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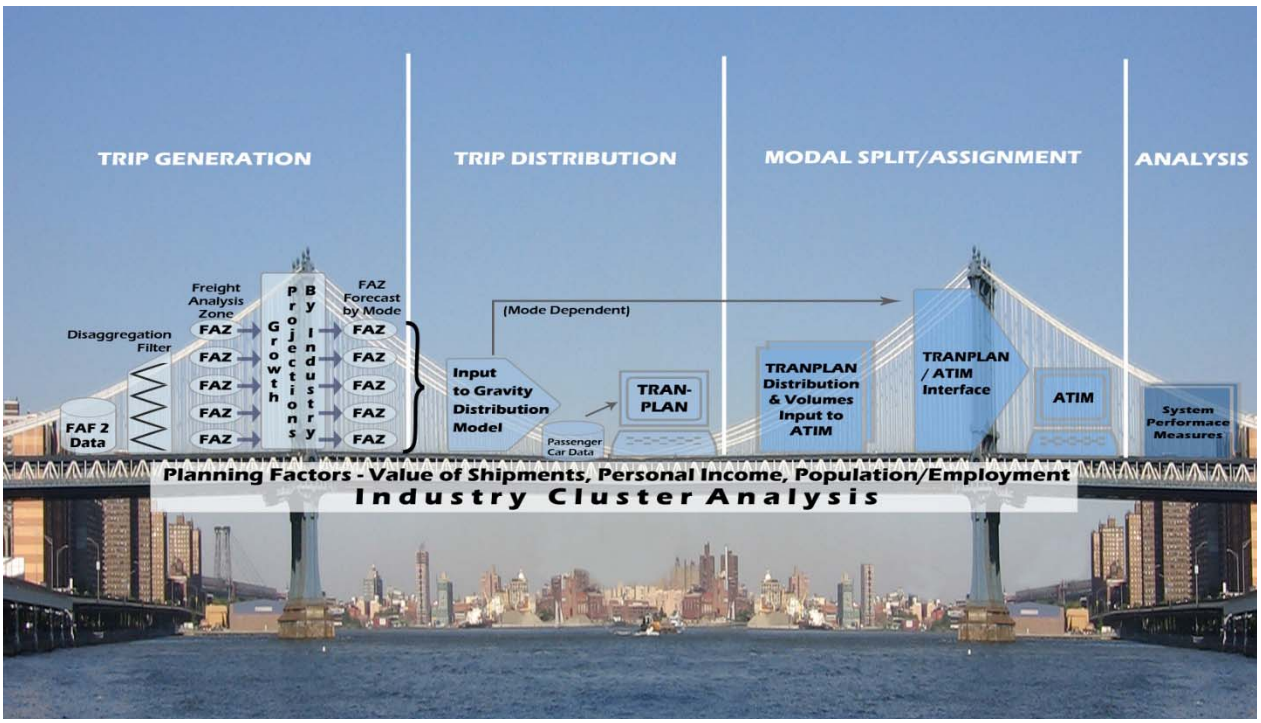
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Transportation Infrastructure in Alabama



Bridging the Data & Information Gap

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1. Executive Summary

The 2007 – 2008 research into Transportation Infrastructure in Alabama had two main focal points and many meaningful findings. The two main focal points were the creation of the Freight Planning Framework, with particular emphasis on the disaggregation and use of national level freight data at the state and local level, and the refinement and continued development of the Alabama Transportation Infrastructure Model (ATIM) for analysis and communication of transportation infrastructure issues. Additional findings of significant interest were insights into freight planning and modeling of operations at ports of entry. Following are the highlights of the research, including the embodiment of the Freight Planning Framework, the development of freight planning factors and Freight Analysis Zonal disaggregation techniques, and the advancement of the ATIM (including a transition to a Java-based platform) and other discrete event simulations of freight movement and processes.

1.1. The Freight Planning Framework (FPF)

Freight planning in the United States has traditionally been performed by the application of backward-looking data analysis and forward-projecting trend line forecasting. This method of data development and analysis is wholly inadequate for the economic environment of today. At best, trend line forecasting assumes that whatever has happened in the past is going to be replicated in the future. It is well known that this does not hold true in the arena of economic development.

In response, the UAH research team has developed the Freight Planning Framework (FPF) which has a foundation in the use of industry sectors to focus the understanding and analysis of the economic factors in an area to allow knowledgeable and informed decisions on transportation infrastructure issues. The concept behind this approach is that if the underlying principles of freight demand generation can be discovered for a particular industry, the ability to accurately predict infrastructure requirements due to the need to access the freight transportation system is enhanced. Once the freight generation principles of an industry is determined, it is theoretically possible to apply those principles anywhere the industry exists to estimate the demand for freight system requirements.

The FPF utilizes Value of Shipments, Personal Income, Population, and Employment as freight planning factors. One factor alone does not adequately define the demand for freight system requirements. The planning factors used are capable of describing the freight generation characteristics of a region and the freight attraction characteristics of that region. Figure E.1 provides a graphic depiction of the FPF.

1.1.1. Trip Generation for the FPF

Research was performed on the factors that influence freight demand as well as the development of Freight Analysis Zones (FAZ) to refine and deepen the effectiveness of the FPF.

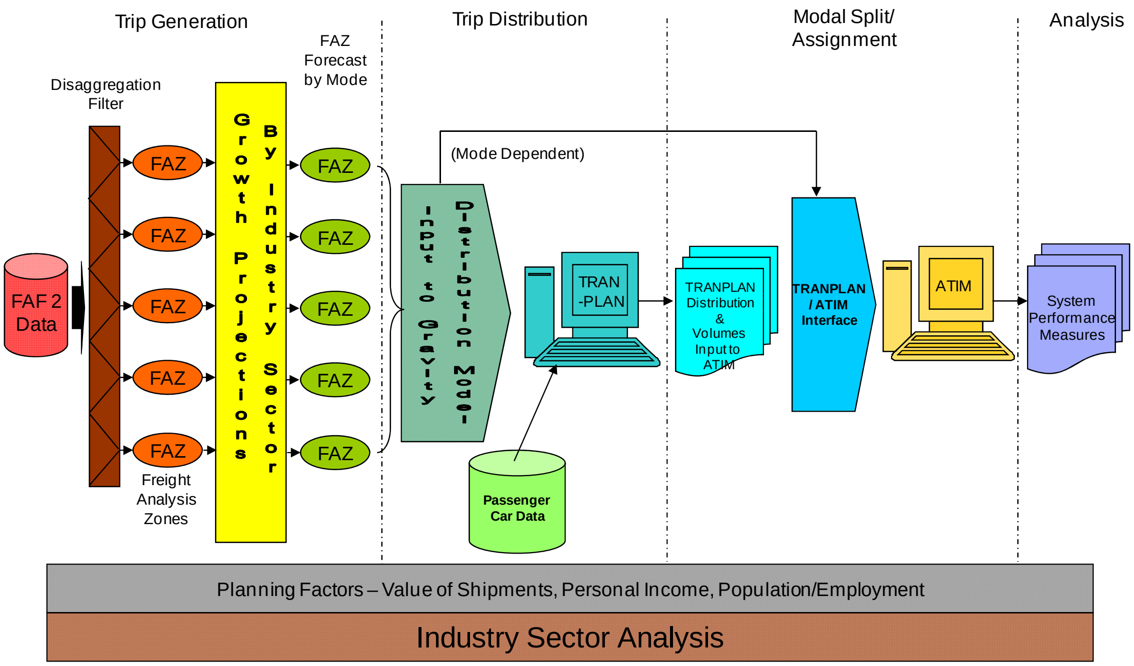

Figure E.1 The Freight Planning Framework.

1.1.1.1. Freight Planning Factors

It is difficult to incorporate freight information into transportation models and plans because freight data is proprietary and the release of that data is considered to be detrimental to the company's competitive position. In the United States, many national freight databases aggregate information to the individual states, or major communities in the states. For example, the Freight Analysis Framework, Version 2 Database (FAF2), developed and distributed by the Federal Highway Administration (FHWA), contains freight flows for 114 zones at the national level.

The use of national freight data at the local level is challenging due to the high level of aggregation. In most instances the disaggregation of freight data from national levels for use in local areas has been based on the factor *Employment* by prorating the employment in the local area to the total employment in the study region. The use of employment as a planning factor has come under scrutiny due to the inability of the factor to accurately estimate the effect of productivity improvements to increase production without increasing employment. To provide insight into potentially new factors to use for freight planning, this research investigated the factors of population, employment, personal income, and value of shipments independently and in combinations. TRANPLAN software was used to assign the truck trips from the FAF2 database according to the freight factors, and these results were compared to actual truck counts conducted by ALDOT.

The results of the research indicate that for trucks carrying an average of 30 tons, the contribution of each variable was mostly similar, with the personal income and value of shipments variables showing a slight advantage over the others as disaggregation factors. A comparative Nash-Sutcliffe statistic was determined for each variable variation, and it was determined that the trips produced by the model had only a mild relationship to the comparison data. Further experimentation was conducted that varied truck capacity from 0 to 30 tons, which indicated that an average truck capacity of 10 tons per vehicle yielded the closest match to the actual counts provided by ALDOT. Figure E.2 depicts the results of this analysis.

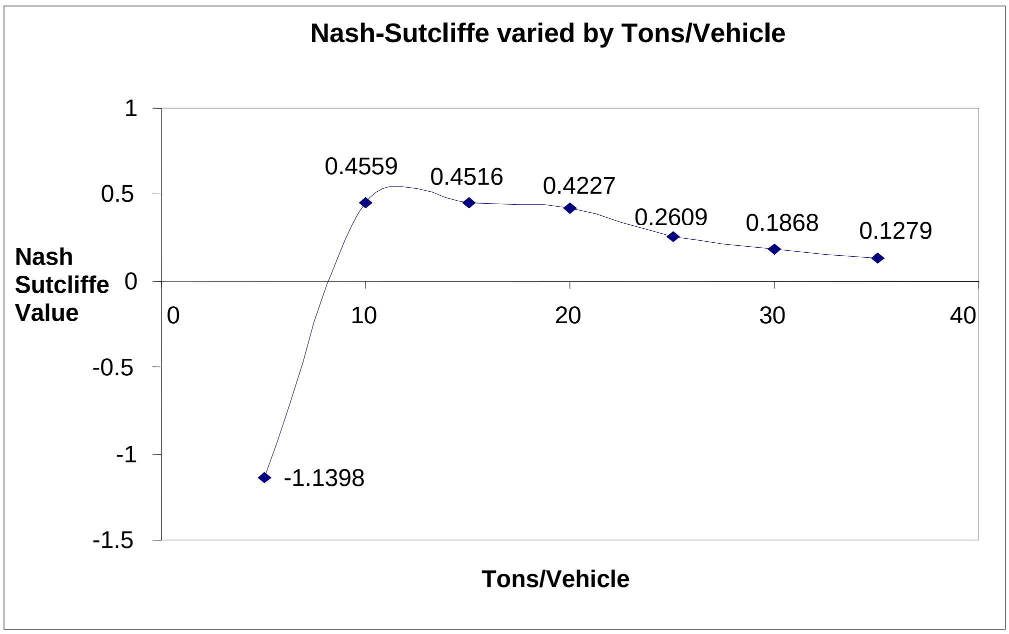

Figure E.2 Nash Sutcliffe's values for various tonnages.

When using 10 tons and varying the factors, the highest achieved N-S coefficient was achieved when the factors *Value of Shipment* and *Personal Income* were used in the analysis, although the number of vehicles developed by the model is still short of the actual counts. These findings indicate that the research has not yet found the best freight factors to use but it would appear that the researchers are actually on the trail of some promising results.

1.1.1.2. Freight Analysis Zones

The ability to plan and forecast freight demand for transportation infrastructure is limited by the lack of available data at the level of detail that is meaningful to the transportation planner. The FAF2 database's 114 nationwide zones (and most states having two zones or less), limits the ability of the State or Metropolitan Planning Organization transportation planner to use the data. As shown in the prior section, disaggregation of the data to a more detailed level is needed to apply the freight flow data to whatever Statewide and Urban Planning model is currently being used. The fundamental problem is how to disaggregate the data to a usable level, without reducing the quality of the data to a point where its use would cause the introduction of excessive error. The idea behind the development of Freight Analysis Zones (FAZs) is to gain the ability to disaggregate national databases freight data into smaller areas that can be utilized for effective freight planning.

In 2006, the Federal Highway Administration funded four pilot projects to develop methods to disaggregate the FAF2 to the county level. Disaggregation at the county level within Alabama would result in a 67 by 67 matrix for each of 42 commodities and 6 travel modes listed in the FAF2. This may be achievable in Alabama but in states such as Texas and Georgia, with significantly more counties, this could be a much more difficult assignment. The research team at UAH believes that the county level may be too detailed for most states to use for freight planning. It is preferable for Alabama (and other states) to find a more "optimal" planning level that is, in the case of Alabama, "larger than 2, but less than 67." This optimal value should result in an aggregation of data that provides a necessary level of information without excessive detail. A guiding principle in the development of FAZs is that the zones should be homogeneous within the cluster, but diverse from the surrounding clusters, thus promoting cross-zonal traffic.

The research team assessed various economic and geographic variables to determine similar clusters of counties throughout the state.

