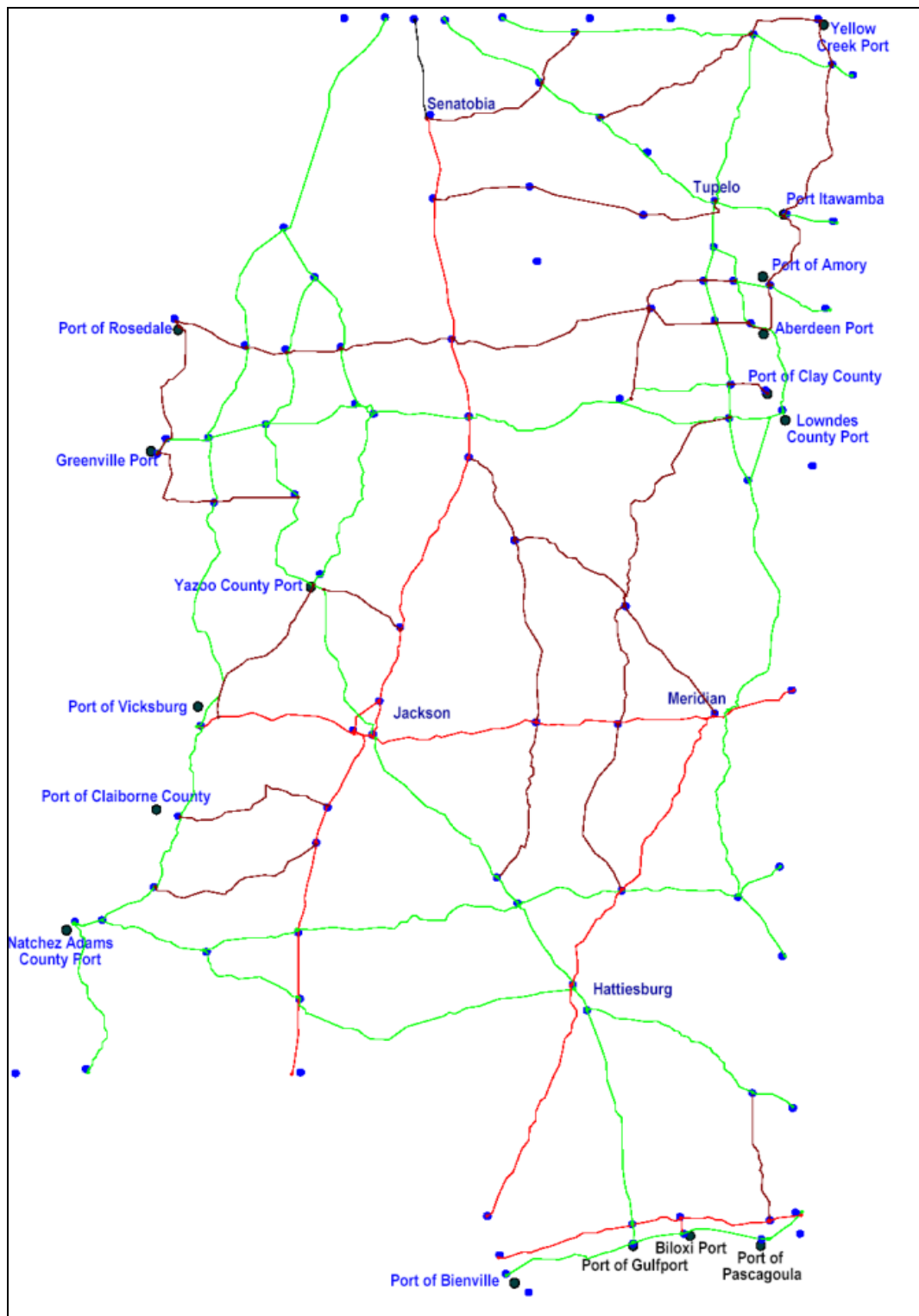


Figure 3.4 All Highway Networks Used in Model

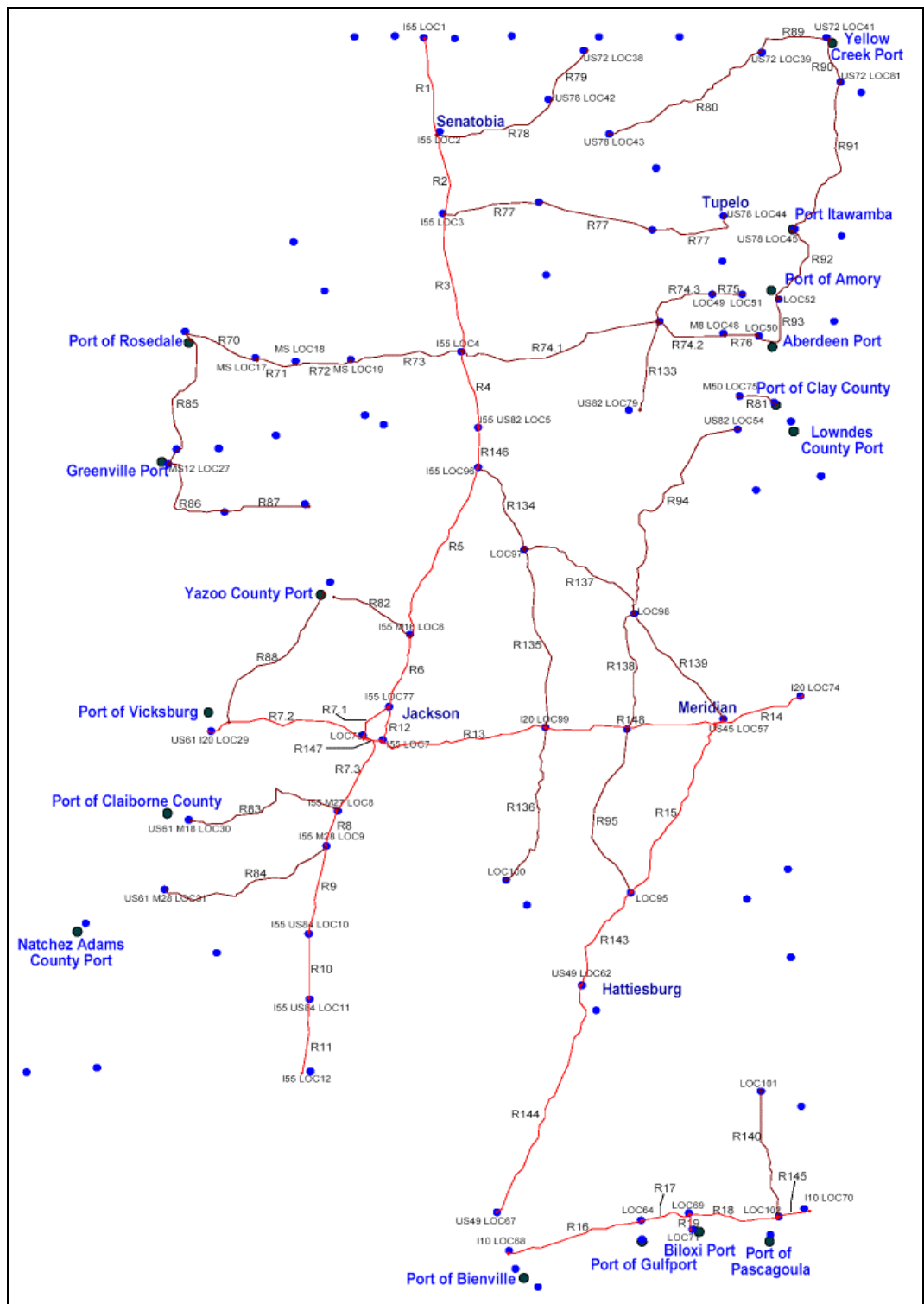


Figure 3.5 All State Highways and Interstates Used in the Model

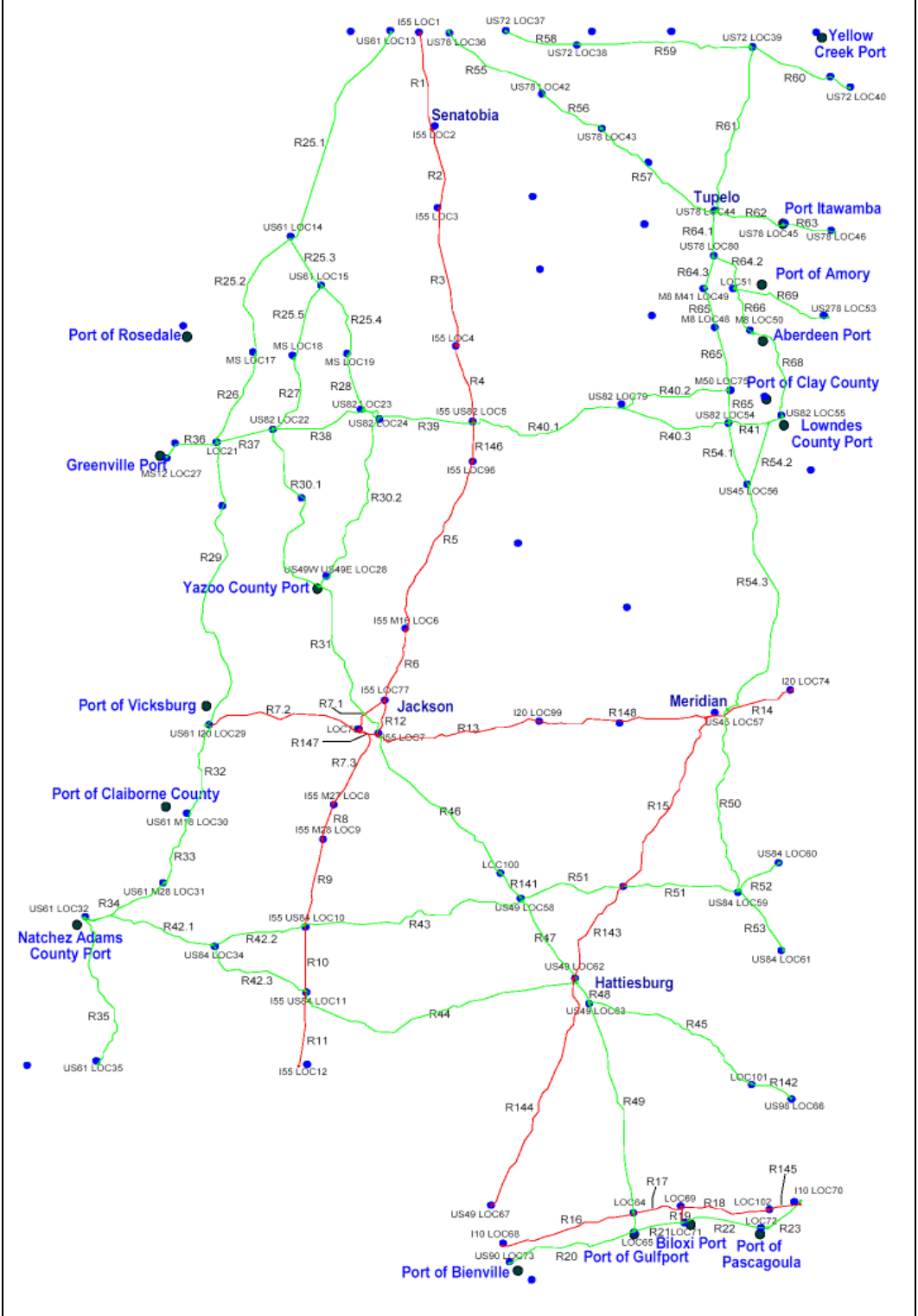


Figure 3.6 All US Highways and Interstates Used in the Model

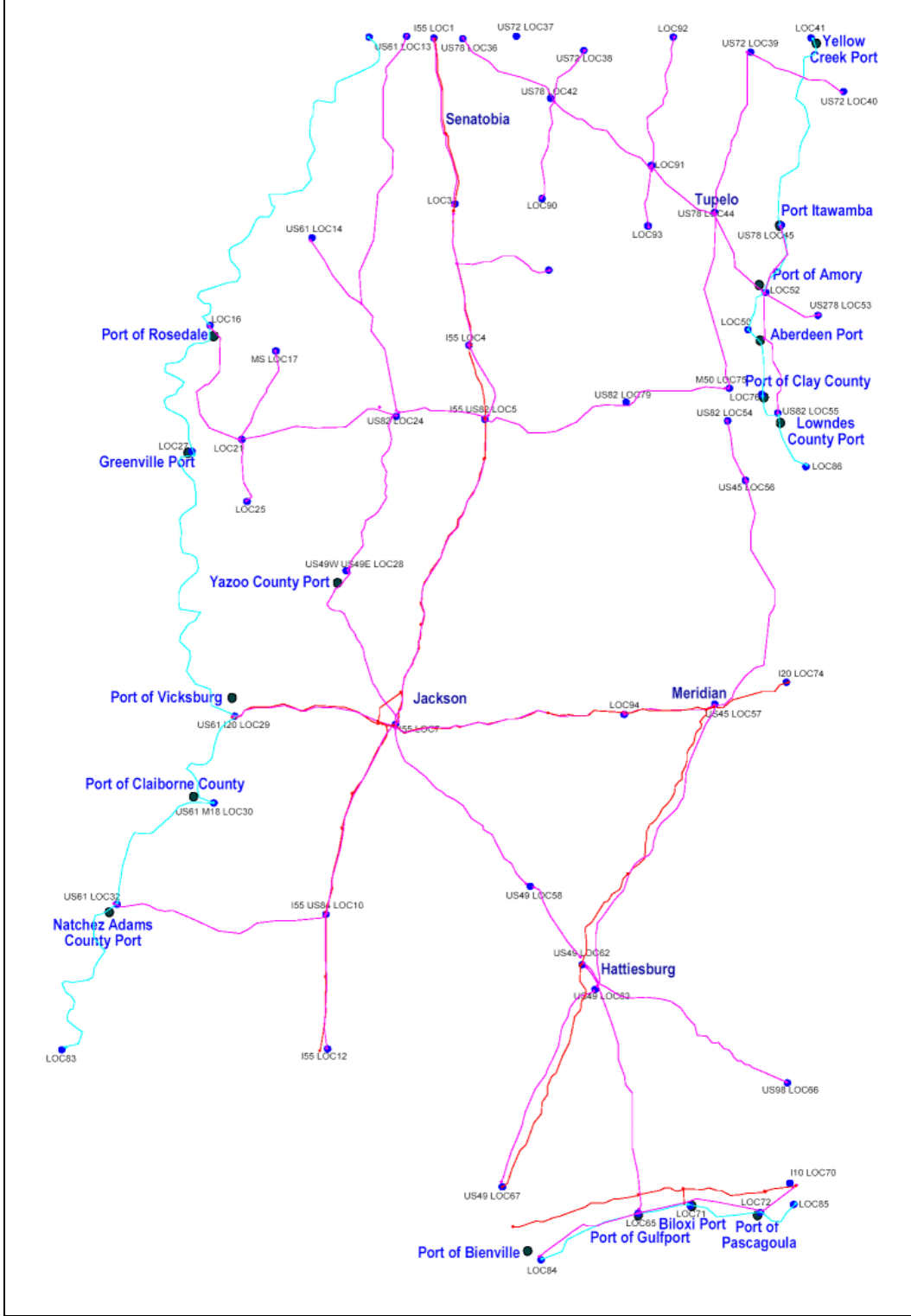


Figure 3.7 All Rail and Waterway Networks (Also Includes Interstates as Reference)

3.2 Vehicle Characteristics

The simulation model requires input of vehicle parameters to handle the movement, as well as keeping track of the tonnage of freight carried. The vehicle characteristics can be modified by the user to better reflect their region of study, if necessary. Details on these inputs are available in the Simulation User Guide.

3.2.1 Trucks

There are several types of trucks carrying freight along highways in the US. The capacity of the trucks vary not only in the number of trailers carried/pulled but also in terms of the dimensions of the trailers. For the purpose of simulation, we used the US Department of Commerce's Vehicle Inventory and Use Survey [32] with reference to US Department of Transportation's Comprehensive Truck Size and Weight Study [22] to create a generalized truck entity. The capacity of this generalized truck entity is a weighted average of the different types of trucks in use. Note that typical weight limits (legal, not physical) were also examined in the determination of this capacity based on figures obtained from Muller's "Intermodal Freight Transportation" publication [24]. The truck entities used in this study have a capacity of 18.5 tons, although this can be easily altered by the user.

Due to the macroscopic nature of the simulated traffic flow over the VITS highway network, individual truck entities you see in the animation represent more than just a single truck. The number of trucks each truck entity represents is fully customizable by the user.

While it is possible to model different truck types in the simulation, current freight data does not reveal the origin and destination by truck type. Improvements in data collection and implementation of intelligent transportation systems (ITS) are required. Speeds of the trucks are governed by speed limits and congestion. More on this will be discussed later.

3.2.2 *Ships and Barges*

Reference to “Intermodal Freight Transportation” by Muller [24] was made to determine the capacities and typical speeds of the barges and ships. Attention was given to the maximum vessel size handled at the ports along the Mississippi Gulf.

From correspondence with the Deputy Director of Operations at the Mississippi State Port Authority, it was determined that the typical vessels operating at the ports on the gulf (in Mississippi) are around 584 to 666 feet long. This translates to a ship capacity of roughly 1,000 Twenty-Foot Equivalent Units (TEUs) or close to 24,000 tons according to Muller [24]. A barge unit is assumed to have a capacity of 1,500 tons. These capacities can be altered by the user if needed.

3.2.3 *Rail*

For rail, the issues of capacities for railcars and the number of railcars were examined. The estimates used in the simulation model were chosen with estimates from a local shortline rail company. Statistics from the Association of American Railroads were also referenced to get better understanding on how trains are configured. A capacity of

100 tons per rail car and a configuration of 50 railcars per locomotive are assumed but this can be altered by the user.

3.3 Vehicle Arrivals and Traffic Pattern

All the arrivals for the different transportation modes are modeled as Poisson processes, which means that there is equal likelihood for arrivals at any time, and also that the arrival of one vehicle at a point in time does not affect the arrival time of any other vehicle [6]. Attributes such as the speed of the entity, entity type, and the destination of the entity are initialized upon arrival at a location.