Figure E.3 shows the final cluster solution, resulting in the formation of 27 FAZ.
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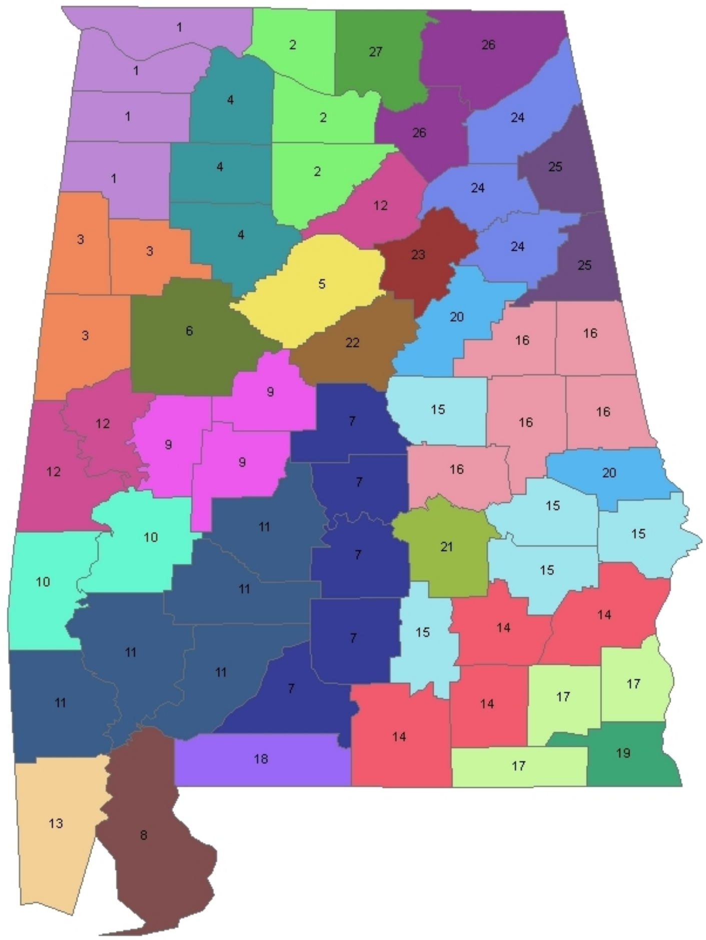

Figure E.3 – FAZ's for Alabama

In order to determine if freight activity, disaggregated to the FAZ level, provides an equivalent evaluation of freight activity at a county disaggregation, a case study was created utilizing the State of Alabama Freight Model. The case study compared the trips assigned to a statewide highway model for a 67 county input file and a 27 FAZ input file. A Nash-Sutcliffe calculation between the outputs of the two runs indicated that there was no statistical difference between either when compared to base ALDOT truck counts. This result supports the hypothesis that FAZs can be used at the state level to limit the data collection needs for freight planning without reducing the quality of the assignment output.

Future research into the concepts of Freight Analysis Zones needs to continue through the examination of freight data disaggregation methods and travel model results. The various methodologies to disaggregate freight to the FAZs will help identify the impact of using FAZs, and the modeling of freight data will provide a mechanism to validate the various FAZs options.

1.2. Expansion and Enhancement of the Alabama Transportation Infrastructure Model (ATIM)

The UAH research team has expanded and enhanced the ATIM as a part of this research. Among the significant strides made to the ATIM were the development of performance measures, time of day procedures, and an interface to link directly to a travel demand model to generate traffic volumes. This interface eased the ability of the model to run various growth scenarios to assess when congestion would occur on the local infrastructure. In addition to these enhancements, the research team has completed the initial stages of a new version of the ATIM that is an agent-based model constructed on a Java platform. The new Java version will overcome many of the deficiencies of the former model.

1.2.1. ATIM Version 2.0

Though the ATIM has been very successful as a communication and educational tool for opening discussion to transportation infrastructure issues in Alabama, the UAH research team realized after two years of continued development that the software used to create and run the discrete event simulation, ProModel, was essentially at the limits of its capabilities. The research team has since switched to a Java platform (ATIM Version 2.0), which expands the capabilities of discrete event modeling into “agent-based” simulation where each entity in the model is capable of using a logic framework to maneuver the simulated network.

The UAH research team has developed a highly flexible and extensible agent-based model of freight traffic on Alabama highways. In the ATIM V2.0, the agent is the unique driver of a vehicle. The logical distinction between the driver and the vehicle is currently under development and the code set supports such a distinction. The logic for each entity type will be developed in the next research effort.

The core functionalities originally outlined for this initial development phase were:

- Fully dynamic movement of individual vehicles
- Dynamic route-planning
- High flexibility of inputs
- Graphical display of vehicles.

All of these original functionalities have currently been achieved. However, the model has just now become a scientific tool. As a science tool, the next and most important step of maturation is co-verification against the TRANPLAN traffic model. Special care must be taken to ensure that the scenarios and metrics are truly comparable. After verification and validation, the core capabilities in the tool can be extended rapidly to provide important future capabilities, including the ability to model multiple lanes, multimodal traffic, and additional routes (either on a statewide basis, such as I-22, or a more localized basis, such as a City or MPO area).

1.2.2. Regionalization

The original ATIM is built upon the same platform as the Mississippi VITS model. It was the desire of the research team at UAH to pursue uniting the two models to investigate the ability of a discrete event simulation to provide meaningful data and analysis capability across state lines. Unfortunately, the research team encountered technical and financial issues that simply could not be overcome to achieve this goal of linking the models in the ProModel discrete event environment. The joining of the models is possible, but with the move to a more advantageous Java-based model, a better solution may be to convert the VITS into a Java application.

1.2.3. Improve Graphics

After a significant level of effort, it was determined that the ProModel programming environment does not provide any opportunity to substantially improve the graphics of the icons. The ATIM V2.0 in a Java based application has the potential to achieve a more appealing graphic presentation. Improved graphics will be pursued with ATIM V2.0.

1.2.4. Freight Scenarios Using ATIM

A detailed understanding of the impact of the projected increase in truck traffic on the existing highway system is needed and important in developing a focused plan to accommodate the anticipated increase. The UAH research team developed a seamless interface between the ATIM and TRANPLAN, a travel demand model, to allow for easy sharing of volume, route and Origin/Destination data. The integration of these models produced a tool capable of quickly analyzing scenarios and events on the transportation infrastructure and can be used to evaluate alternative solutions.

After the models were integrated, it was possible to run several freight scenarios with the ATIM to test the statewide infrastructure. The first scenario tested was a trend line growth projection, which factored the existing year traffic counts to the year 2015 using historic growth rates. Figure E.4 depicts the congested routes that are expected to occur from the trend line scenario (a total of approximately 1,400 miles).

A second scenario tested the statewide network for year 2015 using the freight projected by the FAF2 database and disaggregated according to the FPF. The results of this scenario are depicted in Figure E.5. As shown, approximately 1,800 miles of roadway are projected to be congested under this scenario. Other scenarios of greater growth were modeled, but this example illustrates that existing freight planning techniques have significant shortcomings and, the possibility exists to get more meaningful information for planning purposes from national databases, such as the

FAF2. This ability to quickly develop and test scenarios in the two modeling packages represents a significant improvement, without reducing the accuracy of the models.

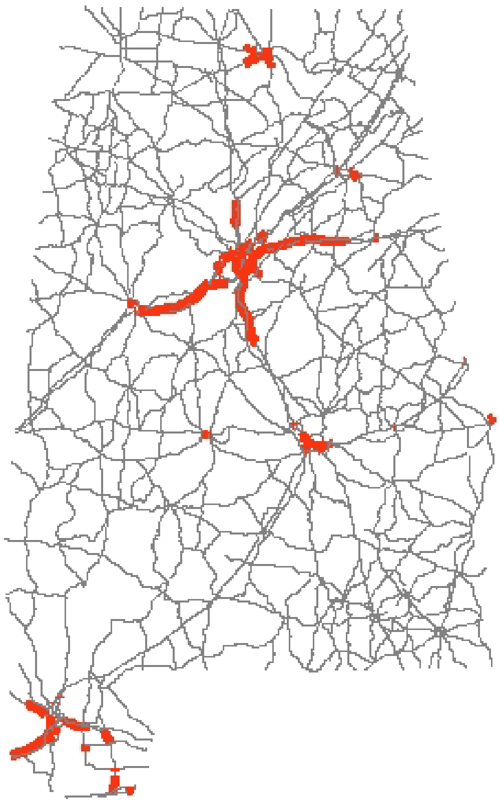

Figure E.4 Congestion from Trend Line Analysis

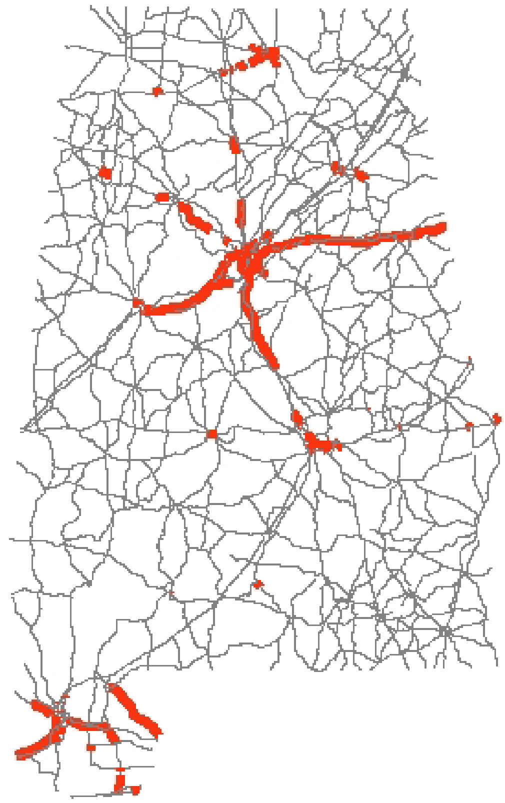

Figure E.5 Congested locations using the FAF2 2015 projection.

1.2.5. Rural Time of Day

Presently, the ATIM creates traffic flows across a highway network for a twenty-four period using independently calculated daily volumes for trucks and passenger vehicles. These daily volumes were initially distributed in the ATIM using a basic 20/60/20 split over the course of the morning, midday, and night time periods of a day. This methodology was effective for simulating the cumulative traffic flow across the network, however, the model could be enhanced if additional information were known regarding hourly volume distributions for either vehicle type and if these distributions varied based on network location (urban vs. rural) or facility (arterial vs. interstate). Research was performed on these parameters to determine if the existing procedure could be improved.

Research of the ALDOT hourly counts and other data sources indicated that enhancements could be made to the existing volume distribution for trucks and passenger cars into the ATIM. The ALDOT data revealed that the volume profile in urban locations was similar for both interstate and arterial routes with distinct morning and afternoon peaking characteristics. The ALDOT data for rural locations was similar to the urban results for arterial routes, but the rural interstate profiles lacked a morning peak. Data from the *NCHRP 365* confirmed the hourly profiles determined from the urban and rural arterial ALDOT data, with a slightly higher peaking characteristic in the afternoon. Truck-specific data found through the *Quick Reference Freight Manual* indicated that the hourly distribution of trucks differs significantly, resembling a bell-shaped curve with a peak around noon. Figures 1.6 and 1.7 depict the recommended hourly distributions for urban routes/rural arterial facilities and rural interstate facilities.

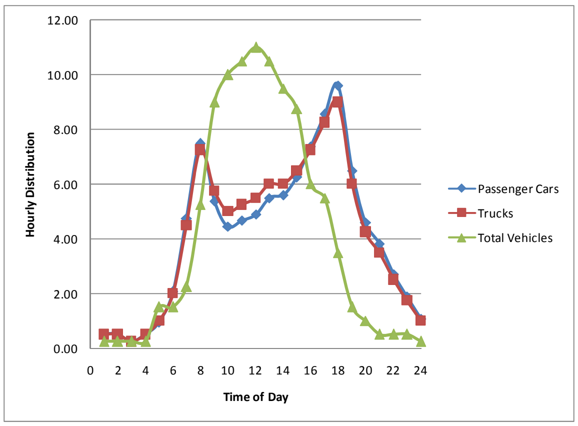

Figure E.6 Recommended Hourly Profile for Urban Routes and Rural Arterial Facilities

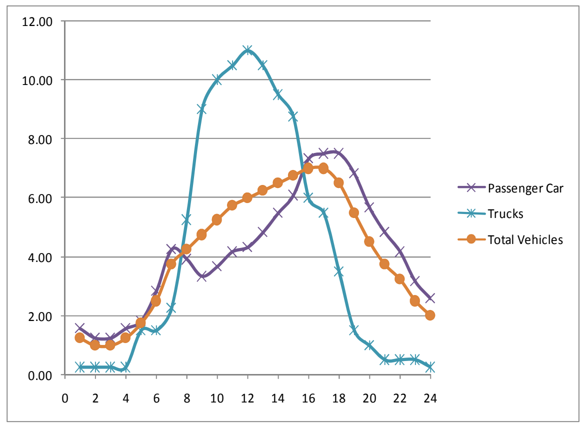

Figure E.7 Recommended Hourly Profile for Rural Interstate Facilities

1.2.6. Evaluation of Commuter Rail Service in an Alabama Metropolitan Planning Organization

A discrete-event simulation of the I-10 tunnel in Mobile was performed to determine the amount of traffic that would need to be diverted in order to increase truck traffic due to the expected increase in container traffic at the Port of Mobile. A simulation of peak hour conditions from basic data obtained from ALDOT indicated that the tunnel was presently operating at volume to capacity of near 0.9, which is the minimum ADLOT threshold for congested conditions. Subsequent simulations demonstrated that existing conditions could be maintained with a 20% increase in truck traffic if 10% of the existing passenger car traffic were shifted to another mode of transportation (such as commuter rail or express bus or ferry).

1.3. Discrete Event Simulation

Conceptual simulation models of intermodal facilities can be used to identify needed improvements and the potential benefits of continuous improvement activities. The use of simulation for intermodal operations at the International intermodal Center at the Huntsville/Madison County International Airport and the Alabama State Docks in Mobile can be used to establish performance targets for planning future process improvement activities. The research team has developed significant contributions to the research of modeling intermodal operations as a result of this effort.