Since actual truck traffic is not spread out evenly over a day, the simulation model varies the truck traffic generation depending upon if the time of the day is nighttime or daytime by adjusting the mean time between arrivals (TBA) of trucks into the network. We define the beginning of the day to be 7AM and the daytime period from 7AM to 5PM (10 hours) as default values. Nighttime, therefore, starts after 5PM and continues until 7AM the next day. In our example, we assume that the majority of the truck traffic occurs during the 10 hour daytime period. However, the user can define the beginning of the day, the duration of the daytime hours, and the percentage of traffic during that period (Note that the definition of the start of day here affects the Integrated Port Model's berth operating hours as well as the access gate operating hours, which is discussed in Chapter 5). Details on setting up the traffic pattern are available in the Simulation User Guide. The following will explain how the truck traffic is varied in the model.

The data preparation step provided the TBA for the trucks over a period of 24 hours, which is denoted as TBA₂₄. TBA_{dt} and TBA_{nt} denote the mean time between

arrivals of truck for daytime and nighttime hours respectively. The following are the derivations for Equations 3.1 and 3.2 that describe the relationship between TBA24 with TBA_{dt} and TBA_{nt}.

Let:

$$t = 24hr$$

$$t_1 = \text{daytime hours}$$

$$t_2 = \text{nighttime hours}$$

$$TBA_{24} = TBA \text{ for } 24hr$$

$$TBA_{dt} = TBA \text{ for daytime}$$

$$TBA_{nt} = TBA \text{ for nighttime}$$

$$C = \text{ratio of trucks during daytime over nighttime} = \frac{\left(\frac{t_1}{TBA_{dt}}\right)}{\left(\frac{t_2}{TBA_{nt}}\right)}$$

Thus, $t_1=24-t_2$ and we have the following,

$$\frac{24}{TBA_{24}} = \frac{t_1}{TBA_{dt}} + \frac{t_2}{TBA_{nt}}$$

Solving for TBA_{dt},

$$TBA_{dt} = \left(\frac{(24 - t_1)(C + 1)}{\left(\frac{24^2}{t_1} - 24\right)C} \right) TBA_{24}$$

This expression can be written as,

$$TBA_{dt} = \gamma TBA_{24} \quad (\text{Equation 3.1})$$

where

$$\gamma = \left\{ \frac{(24 - t_1)(C + 1)}{\left(\frac{24^2}{t_1} - 24 \right) C} \right\}$$

Similarly, solving for TBA_{nt} ,

$$TBA_{nt} = TBA_{24} \left(\frac{24C}{t_1} \gamma - C\gamma \right)$$

This expression can be written as,

$$TBA_{nt} = \beta TBA_{24} \quad (\text{Equation 3.2})$$

where

$$\beta = \left(\frac{24C}{t_1} \gamma - C\gamma \right)$$

Using equations 3.1, 3.2, and the parameters (β and γ) in ProModel, the simulation toggles between arrivals in each time period for the length of the simulation run. The following describes how it is done, letting TBA_i denote the mean time between arrivals for the i^{th} daytime/nighttime period. First, the simulation is initialized by

$$TBA_1 = \gamma TBA_{24}$$

where TBA_1 is the initial TBA_{dt} at time = 0 (7AM).

After initialization, all that is needed is the following repeating sequence for the length of the simulation run.

$TBA_2 = (\beta/\gamma)*TBA_1$ where TBA_2 is the following TBA_{Ant} for the next time period.

$TBA_3 = (\gamma/\beta)*TBA_2$ where TBA_3 is the next TBA_{Dt} after TBA_2 and so forth.

⋮

The following pseudo codes describe the implementation in ProModel.

Initialization: Calculate values of γ and β respectively and set $TBA_1 = \gamma(TBA_{24})$

```
Active Subroutine:   If Clock(hr) Mod 24 <= (t1-1) then //for daytime
                    {
                        If PatternTriggerVar=1 then
                        {
                            TBAmultiplierVar=( $\gamma/\beta$ )
                        }
                    }
                    Else //for nighttime
                    {
                        TBAmultiplierVar=( $\beta/\gamma$ )
                        PatternTriggerVar=1
                    }
                }
```

The modulus function in ProModel is used to alternate the TBA of trucks between TBA_{Dt} and TBA_{Ant} based on the system clock. The current time between arrivals used in the frequency section for the entity arrival table in ProModel is computed by multiplying the $TBAmultiplierVar$ value with the previous period's time between arrivals. These sets of equations hold true only for cases involving just two periods of "daytime" and "nighttime". The result is a more realistic reflection of reality than would be provided by spreading the truck traffic evenly throughout the 24 hour period.

Figure 3.8 shows a plot of a highway link's traveling speed in miles per hour and congestion during a simulation run. Notice that the speed plot cycles between slower speeds during daytime and faster speeds during nighttime, showing the influence of the amount of traffic flow that varies depending on the time of the day. More about speed and congestion will be explained in the speed calculation section.

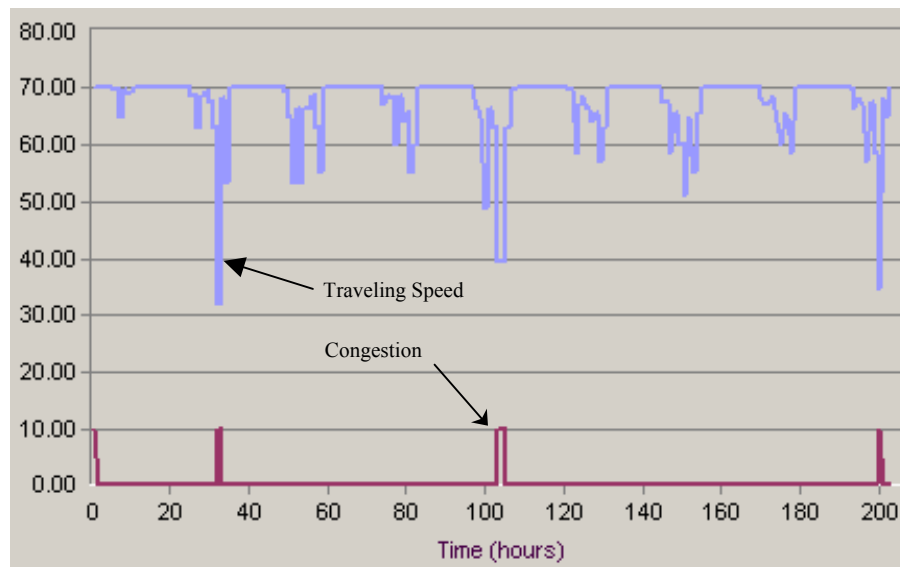


Figure 3.8 Plot of Link Traveling Speed (Light blue) and Congestion (Dark maroon) over Time (Hours)

3.4 Routing of Vehicles

For this VITS version, routing is done based on shortest paths by distance as well as consideration for highway classification. Highways with higher classification (e.g. Interstates) are preferred in the routing choice. These routes are entered in a spreadsheet in the form of a two-dimensional routing array. This array is named $ODarr[x, y]$ in the VITS where x represents the OD pairs (the rows) and y represents the route choices (the

columns) as the entities move from one location to another. Each vehicle will have a “routing counter attribute” that keeps track of where it is in the routing array (keeping up with the “y” value), as it progresses from the initial arrival location to its destination location using the ProModel “ROUTE” command in the Operation Logic section. The key is to determine and read the correct row in the routing array (that corresponds to the vehicle’s origin and destination) when the vehicles first arrive at their origin location. After this initial computation, the vehicle will only need to have its “routing counter attribute” incremented to continue reading the list of routing information to direct it to the next location.

Figure 3.9 illustrates the storage of routing information in the Excel spreadsheet. Take note that the OD locations shown in this snapshot are Locations 1, 2, 7, 11, 12, and 22. In this illustration, OD pairs O1-D1 to O1-D22 would mean 6 rows in the routing array. The columns (Labeled as Block Sequence) of 1 to 20 would mean 20 columns in the routing array. Thus, the array would have a dimension of [6, 20]. Assume that a vehicle just arrived at Location 1 and its destination is Location 11. The simulation would locate row 4 in the array to match the vehicle’s origin and destination. The vehicle’s routing counter attribute is currently 1, which means that it will take route 1 as indicated in the first column (value stored in cell [4,1]). Upon reaching its second destination, the vehicle’s routing counter attribute is incremented to 2, which means that it will take route 1 to the next location (again, according to the value stored in cell [4,2]). The same procedure is applied until it reaches column 13 (with a route number of 3), which will direct it to Location 11. The last columns represent the routing to exit for all the OD

pairs. For example, route 5 in cell [4, 14] will instantaneously route the vehicle to the exit (in which it exits the simulation).

O-D Pair	Mode	Block Sequence (Lag)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
O1-D1	Truck																				
O1-D2	Truck	1	1	4																	
O1-D7	Truck	1	1	2	2	4	4	2	2	2	11										
O1-D11	Truck	1	1	2	2	4	4	2	2	1	2	2	2	3	5						
O1-D12	Truck	1	1	2	2	4	4	2	2	1	2	2	2	3	3	3					
O1-D22	Truck	2	2	2	2	4	5														

Figure 3.9 Example of the Storage of OD Routing Information in Excel

To implement this, OD processing subroutines were written for highway, rail, and waterway modes (within the Operation Logic section of the OD locations). They are named ProcLogicHwyODSUB(), ProcLogicRailODSUB(), and ProcLogicWaterODSUB() respectively. These three subroutines will be referred to as the “OD subroutine” for the rest of the discussion. The parameter for the three OD subroutines is the location number of the origin location (recall the earlier discussion on the numbering of locations).

The location number is the required parameter for the OD subroutine to compute which row in the routing array to read. The idea is to locate the first row in the routing array for the origin location where the subroutine is called, and then based on the vehicle destination attribute, to go down the array to locate the OD pair with the right destination. The following Figure 3.10 illustrates the implementation (truck mode used as an example).

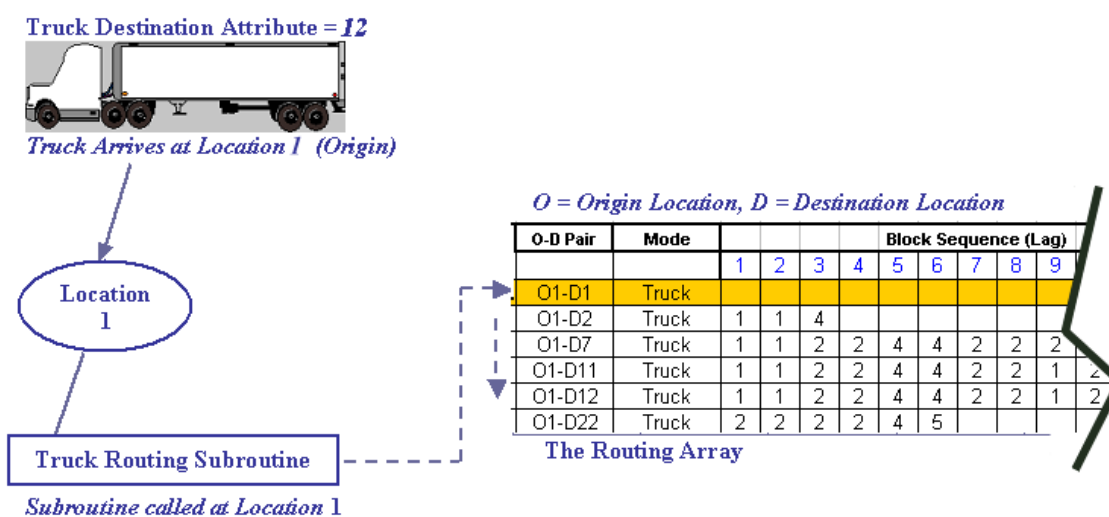


Figure 3.10 Illustration of the OD Subroutine Implementation

The location number entered as a parameter for the subroutine is converted into an index number called “OriginIndexNumber” for the purpose of calculating the row numbers. This is needed because the computation requires integer sequential OD location numbers (1, 2, 3, etc.). For example, OD Location 3 may be converted to an index number of 1, signifying the first location in the OD pair for that particular mode (e.g. truck).

All three subroutines for the three modes will have different OD pairs and thus, their subroutines will have different origin number conversions. A reference table for conversion is included in each of the subroutines for the different modes. The subroutines also contain the number of rows for all OD pairs of the same origin for the modes concerned (called RowsHighway for example, for the case of truck mode) as well as their starting row. This starting row number is the row in which the routing information for that mode starts in the ODarr[] array. The array contains routing information for all three

modes in the simulation. The following segment of code describes how the subroutines (e.g. for highway) determine which row in the routing array to read.

```

If EntityDestinationAttrib = m and FlagAttrib = 1 then
{
RouteAltCounter = n
RowNumberRead = (OriginIndexNumber*RowsHighway + (1-RowsHighway)) + RouteAltCounter
FlagAttrib = 0
}

```

The EntityDestinationAttrib attribute denotes the destination location number, the FlagAttrib attribute (used as a flag) indicates if the row in the routing array to read has been decided (since the vehicle might come across this same routine again if it passes another location which also happens to be an origin), and the RouteAltCounter local variable (a variable declared within a subroutine) is used in the calculation to determine which row to read.

A subroutine called ProcLogicNoODSUB() is used to complete the routing process by invoking the “ROUTE” command as well as advancing the vehicle’s routing counter attribute that keeps track of where it is in the routing array. This subroutine is placed in all locations where vehicle routing to a next location is required.

The advantage of this implementation is that all the origin locations will run the same subroutines when doing routing processes, making any changes and error checking much easier. For locations that are not origins, the ProcLogicNoODSUB() subroutine is the only routing subroutine required, where it will advance the routing attribute of the vehicle to the next value as stated in the routing array, and execute the “ROUTE” command.

3.5 Transfers at Locations

The VITS prototype provides varying levels of detail for modeling locations that process freight transfers. For example, the amount of time it takes to transfer freight from one mode to another can be modeled as a constant time, random variable (statistical distribution), or by a “sub-model” that simulates the use of cranes and all other necessary resources to transfer freight between different modes of transportation.

In this rendition of the VITS, locations that handle freight transfers (such as barges to trucks, etc.) other than the integrated port sub-model have a generic loading/unloading time based on truckloads of freight handled. The default distribution for loading/unloading is the Uniform Distribution.

3.6 Vehicle Speed Calculation

Each vehicle in the simulation model carries a speed attribute that governs their speed. For the non-truck entities, their speed is determined from the vehicle characteristic section of the input spreadsheet. For the truck entities however, their speed can vary on any particular link depending on traffic congestion. Review of traffic engineering literature [6][20] indicates that the volume/capacity relationship with travel speed is best described, in our case, by the Bureau of Public Roads (BPR) equation (a formula suggested by the Bureau of Public Roads to calculate travel time as a function of volume on a highway link).

The BPR equation used in the simulation model is as follows:

$$\text{Calculated Travel Time} = t_i \left[1 + \alpha \left(\frac{x_i}{C_i} \right)^\beta \right] \quad (\text{Equation 3.3})$$

where,

i = Denotes links 1, 2, 3... n;

t_i = Free-flow travel time on link i ;

C_i = Capacity of link i ;

x_i = Flow on link i ;

α = Constant;

β = Constant.

A plot of speed and its relationship with the volume over capacity ratio (relating to the BPR equation) is shown in Figure 3.11.

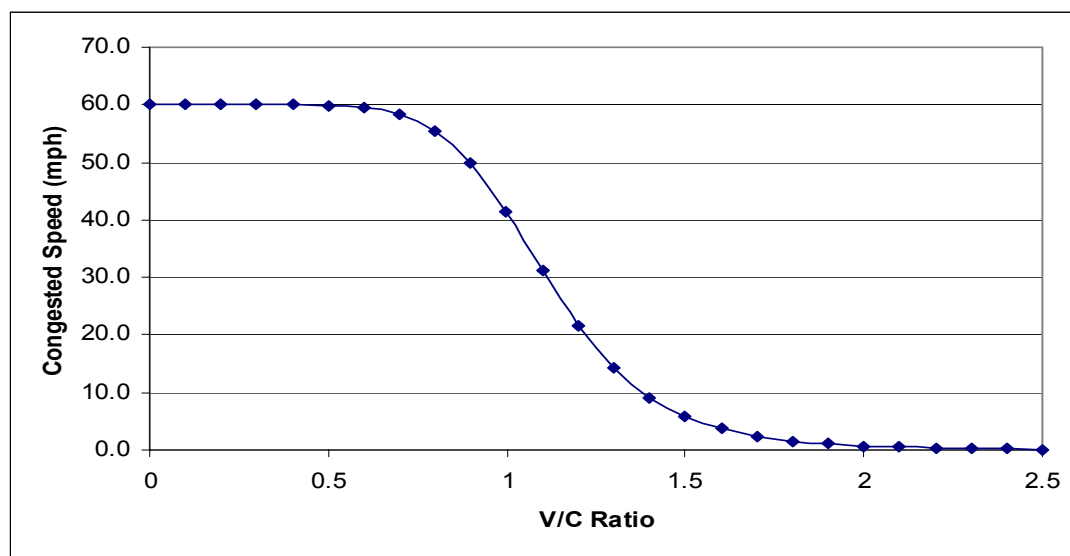


Figure 3.11 Interstate Speed-Flow Curve for $\alpha=0.45$ and $\beta=7.5$ [21]

According to Roess et. al., free-flow speed is defined as the speed that results when the traffic flow and density is zero (uncongested) [20]. Flow is defined as the number of vehicles passing a point per unit time. In our case, the unit time is the user-defined speed update interval. Table 3.2 defines the free-flow speeds and capacities used in the simulation model.

Table 3.2 Speed Limits

Highway Classification	No. of Lanes (both directions)	Free-flow Speed (MPH)	Capacity (PCPHPL)*
Interstate	4,5	70	2400
Interstate	6,7	65	2350
Interstate	8,9	60	2300
US Highway	2	55	2250
US Highway	4	65	2350
State Highway	2	50	2200
State Highway	4	55	2250

*Basic uninterrupted flow capacity in "Passenger Cars per Hour per Lane" adapted from Roess et. al. [20]

According to Grady, the default α and β values have traditionally been 0.15 and 4, respectively. He elaborated that these traditional coefficients have been replaced following more recent research. In his report, the values of 0.45 and 7.5 respectively were used to reflect upon the more current body of research [21]. We used the modern values in our simulation model.