1.3.1. Conceptual Framework

The research team has developed a broad reaching, conceptual framework for the development and operations of simulation models for ports and intermodal sites. Using this framework, the research team was able to simulate specific operational issues at a port container and coal facility as well as an intermodal center. In addition, the resources needed to handle security inspections of containers in a port or intermodal terminal were also addressed.

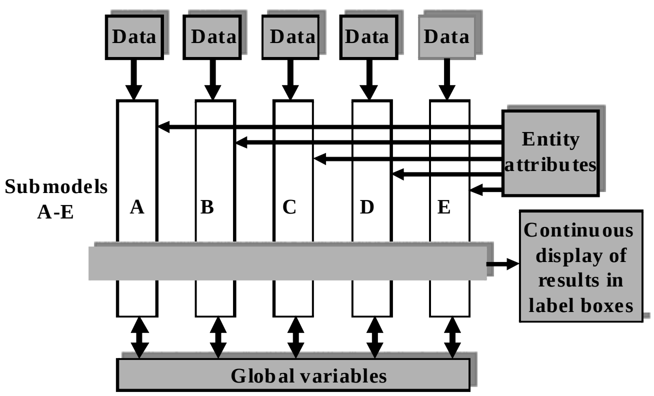

Figure E.8 Conceptual Framework

A diagram of the conceptual framework used for the model development is shown in Figure E.8. The model consists of a number of sub models that run independently with each model having its own data input and entities with specific attributes. For example, the data input can include arrival and service times, storage capacities, and available resources. In the conceptual framework, data are shared between the sub models by the use of global variables. The content of global variables can be altered within any sub model with the new values immediately shared and used by any other sub model. These global variables not only pass data between the sub models, but they can also be used in logic statements to control the movement and routing of entities, branching logic, and updating entity attributes. The framework greatly reduces the time needed for development, modification, model debugging, and verification and validation.

ProcessModel was selected to implement the conceptual framework and specific models were developed for the coal terminal, container terminal and intermodal center. Simulations were run to verify the existing throughput capacities and to assess if future demand could be met.

1.3.2. Port and Intermodal Center Capacity Assessments

The coal terminal simulation tested tugboat alternatives for moving barges that would improve the throughput of coal at the McDuffie Island Terminal in Mobile, AL. The simulation determined that a change in the existing tugboat protocol would result in lower tugboat utilization and larger coal throughput. Subsequent simulations using the enhanced protocol with additional tugboats were not found to substantially increase throughput. The existing protocol required complete utilization of tugboat resources and little opportunity for throughput expansion.

The container terminal simulation was constructed to validate the design capacity of the Mobile Container Terminal (depicted in Figure E.9). Several runs were made that varied the arrival rates between full and empty trains and ships entering the terminal to determine how many containers could be processed given the existing resources. The research indicated that simply reducing the time between arrivals of entities does not necessarily increase container activity. For example, decreasing the time between arrivals of ships requires an adequate arrival of containers from trains and trucks so ships can be loaded and exit the terminal. The results of the simulation indicated that arrival times could be increased with lower terminal time and increased container throughput, however, the sequencing of the entity arrivals can result in lengthy wait times and require the need for large storage yards if not properly structured.

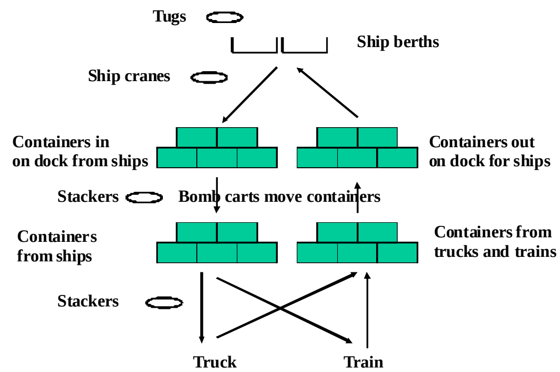

Figure E.9 Container Terminal Model

The International Intermodal Center in Huntsville, AL was modeled to determine if the available throughput can satisfy anticipated demand and if sufficient resources are available to meet anticipated growth in demand. The results of this research indicated the current throughput of the intermodal center can be met with considerably fewer resources than currently offered and that the existing resources can handle considerably more containers without a significant deterioration of entity time through the terminal.

1.3.3. Container Inspection Assessment

Due to the recent facility expansion at the Alabama State Docks and increased global security issues, a simulation tool was developed to determine the resources needed to minimize the disruption caused by container inspections at port terminals. The findings of the simulation indicated that given the currently defined intermodal center operation, the minimum quantity of inspection resources that will not negatively impact entity throughput are six tailgate inspection stations, three intensive inspection stations and one general purpose inspector. The impact of increased container inspection can be minimized or even eliminated by an overabundance of inspectors and inspector stations. Therefore, tradeoffs between inspector and inspector station cost must be made with the time entities at the terminal. The simulation results show that the adding of additional resources can basically eliminate any entity delays. The number of carts for moving containers within the intermodal terminal may be a limiting factor when the number of inspection resources is reduced. An increase in the number of carts resulted in the need for fewer inspection resources.

1.4. Repository for Transportation Data

The research team developed the OFLT Online Information Warehouse in 2007 to manage transportation data used in research and to provide public access to research presentations and publications. The goal of this Online Information Warehouse was to facilitate the effective and efficient retrieval of data and information pertinent to the research process to UAHuntsville personnel and external researchers.

As part of the 2007-2008 research, OFLT revised the Online Information Warehouse and made it accessible through the UAHuntsville College of Business Administration Research Centers website (see Figure E.10). The move from its original website will increase its exposure not only to UAHuntsville personnel and research staff but to outside researchers who visit the College of Business website.

The Online Information Warehouse provides a benefit to UAHuntsville researchers, many of whom work on multiple contracts that utilize data sets developed during previous projects and allowing researchers to find the data, information, reports and presentations used and developed from previous transportation research at UAHuntsville.

Figure E.10 – Screen Capture of Improved Data Repository

1.5. Student Research Initiatives

Doctoral and Masters Students bring fresh ideas and concepts to research. The research performed during this period of performance provided several opportunities for students to not only participate, but take lead positions in performing and managing the projects. These student research initiatives have the potential to encourage the development of new ideas that can be expanded into further research efforts in the coming years. Each of the projects has either been published in conference proceedings or they are in the process of being submitted for publication. Other than formatting of report section titles, no changes have been made to the submitted student research presented here. The student projects during this research period covered the following topics:

- A Methodology to Use FAF2 Data to Forecast Statewide External-External Trips
- Final Report The Impact of BRAC on Freight Movement Within North Alabama
- Effectively Using the QRFM to Model Truck Trips in Medium-Sized Urban Communities

1.6. Conclusions and Next Steps

There were two main topics to be considered when this research began, the development of freight analysis zones and the continued development of ATIM. As the research progressed, it became obvious that there was something larger than simply disaggregating national data through freight analysis zones and that the ProModel platform for ATIM was restricting the development of the simulation into the decision analysis tool that all thought it could be.

The freight analysis zone research led to the development of a methodology for integrating freight into the transportation models and plans at the state level and at the Metropolitan Planning Organization (MPO) level. It is believed that this Freight Planning Framework (FPF) is a significant step forward in freight planning and modeling. There is also a significant amount of research to do to refine each individual part of the FPF process. This will be a main focus as the UAHuntsville research team continues on the path to improve the ability of states, regional planning offices (RPOs) and MPOs to integrate freight considerations into plans and activities.

The limitations encountered in the discrete event simulation of the Alabama transportation network led to a breakthrough in the overall development of the tool. The step made to revise the ATIM and develop Version 2.0 in a Java based environment provides significant opportunities for tool enhancement. An agent-based system will provide significantly upgraded capabilities to communicate transportation issues to stakeholders at all levels. There will be significant resources applied to the refinement and continued development of the ATIM V2.0 tool.

2. Introduction

Alabama is standing at the threshold of a potentially dramatic change in the global perception of the state. Over the last decade, Alabama has been recognized as a superlative state in terms of general business climate, start up capability, and training and development programs. Table 2.1 presents the Alabama rankings since 2004 for business climate in the opinion of several ranking organizations.

Table 2.1 State Business Climate Rankings 2004 – 2007

Ranking Organization	2004	2005	2006	2007
Pollina Corporate Top Ten Pro-Business States	4	5	9	8
Small Business and Entrepreneurship Council – Small Business Survival Index	8	8	4	10
Fortune Small Business - 10 Best States for Starting a Business	--	--	3	10
Site Selection Magazine – Business Climate Survey	10	7	8	5

In addition to these rankings, the Alabama Development Office has been touted in several major business and economic development journals and magazines as the first place to look for expansion projects. The Alabama Development Office has been ranked 1st, 2nd or 3rd by Site Selection magazine since 2004. Further, the Alabama Industrial Development and Training (AIDT) department was recognized as the leading industrial development and training team in the nation in 2006 and 2007. Table 2.2 presents the rankings of AIDT since 2000. All of this recognition of Alabama as a leading location for locating and operating a business in the United States means that the state is truly positioned to make a major step forward in the economic development sweepstakes.

Table 2.2 Expansion Management "work force training rankings" – AIDT

2000	#7		**2004**	#1
2001	#7		**2005**	#2
2002	#4		**2006**	#1
2003	#6		**2007**	#1

While the business climate and development organization recognition for Alabama is noteworthy, the score on transportation infrastructure is not as positive. Transportation infrastructure is a very important component necessary for the State to reach full economic potential and has not achieved the same high ranking as the economic development efforts.

An investigation into infrastructure on bridge deficiencies shows that Alabama has made progress since 1990 when 41% of the bridges were declared structurally or functionally deficient. In 2008, 25% of the bridges in the state are structurally deficient or functionally obsolete. The PEW Foundation graded Alabama infrastructure with a “D” in 2005 and a “C+” in 2008. The Corporation for Enterprise Development accentuated the difference between business climate and transportation infrastructure when they ranked Alabama #1 in 2007 in industrial diversity and loans to small business but graded the State’s infrastructure as an “F”, which was the lowest score of any state. The Reason Foundation Report on System Performance of State Highway Systems stated that Alabama ranks:

- 29th in overall performance and cost-effectiveness (in 2007 Alabama ranked 43rd overall).
- 29th in urban interstate congestion, with 45.98 percent congested.
- 39th in rural and urban interstate condition.
- 28th in deficient bridges — 24.93 percent of the state’s bridges are deemed structurally deficient or functionally obsolete.
- 40th in the nation in fatality rates per 100 million vehicle miles traveled.

It is encouraging to see the State progress in these national rankings, but it is also obvious that there is significant opportunity for continued improvement. In a speech at the 2008 Economic Summit for Alabama Leaders in Birmingham on October 15th, 2008, Governor Bob Riley stated that “Alabama is on the cusp of magnificence.” This does, in fact, seem to be a time of great opportunity for the State of Alabama, if the state can organize and step forward to take advantage of the situation.

2.1. Alignment of Research with Proposal Tasks

Since 2003, the research at the University of Alabama in Huntsville has focused on the interrelationships between economic growth and transportation infrastructure. The investigation of these interactions have led the research team in the Office for Freight, Logistics & Transportation to develop core competencies that are now starting to gain traction with transportation professionals at the state and national level and to provide the opportunity for value-added academic research into areas of freight transportation that have been ignored in the past.

These competencies are reflected in the tasks for the past year of research and the development of insight and tools available for the integration of freight planning into overall transportation plans at the state and Metropolitan Planning Organization levels.

The following sections will serve as a crosswalk for the research agenda set forth in the FY2007 research proposal, and the resulting research performed. This crosswalk is necessary as many of the projects accomplished mimic the real world of transportation in that the research is as integrated as the issues studied.

2.1.1. Task 1. Development of Freight Analysis Zones

The data provided by the FAF2 database is presented in a 114 origins and destinations (O-Ds) format of which the state of Alabama is represented by two of these O-Ds. It is important to derive the potential freight that is destined for, originating from, passing through, and internal to Alabama.

The FAF2 database is very large and trying to perform the derivation of Alabama-specific data manually would be tedious and resource consuming. The freight destined for and originating in Alabama is fairly easy to derive since only a sort of the existing FAF2 database is required. The freight that is simply passing through Alabama because of the geographic destination or origination point being such that Alabama is simply in the way is a more difficult task.

To determine what freight is passing through Alabama on the way to its destination, the origins and destinations that do not include one of the Alabama points must be evaluated as to the route most likely to be taken and whether or not that freight would pass through a highway in Alabama. This is a difficult task that necessitates the use of a computer program. In terms of trips originating in and destined to locations in Alabama (internal trips), the aggregate value is easy to determine and only requires a database search. However, since the zone structure for the database is limited within the state (there are only two zones representing Alabama), the development of an understanding of the freight patterns within the state is a challenge.

Once the freight destined for, originating in, internal to, and passing through Alabama is compiled, the manner of disaggregation must be applied to predict what segments of that freight will be destined for or originating in the particular points within Alabama. This could be performed at a county level, a metropolitan level, or in configured Freight Analysis Zones (FAZs).

In a state such as Alabama, it might be feasible to perform the disaggregation at a county level since there are only 67 counties. This would result in a 67 by 67 matrix of freight data. However, using the county level as the universal disaggregation method would create an unmanageable freight matrix for states that have significantly more counties, such as Texas and California. Additionally, there are many counties where the level of freight activity is so low that it really does not justify the expending of resources to include them in an analysis as an independent entity.

The use of metropolitan areas leaves out significant portions of state infrastructure that may need to be included in a freight analysis. The appropriate approach seems to be the development of FAZs that can be sized in such a way that each FAZ contains approximately equal proportions of freight activity. This could mean that a significant industrialized metropolitan area may be a FAZ and an aggregation of several rural counties may constitute a FAZ.