To implement this functionality in the VITS, the BPR Equation is executed at time intervals specified by the user (from the input spreadsheet) to update the speeds on all links in the model. The time interval defined by the user controls the arrival of a dummy entity to a location named “TruckSpeedCalcLoc”. The codes for calculating the travel times for all the highway links in the model are executed at the Operation Logic section of this location. The calculated travel times for all the highway links are then stored in arrays called “RoadCfgSB_arr[n,1]” for traffic in one direction and “RoadCfgBS_arr[n,1]” for traffic in the other direction where “n” denotes link n (note the “SB” and “BS” notation used in the naming of the array). Truck entities are assigned this calculated speed as they enter a link. This is done via a subroutine called “SpeedSUB(ArrPt, SborBS)” where the parameter “ArrPt” indicates the particular link the vehicle will travel on while the parameter “SborBS” denotes the direction of travel. The following will show how this subroutine works. Note that speed variation is introduced via the Normal Distribution and is controllable using the StdDevSpdInt_macro “macro” that represents the standard deviation. A small routine is also included to avoid obtaining negative speeds from the Normal Distribution.

```

If SBorBS=1 then
{
    Speed_EntAtt=N(PathLength_arr[ArrPt]/RoadCfgSB_arr[ArrPt,1],StdDevSpdInt_mac)

    //----- To avoid -ve speeds -----
    While Speed_EntAtt<0 DO
    {
        Speed_EntAtt=N(PathLength_arr[ArrPt]/RoadCfgSB_arr[ArrPt,1],StdDevSpdInt_mac)
    }
    //-----

}

If SBorBS=2 then
{
    Speed_EntAtt=N(PathLength_arr[ArrPt]/RoadCfgBS_arr[ArrPt,1],StdDevSpdInt_mac)

    //----- To avoid -ve speeds -----
    While Speed_EntAtt<0 DO
    {
        Speed_EntAtt=N(PathLength_arr[ArrPt]/RoadCfgBS_arr[ArrPt,1],StdDevSpdInt_mac)
    }
    //-----

}

```

Due to the macroscopic nature of the simulation model when traffic flow is concerned, individual truck entities you see in the animation represent more than a single truck. Although the user can change the number of actual trucks a single entity represents, this entity resolution influences the outcome of the speed calculation.

A vehicle's speed can only be set at locations where logic can be executed. In the case of using ProModel, the codes for setting the speed is implemented at the move logic section of all the locations in the model. The move logic section allows the speed to be set before the vehicles are released onto a link in the network. This means that once the speed is set at a location, its speed can no longer change until it reaches the next location. Since the speed of the entity is directly influenced by the traffic preceding it on that link, the inability to drastically change speeds while on a link is not a significant issue for a macroscopic level analysis.

While the data derived from the CFS Database is in terms of trucks, the capacities on the highways are expressed in terms of passenger cars. An equivalent factor of one truck to 2.5 passenger cars was chosen after an examination of Mississippi terrain and highway characteristics. Future versions of VITS can include more detail such as a variable factor that accounts for the terrain conditions in different traffic zones. Table 3.3, adapted from Roess et. al. [20], was used in the estimation of the passenger car equivalent factor:

Table 3.3 Passenger Car Equivalents on Extended General Highway Segments

Category	Type of Terrain		
	Level	Rolling	Mountainous
Trucks/Buses	1.5	3.0	6.0
Recreational Vehicles	1.2	2.0	4.0

Another issue concerns passenger car traffic on the simulation network. Since this study is focused on freight traffic, passenger car traffic is estimated as a ratio of truck to passenger cars on different classes of highways. According to the Nevada Department of Transportation, it is estimated that 10% of urban interstate highway traffic involves trucks, but the figure is higher at 31% for rural interstate highways in 2001. Our estimate for the State of Mississippi, for the interstates (considering both rural and urban) is around 25%. Similarly for other major arterials, the estimate is 9% and 21% respectively for the state of Nevada. Our estimate for Mississippi is 17% (a weighted average for both rural and urban arterials). These estimates assume that the majority of non-truck traffic

can be treated as passenger car traffic [33], and the values can be easily adjusted in the model. It is feasible to include actual ground counts of passenger cars as background traffic in future versions of VITS if sufficient data is available.

We have discussed the computation of truck speeds based on the amount of traffic flow on a particular link. In order to determine congestion, two speed threshold values were implemented. Contained in the input spreadsheet (ODfile.xls) under the “Model Settings” section, “Speed Threshold 1 (Yellow)” and “Speed Threshold 2 (Red)” were defined. The threshold values are the percentages of the free-flow speed. For example, a threshold value of 0.6 means 60% of the free-flow speed. These values determine if a truck changes color from green (free-flow speed) to either yellow (moderately congested) or red (severe congestion) depending upon the travel speed. The values can be customized by the user to define how much of truck speed slowdown is required to reflect moderate or severe congestion. In this thesis, the value of 0.8 was used for Speed Threshold 1 and the value of 0.6 was used for Speed Threshold 2. For the purpose of dynamic plotting during the simulation run, congestion variables for selected links were assigned the value of “0” for no congestion and the value of “10” whenever severe congestion is encountered. The average value of a corresponding congestion variable should be divided by ten to obtain the percentage of time that particular link was congested. Referring to Figure 3.11, a speed that is 60% of the free-flow speed corresponds to a V/C ratio of about 1. This means that the traffic condition is unstable, with possible stop-and-go situation, signifying severe congestion.

3.7 Simulation Animation and Graphics

Animation properties for indicating movements, slowdowns, and congestions are done via several customized graphics for the simulation entities. The speed threshold levels described earlier (expressed as a percentage of free-flow speed) are used to determine when truck entities change colors to reflect that they are traveling at lower speeds. Table 3.4 describes the colors codes used for the truck entity.

Table 3.4 Color Coding for Truck Entity in the Simulation Model

Truck Entity Color Code	Description
Green	Non-congested
Yellow	Medium congestion
Red	Heavy congestion
Purple	Trucks carrying wood products

The simulation has the ability to display trucks carrying different commodities using additional color codes. For example, the VITS prototype denotes trucks carrying wood and wood products with the color of purple. Figure 3.12 illustrates the color coded animation of the simulation around the Meridian region in Mississippi as an example.

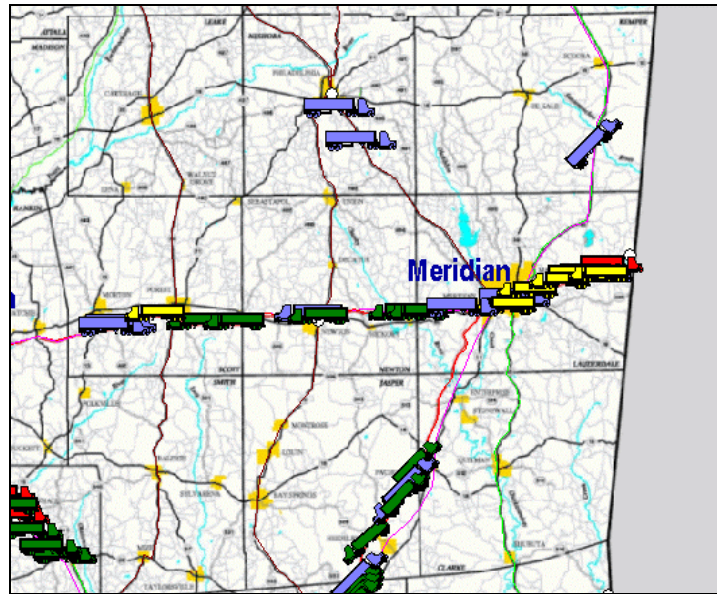


Figure 3.12 Screenshot of Vehicle Color Coding

Individual graphics were designed for each colored truck entity and imported into ProModel. Additional graphics were also designed for the VITS such as barges, ships, and trains. The implementation is done via a subroutine called MoveGraphicsSUB(DIR, Link) that is executed at the Move Logic section in ProModel. The Move Logic section provides the ability to define the method of movement, as well as any logic that is to be executed upon the movement of the entity [30]. The subroutine selects the graphic to be displayed when the vehicle is traveling in a certain direction using a parameter called “DIR”. It also changes the color of the vehicle when congestion occurs (for truck mode) on a link using references from the “Link” parameter.

3.8 Simulation OD Data Preparation

The process of deriving reasonably accurate data necessary for transportation planning is not trivial. The data that drives the simulation is based on the Origin and

Destination (OD) data derived from the study “Intermodal Freight Transportation Planning Using Commodity Flow Data” conducted at the National Center for Intermodal Transportation (NCIT) [34]. The OD for the simulation is defined in terms of vehicle trips (e.g. Trucks). However, the VITS simulation model can also accept OD data derived from other techniques.

To develop the OD data for the simulation model, traffic analysis zones were created from combining counties in the state. This was done to designate centroids (of the TAZs), which are part of the OD locations within the state boundaries. The U.S. Census Bureau defines traffic analysis zones as, “a special area delineated by state and/or local transportation officials for tabulating traffic-related data” [35]. In our case, the TAZs for the simulation was aggregated from the 82 counties in the state based on the population densities of the different counties. The eleven TAZs are intended to distribute the traffic volumes (based on the attraction and production of traffic) evenly. The zones are illustrated in Figure 3.13.

The prototype covers the flows within the state of Mississippi as an example, but can be configured for other states and regions as well. The following describe the flow components and OD locations used in this example:

- For *Coming-Into* traffic, arrival locations are the locations on the Mississippi state boundaries. The centroids defined for the simulation (within the simulation traffic zones) are the destinations.
- For *Going-Out* traffic, the destination locations are the boundary locations on the Mississippi State border and the centroids are the arrival points.

- For *Within* traffic, the centroids for different zones represent both the arrival and destination locations.
- For *Through-Traffic*, the boundary locations on the Mississippi State border represent both the arrival and destination locations.

Based on the simulation network, traffic assignment was done using TransCAD (a traffic planning software). From the results, the traffic flow between the 82 counties in Mississippi and the other 47 states was distributed to the 11 traffic zones in the simulation model. More details on the OD data preparation will be discussed later.

Figure 3.14 shows the grouping of boundary points into 10 groups numbered 12 to 21 (numbers 1 to 11 are used for naming the centroid of the 11 traffic zones). The grouping is necessary in order to reduce the complexity of the simulation OD derivation process since having more points would result in a much larger OD matrix.

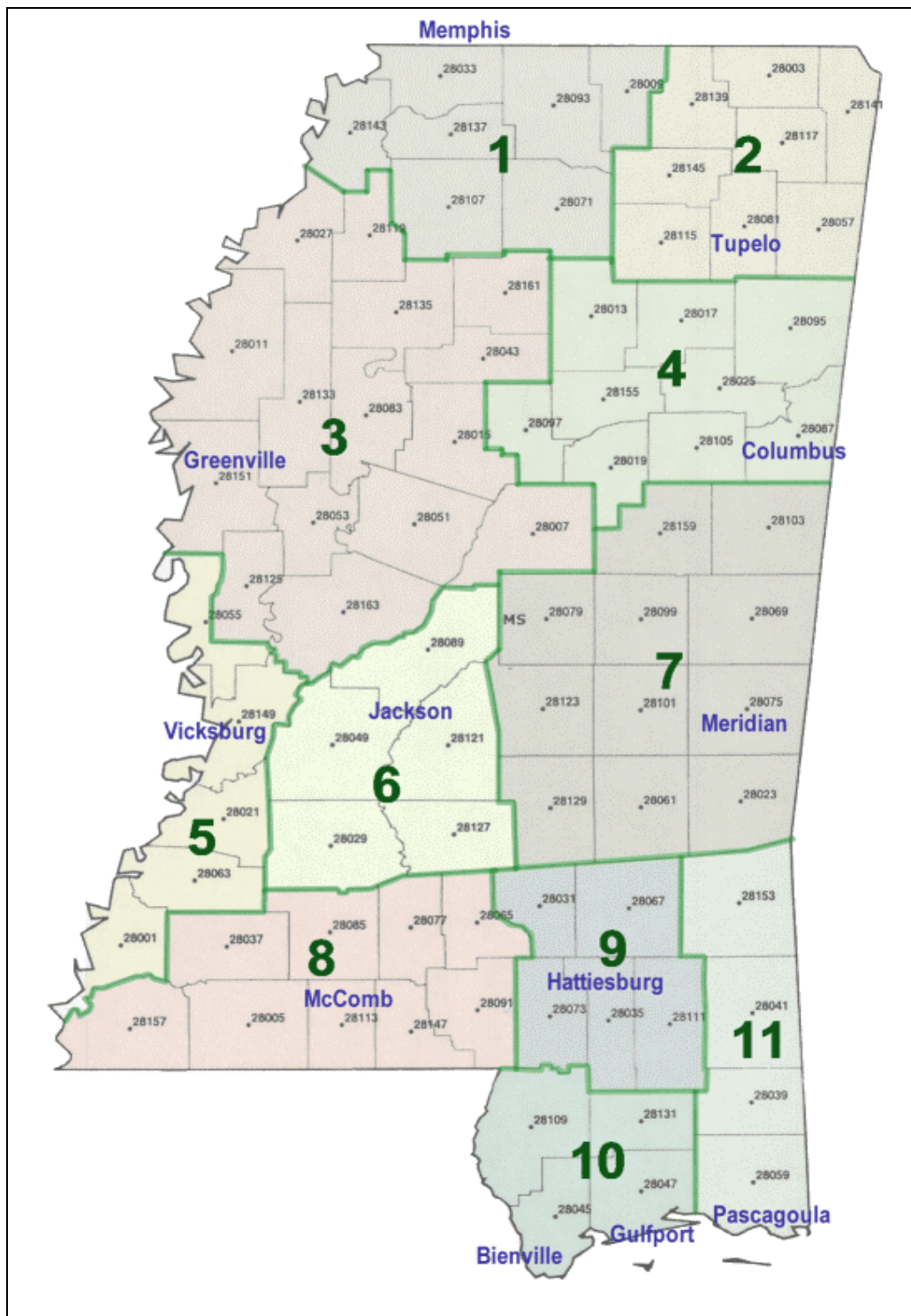


Figure 3.13 Traffic Analysis Zones in the Simulation Model (County Map Generated Using TransCAD and Zones added Using a Graphics Editor)

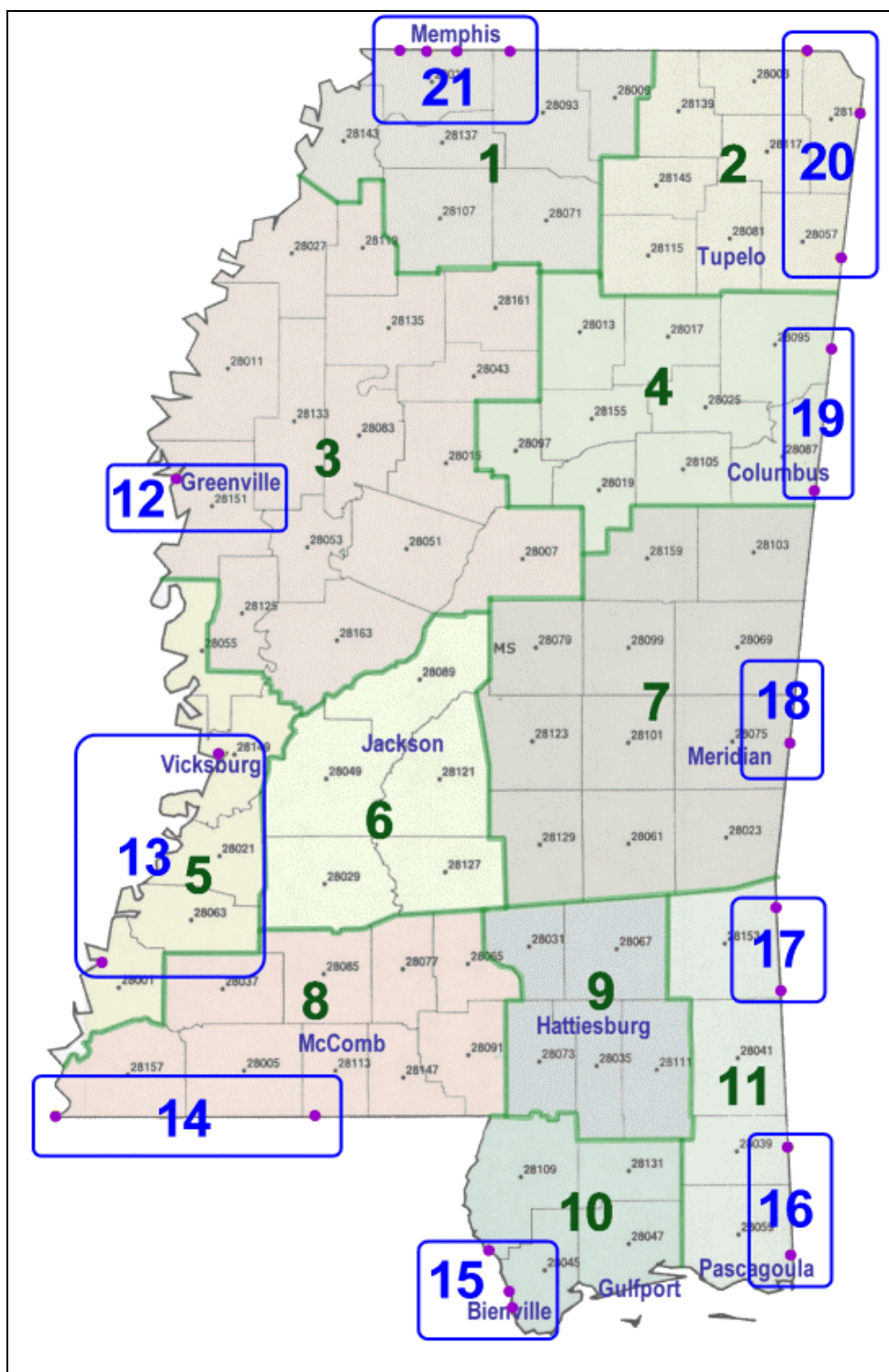


Figure 3.14 Boundary Points and the Groupings Used for Simulation Data Preparation Assignment

Based on the truck OD data that is derived from the CFS database, Critical Link Analysis in TransCAD (refer to Figure 3.15) was used to transfer the remote origins and destinations (such as the State of California) to the 10 boundary point groups (numbered 12 to 21 in Figure 3.14) around the State of Mississippi. This is needed because unlike the highway network in TransCAD that spans the entire continental U.S., the simulation transportation network does include highways beyond the state boundary. The commodity data associated with the State of Mississippi was redistributed to the OD data based on the eleven traffic analysis zones and ten entry points OD data. The rail OD data was derived following the same rules and procedures while the water OD are estimated based on the “Comprehensive Assessment of the Ports in Mississippi” report prepared by Parsons Brinckerhoff [36] with reference to the CFS database.