The specific tasks to be performed during this period of performance were:

- Develop the methodology for the establishment of Freight Analysis Zones in Alabama.

- Apply the FAZ methodology to freight in Alabama through the development of various freight flow models using the different zone structures.

- Perform analysis to compare different FAZ structures to county level freight planning zones to determine the benefits and costs.

Table 2.3 shows that the specific research items in the bulleted list above were performed with results presented in sections 3 and 4 of this report. Additionally, the Freight Analysis Zone approach to the study of freight movement is beginning to show true merit as a cost effective method in which to analyze freight demand and movement.

2.1.2. Task 2. Expansion and Enhancement of the Alabama Transportation Infrastructure Model (ATIM)

The Alabama Transportation Infrastructure Model (ATIM) developed in 2005 is a discrete event simulation that generates traffic flows over a twenty-four hour day. Automobile traffic and truck traffic are independently calculated and used to simulate overall traffic flows. The model also incorporates dynamics between modes of shipping. The ATIM is stochastic in that it incorporates 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.

The ATIM can estimate how changes in the network or changes in utilization of network components will affect the performance of the overall transportation system and effectively communicate the expected performance of system investment alternatives through powerful visualization and animation presentations.

In 2006, the model network and loading of data was completed and validation of the highway mode initiated. Validation and calibration of the model is ongoing with alternative data sets needed. To validate the rail and waterway modes, it is necessary to collect and analyze additional data. Access to this data is being pursued and headway should be made in the very near future.

The specific items to be researched during this period of performance were:

- Regionalizing through tying ATIM and VITS (the Mississippi model)

- Improving the Graphics

- Applying system performance measures within ATIM

- Exercising ATIM through running scenarios from other transportation entities

- Developing a methodology for determining rural time of day percentages

- Evaluating Commuter Rail Service in an Alabama MPO

Table 2.3 shows that the specific research items in the bulleted list above were performed with results presented in sections 5 and 7 of this report. The investigation into this task eventually led the team to the realization that the programming platform of the model should be changed from ProModel to a Java-based discrete event simulation.

2.1.3. Task 3. Modeling Intermodal Operations Using Discrete Event Simulation

Conceptual simulation models of intermodal facilities were developed and exercised. The models were used to present the benefits of simulation and modeling to the mangers of the intermodal operations for decision making. These conceptual models demonstrate proof of concept for presentation to intermodal facility managers in the region. Projects involved the International Intermodal Center at the Huntsville/Madison County International Airport and the Alabama State Docks in Mobile. The models developed during the projects focused on the effect of increasing freight volume on the immediate egresses to and from each facility and the resulting volumes on connector facilities in the region.

Table 2.3 shows that the specific research items were performed, with results presented in sections 5, 6 and 7 of this report. Discrete event simulations have produced the greatest opportunities for publishing of any of the topics the research team has promoted.

2.1.4. Task 4. Continuous Improvement in Logistics & Transportation Systems

A study of logistics operations was performed to understand the opportunities Alabama has in the transportation and logistics industry cluster identified in the 2005 report to U.S. DOT “Transportation Infrastructure in Alabama – Meeting the Needs for Economic Growth” produced with the support of the Office of the Secretary, U.S. Department of Transportation Grant No. DTTS59-03-G-00008.

Specific items researched in this period of performance are:

- What are the best performing logistics companies?
- What are the characteristics of the best performing companies?
- How do their activities relate to lean thinking?
- Development of lean logistics & transportation principles.

Table 2.3 shows that the specific research items in the bulleted list above were performed with results presented in sections 6, 7 and 8 of this report. The bulk of the research on this task appears in section 7, but there are related items in sections 6 & 8.

2.1.5. Task 5. Develop the Repository for Transportation Related Data and Information for Alabama and the Tennessee Valley Region

State level economic data is a major component of the Freight Planning Framework being developed by OFLT. Systems are in place for the continued development of the data repository. The data repository is accessible via the Internet with links to various datasets and research reports developed and compiled by OFLT. This report and all previous reports are available in the repository. Table 2.3 indicates that the repository itself is discussed in section 8.

2.1.6. Task 6. Student Research Initiatives

Doctoral and Masters Students bring fresh ideas and concepts to research. The OFLT utilized opportunities to support research with graduate student involvement in all research tasks in this period of performance. In addition, the student research initiatives have the potential to encourage the development of new ideas that can be expanded into further research efforts in the coming years. Specific research championed by graduate students is presented in section 9.

Table 2.3 Tasks – Research Matrix.

	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8	Section 9
Task 1	X	X					
Task 2			X		X		
Task 3			X	X	X		
Task 4				X	X		
Task 5						X	
Task 6							X

3. The Freight Planning Framework

Freight planning in the United States has traditionally been performed by the application of backward-looking data analysis and forward-projecting trend line forecasting. This method of data development and analysis is wholly inadequate for the economic environment of today. At best, trend line forecasting assumes that whatever has happened in the past is going to be replicated in the future. It is well known that this does not hold true in the arena of economic development.

The existing transportation infrastructure, which has outperformed original lifecycle projections, is quickly becoming inadequate and the speed at which capacity can be added is significantly slower than the pace at which current and future needs appear. Therefore, it is imperative that a new method for analyzing and forecasting freight demand on transportation infrastructure be developed, to ensure that the capacity improvements that are possible can be appropriately allocated from the scarce funds available. This belief has led the research into the Freight Planning Framework.

The Freight Planning Framework (FPF) was initially presented in the 2007 report on "Transportation Infrastructure in Alabama - Tools for Solutions", sponsored by the U.S. Department of Transportation, Federal Transit Administration, Project No. AL-26-7262-00, is a comprehensive methodology to incorporate freight transportation needs into the forecasting process. In that report, the FPF was described and components of the framework were discussed. To facilitate the discussion of the FPF, a short description is provided to familiarize the reader with the individual components.

As documented in the previous report, research was begun on several FPF components and the research approach was described. Significant headway has been made into several critical components of the FPF, illustrated in figure 3.1, and each component will be described in the following narrative.

The foundation of the FPF is the use of industry sectors to focus the understanding and analysis of the economic factors in an area to allow knowledgeable and informed decisions on transportation infrastructure issues. The concept of FPF is if the underlying principles of freight demand generation can be discovered for a particular industry, the ability to predict accurately the infrastructure requirements due to the need to access the freight transportation system is enhanced. Once the freight generation principles of an industry are determined, it is theoretically possible to apply those principles anywhere the industry exists to estimate the demand for freight system requirements.

The FPF utilizes Value of Shipments, Personal Income, Population, and Employment as planning factors. One factor alone cannot adequately define the demand for freight system requirements. The planning factors used are capable of describing the freight generation characteristics of a region and the freight attraction characteristics of that region.

If employment is the only planning factor used for freight planning, increases in production output as a result of productivity improvement initiatives would not be captured, since employment stayed level. Therefore, there would be no indication, from the freight factor, that the demand for additional freight capacity was taking place. If the same amount of production is accomplished with fewer employees due to the implementation of technology or productivity improvements, using employment as the sole planning factor would actually forecast a decrease in the demand for freight requirements. Value of Shipments (VoS) is used to overcome the problems with employment as a factor. As productivity increases, VoS increases, regardless of employment. Seasonal or structural fluctuations in employment do not affect VoS. Overall, VoS provides a more consistent factor to use as a freight factor.

Personal Income (PI) can be used as a proxy for the attraction of freight to an area. Perceived affluence of an area increases as PI increases and as the perceived affluence of a region increases, people are willing to spend more, creating demand for products. As PI decreases in a region, the population perceives a loss of affluence and spending slows, reducing demand for products in the region, thus reducing the need for freight system access.

Population and employment are traditional factors used in transportation planning. Population is a proxy for the volume of vehicles in the region, from which the number of trips and distances can be derived. Employment has traditionally been used as a proxy factor for freight. These factors were developed to use in a time when the capacity for freight was not constrained and thus more emphasis was placed upon the personal vehicle traffic to and from a workplace but not for the volume of freight.

The Freight Planning Framework (FPF) builds upon the traditional four-step transportation planning process by creating a forward looking approach to the trip generation issues described previously. This discussion of the FPF will be formed around each of the four major steps: Trip Generation, Trip Distribution, Modal Split/Assignment, and Analysis.

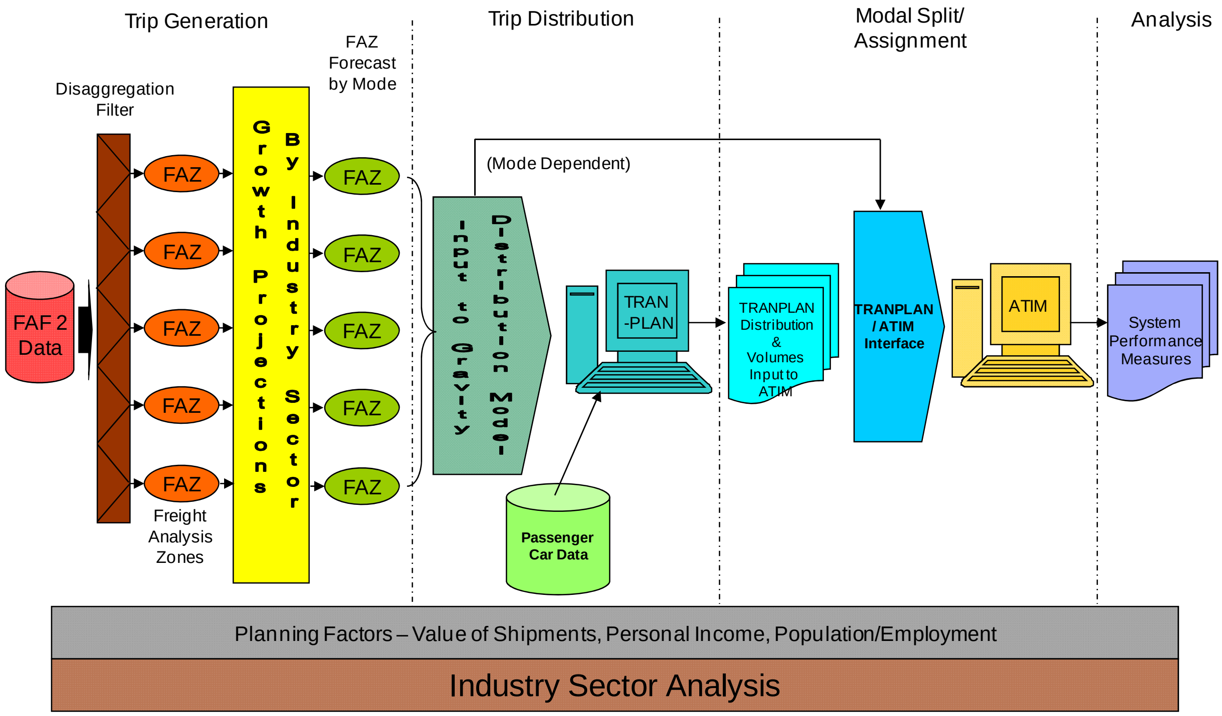

Figure 3.1 The Freight Planning Framework.

3.1. Trip Generation

The trip generation step of the FPF consists of four components. The first is the data used to fuel the analysis. The data currently under investigation is the Freight Analysis Framework Version 2.2 Database. This publicly available data is derived from the Commodity Flow Survey and is updated every five years. This data is supplemented by industry surveys of the area under study. These local surveys provide insight into the type of industry in the study area and the manner in which those enterprises access the freight system. This access mode is important since we know there are differences in broad industry sectors in different parts of the country. The computer and electronics industry in Alabama is different from the computer and electronics industry in California. It is important to develop accurate conversion factors for determining the number of shipments by mode that the data represents. There are some national approaches to conversion factors and the local surveys provide insight.

The FAF2 data are aggregated into 114 zones throughout the nation, shown in Figure 3.2., and contain origin and destination data for each zone pair. Following the FPF, the highly aggregated data is then disaggregated into Freight Analysis Zones (FAZs). The FAZs are necessary to provide a smaller analysis unit. The FAZs can be a region, county or sub-county zone that is smaller than the state, or the two sub-state zones in Alabama, yet large enough for the expenditure of time and resources to analyze the freight originating, destined for and passing through the area, to make sense. Value of Shipments, Personal Income, Employment and Population are then used to disaggregate the FAF2 data into the appropriately sized FAZ.

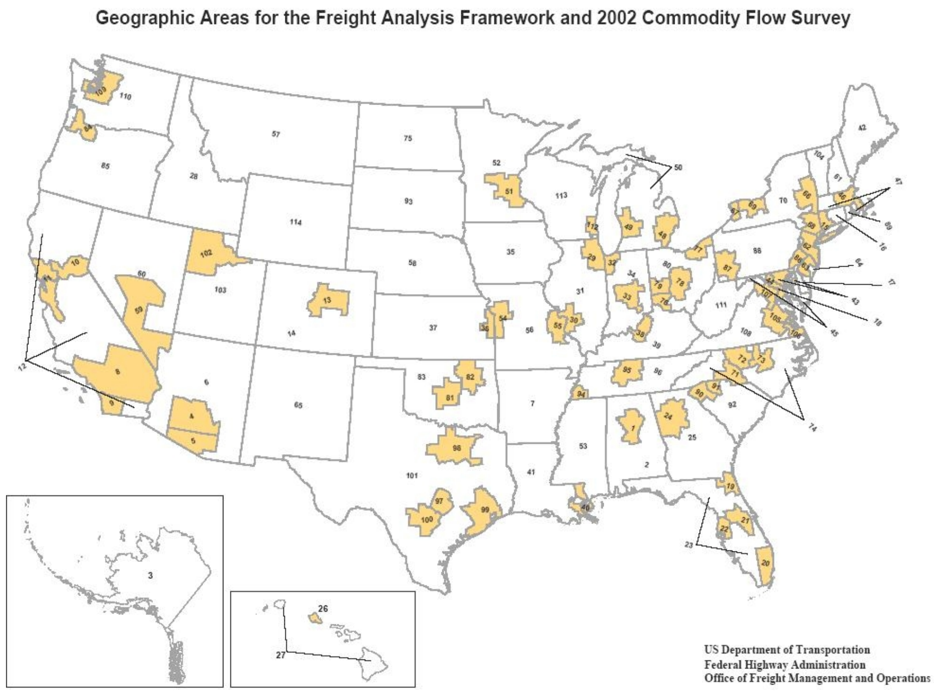

Figure 3.2 Geographic locations for FAF2 data.
(http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/cfs_faf_areas.htm)

The disaggregated FAF2 data is combined with the local knowledge of existing conditions in the study area to create the current state. After the current state is known, growth factors by industry sector can be used to develop a growth projection specific to the study area. The growth projections are applied to the current state to develop the forecasted origin and destination data sets.

There is one area of freight data that the methodology described above does not provide and that is the freight passing through an area simply because of the study area's location on the national freight network. To overcome this void, a national network for interstate highways was developed in a gravity distribution model and a C++ program was written to allow researchers to parse through the FAF2 database and determine what freight would travel on specific highways.

3.2. Trip Distribution

The freight current state and projection by FAZ are then distributed into origin/destination pairs for modeling purposes. A gravity model, such as TRANPLAN, which was used in Alabama, is then employed to distribute the freight volume across the network. A traditional gravity model distribution is performed using the quantity of freight, segregated by commodity, produced and attracted for each FAZ along with friction factor values associated with the distance the specific commodity would likely be transported. The results from the gravity model are arranged into an Origin/Destination (O/D) matrix for the study area.

The freight O/D matrix is assigned to the transportation infrastructure network developed to determine the travel paths for validation. It is possible to test the base year O/D patterns through a comparison of actual freight volumes on the existing infrastructure. Passenger car volumes are introduced to the Interstate and highway infrastructure as a separate travel model and rely on traditional transportation planning techniques

3.3. Modal Split/Assignment

The gravity distribution model from the previous step distributes the freight and passenger car volumes over the transportation network. This step is used to understand how the transportation system, and the built in constraints of that system, interacts with freight demand. The tool used for this purpose is the Alabama Transportation Infrastructure Model (ATIM), a discrete event simulation used to evaluate the impact of changing freight patterns in order to more accurately plan for future transportation infrastructure needs. The ATIM is a statewide multi-modal freight transportation model with the ability to rapidly evaluate the impact of system decisions on the statewide freight transportation system including highway, rail, and water routes. The transportation network also includes intermodal transfers between truck, rail, and water at the transfer points in Huntsville, Birmingham, Montgomery, and Mobile, Alabama. The ATIM can also be scaled down to a sub-state representation.

3.4. Analysis

The fourth step of the FPF is the ability to measure the performance of the transportation system. The FPF is a tool to use for continuously improving the transportation system’s ability to efficiently, effectively and safely move people and freight. Without a measurement system, improvement is not truly possible. Metrics that accurately portray the performance of the system as a whole are a missing tool needed for transportation system planners and managers to optimize the performance of the entire system.

Access to a safe, effective and efficient transportation system is a key element to the promotion of economic growth and development within a region. The design and methodology of the FPF and systems view of transportation, which relates all of the components to economic growth, are obviously needed. As with all new ideas, significant research is needed within each step and component of the FPF to ensure the final product provides value added information and data to transportation planners in Alabama and throughout the nation. The next several sections of this report will discuss, in detail, the research performed on specific components of the FPF over the period of performance.

4. Research Activity into Trip Generation of the Freight Planning Framework

In this section of the report, the specific research will be described in each of the following components of the Trip Generation step of the Freight Planning Framework:

- Investigation of Freight Planning Factors
- The Development of Freight Analysis Zones
    - At the State Level
    - At the Metropolitan Planning Organization Level

4.1. Investigation of Freight Planning Factors

It is difficult to incorporate freight information into transportation models and plans because freight data is proprietary and the release of that data is considered to be detrimental to the company's competitive position. Due to the difficulty in acquiring freight data, the inclusion of freight in most transportation plans and models has either been limited in scope or based upon limited sample sizes without knowledge of contents. In the United States, many national freight databases aggregate information to the individual states, or major communities in the states. For example, the Freight Analysis Framework, Version 2 Database (FAF2) developed and distributed by the Federal Highway Administration (FHWA) contains freight flows for 114 zones at the national level, as shown in Figure 3.2 [1].

The use of national freight data at the local level is challenging due to the high level of aggregation. In most instances the disaggregation of freight data from national levels for use in local areas has been based on the factor "employment" by prorating the employment in the local area to the total employment in the study region. The use of employment as a planning factor has come under scrutiny due to the inability of the factor to estimate accurately the effect of productivity improvements to increase production without increasing employees [2]. To provide insight into potentially new factors to use for freight planning, this research investigated the factors of population, employment, personal income, and value of shipments independently and in combinations.

The FAF2 database contains 114 origin/destination locations with values for tonnage and shipments, identified for six unique transport modes and 42 individual commodities identified using the Standard Classification for Transported Goods (SCTG) [3]. There are two zones designated for Alabama in the FAF2 database. The disaggregation of this data is not merely a reduction of data; there is a process of defining the data into nine unique trip purposes.

- Internal-Internal for Zone 1 and Zone 2. The internal trips for the individual zones are defined as the total trips that are both produced and attracted in the zone of interest. These trips are disaggregated into production and attraction values for the individual zones using the socio-economic factors.

- Internal to Zone 1
- Internal to Zone 2

- Values exchanged between Zone 1 and Zone 2. The freight values produced in one Alabama zone and attracted to the other Alabama zone are handled by applying the disaggregation factors to both the counties as a function of the total trips produced or attracted.
    - From Zone 1 to Zone 2
    - From Zone 2 to Zone 1
- Values exchanged between Alabama and the remainder of the U.S. The freight values are disaggregated through the use of the socio-economic factors for Alabama counties.
    - From Zone 1 to locations outside Alabama
    - From Zone 2 to locations outside Alabama
    - From outside Alabama to Zone 1
    - From outside Alabama to Zone 2
- Alabama pass through. The final purpose is the freight that does not originate nor terminate in Alabama, but travels on Alabama roadways on its way to its destination. These trips are defined using the following relationship:

$$FAF2(ee) = [\ FAF2 - FAF2\ (origin\ AL) - FAF2\ (to\ AL) - FAF2\ (not\ AL)] \qquad (eq.\ 1)$$

Where:

FAF2 (ee)	= pass through on Alabama Roadways
FAF2	= entire database
FAF2 (origin AL)	= values originating in Alabama
FAF2 (to AL)	= values terminating in Alabama
FAF (not AL)	= values that do not travel through Alabama.

4.1.1. The Experiment Design

A travel demand model network was developed in CUBE/TRANPLAN and used to assign the trips obtained from the FAF2 database. The model consists of all Interstates, U.S. Highways and many Alabama Highways totaling nearly 5,000 miles of roadway in the state. The roadways are attributed with posted speed limits and capacities, using approved Alabama DOT capacities for travel modeling purposes, shown in Figure 4.1.

The experimental model contains 67 internal zones, representing each county in Alabama and has 15 external roadways connecting Alabama with the remainder of the nation. The counties are also shown in Figure 4.1. A gravity distribution model has been incorporated to distribute the trips between the counties using the nine trip purposes previously described. The assignment is performed using an all-or-nothing assignment. It is assumed that freight will not deviate from the shortest path because the driver does not typically possess knowledge regarding an alternative path when assigning trips for potential out-of-town shippers.

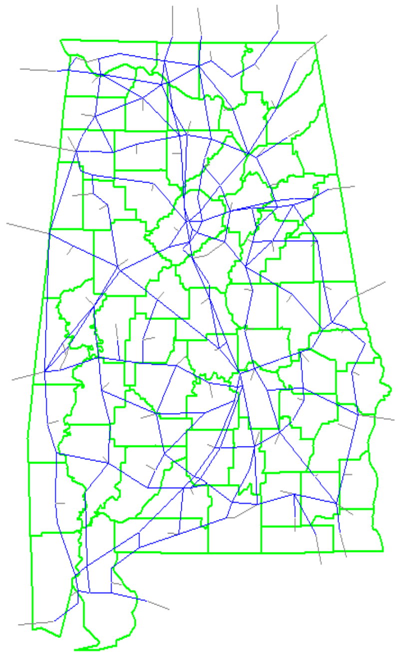

Figure 4.1 Modeling Network.

4.1.2. Experimental Procedure

The purpose of this research was to analyze the contribution of each potential freight factor to the input of the modeling software resulting in an improved modeled freight flow. This was achieved by varying the input data of the software and analyzing the impact over the final output of the model. For a better understanding, the procedure is displayed as Figure 4.2.

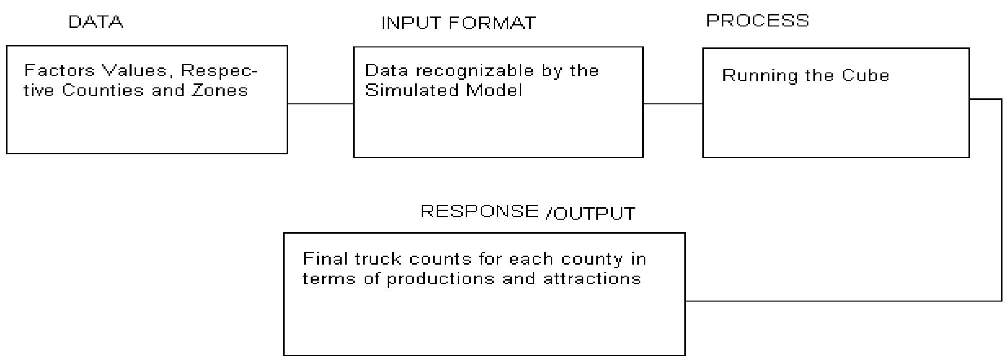

Figure 4.2 Experimental Procedure.

This research was accomplished by the execution of three tasks:

- Generating the input (INPUT)
- Running the modeling software (PROCESS)
- Analyzing the output (OUTPUT)

The input that is accepted and required for the modeling software is the number of trucks carrying freight visiting each county (PA_i). Productions are defined as the number of trucks going out and attractions are the number of trucks traveling to each county. The zonal truck counts for each county were developed by employing equation 2.

$$PA_i = (NFD_{ab}) * \frac{(WF) * Factor_i}{\sum Factor_{ij}} \quad \text{(eq. 2)}$$

Where:

PA_i = Truck passing County i

NFD_{ab} = Truck Counts from Zone-a to Zone-b taken from the National Freight Flow

WF = Weight of the factor (or) importance of the factor (or) proportion of the factor considered for disaggregating

$Factor_i$ = Factor level for county i

$\sum Factor_{ij}$ = Total Factor level for the corresponding Zone of county i

i = county number (1, 2, 3, 4……67)

j = Zone number (1, 2)

When the factors population, personal income, employment, and value of shipment were substituted in place of '$Factor_i$' in the above equation, it is of the form:

$$PA_i = (NFD) * \left[\frac{W_1 * P_i}{\sum P_j} + \frac{W_2 * PI_i}{\sum I_j} + \frac{W_3 * E_i}{\sum E_j} + \frac{W_4 * VOS_i}{\sum VOS_j} \right] \quad \text{(eq. 3)}$$

Where:

P = population

PI = Personal Income

E = Employment

VOS = Value of shipment

W_1, W_2, W_3, W_4 are the weights or contribution levels of population, personal income, employment and value of shipment respectively in calculating the county level truck counts (input). The amount of each factor used for disaggregating the National Freight

Flow data is given by these weights. For example, if the contribution of each factor is considered to be the same in calculation of truck counts, then W_1=W_2= W_3=W_4=0.25. This equation aids us in disaggregating or distributing the zonal truck counts from the National Freight data to the county level. Therefore, the total number of trucks before and after disaggregating must be equal.

$$\sum PA_i = \sum NFD_{ab} \qquad \text{(eq. 4)}$$

For satisfying criterion, there are two constraints in the equation involving W_1, W_2, W_3 and W_4

1. $\sum_{i=1}^{4} W_i = 1$ (eq. 5)

2. $W_i = Range(0,1)$ (eq. 6)

These levels sum to 1 because if $\sum W_i > 1$, the total number of modeled trucks would exceed the total actual trucks. This would add more trucks to the model than are actually present. For example, if $\sum W_i = 2$, the modeling would forecast double the amount of actual total freight traffic inside Alabama. Therefore, $\sum W_i = 1$ and range of W_i = (0, 1), as it was assumed that none of the variables had a negative impact on freight By assigning a number within the range (0, 1) to these weights, we are able to predetermine the contribution level or the importance of each factor in generating the input.

After generating the input (disaggregated zonal truck counts) the next step is to enter the data into the modeling software and extract the output. The output is the freight truck traffic generated on Alabama roadways. This is displayed in the form of an excel file containing various roadways numbered from 1 to 383, matching the quantity of roads in the model. The assignment of the forecasted truck counts for each roadway is contingent to the input, PA_i entered in the model.