For commodity moved by truck, population and employment factors (as the production and attraction index) were used to break down the state level OD data to county level. The assignment results from different OD pairs were combined to get the commodity tonnage on the network in the State of Mississippi. Yearly truck traffic was converted to average daily truck traffic based on the truck usage information for the Vehicle Inventory and Use Survey (VIUS) Database. A limitation of using the averaged daily truck traffic is that traffic pattern changes based on the hour of the day. Truck traffic is not spread out evenly over the entire 24-hour day. Therefore the simulation distributes the averaged daily truck traffic between daytime and nighttime hours as described earlier in Section 3.3.

For rail movements, the production and attraction points were determined based on the rail network and major rail-served intermodal facilities as identified by Mississippi's Multiplan study [18]. However since most railroads are privately owned and operated, the attraction and production percentage for different OD are approximated based on the capacity of each rail-served intermodal facility. With more specific data that includes schedules and commodities carried, more robust methodologies can be developed in the future to supplement the incomplete data in the CFS database.

For water movements, all 17 active ports in the state are identified in the VITS network. The tonnages handled in each port were obtained from the Comprehensive Assessment of the Ports of Mississippi study results [36]. These tonnages are used to estimate the percentages of port traffic. Looking at the amount of tonnage handled at each port, the total tonnage transported in the state from the CFS data analysis, along with the results from Multiplan study, the water OD was derived. The active port locations that handle freight within Mississippi included in the VITS are listed in Table 3.5.

Table 3.5 Mississippi Ports Included in the VITS

Yellow Creek Port	Port of Vicksburg
Port Itawamba	Port of Claiborne County
Port of Aberdeen	Port of Natchez
Port of Clay County	Port of Pascagoula
Lowndes County Port	Port of Gulfport
Port of Rosedale	Port of Bienville
Port of Greenville	

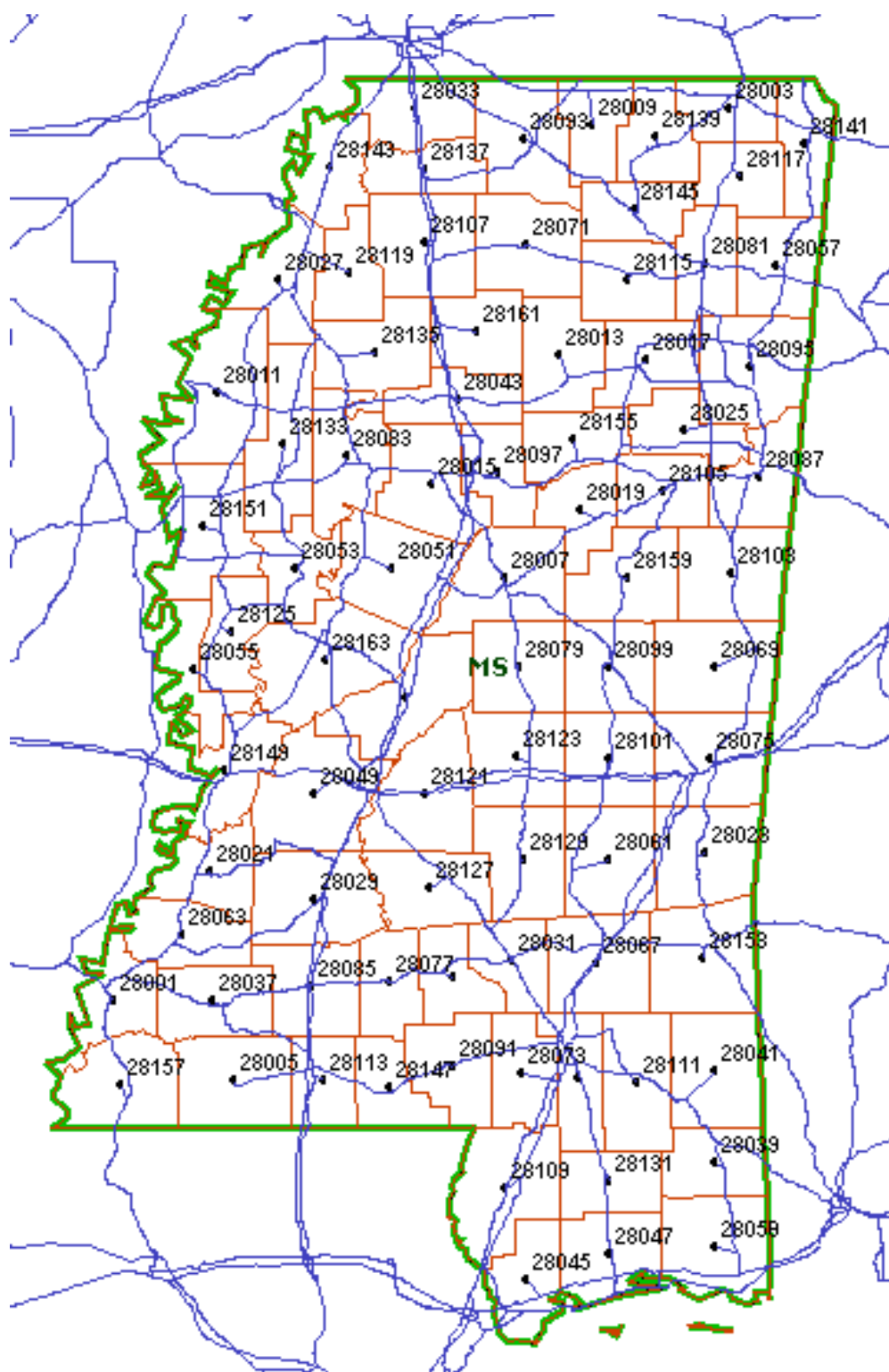


Figure 3.15 Network Used for Critical Link Analysis in TransCAD

3.9 Performance Measures Implemented

In this section we discuss the performance measures implemented in the prototype VITS. The performance measure implemented for the transportation networks will be directly related to the macroscopic flow parameters such as service volume, capacity, and saturation flow rate [6].

3.9.1 Link Average Speed and Congestion

The traveling speed (miles per hour) and congestion figures for each highway link are recorded in arrays within the model. Several key links in the model are assigned variables to which the changes to both the traveling speed and congestion can be observed via dynamic plots when the simulation is running. The statistics for these travel speed and congestion variables for the links can be obtained from the standard ProModel output report at the end of the simulation run. The codes for this implementation are located in the Operation Logic section of a location called “TruckSpeedCalcLoc”.

Note that for the congestion measure, a severe congestion on a link (noted by red trucks when the model is running) is reflected by a value of ten (but can be changed to any other positive integer) whereas the non-congested condition is simply represented by a value of zero. By doing so, the average congestion value for a link divided by ten will simply denote the percentage of time the link is congested. The value of ten was chosen to provide enough contrast between zero and ten when observing the dynamic plot of congestion value.

3.9.2 Fuel Efficiency

One consideration when selecting modes is fuel efficiency, which is also closely related to vehicle emissions. While modes such as water may be slower in transit compared to trucks, greater fuel efficiency and concepts such as “warehouse-in-transit” (for which constant and reliable deliveries are required) make water a good mode choice [37].

To see the effects of mode choice on fuel efficiency, we calculate the ton-miles of each mode as well as the gallons consumed per mode. With this information, the ton-mile per gallon for the entire system can be calculated to show the impact of changes to the system. This calculation is updated every time the speed calculation is initiated, thus the updates are done every speed update time interval. Note that the gallons consumed are derived from the average fuel efficiency of that particular mode as shown in Table 3.6.

Table 3.6 Fuel Efficiencies

Mode	Ton-Miles per Gallon
Rail	202.0
Highway	59.2
Waterway	514.0

Source: Fuel Efficiency in Freight Transportation, Samuel Ewer Eastman

System ton-mile are calculated as follows:

$$\text{System Ton-Miles per Gallon} = \frac{TM_{tot}}{G_{tot}} \quad (\text{Equation 3-4})$$

where, TM_{tot} is the total ton-miles transported by all the three modes and G_{tot} is the total gallons consumed by the three modes. This value may increase or decrease as the simulation model is running, responding to changes in the mix of modes and their distance traveled during the simulation run.

The subroutine named PerformanceSUB(ArrPt) is used to implement the tracking of total miles traveled, tonnage carried, and gallons of fuel consumed for all the modes on the transportation network within the VITS. This subroutine is invoked at the Move Logic section. The ArrPt parameter is used to determine the length of the link involved (e.g. a highway link) by referencing the associated cell in the PathLength_arr[ArrPt] array. Future implementations of additional performance measures such as vehicle emissions, operating costs, etc. that are tied to vehicle movement can be implemented within this subroutine.

3.9.3 Zone Utilization of Highways

Utilization of highways in the 11 simulation TAZs are calculated by first totaling the capacities of the highways included in each zone, followed by the calculation of the ratio of total truck flow in the zone over the total capacity as shown in Equation 3-5.

$$Utilization_i = \frac{Flow_i}{Capacity_i} \quad (Equation\ 3-5)$$

where,

$$i = zone\ 1, 2, 3... 11.$$

Note that the total flow in each zone is updated each time that truck speeds are updated (e.g. every half-hour). Since the capacities are defined as an uninterrupted flow capacity under prevailing conditions, it is possible under situations of heavy traffic to have utilizations of over 100%. Refer back to Figure 3-11 to see how a volume/capacity ratio that is approaching or exceeds 1 impacts the speed of the vehicle. In instances where a network link overlaps two zones, truck count is incremented for both zones.

The zone utilization initialization codes are located in the initialization logic section in ProModel. The capacity of each zone is obtained by summing the capacities of all the links in that particular zone. To do this, an array called Util_Arr[] is referenced to determine the zone in which that particular link is located. The capacities for the 11 zones are then stored in an array called ZoneCap_arr[]. The following pseudo code shows parts of the implementation using link numbered “a” as an example. In this example, we determine that link “a” belongs in zone 1 by checking the Util_Arr[] array. The code then proceeds to add the capacity of link “a” in both directions to the array that stores the capacities of all the zones. UpdSpdInt is the value of the interval between speed updates for the truck entities. For example, if truck speeds are calculated every half hour, then this value is 0.5. This is needed in the capacity calculation because highway capacities are expressed in terms of passenger cars per hour per lane or PCPHPL.

3.10 VITS Assumptions and Considerations

In this section, we review the various assumptions and considerations made for the building of the prototype VITS.

3.10.1 Truck Mode Assumptions

- All the arrivals for the truck mode are modeled as a Poisson process.
- For locations without a detailed terminal/port model, the distribution for loading/unloading times is the Uniform Distribution with parameters of (0.25, 1) hours.
- Routes are chosen at the beginning of the trip and do not change dynamically thereafter. Routing decision can be based on several criteria but in this case, the shortest path was chosen to relate to our traffic assignment procedure, which was done using shortest path in an “all-or-nothing” rule.
- Trucks that arrive at the final destination exit the system. Less-than-truckload situations for the return trips are considered using an estimated expansion factor derived base on a study conducted by Monsere et. al. [23].
- Background traffic levels (passenger cars) for each highway network class are calculated by specifying a ratio of trucks to passenger cars. These ratios are predefined by the user for Interstates, US Highways, and Mississippi Highways with values of 0.25, 0.17, and 0.17 respectively. A study of passenger flows would be needed to more accurately include background traffic.
- Truck speeds are varied according to the Normal Distribution with the mean speed being the computed speed using the Bureau of Public Roads (BPR) traffic volume equation and a user specified standard deviation. Three user customizable standard deviations are specified for Interstates, US Highways, and Mississippi Highways with the default value being 0.00001. Truck speeds are governed by the BPR equation and

are subject to the assumptions and constraints of the BPR model. The alpha and beta parameters used are 0.45 and 7.5 respectively.

- Trains and barges are always available at a location to load incoming freight from trucks for the intermodal scenario.
- Specific highway link capacity reflects the number of lanes that are most prevalent on that link.
- Truck traffic pattern is assumed to have a daytime duration and a nighttime duration. The beginning of the simulation signifies the beginning of the day.

3.10.2 Rail Mode Assumptions

- All the arrivals for the rail mode are modeled as a Poisson process.
- For locations without a detailed terminal/port model, the distribution for loading/unloading times is the Uniform Distribution with parameters of (8, 24) hours.
- Railcars per train vary depending on the type of locomotive used, commodity carried, gradient, and rail track conditions. As such, we use an average count of railcars per train that can be adjusted if needed. We assume, in this model that all trains consists of 60 one hundred-ton railcars.
- With the limited information available on train schedules, it is possible to observe two trains in the simulation passing each other on a single track. While this is not possible, the rail freight movement captured in the model shows only the tonnage and direction. As such, the arrivals of the trains may not match actual schedules, but are assigned randomly over the run-length of the simulation. The frequency of arrivals, however, is estimated based on annual averages (tonnage).

- Regional rail lines serving industries within Mississippi appear to carry only a small percentage of the total tonnage of freight within Mississippi. With limited data, we did not consider these flows at the present iteration of the model.
- Through traffic and mixed mode flows were not considered in the simulation due to limitation of data.
- By assigning attraction points within the state of Mississippi to estimate the volume of freight on each assigned rail link, we assume that the train moves directly from the point of entry to the point of destination without any interruptions, such as those which may be encountered at a switching station.
- All trains are moving with a full load based on user-defined characteristics (refer to the Simulation User Guide on vehicle specifications).

3.10.3 Water Mode Assumptions

- All the arrivals for the water mode are modeled as a Poisson process.
- For locations without a detailed terminal/port model, the distribution for loading/unloading times is the Uniform Distribution with parameters of (8, 24) hours.
- The barges along the Tenn-Tom and Mississippi River are assumed to be break-bulk barges with an average capacity of 1500 tons. In the simulation, we model barge movements as single unit movements (one barge entity shown in the simulation animation represents one actual barge).
- The cargo ship along the gulf coast are standardized for the simulation model as a 630' First Generation class with capacity of 1000 TEUs (Approx. 24,000 tons)

- Due to data limitations, through flows and mixed-mode freight flows that involve freight were not included in the model.

3.10.4 Intermodal Assumptions

Many factors affect the transfer time from one mode to another such as capacity of the terminal and traffic conditions of the surrounding area. In this model, we assume that a terminal's capacity is not a limiting factor (other than the integrated port model). All loading and unloading times for the trucks, rail, barges, and ships (at exchange points) are approximated as uniformly distributed times and are user-definable in the model (mean unloading times used in the model for a barge, the entire train, and truck is 16, 16, and 0.625 hours, respectively). The integrated port modeling methodology presented in Chapter 5 was developed to include detailed models of terminals to simulate delays based on realistic terminal capacity constraints. This feature is particularly useful for assessing the need for upgrades at an intermodal transfer facility and how the upgrade would affect the movement of freight in the region.

3.10.5 Fuel Consumption Assumption

We assume an averaged, fixed fuel efficiency for each mode. This means that trucks carrying the same load will consume the same amount of fuel whether moving in free-flow speed, or moving in congested traffic. With more data available it is possible in the future to code a more accurate vehicle fuel consumption model that responds to traffic conditions and terrain variances.

CHAPTER IV

VITS RESULTS

In this chapter, a series of scenarios will be presented to show the results of the VITS from the methodology discussed in Chapter 3. A discussion of simulation validation will also be included using the Mississippi Department of Transportation truck count data for comparison.

4.1 Scenarios for the VITS

We present a series of scenarios to illustrate the utility of a VITS planning tool. The first scenario is driven by our 1997 freight volume data and is considered the base condition. The second scenario is a future scenario where the freight volume is doubled, and the third scenario is similar to the second except that some freight is handled by intermodal shipments. A fourth scenario was also created in response to the simulated results from the third scenario.

For each scenario, the simulation model is run for 60 days including 6 hours for warmup using a single replication for the purpose of demonstration. Figure 4.1 presents the links and the direction of freight flow (highlighted in blue) that are of particular interest in the scenarios. The boxes next to the highlighted links contain the link codes for reference.

Common random numbers are used in the form of specified random number seeds in activities that contains random variation. This is important due to the comparison between scenarios that will be conducted, as we want to ensure that any observable differences are due to changes in the system and not due to random variation.

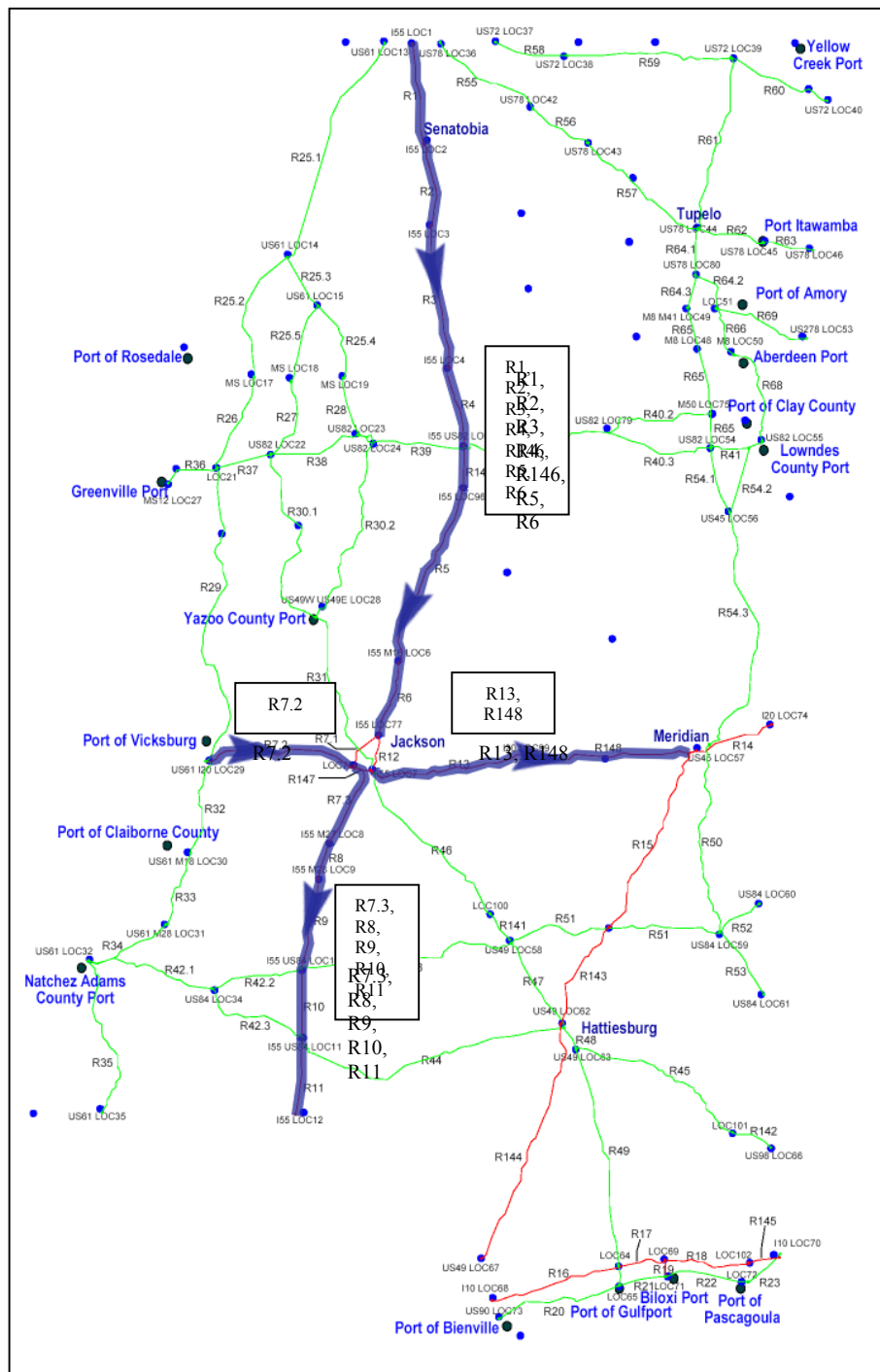


Figure 4.1 The Selected Highway Links and the Direction of Flow for Traveling Speed, and Congestion.

4.1.1 Scenario 1: Base Condition

Table 4.1 summarizes the performance of the system under the base condition with respect to the performance measures described in Section 3.10 of Chapter 3.

Table 4.1 Summary of Results for Base Condition (Scenario 1) Simulation

Zone	Avg. Zone Highway Utilization	Mode	Avg. Daily Ton-Miles	Avg. Daily Gallons
1	15.59%	Water	490,903	955
2	4.02%	Rail	4,431,333	22,028
3	7.20%	Highway	171,525,000	2,897,383
4	5.46%	System Ton-Miles per Gallon		60.42
5	8.46%			
6	23.34%			
7	12.82%			
8	13.69%			
9	15.86%			
10	15.43%			
11	10.89%			

Note that the “Average Zone Highway Utilization” is the time-weighted average of the utilization for highways links that are included in the model within the particular zones. The Ton-Miles and Gallons values are the average daily values. Also, note that no passenger car information is included for the links without truck traffic, and therefore, the passenger cars count on those links is neglected. As a result, the percentage utilizations reported in the output are expected to be lower for some zones.

Table 4.2 summarizes the average traveling speed (miles per hour) and congestion statistics for the 15 selected links in the scenario. We can see that for the base scenario, link R1 for example (an I-55 link above Senatobia), experiences very little congestion with an average traveling speed of 69 mph. The link was never congested over the

simulation time. Because the average link congestion is a time-weighted average figure, a dynamic plot is useful in displaying the status of congestion (in dark maroon) for a link over the simulation run as shown in Figure 4.2. This plot allows us to observe how congestion and speed changed for link R1 during the simulation.

Table 4.2 Summary of Average Traveling Speed and Congestion Statistics for the Base Condition

Link Code	Link Name	Avg. Link Traveling Speed	Average Link Congestion
R1	I55_Net1	69	0.00
R2	I55_Net2	69	0.00
R3	I55_Net3	69	0.00
R4	I55_Net4	69	0.00
R146	I55_Net146	69	0.00
R5	I55_Net5	69	0.00
R6	I55_Net6	69	0.00
R7.2	I55_I20_I220_Net7 Path 2	67	0.01
R13	I20_Net13	70	0.00
R148	I20_Net148	70	0.00
R7.3	I55_I20_I220_Net7 Path 3	69	0.00
R8	I55_Net8	69	0.00
R9	I55_Net9	69	0.00
R10	I55_Net10	69	0.00
R11	I55_Net11	70	0.00

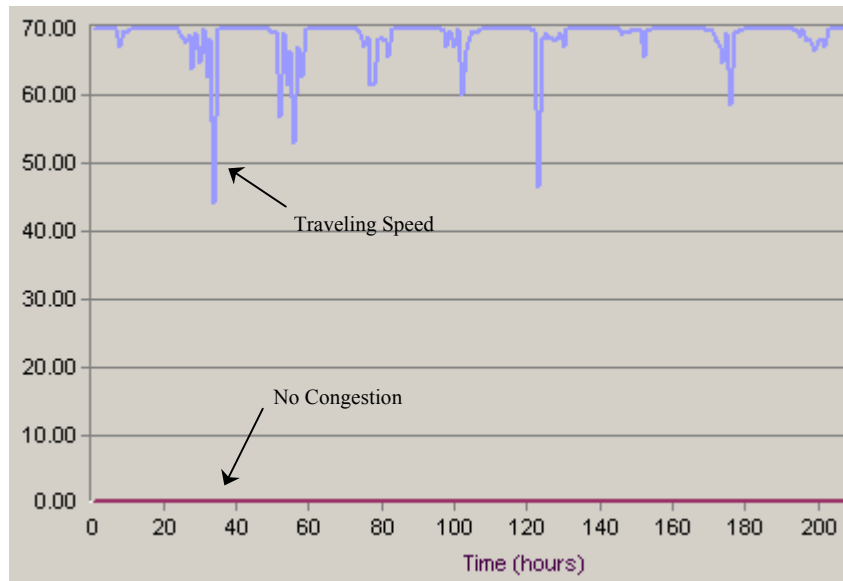


Figure 4.2 Plot of Scenario 1 Traveling Speed (Light Blue) and Congestion (Dark Maroon) over Time (Hours) for Link R1

4.1.2 Scenario 2: Freight and Passenger Traffic Volume Doubled for Each Mode of Transportation

In this scenario, there is a 2X increase in overall traffic. This assumes that the transportation infrastructure remains identical to the base scenario and vehicle characteristics and their route choices remain constant. Tables 4.3 and 4.4 summarize the performance of the system.

Table 4.3 Summary of Results for Scenario 2 Simulation (2X Increase)

Zone	Avg. Zone Highway Utilization	Mode	Avg. Daily Ton-Miles	Avg. Daily Gallons
1	32.12%	Water	990,045	1,926
2	8.35%	Rail	8,781,217	43,689
3	14.75%	Highway	350,766,667	5,925,117
4	11.29%	System Ton-Miles per Gallon		60.38
5	17.49%			
6	47.25%			
7	26.32%			
8	27.58%			
9	32.60%			
10	31.39%			
11	22.02%			

Table 4.4 Summary of Average Traveling Speed and Congestion Statistics for Scenario 2 (2X Increase)

Link Code	Link Name	Avg. Link Traveling Speed	Average Link Congestion
R1	I55_Net1	47	0.39
R2	I55_Net2	53	0.26
R3	I55_Net3	53	0.25
R4	I55_Net4	52	0.29
R146	I55_Net146	53	0.26
R5	I55_Net5	55	0.24
R6	I55_Net6	55	0.24
R7.2	I55_I20_I220_Net7 Path 2	44	0.40
R13	I20_Net13	69	0.02
R148	I20_Net148	69	0.00
R7.3	I55_I20_I220_Net7 Path 3	54	0.25
R8	I55_Net8	53	0.27
R9	I55_Net9	52	0.28
R10	I55_Net10	53	0.27
R11	I55_Net11	70	0.00

It can be clearly seen from Table 4.4 above that an increase of 2X in traffic flow creates a more congested highway transportation system. The average traveling speed on link R1 is now 47 mph and it is congested 39% of the time (The speed and congestion plot for this link can be seen in Figure 4.3). This is an important aspect when conducting transportation planning because average truck traffic over a 24hr period excludes how traffic fluctuates over time. The system performance at such high traffic volumes is very poor, creating stop-and-go traffic conditions on this link during peak times.

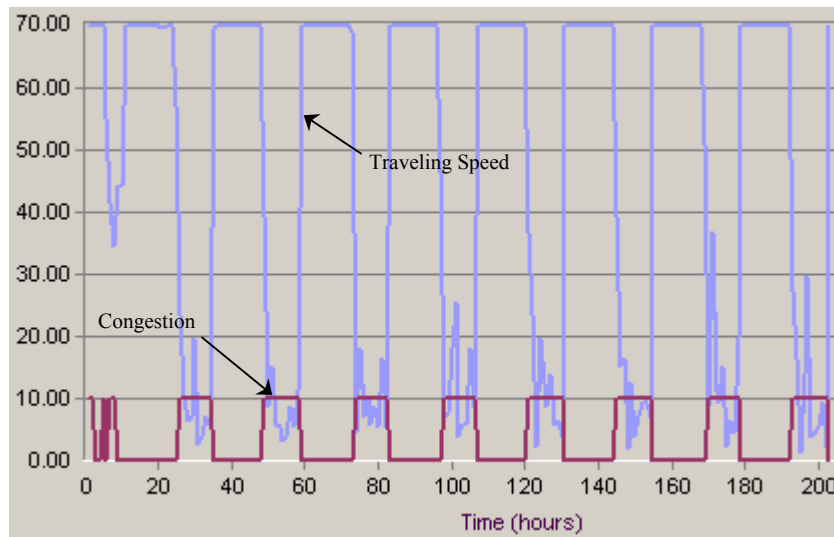


Figure 4.3 Plot of Scenario 2 Traveling Speed (Light Blue) and Congestion (Dark Maroon) over Time (Hours) for Link R1

4.1.3 Scenario 3: Increased Use of Intermodal Transportation for Scenario 2

This scenario experiences the same 2X increase in traffic as was used in Scenario 2. However, in this case, the freight normally arriving into the state by trucks through Location 1 and traveling by highway to Location 12 is changed to arrive using barges

through Location 1 and traveling down to Location 29 (Vicksburg) via the Mississippi River (see Figure 4.4). We assume, for the sake of discussion that the all the trucks are carrying a general commodity for Location 12 to be used by the local industry. Another assumption is that the Mississippi river and the port at Vicksburg have sufficient capacity to handle the influx of barges.

It is possible that the industries (could be the plastics or packaging manufacturers) located in McComb (near Location 12) are looking into alternative modes of transportation in getting raw materials from their suppliers north of Mississippi. This is consistent with the supply chain principle where the manufacturers play an active role with their suppliers in coordinating shipments to best serve their production needs. Some industry experts have mentioned the idea of “warehouse-in-transit”. The slower moving barges are an excellent example of this concept.

After the trucks are loaded with freight from the barges, the journey is then resumed using from Location 29 to Location 7. From Location 7, they travel to the final destination at Location 12.

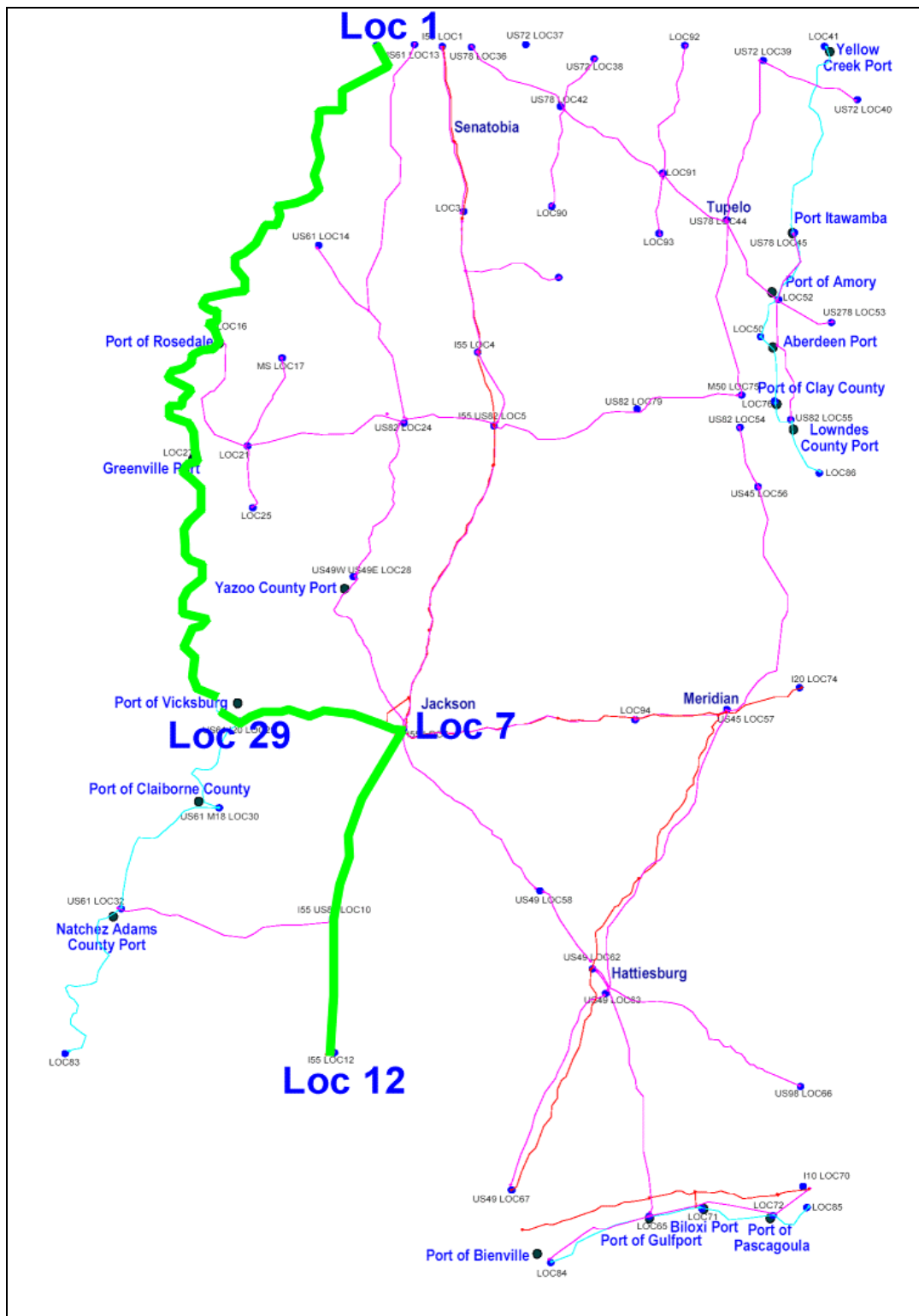


Figure 4.4 Route Shift (Intermodal) for Future Scenario

Table 4.5 and Table 4.6 summarize the performance of the system for Scenario 3. Comparing this scenario with Scenario 2, we can see an increase in the System Ton-Miles per Gallon from 60.38 to 66.80. This is an increase of 10.63%, which is a significant difference, considering the limited intermodal use in this scenario.

Table 4.5 Summary of Results for Scenario 3 Simulation (With Intermodal)

Zone	Avg. Zone Highway Utilization	Mode	Avg. Daily Ton-Miles	Avg. Daily Gallons
1	22.31%	<i>Water</i>	40,204,500	78,219
2	8.31%	<i>Rail</i>	8,781,217	43,689
3	9.71%	<i>Highway</i>	318,280,000	5,376,350
4	7.85%	System Ton-Miles per Gallon		66.80
5	20.91%			
6	41.97%			
7	26.17%			
8	25.51%			
9	32.49%			
10	31.24%			
11	21.89%			

Table 4.6 Summary of Average Traveling Speed and Congestion Statistics for Scenario 3
(With Intermodal)

Link Code	Link Name	Avg. Link Traveling Speed	Average Link Congestion
R1	I55_Net1	70	0.00
R2	I55_Net2	70	0.00
R3	I55_Net3	70	0.00
R4	I55_Net4	70	0.00
R146	I55_Net146	70	0.00
R5	I55_Net5	70	0.00
R6	I55_Net6	70	0.00
R7.2	I55_I20_I220_Net7 Path 2	35	0.46
R13	I20_Net13	69	0.01
R148	I20_Net148	69	0.01
R7.3	I55_I20_I220_Net7 Path 3	57	0.21
R8	I55_Net8	58	0.19
R9	I55_Net9	57	0.20
R10	I55_Net10	57	0.19
R11	I55_Net11	70	0.00

Looking at the average traveling speed and congestion for the highway links from Table 3.12, we can see that traffic is taken from highway designated R1, R2, R3, R4, R146, R5, and R6 when compared with the previous scenario. While this significantly reduces the congestion on Interstate 55 north of the city of Jackson (notice that R1 is no longer congested), the unloading of the barges onto truck at Vicksburg (Location 29) creates a huge traffic bottleneck for trucks moving from Vicksburg to Jackson. The result is frequent gridlock on that link R7.2 with an average speed of 35 mph, and being congested 45.76% of the time (see Table 4.6). Figure 4.5 illustrates this new dilemma, indicating the traveling speed and congestion for Link R7.2 during the simulation run.