One way to measure the impact on output of this model is to measure the deviation or difference of each data point with respect to the actual counts. The measurement in this case is the difference between the model output and the actual truck traffic in the Alabama network provided by the Alabama Department of Transportation (ALDOT). The closer the modeled values are to the actual counts, the more accurate the forecast and thus the contribution of the factors. Minimizing the difference between actual counts and modeled values can be achieved by varying the factor contribution in disaggregating the zonal truck counts. By this analysis the researchers can deduce a combination of factor contributions that aid in forecasting the truck counts

4.1.3. Analysis Technique

Root Mean Square Error (RMSE) is a common measure of the variability of the error (difference between model and actual counts) of any model. The greater the RSME, less accurate is the model.

$$RMSE = \frac{\sqrt{\sum (Model_i - Ground_i)^2 / (NumofCounts - 1) * (100)}}{\sum Ground_i / NumofCounts}, \quad [4] \qquad \text{(eq. 7)}$$

Where:

RMSE	= root mean square error
$Model_i$	= Modeled Value for the roadway i
$Ground_i$	= Actual Counts for the roadway i.

The next measure used in this analysis was the Nash Sutcliffe's (NS) coefficient which can range from -∞ to 1. An efficiency of 1 (E=1) corresponds to a perfect match of forecasted counts to actual counts. An efficiency of 0 (E=0) indicates that the forecasted values are as accurate as the mean of the actual counts, whereas an efficiency less than zero ($-\infty<E<0$) occurs when the forecasted mean is less than the actual values. The NS coefficient gives us a measure of scatter variation from the 1:1 slope line of modeled truck counts versus the actual counts. The NS Coefficient can be calculated using the formula:

$$1 - \frac{\sum_1^n (ModeledCounts - GroundCounts)^2}{\sum_1^n (GroundCounts - MeanGoundCounts)^2} \quad [4] \qquad \text{(eq. 8)}$$

The Nash Sutcliffe's statistic is considered to be the best measure of deviation between two data sets and is used in many similar instances.

Another measure used was the percent error between the forecasted and the actual counts. It is shown as the percentage of difference between the data sets.

$$Percenterror = \left(\frac{Model(i) - Ground(i)}{Ground(i)}\right)(100)/N \quad [4] \qquad \text{(eq. 9)}$$

Where,

$Model_i$	= Modeled Value for the roadway i
$Ground_i$	= Actual Counts for the roadway i
N	= Total number of modeled values.

4.1.4. The Experiment

Since the aim of this research was to investigate relevant factors for disaggregating the zonal truck values, various combinations of factor contributions or factor importance levels were executed as shown in Table 4.1 for which all three metrics have been calculated.

Below is the output of model runs containing a combination of factor proportions (W_i) for each run in the experimental design which was generated. The potential runs were generated using Minitab® 14.0 under the Mixture Experiments option. The column under each factor represents the contribution proportion of each factor in disaggregating the zonal truck counts. Since all the weights must sum up to one, all the run totals are equal to one and no single factor exceeds this value.
The total number of trucks and the weight of freight used for disaggregating the zonal values are always constant and the ingredients to make up this constant value are the factor contribution levels in this case. A factorial experiment would not apply for this situation since any design would not confine to the assumptions such as dependency, and orthogonality.

The assignment metrics were calculated for each run of the model. All NS coefficients are approximately equal to 0.19, indicating that the contribution of each variable is similar. When scatter plots were graphed between the modeled trucks counts versus the actual counts from the ALDOT, for all the runs, there was essentially no difference in the scatter pattern. This would indicate that there is little impact attributed to the variation of factor levels for generating the input. Additionally, the RSME (root mean square error) and the percent error showed constant results. A NS coefficient of .19 is not necessarily a desirable outcome since it indicates that the model data is essentially equivalent to the mean of the comparison data. Even so, run 9 has the best NS-coefficient of all of the runs, utilizing Personal Income and Value of Shipments as factors for disaggregating freight.

Table 4.1 Set of Model Runs containing various factor levels.

	Factor Weights				Assessment Metrics		
RUN	**P**	**PI**	**E**	**VOS**	**NS-Value**	**RMSE**	**%Error**
1	1	0	0	0	0.195821	105.92	86.44
2	0	1	0	0	0.197551	105.8	87.97
3	0	0	1	0	0.195821	105.92	86.36
4	0	0	0	1	0.193561	105.92	86.44
5	0.5	0.5	0	0	0.195821	105.85	86.39
6	0.5	0	0.5	0	0.196825	105.84	86.31
7	0.5	0	0	0.5	0.196985	105.86	86.26
8	0	0.5	0.5	0	0.196642	105.8	87.97
9	**0**	**0.5**	**0**	**0.5**	**0.197551**	**105.82**	**87.12**
10	0	0	0.5	0.5	0.197239	105.87	86.61
11	0.33333	0.33333	0.33333	0	0.1965	105.85	86.04
12	0.33333	0.33333	0	0.33333	0.196835	105.92	86.36
13	0.33333	0	0.33333	0.33333	0.195821	105.91	86.42
14	0	0.33333	0.33333	0.33333	0.195952	105.9	86.11
15	0.25	0.25	0.25	0.25	0.19606	105.89	86.18
16	0.625	0.125	0.125	0.125	0.196219	106.07	85.57
17	0.125	0.625	0.125	0.125	0.193561	106	85.67
18	0.125	0.125	0.625	0.125	0.194573	105.83	85.96
19	0.125	0.125	0.125	0.625	0.197182	105.82	86.53

Where:

P =population **PI** =personal income
E = employment **VOS** = value of shipments

All the above model runs were performed with a freight transfer of 30 tons per vehicle. The truck capacity is an attribute in the modeling software that can be modified. Up to this point in the research it had been assumed that all trucks were at a carrying capacity of 30 tons. Since the previous experiment had not delivered the adequate number of trucks in the model to compare with actual counts, it was determined that an experiment should be run where the researchers vary the tonnage from 0 to 30 tons in 5 ton intervals. With this subsequent analysis, the conclusion regarding the factors helping the desegregation of truck counts can be investigated.

Since the varying of coefficients had a limited impact on the final truck counts for the 30 tons per vehicle, one combination of the coefficients was predefined and a set of runs were carried by varying the tonnage of the trucks. Figure 4.3 presents the resulting Nash Sutcliffe's coefficient when truck tonnage is varied. When trucks with a capacity of 10 tons per vehicle were used for the modeling network, it yielded the truck counts closest to the actual truck counts (actual counts) provided by ALDOT.

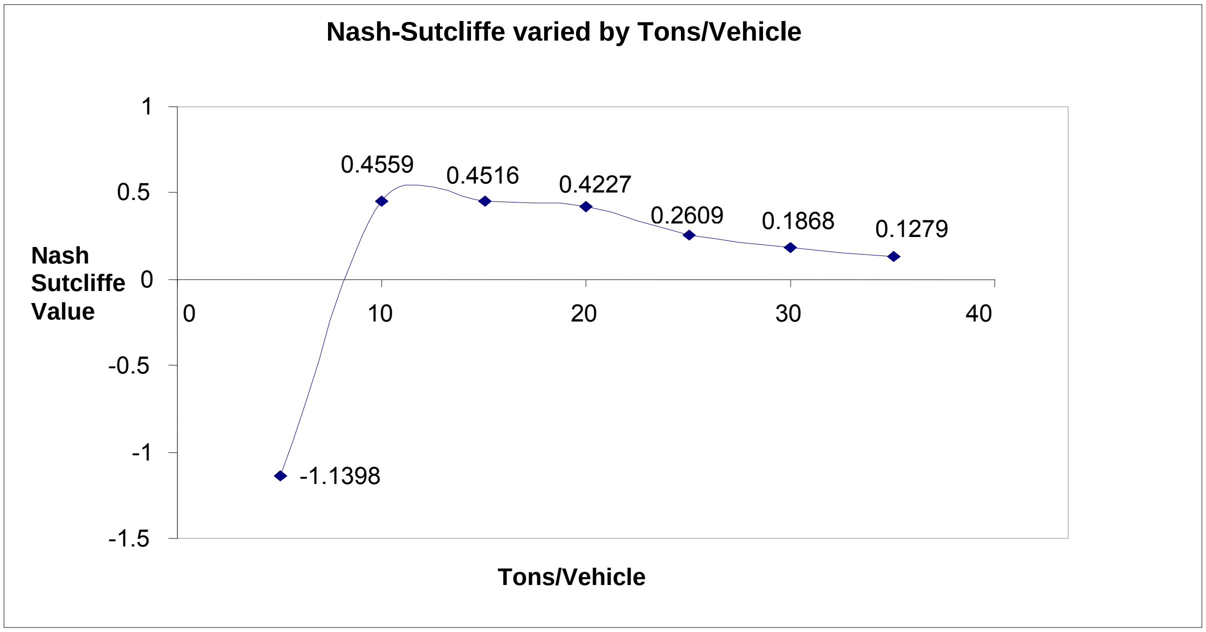

Figure 4.3 Nash Sutcliffe's values for various tonnages.

As a result of this finding, a micro level analysis similar to that performed for 30 tons per vehicle was performed for the 10 tons per vehicle model and analyzed to determine if disaggregating based on county level factors impacted the response.

A similar experimental design was performed for the 10 tons per vehicle as was performed for the 30 tons per vehicle investigation. The resulting output from the experiment runs is shown in Table 4.2. From this experiment some initial conclusions as to what factors really impact the modeled traffic flow can be made.

In both cases, the Nash Sutcliffe's statistic was different but a higher value was derived for the 10 tons per vehicle model runs. This indicates that the modeled values were much closer to the actual counts for model runs containing the 10 tons per vehicle. By varying the factors and the attribute within software, the approximate maximum Nash-Sutcliffe Value was around 0.47. The highest achieved values were when Value of Shipment and Personal Income were used in the analysis, although the number of vehicles developed by the model is still short of the actual counts. These findings indicate that the research has not yet found the best freight factors to use but it would appear that the researchers are actually on the trail of some promising results.

Table 4.2 Run results for the 10 tons per vehicle data.

RUN	P	PI	E	VOS	NS-Value	RMSE
1	1	0	0	0	0.4559	77.4425
2	0	1	0	0	0.460142	77.1463
3	0	0	1	0	0.462018	75.5991
4	0	0	0	1	0.47171	74.5071
5	0.5	0.5	0	0	0.459501	77.1895
6	0.5	0	0.5	0	0.472021	76.3102
7	0.5	0	0	0.5	0.469717	75.7614
8	0	0.5	0.5	0	0.463931	76.1724
9	**0**	**0.5**	**0**	**0.5**	**0.481489**	**75.6334**
10	0	0	0.5	0.5	0.469971	74.9775
11	0.33333	0.33333	0.33333	0	0.468871	76.5275
12	0.33333	0.33333	0	0.33333	0.464233	76.1502
13	0.33333	0	0.33333	0.33333	0.468771	75.6167
14	0	0.33333	0.33333	0.33333	0.469662	75.5556
15	0.25	0.25	0.25	0.25	0.467459	75.9246
16	0.625	0.125	0.125	0.125	0.467388	76.6304
17	0.125	0.625	0.125	0.125	0.469834	76.4629
18	0.125	0.125	0.625	0.125	0.469302	75.7198
19	0.125	0.125	0.125	0.625	0.46922	75.1712

4.2. The Development of Freight Analysis Zones

The ability to plan and forecast freight demand for transportation infrastructure is limited by the lack of available data at the level of detail that is meaningful to the transportation planner. The FAF2 database, based upon the Commodity Flow Survey, provides a publicly available freight knowledgebase for planning use. However, with 114 zones nationwide (and most states having two zones or less), the ability of the State or Metropolitan Planning Organization transportation planner to use the data is limited.
Disaggregation of the data to a more detailed level is needed to apply the freight flow data to whatever Statewide and Urban Planning model is currently being used. The fundamental problem is how to disaggregate the data to a usable level, without reducing the quality of the data to a point where its use would cause the introduction of excessive error.

The original idea behind the development of Freight Analysis Zones (FAZs) was to gain the ability to disaggregate national database freight data into smaller areas that can be utilized for effective freight planning. The original concept for disaggregation was based upon the use of counties, defined by a project sponsored by the Federal Highway

Administration to investigate disaggregation methods utilizing the Freight Analysis Framework 2 database, to the state level. Since that project, the research team at UAH identified an opportunity to apply the methodology used to disaggregate to the county level, to the disaggregation of freight data to the Metropolitan Planning Organization level. The following sections will describe the research in further detail.

4.2.1. Cluster Analysis

Cluster analysis is a multivariate technique employing statistical procedures to form groups of entities called clusters based on pre-determined characteristics. A cluster is a collection of entities that have certain levels of similarity or internal homogeneity between them and a distinct level of dissimilarity or external homogeneity with the entities forming other clusters. Two primary aspects under consideration for formation of clusters are: the type of similarity criteria and type of clustering method/technique. The type of similarity criteria is often based on a certain type of measure or concept that is common to all the entities across the potential cluster elements. Two entities could be part of a cluster if they are within a certain geometric distance from each other or if they represent commonality with regard to a descriptive concept. This approach is similar to that used by Moudon, et al. [1] in the development of traffic analysis zones for metropolitan transportation planning.

Distance measures such as Euclidean distance, Mahalanobis distance, Minkowski metric, Canberra metric, Czekanowski coefficient, Hamming distance etc. can be used to form distance-based clusters. Conceptual clustering uses formal definition of concepts generated by description languages along with the inherent structure of data to form clusters. COBWEB [2], CLUSTER/S [3] and LABYRINTH [4] are some examples of description languages that are used for concept definition. Due to stringent requirements related to formal definition of concepts and wider base of pre-requisite knowledge of the entities and attributes prior to clustering, conceptual methods are more difficult to implement and validate. Due to the complexity of the different economic attributes under consideration and the geographical zones in this research, it was determined that distance-based methods provided a simpler and effective foundation for cluster formation.