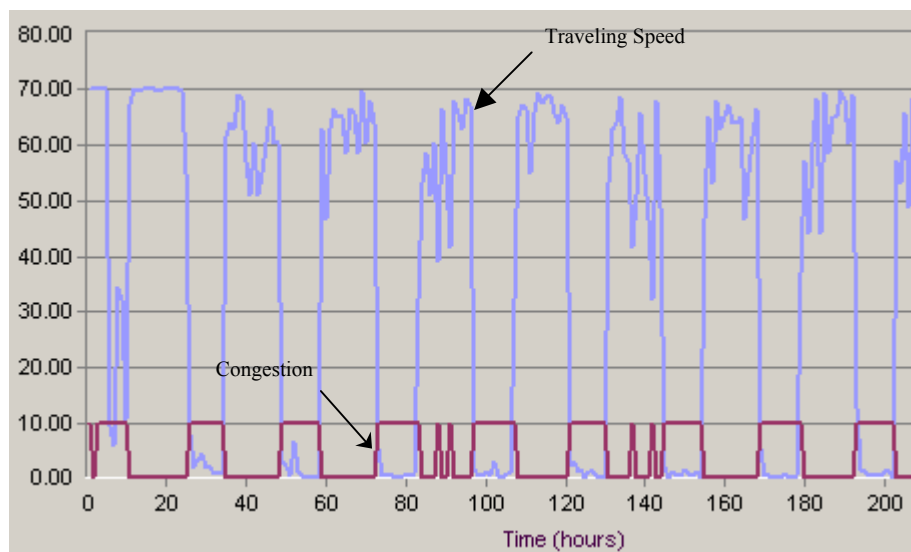


Figure 4.5 Plot of Scenario 3 Traveling Speed (Light Blue) and Congestion (Dark Maroon) over Time (Hours) for Link R7.2

Realizing that link R7.2 is too heavily congested, we doubled its capacity to examine if that will help (let's call this Scenario 4). While the average traveling speed increases from 35 mph to 60 mph on this link (see Table 4.7 and Figure 4.6), it is certain that some other strategy or combinations of strategies can be applied to further improve the traffic flow on this link, since there are instances where the traveling speed is significantly below the free-flow speed.

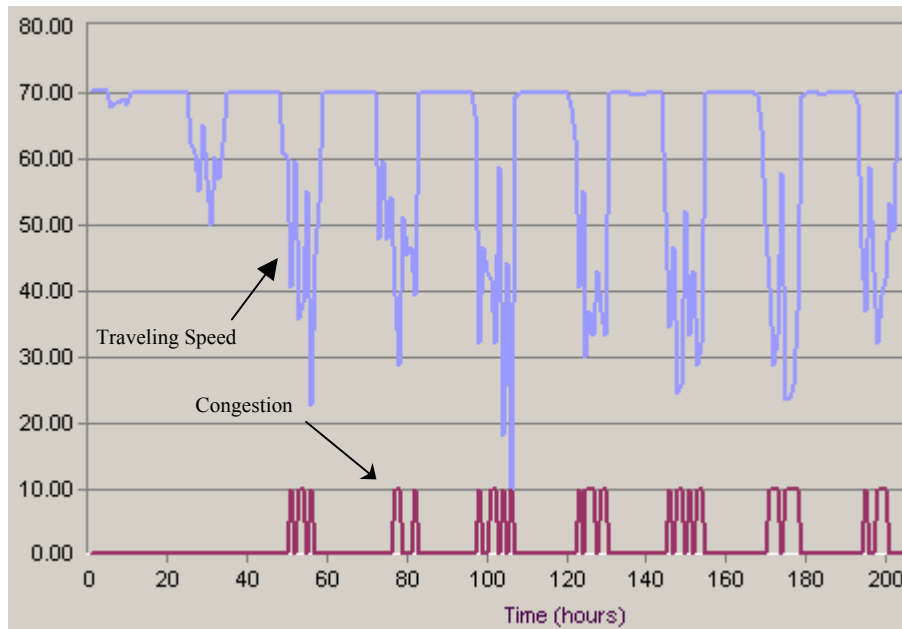


Figure 4.6 Plot of Scenario 4 Traveling Speed (Light Blue) and Congestion (Dark Maroon) over Time (Hours) for Link R7.2

Although this scenario is relatively simple, this is an example of how a simulation model can bring attention towards unanticipated results of intermodal policy changes.

Table 4.7 shows the overall summary of comparison between the four scenarios.

Table 4.7 Overall Summary of the Four Scenarios

	<i>Scenario 1</i>	<i>Scenario 2</i>	<i>Scenario 3</i>	<i>Scenario 4</i>
Avg. Daily Ton-Miles	176,447,236	360,537,929	367,265,717	370,437,383
Avg. Daily Gallons	2,920,366	5,970,732	5,498,258	5,551,841
System TMPG	60.42	60.38	66.80	66.72
Link Codes	Average Link Traveling Speed			
R1	69	47	70	70
R2	69	53	70	70
R3	69	53	70	70
R4	69	52	70	70
R146	69	53	70	70
R5	69	55	70	70
R6	69	55	70	70
R7.2	67	44	35	60
R13	70	69	69	69
R148	70	69	69	69
R7.3	69	54	57	61
R8	69	53	58	61
R9	69	52	57	61
R10	69	53	57	61
R11	70	70	70	70

This overall examination yields an interesting observation. The system ton-miles per gallon is slightly lower for Scenario 4 than in Scenario 3. This can be attributed to the lowering of congestion on the critical link (in this case), R7.2, thus allowing more truck movement on that link in Scenario 4. With the increase in truck flow, the truck mode ton-miles is now slightly higher. Because the system ton-mile per gallon is calculated by taking the total ton-miles for the water, rail, and highway modes, and dividing that by the total gallons consumed, the result is a slightly lower system ton-miles per gallon value.

Note that the ton-miles for the water and rail modes (in Table 4.8) are the same across Scenarios 3 and 4. The ton-miles per gallon is 66.72 for Scenario 4, which translates to a 10.5% increase over Scenario 2.

Table 4.8 Summary of Results for Scenario 4 Simulation (With Intermodal)

Zone	Avg. Zone Highway Utilization	Mode	Avg. Daily Ton-Miles	Avg. Daily Gallons
1	22.44%	<i>Water</i>	40,204,500	78,219
2	8.38%	<i>Rail</i>	8,781,217	43,689
3	9.81%	<i>Highway</i>	321,451,667	5,429,933
4	7.93%	System Ton-Miles per Gallon		66.72
5	19.42%			
6	41.05%			
7	26.39%			
8	26.04%			
9	32.87%			
10	31.44%			
11	22.10%			

Figures 4.7 show the close-up screenshots of the VITS animations for the four scenarios, which was taken at hour 95 of the simulation time. They show the traffic activity in the area surrounding Jackson for the four scenarios (look closely at the traffic conditions on link R7.2 between Vicksburg and Jackson across all four scenarios).

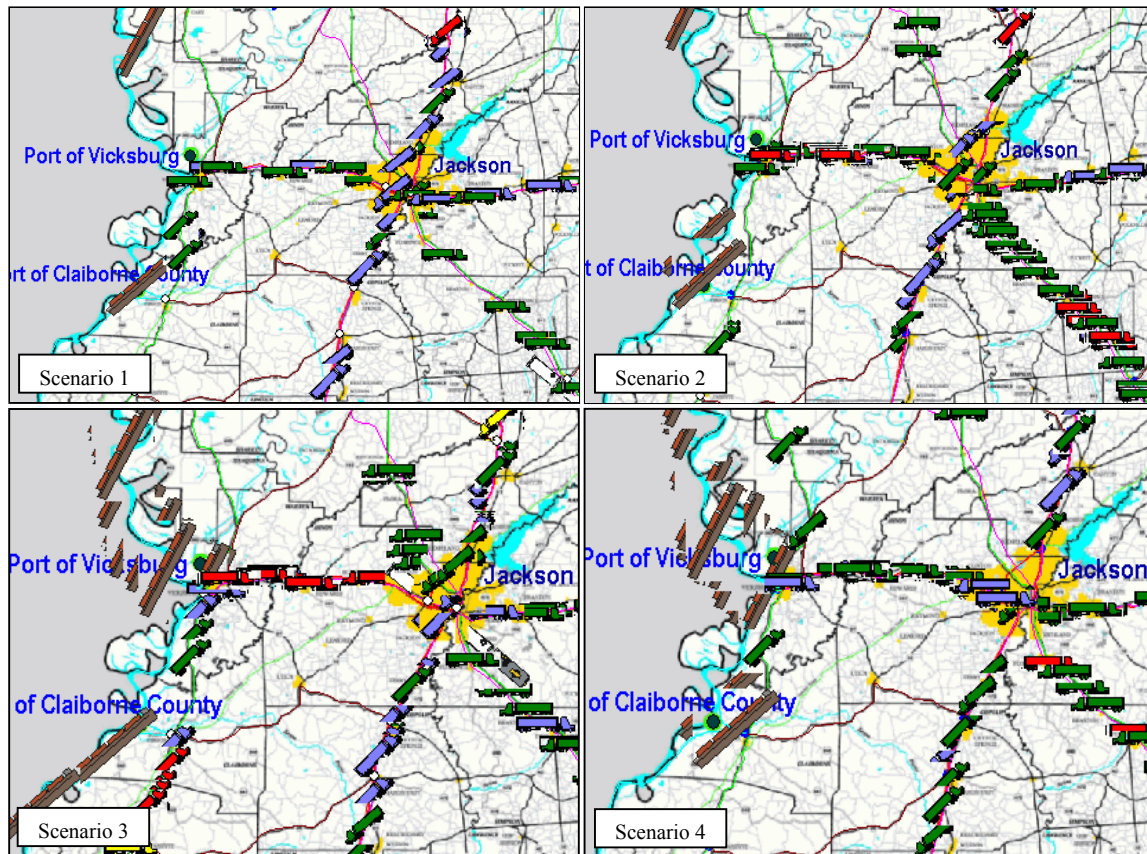


Figure 4.7 Screenshots of the VITS Animations for Scenarios 1, 2, 3, and 4.

4.2 Validation

The validity of the results produced by VITS simulations of transportation systems is highly dependent on the accuracy of the input data supplied to the VITS. In this case, a transportation planning software, TransCAD was used to provide the VITS the OD data.

For validation, we looked at the average daily truck counts on locations throughout the entire transportation network, simulated on the VITS using 1997 freight

data (base condition) for five replications. This truck count is also commonly referred to as “ground counts”. We compared the VITS simulated ground counts for 34 locations within Mississippi with the truck ground counts recorded by the Mississippi Department of Transportation. The total number of simulated trucks moving through the 34 locations was within 22.27% of actual ground count, which is consistent with results from other studies [38][39].

4.3 Conclusion for the VITS

The interactions between different modes in a transportation system, especially on a statewide level, are often overlooked due to lack of effective tools. Problems like these can limit effective planning and thus, sub-optimal use of limited resources. The VITS prototype shows that a statewide intermodal freight transportation simulation model is a viable tool and can be used to examine the “big picture”, instead of the usual narrow, mode specific analyses. Being able to observe the pattern and flow of traffic over time with powerful animations provides new dimensions to the transportation problems not seen previously with traditional tools.

CHAPTER V

ADDING MICROSCOPIC DETAILS: THE INTEGRATED PORT MODEL

This Chapter will discuss the need, the research involved, and the methodology for integrating microscopic port models within the VITS framework. A brief introduction as well as the justification for the port model is presented in Section 5.1 and Section 5.2 respectively.

5.1 Introduction

Effort has been made by various groups to develop models of ports that can be used to aid the transportation planning process. An early effort involved the U.S. Department of Transportation, Maritime Administration (MARAD) that developed six modules that draw from average throughput of a small sample of US Ports [5]. From the LATTs study conducted by Wilbur Smith Associates [3], estimates of investment needs for the port systems were done in part using “Idealized Terminal Modules” that includes Container, Neo-Bulk, Break-Bulk, Dry-Bulk, and Liquid-Bulk Facilities. The Louisiana Statewide Intermodal Study presented the “Stock and Flow” methodology to calculating capacities [5].

The MARAD six port modules are basically templates (of different terminal types) that draw from the average capacities as sampled from actual throughput as reported by a small population of US ports [5]. This information would be too aggregated

to be applied to any particular statewide intermodal planning effort. The “Stock and Flow” methodology on the other hand, breaks down the terminal into more detailed components to better match the port of interest, although it assumes that the terminal components are independent of each other. This is to simplify the calculation of capacities using algebraic equations. The slowest component, being the bottleneck, therefore determines the capacity of the entire terminal. The LATTIS study on the other hand, uses a collection of terminal features (such as the acreage, number of berths and berthing factors, types of cargo, etc.) to determine the capacities based on reference to industry standards.

These estimates and averaged figures do not provide any information on the fluctuations that occur during the actual operation of the terminals. It is important to understand that the capacity issues are highly influenced by interactions between terminal components, as well as subjected to random variations. Interactions occur when the operation of one component affects the performance of other component(s) [40]. A simulation gains its forte in this aspect by having the ability to consider the effects of interactions and variability in the analysis.

5.2 The VITS Integrated Port Model

The objective is to construct a “template” in which ports in a region of study can be defined, modeled, and analyzed within the VITS framework without the need for conducting a detailed model of the individual ports. In this respect, the level of detail of the VITS Integrated Port Model lies in between the basic models used for capacity estimation [3] and the detailed port models such as those used for optimizing container

storage space [10]. The VITS integrated port modeling method is designed to be user customizable via key inputs of port characteristics such as the acreage of different storage areas, berth operating hours, loading and unloading rates, etc. The Port of Gulfport was used as an example application of the integrated port modeling method. This port was chosen because it is a major freight port in the State of Mississippi.

In the LATTS study of ports [3], output data for the storage throughput capacity (tons/year), berth throughput capacity (tons/year), calculated practical capacity, and maximum practical capacity was estimated based on industry data. Combining some of the industry figures with the “Stock and Flow” concept, the VITS integrated port modeling method was used to develop a simulation model of the Port of Gulfport that has three major components that consist of the storage area (stock component), the berthing area (flow component), and the access gate (flow component). These three components will form the structure for both container terminals and non-container terminals. According to Muller [24], container terminals have very different requirements than breakbulk terminals in that container terminals require more land for parking, movement of containers, and vehicular access. As such, the differentiation in the storage capacities of the various terminal types is implemented by having input parameters for six different terminal types. The other resources such as yard hustlers, forklifts, etc. are represented in the VITS integrated port model in terms of wait times (based on statistical distributions) for the transfer of cargo.

A methodology had to be devised to determine the volume of truck traffic coming into and going out of a port based on the OD data given that the OD data is not that

specific. This is achieved in the Gulfport example using two percentage figures called “% Gulfport Truck Traffic Going Into Port” and “% Gulfport Truck Traffic From Port” that are customizable by the user via a spreadsheet called the “Integrated Port Input” (we will refer to this spreadsheet as the “port input spreadsheet”). It is basically the estimated percentage of the traffic to and from the City of Gulfport that goes into or out of the Port of Gulfport (since not all freight traffic going into or out of the city is related to the port). The truck traffic associated with the port can also be independently increased or decreased without affecting the volume of city truck traffic. Instruction on how to do this is available in the Simulation User Guide under Section C in “Guide to User Inputs”. The user guide can be obtained from the National Center for Intermodal Transportation.

5.3 Elements of the Port Model

The following terminals and the default input parameters listed are obtained from the LATTIS study [3]. These parameters can be changed by the user via the port input spreadsheet to better match any port of interest.

We define a terminal as a facility for loading or unloading cargo one vessel at a time (i.e. each terminal has a single berth). The following details the six different terminal types that are available for the modeling of integrated port models in the VITS. Note that the port models can have any combination of terminals although the current version can support up to ten berths per port.

1. Container Terminal

Container cargo is defined as any freight stored in closed boxes that are typically 20 or 40 feet long. The following features are considered in a container terminal simulation:

- One berth to accommodate container vessels of 800 to 1,150 feet in length.
- Two 100-foot-gauge container gantry cranes.
- Eight-lane terminal gate.
- 25 to 30 acres of paved and striped outdoor storage;
 - Wheeled 90 TEU/acre,
 - Grounded (RTG) 200-250 TEU/acre,
 - Other/Mixed 150 TEU/acre.

2. Break-Bulk Terminal

Break-bulk cargo is defined as freight that is often loaded and unloaded piecewise and usually palletized. The following features are considered in a break-bulk terminal simulation:

- One berth to accommodate vessels up to 600 feet in length.
- One 120,000-square-foot covered storage for 7,000 short tons of cargo.
- Four acres of paved outdoor storage with average capacity of 10,800 short tons.
- Storage Area;
 - Outside Storage 2700 tons/acre,
 - Mixed Storage 2600 tons/acre,
 - Warehouse Storage 2700 tons/acre.

- Ship's gear or two 50-ton mobile cranes.
- Four-lane terminal gate.

3. Dry-Bulk Terminal

Dry-bulk cargo is defined as freight that is loose and non-liquid that can be loaded or unloaded by a conveyor or clamshell cranes. The following features are considered in a dry-bulk terminal simulation:

- One berth to accommodate vessels up to 900 feet in length.
- Mobile ship loaders and/or reclaimers with the capacity to load/unload 500 to 1,200 tons per hour.
- Silo or open storage areas;
 - Outside storage 32,700 tons/acre,
 - Mixed storage 21,800 tons/acre,
 - Silo Storage 43,600 tons/acre.
- Truck transfer and parking areas.
- Four-lane terminal gate.

4. Neo-Bulk Terminal

Neo-bulk cargo is defined as freight that consists of wheeled containers or vehicles that are rolled on and off via a ramp. Muller [24] describes neo-bulk cargo as a special class of break-bulk cargo that is transported in smaller quantities per shipment with cargo separation maintained during loading, transport, and unloading (such as different

automobile models). Examples of neo-bulk cargoes include automobile, steel, lumber, and paper). The following features are considered in a neo-bulk terminal simulation:

- One berth to accommodate vessels up to 600 feet in length.
- One 60,000-square-foot transit shed/warehouse with a static storage capacity of approximately 3,500 short tons for cargo requiring protection from the weather.
- 6-acres of paved outdoor storage with capacity of approximately 16,200 short tons consisting of four acres for wheeled (automobile) storage and two acres of open storage.
- Ship's gear or two 50-ton mobile cranes.
- Storage area;
 - Outside Storage 2700 tons/acre,
 - Mixed Storage 2600 tons/acre,
 - Warehouse Storage 2500 tons/acre.

5. Liquid-Bulk Terminal

The following features are considered in a liquid-bulk terminal simulation:

- One berth to accommodate vessels up to 900 feet in length.
- One liquid cargo manifold.
- Nine tanks with 14500 short tons capacity each or 115,000 US barrels.

6. Generic Terminal

This terminal is used when the port data contains insufficient detail to determine the cargo type. This is typical if the OD data is derived from a survey database that reports only the tonnage transported. The user can adjust/customize the parameters for this terminal type based on a weighted average of the parameters of the other terminal types that best suit the port under study.

For the Port of Gulfport, the locations (such as access gate, berths, etc.) in the port simulation model follow a naming convention that consists of the letters “GP” in front of all the location names. For example, the location for arriving vessels to the port is named “GPIncomingWaitingLoc”. “GP” is short for Gulfport and is used to differentiate ports in the region of study (should more port models be integrated into the VITS). In short, all the locations within the integrated Port of Gulfport have the letters “GP” in front of the locations names. The same naming convention applies also to all macros and variables used in the port model.

Figure 5.1 illustrates the Port of Gulfport simulation model and Figure 5.2 shows the flow diagram that describes the components and processes of the idealized port model. The 3D boxes represent locations within the simulation model and the diamond shaped boxes represent some logic/decision making process that is mainly written as subroutines.

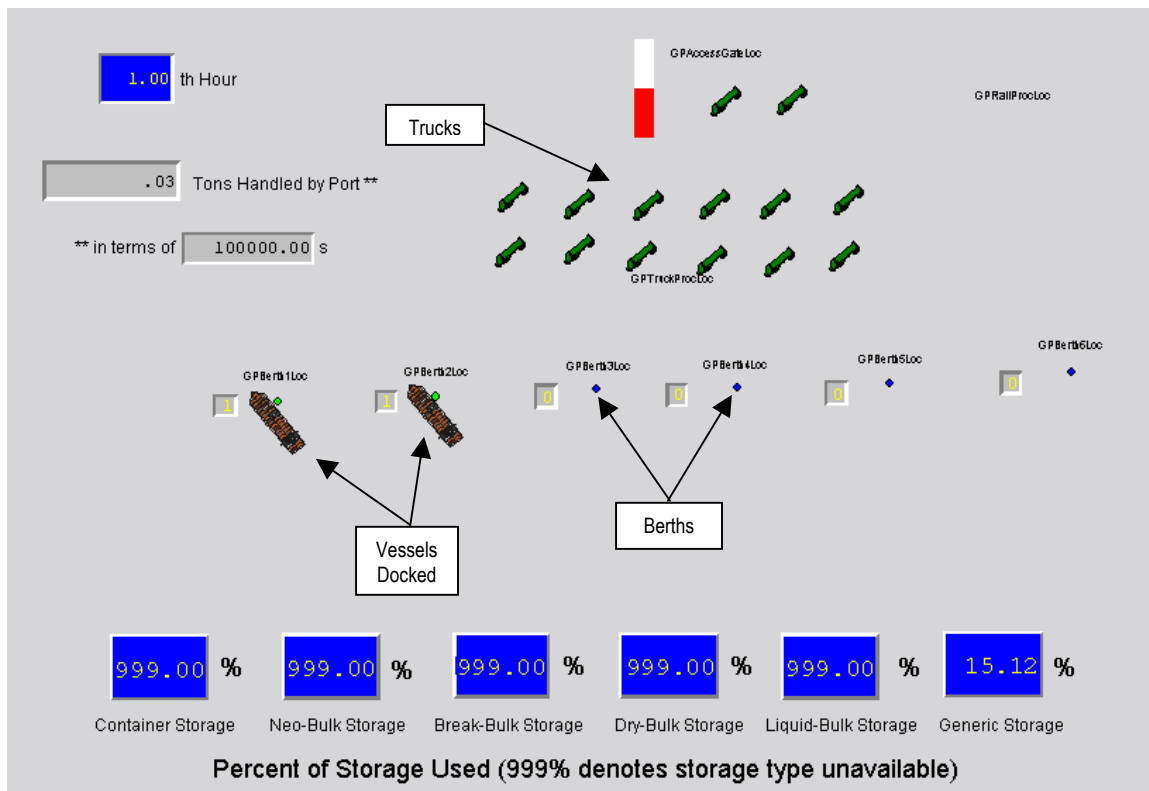


Figure 5.1 Partial Screenshot of the Port of Gulfport Integrated Port Simulation Model

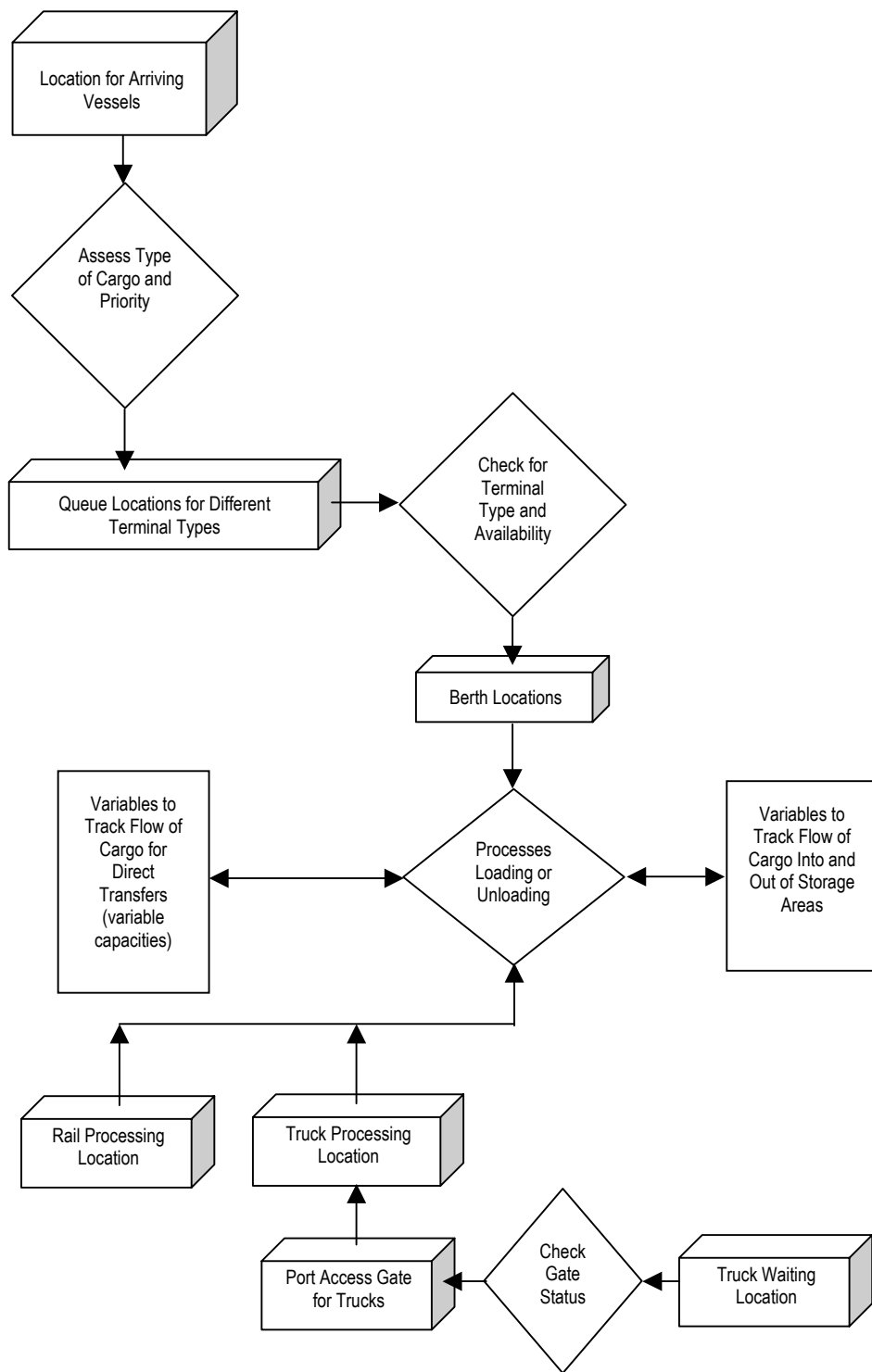


Figure 5.2 Flow Diagram of the Integrated Port Model

The following will briefly describe the elements of the flowchart shown in Figure 5.2.

- Location for Arriving Vessels – This location is where waterborne vessels arrive before they are directed to the appropriate berth at the port. A subroutine is used to determine the type of cargo carried by the vessel (container, break-bulk, etc.) and the priority of the shipment.
- Queue Locations for Different Terminal Types – There are six different queue locations, corresponding to queues for container, break-bulk, dry-bulk, neo-bulk, liquid-bulk, and generic cargo terminal types. Vessels at these queues would already be in order of priority for processing. Subroutines in these queue locations will check the berths to determine the type of cargo they handle as well as the availability of the berths. Ships will wait at the queue location until a berth that handles its cargo type is available.
- Berth Locations – These are locations on the port that the vessels are either loaded or unloaded. The subroutine at these locations will discern whether the particular vessel is to be loaded or unloaded. The subroutine will also update variables that keep track of available storage and the amount of cargo (in tons) currently stored.
- Rail Processing Location – This is the location to which the trains arrive and have their railcars either loaded or unloaded.
- Truck Processing Location – This location is where the trucks undergo the loading or unloading process.
- Truck Waiting Location – This location is where the incoming trucks wait if the access gate to the port is closed. This location simulates the trucks waiting in the

proximity of the port (not necessarily a single physical location). A ProModel wait instruction is implemented at this location to have the trucks wait until the gate is open.

- Port Access Gate for Trucks – This is the location where trucks stop and undergo a check-in or check-out procedure before being let in or out of the port. The capacity of this location represents the number of parallel processing lanes going through the gate.
- Cargo Tracking Variables – There are two categories of variables used in the simulation to track cargo flow. One tracks flow into or out of the port, while the other tracks direct transfers. Direct transfers involve vessels that transfer cargo onto/from other mode(s) of transportation directly without involving the storage available on the port.

5.4 Capacities for the Locations in the Port

Some of the capacities for the locations within a port are defined using ProModel macros that can be modified using ProModel’s “Run-Time-Interface” before the simulation is run. The “Run-Time-Interface”, also known as the RTI is a custom interface that allows the user to modify aspects of the model without changes to the model’s code [30]. The capacities of locations may be changed to examine the effects on the operation of the port such as increasing the number of lanes at the access gate. The following locations have their capacity defined using macros:

- Location for Arriving Vessels – using the macro “GPShipWaitingAreaMac”.
- GPAccessGateLoc – using the macro “GPTruckAccessGateLanesMac”.

- GPTruckProcLoc – using the macro “GPTruckProcLocCapMac”.

There are other locations that are modeled with pre-defined/fixed capacity. These are the locations where the capacity is not likely to be changed after the port is defined.

The following lists these locations:

- Queue Locations for Different Terminal Types – capacity of ten each.
- Truck Waiting Location – infinite capacity (or some large figure since this represents the city area where the trucks can wait before gaining access to the port).
- Berth Locations – capacity of one each.
- Rail Processing Location – capacity of one.

5.5 Entity Attributes

These are attributes used in the various ProModel Operation Logic sections and subroutines in the port model. These attributes are essential in controlling the movements, berthing, as well as loading/unloading processes for all entities at the port model. They also allow the simulation to keep track of the storage capacity used and the type of transfers/wait times.

The list of these attributes, their application, and possible values is available in detail in the Simulation User Guide under the section “Technical Guide for the Integrated Port Model”. Explanation of these attributes is important to aid the understanding of how the subroutines for the port model work.

5.6 Subroutines for the VITS Integrated Port Model

There are a total of ten subroutines that were designed to model ports in the VITS. The following will describe the subroutines, their function, and the parameters required. The full technical details including the subroutine placement, the pseudo-codes, and the entity attributes are available in the Simulation User Guide.

In most instances, instructions on the use and placement of the subroutines are documented within the subroutine themselves for quick reference by the user. Some port model subroutines require the parameter for the port number, which will be the location number where the port resides. For example, the City of Gulfport is located at Location 65 in the ProModel model. Therefore the Port of Gulfport will be recognized in some subroutines as port number 65.

5.6.1 Subroutine *BerthTypeSUB()*

This subroutine requires no parameters but it contains code that direct arriving vessels (both ships and barges) to the appropriate queues for the berths based on their cargo type (there are six different queues for the six cargo types). The identification of cargo type is done via the entity attribute called “EntityType_At”.

This subroutine is invoked at the vessel arrival area where there are always six possible routes for the vessels (to either one of the six queues for the six different cargo types). By checking the “EntityType_At” attribute, the subroutine will issue the appropriate ProModel ROUTE command and the vessels will be directed to the right queue for the berth, thus not requiring the user to specify a port number as a parameter for the subroutine.

5.6.2 Subroutine *BerthigSUB(CargoTypePAR, PortNo)*

This subroutine requires a parameter called “CargoTypePAR” and another one called “PortNo”. This subroutine is executed after the vessels have been sent to the appropriate queues. It instructs the ship to dock at the berth (up to 10 possible berths) when it is available. The subroutine determines if a particular berth supports the cargo type and chooses one that is not currently occupied. For example, if berth number 1 is available for the cargo type on board a vessel, then that vessel will dock there and if not, the subroutine checks the next berth and so on. Therefore, if all berths are configured as container berths and the ship’s cargo type are containers, then the last berth will be chosen only when all other berths are occupied. Future programming can be done to give priority to a certain berth based on some user-defined values.

The “CargoTypePAR” subroutine parameter refers to the queue cargo type. For example, the subroutine placed at a queue for berths with a container terminal will have a parameter of “1”, corresponding to the container cargo type. Table 5.1 lists the parameter values and the corresponding cargo types. For ease of discussion, the term Type 1, 2, 3, 4, 5, or 6 will be used to denote the cargo type handled in the context of Type 1 Queue, or Type 3 Berth, and so on. The “PortNo” parameter is the identifier for the port. For example, if the Port of Gulfport is located in Location 65 in the VITS, the “PortNo” for this subroutine will be 65.

Table 5.1 Definition of Parameter Values

Parameter Value (CargoTypePAR)	Cargo Type
1	Container
2	Break-Bulk
3	Dry-Bulk
4	Neo-Bulk
5	Liquid-Bulk
6	Generic

5.6.3 Subroutine *BerthOpHoursSUB(PortNo)*

This is an interactive subroutine that is executed at the beginning of the simulation run (at time = 0, which represents 7 AM). As an interactive subroutine, it is activated at the beginning of the simulation run, and runs continuously, independent of the events that occur during the simulation. It keeps track of the time of the day in order to determine whether a particular berth is open for operation or closed for the day. There is only one parameter required, which is the port number. The following Table 5.2 describes the clock hours used.

Table 5.2 The Translation of Simulation Clock Hours

Clock Hr.	Time	Clock Hr.	Time	Clock Hr.	Time	Clock Hr.	Time
0	7 AM	7	2 PM	14	9 PM	21	4 AM
1	8 AM	8	3 PM	15	10 PM	22	5 AM
2	9 AM	9	4 PM	16	11 PM	23	6 AM
3	10 AM	10	5 PM	17	12 AM	24	7 AM
4	11 AM	11	6 PM	18	1 AM	.	.
5	12 PM	12	7 PM	19	2 AM	.	.
6	1 PM	13	8 PM	20	3 AM	.	.

5.6.4 Subroutine *BerthLoadUnloadSUB(berthTypePAR, PortNo)*

This subroutine handles the loading and unloading processes of the waterborne vessels (can be ships or barges). The first parameter required is called “berthTypePAR”

and is used to denote the type of cargo handled. The other parameter is the port number. A local variable named “vesselTons” is used as a counter to keep track of the tonnage transferred between the facility and the vessel. The subroutine begins by determining if the vessel is a barge or a ship and then assigning the capacity of the vessel to the local variable.

Next, the subroutine uses the parameter “berthTypePAR” value to determine the type of cargo transferred. An attribute will be used to determine if it is a loading process or an unloading process. A ProModel “WAIT” statement is used in the subroutine to represent the loading or unloading time, which is modeled here according to the Triangular Distribution with the required parameters obtained from the integrated port input spreadsheet that can be customized by the user. The Triangular Distribution can be replaced with any appropriate distribution. This subroutine also tracks the tonnage processed and the percentage of storage capacity used.

5.6.5 Subroutine *DirectLU_SUB(PortNo)*

This subroutine is used for direct transfers that may occur between modes at the port that does not involve port storage resources. The port number is the only parameter needed. There is a global variable named “GPDirectTransVesselStoVar” that is used to keep track of direct transfer storage capacity. An array is used to store the parameters for the transfer times that are obtained from the port input spreadsheet. Again, the Triangular Distribution is used in this case but can be replaced with any appropriate distribution.

5.6.6 Subroutine *PortLandsideLU_SUB(PortNo)*

This subroutine is used to handle the loading and unloading processes for trucks and trains going into and leaving the port and requires the port number as the parameter. As before, an array is used to obtain values for the transfer time parameters from the port input spreadsheet for the Triangular Distribution used.

The “EntityType_Att” attribute is used to determine the type of cargo handled. This allows the appropriate updates to the variables that keep track of the storage capacity. Similar to the subroutine for handling loading/unloading processes for vessels, there are variables that are used to keep track of the tonnage as well as displaying the percentage of capacity used.

5.6.7 Subroutine *TruckAccessGateSUB(PortNo)*

This subroutine is implemented to handle wait times at the access gate for trucks. It determines the wait times based on the Triangular distribution with parameters obtained from the port input spreadsheet using an array (this distribution can be altered by the user if needed). The only parameter required is the port number.

5.6.8 Subroutine *AccessGateHoursSUB(PortNo)*

This is an interactive subroutine used to determine if the access gate is open or closed based on the hour of the day. This subroutine is similar in structure to the *BerthOpHoursSUB()* subroutine discussed earlier and requires the port number as a parameter.

5.6.9 Subroutine *TruckResolutionSUB(Resoln, PortNo)*

This subroutine handles the issue of truck resolution. Since a truck entity from the highway networks represents more than one truck, it is necessary to change this truck resolution to a single truck to better suit the microscopic nature of the port model.

The two parameters required for this subroutine are “Resoln” and “PortNo”. The “Resoln” parameter controls how many trucks a single truck entity represents and is set by the user in the vehicle specification spreadsheet. The “PortNo” is simply the port number as used in the other subroutines. For trucks coming into the port, the “Resoln” value is used to split the highway truck entity into individual truck entities with a resolution of one for processing at the port. For trucks leaving the port, the “Resoln” value is used to combine the port truck entities into highway truck entities before releasing them onto the highway. For example, if one highway truck entity is setup to represent 15 trucks, the “Resoln” value will be 15. Thus, the subroutine will gather 15 outbound trucks from the port to form a single highway truck entity with a resolution of 15 to be released onto the VITS highway network.