With a large number of entities and attributes associated with each entity, consideration of every single possibility/configuration becomes computationally expensive. To overcome the computational issue, the application of approximation methods or algorithms resulting into reasonable clusters is called for. These algorithms can be hierarchical, resulting in a process that incrementally builds clusters through a series of partitions, or non-hierarchical by identifying a seed as a central point and measuring distances from the same point. Hierarchical methods can be either agglomerative by treating each entity as a cluster and iteratively combining entities to form clusters until a single cluster remains or divisive, starting off by treating all entities as a single cluster and iteratively splitting entities to form clusters based on relative dissimilarities. The accurate determination of an initial seed in non-hierarchal methods can be cumbersome, and computationally expensive, hierarchical methods provide an efficient alternative for this research.

In hierarchical agglomerative methods, it is possible to form clusters on the basis of minimum distance, maximum distance, average distance, minimum error sum of squares between clusters (Ward's method) and minimum distance between centroids of clusters (Centroid method). Ward's hierarchical clustering method proves effective when the intent is to minimize the loss of information associated with any iterative step in cluster formation. More formally, if the error sum of squares is represented by ESS_k for the k^{th} cluster then the total error sum of squares is given by $ESS_{total} = ESS_1 + ESS_2 + \ldots + ESS_k$. At any iteration, all possible combinations of entities are considered and the combination resulting into the smallest increase in the total error sum of squares is chosen for the union. This method is based on an assumption that clusters of multivariate observations are approximately elliptical in distribution. For the present research involving variables related to distance and economic parameters represented by different units and scales, controlling the loss of information per cluster formation and producing clusters of almost equal sizes are critical. Thus, Ward's method provides the necessary flexibility and setup to cater to the current problem statement.

Statistical packages such as Minitab™ and Clustan™ provide efficient platforms for clustering algorithms and offer wide range of options for data display and graphical output providing useful and easy interpretation. For hierarchical agglomerative procedures, Minitab™ provides the user with a wide range of options for linkage methods and distance measures for standardized and non-standardized variable formats for entities. It also gives the user the ability to control the final number of clusters and options for forming clusters based on either a distance measure or a similarity level. The matrix of distance between all pairs of cluster centroids and the cluster number for each entity can be stored separately based on user requirements.

A graphical representation of the sequence of cluster formation relative to the distance measure or the similarity level, also known as a dendrogram, shown in Figure 4.4, can be plotted using Minitab™. The same functionalities are provided if cluster analysis is performed for attributes. Upon executing the routine, a dendrogram depicting the sequence of cluster formation is created. The console reveals useful information revealing the cluster number for each entity and the distance metric. Minitab™ thus provides useful features for statistical analysis required for a problem statement under consideration.

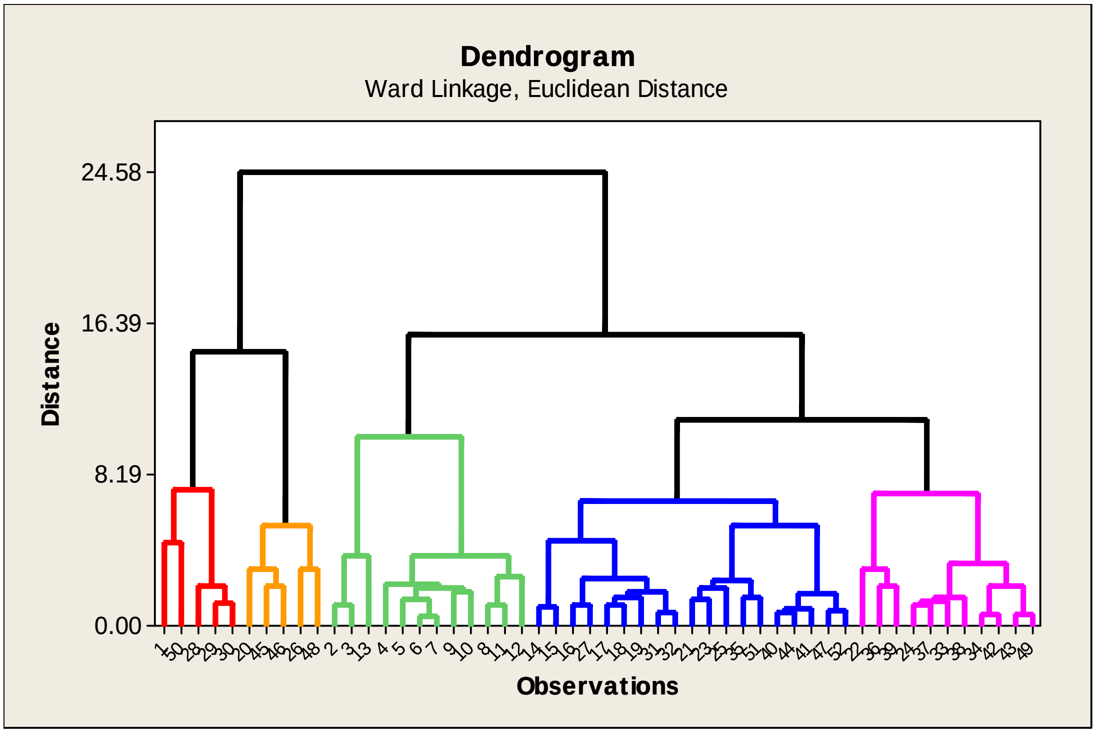

Figure 4.4 Sample Dendrogram from Minitab™.

4.2.2 FAZs at the State Level

In the FY2007 report on Transportation Infrastructure in Alabama – Tools for Solutions, an initial investigation into Freight Analysis Zones was discussed. The information in the following section details the research performed into this concept at the state level.

In the FAF2 database Alabama has two designated zones, eight counties consisting of the Birmingham area, and the remainder of Alabama. This high level of aggregation is not effective for use in freight planning at the state or local level. In 2006, the Federal Highway Administration funded four pilot projects to develop methods to disaggregate the FAF2 to the county level. Disaggregation at the county level within Alabama would result in a 67 by 67 matrix for each of 42 commodities and 6 travel modes. This may be achievable in Alabama but in states such as Texas and Georgia, with significantly more counties, this could be a much more difficult assignment.

With resources for transportation planning already strained in most transportation budgets, effort applied to perform freight planning for areas where insignificant economic activity exists is not a responsible use of funds. However, areas of lower economic activity can be aggregated into larger areas that contain enough economic activity to justify expending resources to plan for freight activity. The research team at UAH believes that the county level may be too detailed for most states to use for freight planning. It is preferable for Alabama (and other states) to find a more "optimal" planning level that is, in the case of Alabama, “larger than 2, but less than 67.” This optimal value should result in an aggregation of data that provides a necessary level of information without excessive detail. A guiding principle in the development of FAZs is that the zones should be homogeneous within the cluster, but diverse from the surrounding clusters, thus promoting cross-zonal traffic.

The process for the development of FAZs was initiated with the identification of the basic set of economic data that would be analyzed in order to define the analysis zones. The counties were established as the basic unit of analysis. Data was obtained on the employment level, payroll, value of shipments, population, and personal income for each of the 67 counties in Alabama. Hierarchical clustering analysis was used to form clusters based upon this data set. Ward’s method was used to form the clusters because it minimizes the within-cluster variance [5]. The distance between clusters considered for aggregation was measured using Euclidean distance.

In the quest to develop FAZs the UAH researchers considered a variety of options but ultimately focused on clustering counties based on economic data and resulting in the development of eight potential solutions. All of the solutions utilized the economic data, however, in each of these cases the end result was several clusters that, while similar based on economic factors, were often widely dispersed geographically, a result that would not be conducive to effective freight planning and analysis.

As a result, proximity measures were added to ensure that the location of the counties was taken into account in the development of the zones. The UAH research team also noticed that the early outcomes seemed rather arbitrary and that there was a need to establish some initial boundaries to segment the state into regions to develop a more systematic way to grouping the counties. The final solution establishes clusters of counties within regions defined by the interstate highways that traverse Alabama.

One of the initial solutions investigated the formation of 11 clusters based on the variables population, value of shipments, and personal income. Figure 4.5 clearly shows that without inclusion of proximity measures the clusters contain counties that are much more geographically dispersed. Due to this finding, all future solutions included one or more measures of geographic proximity.

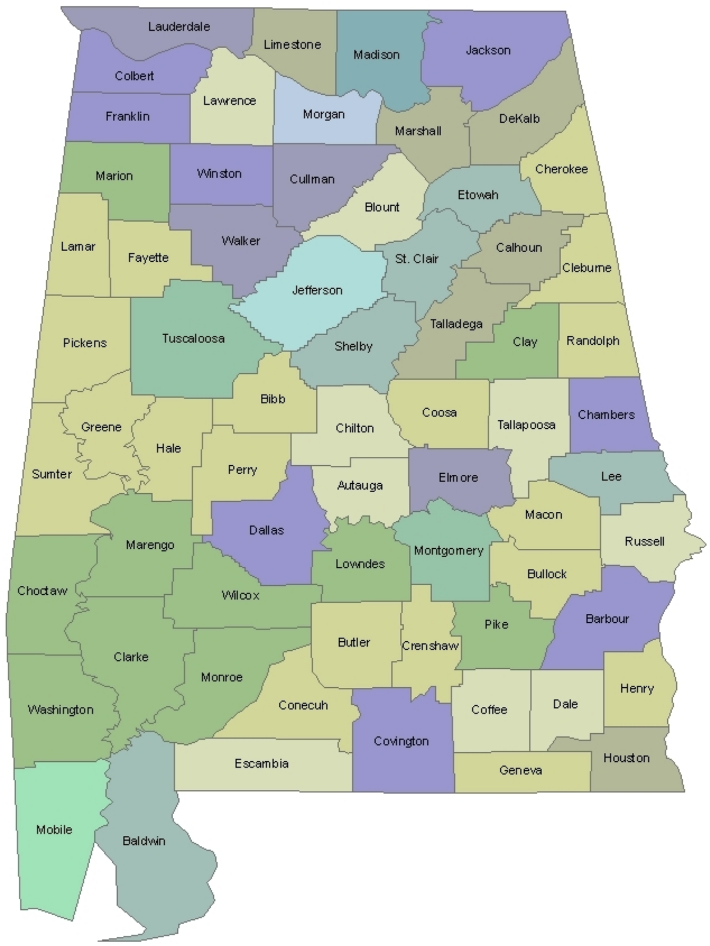

Figure 4.5 Cluster Solution of Counties Based Only on Economic Variables.

As stated above, the research team felt that regions of the state bounded by the interstates provided a more logical basis for defining sectors within the state. Figure 4.6 shows the location of interstate routes in Alabama. The basis of sectors for other states might well be other transportation landmarks such as railroads or waterways. The use of interstates provided Alabama several attractive features because they provide natural boundaries and the objective was to pick up as much traffic flow on the interstate as possible and the most interstate traffic between zones to enhance the value of the data used in freight planning activities. Therefore, the UAH team chose to use interstate boundaries to divide the state into six planning sectors and counties were allocated to sectors based on their proximity.

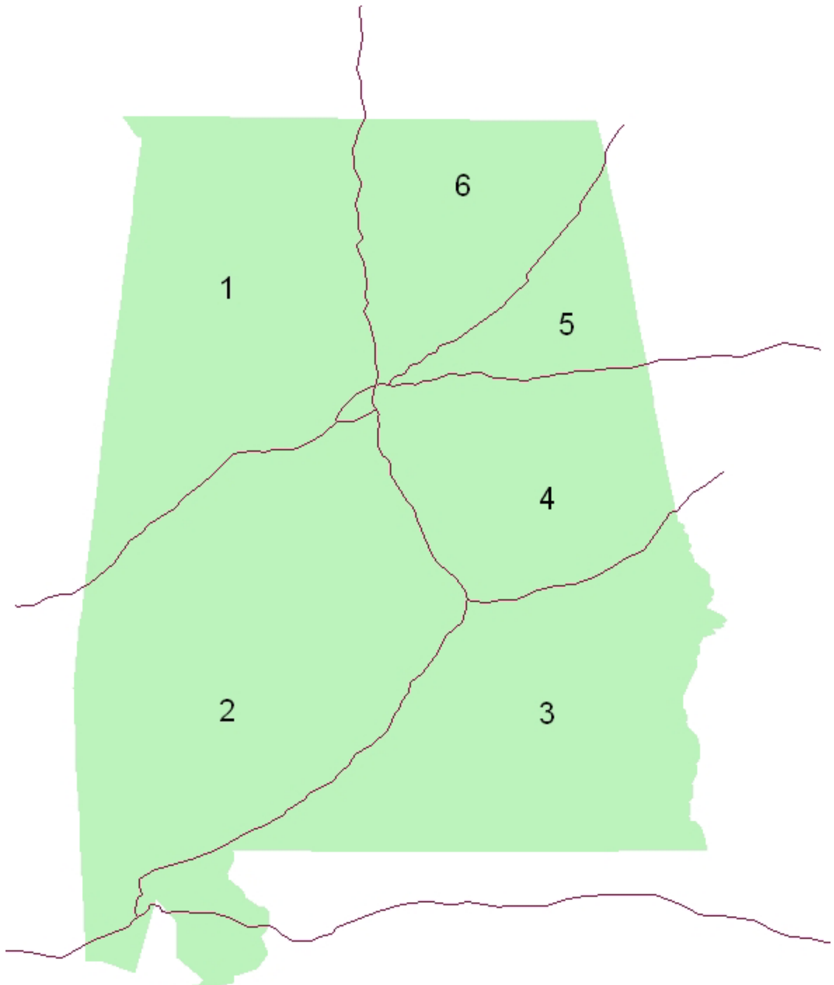

Figure 4.6 Interstate Based Sectors for Alabama.