5.6.10 Subroutine *EntityCargoLUSUB(EntityType, CargoType, Luattrib, VesselType)*

This subroutine is used by entities involved with ports. These are entities (can be trucks, vessels, or trains) with an origin or destination that involves the city, or centroid where the port is located (City of Gulfport in our example). Its primary function is to assign entity attribute values used in the port operations such as cargo type, the loading/unloading attribute, and for truck entities, the “ResolutionFlag_EntAtt” attribute that controls the truck resolution changes.

The parameter called “EntityType” is to tell the subroutine what kind of mode it is (trucks, rail, or vessels). The parameter “CargoType” assigns the type of cargo that entity carries. “Luattrib” assigns the loading/unloading controlling attribute, and “VesselType” differentiates ships from barges. In the case of a non-waterborne mode, the “VesselType” parameter value can be entered as any integer value (such as 999) but will not be used by the subroutine. Note that the port number is not required in this subroutine. This is because this subroutine applies to all entities involved with ports in general and is not port specific.

5.6.11 Subroutine ProcLogicNoODSUB()

This subroutine contains a segment of code that directs vehicles into or out of the port model from the City of Gulfport (Location 65 in this case). The percentage of city traffic involving the port is utilized here as a deciding factor. This subroutine is required in overriding the routing information contained in the OD array whenever the truck traffic is determined to be port traffic and routes the vehicles to the appropriate locations at the port model. It requires no parameters. There is no port number required as a parameter here because the subroutine utilizes the “Location()” function to know which location it is invoked in.

5.7 Performance Measures for the Port

This section describes the performance measures used in the integrated port model.

5.7.1 *Percentage Storage Used and Available Capacity*

These activity indicators indicate the amount of resources that are currently used at the port. The percentage figures shown at the bottom of Figure 5.3 are used to denote the amount of storage used for each of the storages types at the port (e.g. container storage type). A figure of 999% means that the particular storage type is either unavailable at that port or not modeled.

The vertical red bar next to the access gate location (named as GPAccessGateLoc in Figure 5.3) indicates the amount of the location capacity used. In the example in Figure 4-2, there are trucks at the access gate, as indicated by the red vertical bar.

The percent utilization for the berth locations and the access gate location is obtained from the ProModel output report. The reported access gate utilization is expected to be less than 50% (under normal, non-congested situation) because it is closed for 14 hours, which is from 6PM to 8AM in this case (default value). The actual utilization during working hours is a simple matter of multiplying the average percent by 24 hours and dividing that value with the hours of gate operation per day. The maximum and average numbers of vehicles in these locations are also available.

5.7.2 *Average Time Spent at the Port*

The average time spent for each vessel at the berths and the amount of time waiting to berth (wait time in the queue) is reported. This information is available from the ProModel output report at the end of the simulation run under the section “Locations”. The particular statistic is called “Average Hours per Entry”. It is obvious that as the port reaches capacity, the time spent at the port for the vehicles will increase.

Similarly, the average wait times for trucks to enter the port can also be obtained via the average wait times at the truck waiting location outside the port.

5.7.3 Port Tonnage Handled

A variable (portTonsHandledVar) was devised to keep track of the total tonnage handled at a Port. In the case of the Port of Gulfport, this variable was named “GPportTonsHandledVar”. It keeps track of all the freight tonnage that is being transferred at the port and indicates the throughput of the port. This variable is divided by the user-defined “Output Divisor” that will be discussed later. This allows the scaling of the variable in terms of a hundred thousandth of tons (00,000s’), as an example. An on-screen variable display was implemented to allow the user to observe the total tonnage being handled over the simulation run (refer to Figure 5.3). Note that this variable accumulates the tonnage over the entire simulation run. If a daily average tonnage handled is required, this figure should be divided by the number of simulated days.

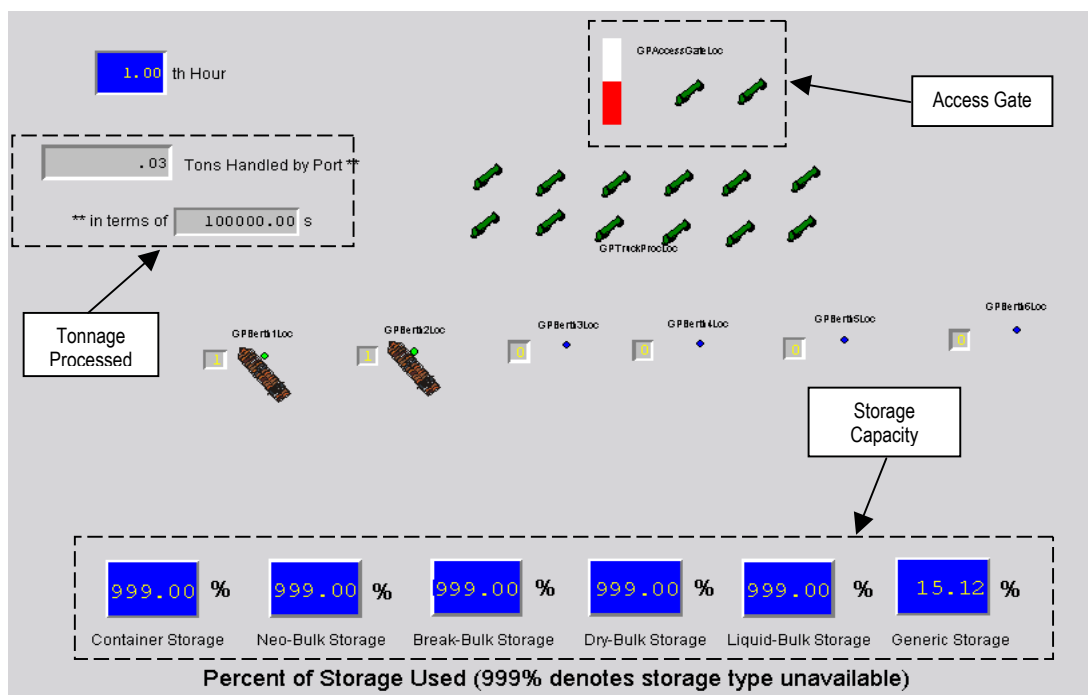


Figure 5.3 Animation Screenshot of the Port Model Showing the Activity Indicators

5.8 Assumptions of VITS Integrated Port Model

In this section, we will discuss the assumptions of the integrated port model. The listing for the assumptions will be organized based on the processes listed on the flowchart in Figure 5.2.

5.8.1 Location for Arriving Vessels

For the Port of Gulfport example, the capacity of this location for arriving vessels is user customizable via a macro called “GPShipWaitingAreaMac” with an assumed default value of 20 vessels. Note that vessels are being queued for the port at this location based upon their priority attribute.

5.8.2 *Queue Locations for Different Terminal Types*

All queues for the berths in the port model are assumed to have a capacity of ten vessels. We assumed that no balking of vessels occur while they are in the queue. Vessels wait at the queuing area if the berth is closed or unavailable. Unless the queue capacity is reached, newly arrived vessels will proceed to the queue regardless of the current waiting time in queue for the vessels that are already there.

5.8.3 *Berth Locations*

Berth locations are assumed to have no downtimes and have a capacity of one vessel. The berths are cargo type specific where we assume no sharing of berth resources between terminals of different cargo types.

5.8.4 *Berth Loading/Unloading Processes*

The loading and unloading processes at the berths handling the generic cargo type are assumed to be triangularly distributed with parameters of 20, 30, and 48 hours (minimum, most likely, maximum). The berths will finish the loading/unloading process past the closing time if the process is not completed by the berth closing time (which can be independent of the access gate operating hours).

5.8.5 *Rail Processing Location*

Rail processing times (loading or unloading) are assumed to be triangularly distributed with parameters of 24, 48, and 72 hours (minimum, most likely, maximum).

5.8.6 *Truck Processing Location*

Truck processing times (loading or unloading) are assumed to be triangularly distributed with parameters of 0.333, 0.5, and 1 hour (minimum, most likely, maximum).

5.8.7 *Port Access Gate for Trucks*

Processing times at the access gate for trucks are assumed to be triangularly distributed with parameters of 0.1667, 0.0333, and 0.0667 hours (minimum, most likely, maximum). The access gate is assumed to be applicable for both in-going as well as outgoing truck traffic. It is also assumed that all port incoming trucks that originate from other locations are loaded with freight (to unload at the port) while trucks that originate at the port are there to be loaded.

5.8.8 *Truck Waiting Location*

The truck waiting location is assumed to be the city surrounding area close to the port where trucks can wait before they gain access to the port. The capacity of this location is assumed to be infinite.

CHAPTER VI

INTEGRATED PORT MODEL RESULTS

In this chapter, a series of scenarios will be presented to show the results of the VITS Integrated Port Model from the methodology discussed in Chapter 5. The port simulation validation will also be discussed.

6.1 Scenarios for the Port Model

These scenarios will demonstrate the functioning of the integrated port model within the VITS framework using the Port of Gulfport as the example. For each scenario, the simulation model is run for 60 days including 6 hours for warmup using a single replication for the purpose of demonstration. Note that the base condition in our scenarios refers to our 1997 freight volume data [34].

6.1.1 Scenario 1: The Integrated Port Model Within the VITS Framework

In this scenario, the integrated port model of the Port of Gulfport will be used with the data from the base condition. Since the data used to drive the VITS does not contain information on the type of cargo transported, a generic cargo type will be assumed. There are nine berths configured for the Port of Gulfport example used here and the access gate currently has a capacity of four parallel lanes. Table 6.1 shows the summary of the results using base condition data.

Table 6.1 Results of Port Scenario 1 Using Base Condition Data

Average Hours for Vessels Waiting for Available Berth	3.01 hrs
Time-Weighted Average Percentage of Generic Storage Used	32.58 %
Average Hours Spent at Berth 1	63.97 hrs
Average Hours Spent at Berth 2	66.88 hrs
Average Hours Spent at Berth 3	65.23 hrs
Average Hours Spent at Berth 4	76.38 hrs
Average Hours Spent at Berth 5	0.00 hrs
Average Hours Spent at Berth 6	0.00 hrs
Average Hours Spent at Berth 7	0.00 hrs
Average Hours Spent at Berth 8	0.00 hrs
Average Hours Spent at Berth 9	0.00 hrs
Average Truck Wait Time for Entry Into Port	1.30 hrs
Average Time Spent at Truck Access Gate	0.05 hrs
Average Daily Short Tons Handled	21,321 tons

In this case, we can see that on the average, vessels spend about 3 hours before berthing. This is partly due to the fact that some vessels arrive when the berths are closed (past working hours). Only 4 berths are used over the 60 days that the simulation was run signifying that the available number of berths is sufficient to meet demand. The average time vessels spend at the berth is a little less than 3 days. For trucks going into and out of the port, we can observe that the average truck spends about 3 minutes at the access gate after waiting for an average of 1.30 hours to gain access into the port. This is reasonable since some trucks may arrive to the location at night when the port is closed. The access gate operating hours used in this scenario is from 8 a.m. to 6 p.m. The port handles about 21,321 short tons per day on the average.

6.1.2 Scenario 2: Increase in Freight Traffic

In this scenario, the amount of traffic in the system has doubled that of the base condition. However, all other aspects of the port are kept the same. Specifically, the storage capacities of the port as well as the access gate capacity (the number of parallel lanes) are the same as in Scenario 1.

We can see from Table 6.2 that the number of berths utilized has increased. The port now handles about 37,407 short tons per day on the average. This figure is slightly lower than expected due to the fact that the access gate is limiting the flow of trucks into the port. This is evident by the 79.40 hours average time spent by trucks waiting in the surrounding area of the port before getting access into the port. This suggests that the access gate capacity should be increased to allow better flow of trucks into the port.

Table 6.2 Results for Port Scenario 2 With Doubled Traffic Flow

Average Hours for Vessels Waiting for Available Berth	3.65 hrs
Time-Weighted Average Percentage of Generic Storage Used	71.28 %
Average Hours Spent at Berth 1	64.05 hrs
Average Hours Spent at Berth 2	60.84 hrs
Average Hours Spent at Berth 3	58.01 hrs
Average Hours Spent at Berth 4	66.41 hrs
Average Hours Spent at Berth 5	69.80 hrs
Average Hours Spent at Berth 6	61.25 hrs
Average Hours Spent at Berth 7	69.79 hrs
Average Hours Spent at Berth 8	0 hrs
Average Hours Spent at Berth 9	0 hrs
Average Truck Wait Time for Entry Into Port	79.40 hrs
Average Time Spent at Truck Access Gate	0.09 hrs
Average Daily Short Tons Handled	37,407 tons

6.1.3 Scenario 3: Improvements to the Port to Handle Increased Traffic

Building from Scenario 2, some changes were implemented to the port in order to reduce the excessive amount of time that trucks wait before gaining access to the port. This is done by first increasing the access gate capacity to ten parallel lines. The capacity of the truck processing area will be doubled to handle increased truck traffic. Observe that the average percentage of freight storage capacity used in Scenario 2 is 71.28%. According to the LATTs study [3], the “Sustainable Practical Capacity” or SPC is typically around 75% of the maximum capacity. The SPC is defined as the capacity at which the port can operate at sustainable, safe, and economical levels. In lieu of this, the storage capacity of the port may not be adequate with the current level of freight traffic so the storage capacity will be doubled in this scenario.

Table 6.3 Results for Port Scenario 3 With Increased Port Capacities

Average Hours for Vessels Waiting for Available Berth	3.65 hrs
Time-Weighted Average Percentage of Generic Storage Used	65.99 %
Average Hours Spent at Berth 1	60.61 hrs
Average Hours Spent at Berth 2	60.77 hrs
Average Hours Spent at Berth 3	58.12 hrs
Average Hours Spent at Berth 4	66.44 hrs
Average Hours Spent at Berth 5	69.78 hrs
Average Hours Spent at Berth 6	61.22 hrs
Average Hours Spent at Berth 7	69.92 hrs
Average Hours Spent at Berth 8	0.00 hrs
Average Hours Spent at Berth 9	0.00 hrs
Average Truck Wait Time for Entry Into Port	39.31 hrs
Average Time Spent at Truck Access Gate	0.14 hrs
Average Daily Short Tons Handled	39,966 tons

As we can see in Table 6.3, the percentage of storage capacity used is now around 66%. The average daily tonnage is now nearly 40,000 tons, which is consistent with

doubling of freight in the system (compared with base condition). There is also significant improvement in terms of wait times for the trucks entering the port by a reduction of 50.5%, although it is still high at 79.40 hours.

6.2 Validation

The accuracy of the VITS Integrated Port Model depends on the quality of the data provided and the estimated parameters assigned to the processes and capacities. Simulating using base condition data for 60 days, running five replications, we compared our results with data from the Port of Gulfport [19] to gauge our port simulation model.

According to Couvillion and Allen [19], the Port of Gulfport personnel reported that berth space was not a problem, and that the current berths could accommodate more vessels. Our simulation result shows that the berth utilization averages around 20.29%, which is consistent with that report. The lowest utilized berth had an average utilization of 21.12% while the highest utilized berth had an average utilization of 58.87% (out of the four busiest berths at the port). The other five berths are mostly unoccupied with less than 10% utilization. On the issues of vessel dwell times, vessels spend approximately 2.03 days docked at the Port of Gulfport with a range of less than a day to over 10 days. Our simulated figure for this time spent at the port is 3.06 days with a range of 2.36 days to 9.72 days. These results indicate that the VITS integrated port model can reasonably simulate port operations.

6.3 VITS Integrated Port Model Conclusion

There are numerous decision variables that can affect the entire port operation. Decision variables such as the access gate capacity, access gate operation hours, berth operation hours, number of loading/unloading resources, cargo type handling, and the amount of port storage capacity can be considered with the VITS integrated port model. The scenarios showed that a simple doubling of resources does not always produce a doubling in throughput as would normally be assumed. They also demonstrate the interactions that occur between port resources, and the bottleneck that could occur under different operating conditions. This is where the VITS would be a more robust tool compared with the current planning tools that estimate throughput based on documented port capacities.

CHAPTER VII

CONCLUSION AND FUTURE WORK

Intermodal freight transportation planning is a complex effort that currently suffers from lack of a comprehensive planning tool. The overall purpose of this research is to determine ways to integrate fragmented transportation research effort and knowledge towards the building of a large-scale (e.g. statewide) intermodal freight transportation simulation modeling methodology that captures the random variation inherent in transportation systems, as well as complex interactions of how freight moves over the network and through intermodal terminals, and to demonstrate the utility of such modeling and analysis tool.

The VITS prototype was successful in using transportation OD data as input, applying the appropriate level of detail for simulating major modes and intermodal connectors in a statewide network, and developing transportation planning functionalities to account for deficiencies in existing simulation software. Two groups of scenarios demonstrated the viability of a statewide freight for planning and improving intermodal transportation systems.

There are numerous opportunities for improving the innovative VITS concept. Since the accuracy of the VITS is dependent on the quality of the input data, future effort in data derivation is important. The following will describe some specific future work that can be done to improve to the existing prototype.

Flexible routing algorithms that support user defined methods should be researched and implemented in future versions. This will allow users to define different dynamic routing objectives for the vehicles based on criteria such as minimizing distance, cost, time, etc.

Automated creation of network from existing transportation planning packages or geographic information software (GIS) would aid the building the initial VITS network. This allows easier matching between the transportation network from the traffic demand modeling software with the VITS transportation network. Having closely matched transportation network will facilitate freight data input into the VITS. A more automated process of generating the VITS transportation network would facilitate keeping the VITS current with the actual transportation network.

To enhance the ease of use, a built-in interface for user input should replace the Excel input spreadsheets. This will allow the user to set vehicle characteristics, port characteristics, and other simulation parameters all in one place without the need to access external spreadsheets.

The future VITS will benefit from the ability to define more vehicle types (differing capacity) to examine impact of vehicle types such as different truck sizes. The inclusion of different vessel types and sizes would allow users to model berths at ports with more precision in that the drafts are also considered when berthing. All of this will require more detailed and complete freight data, as well as vehicle inventory and use data.

To more accurately capture background traffic (non-freight) for the VITS, the inclusion of OD data for passenger traffic is needed. The future VITS should also include new and improved systemwide performance measures from the forthcoming NCIT study. This will allow the users of the VITS to make comparisons between systems and modes of transportation in ways not previously possible.

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