A solution was generated based on a cluster analysis of counties within each interstate sector using economic variables as well as the county's longitude and latitude, and the distance from the interstate. This latter variable could be potentially important because it had been observed that counties within a few miles of the interstate appear to have more freight traffic than counties further way from the interstate.

The solution shown in Figure 4.7 clustered counties within interstate sectors based on the economic variables, the proximity variables, and the distance of the county from the interstate, resulting in 34 clusters. A review of the solution revealed that interstate sectors 3, 4, 5, and 6 contained too few counties for appropriate clustering. As a result, the research team decided to modify these interstate sectors by combining sectors 3 and 4 and sectors 5 and 6, resulting in a total of four interstate sectors. This modification resulted in fewer clusters but more homogenous clustering. The results are shown in Figure 4.8.

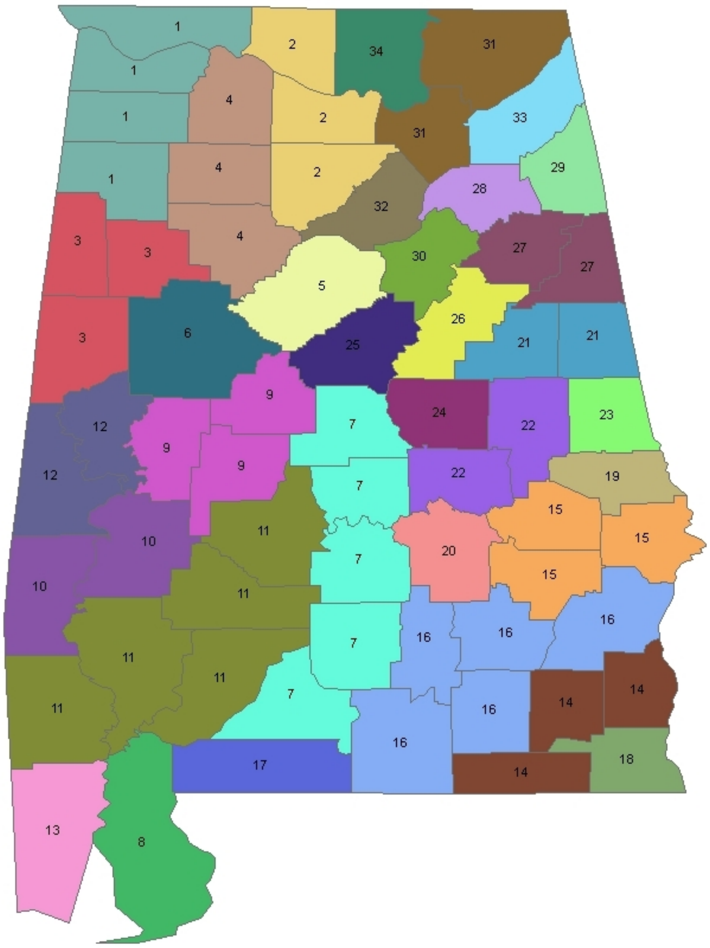

Figure 4.7 Cluster Solution within Interstate Sectors based on Economic. Variables, Longitude, Latitude, and Distance from Interstate.

This approach resulted in a total of 27 clusters. The research team felt that this solution showed the most promise because the clusters were in close proximity within the natural boundaries provided by the interstates traversing Alabama.

After completion of the cluster analysis, a refining step was added to the process where the 27 clusters were evaluated based on the type of industry and growth in each of the clusters. This step was performed in order to validate the defined clusters, and to refine or modify the solution.

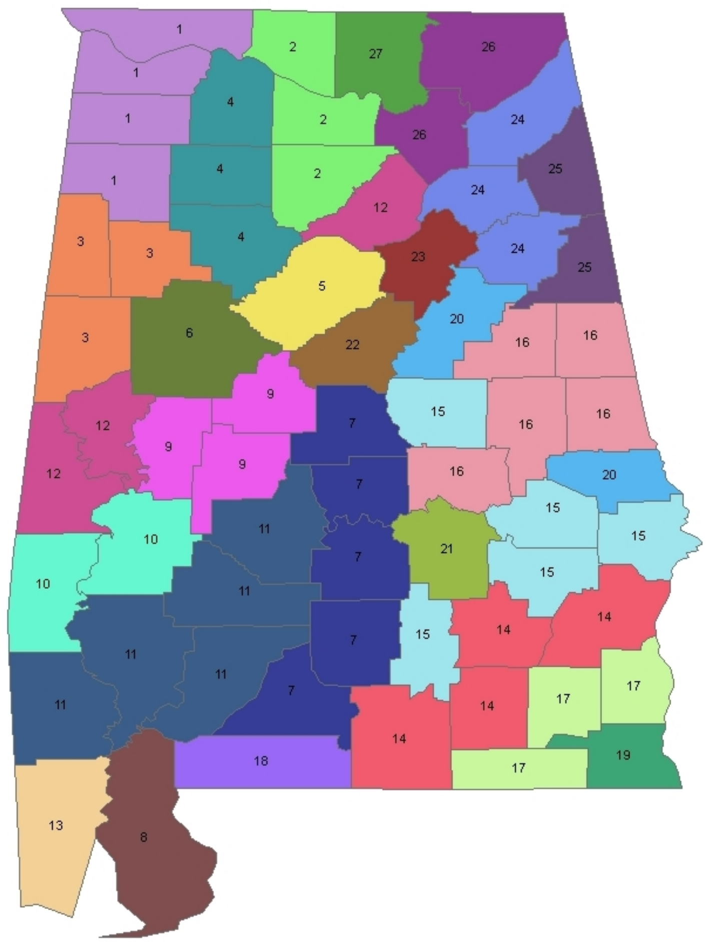

Figure 4.8 Cluster Solution within Modified Interstate Sectors based on Economic Variables, Longitude, Latitude, and Distance from Interstate.

Figure 4.9 shows the final cluster solution arrived at based on an evaluation of the solution shown in Figure 4.8 in which the individual clusters were refined based on types of industry and growth projections. The industries shown are the 17 largest industries in Alabama based upon employment [6]. Each industry listed employs more than 1000 people in the state.

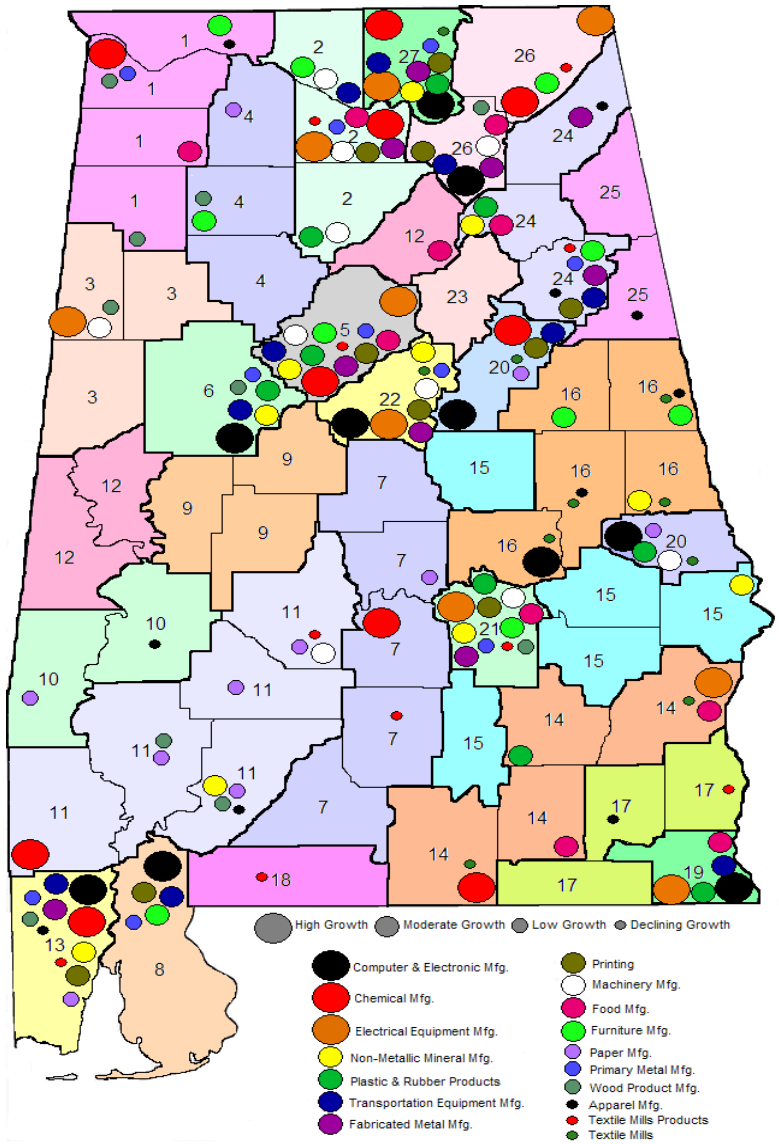

Figure 4.9 Final Cluster Solution with Industry Type and Growth Highlighted.

4.2.3. Final Cluster Solution Comparison

In order to determine if freight activity disaggregated to the FAZ level provides an equivalent evaluation of freight activity at a county disaggregation, a case study was created utilizing the State of Alabama Freight Model. A 67 county input file was created through a direct disaggregation of the FAF2 data using freight factors from the FPF proportional to the county's contribution. The aggregation of the 67 county data to FAZs established a 27 FAZ input file. The aggregated trips were assigned to a point within the FAZ that best represented the economic center of the zone.

The distribution of freight was performed using a gravity model on the truck production and attraction values by developing the relationships between probable truck trip origins and destinations. The assignment of the truck trips was based on an All-or-Nothing procedure where all trips will take the shortest travel path from an origin to a destination. The shortest path was calculated as each segment of road in the model was attributed with segment distance and posted speed limit. The model operates in the TRANPLAN/CUBE® environment. The transportation network contains almost 5,000 miles of roadway for Alabama and 15 roadways that serve as connections to surrounding states and is shown in Figure 4.10.

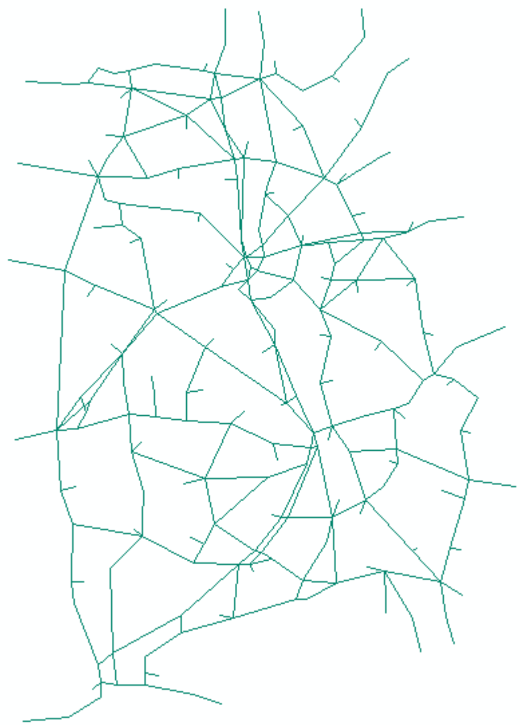

Figure 4.10 Network for the Alabama Distribution and Assignment Model.

To compare the models, two data input sets were developed from the FAF2, one with counties as the level of disaggregation and the second with the 27 FAZs. The disaggregation of the FAF2 data included truck trips internal to Alabama, truck trips between Alabama and the other 49 states, and truck trips passing through Alabama and was performed using a proration of the economic factors, proportional to each county of FAZ contribution to the total Value of Shipments, Personal Income, Employment and Population of Alabama. After assigning the traffic to the network, the assignment can be reviewed visually for accuracy, shown in Figure 4.11.

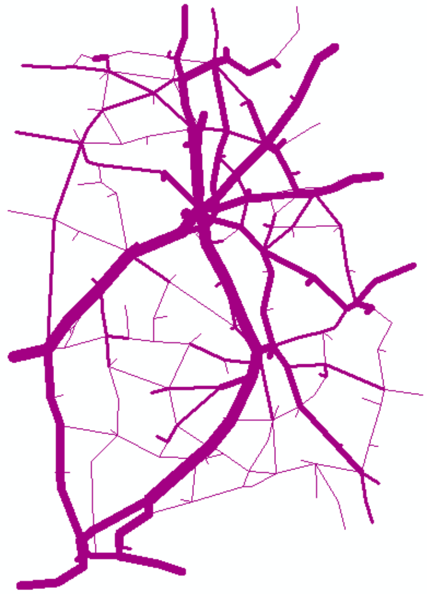

Figure 4.11 Assignment to the Network with Line Thickness Proportional to Assigned Volume.

For comparison of the two approaches (i.e., 67 counties versus 27 FAZs), Alabama Department of Transportation (ALDOT) truck counts were added to the attributes for the network roadway segments. The ALDOT values for all roadway segments where the truck volume exceeded 1,000 trucks per day are identified in Figure 4.12.

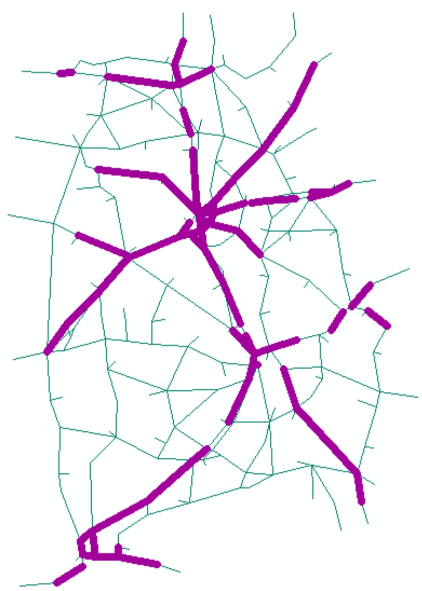

Figure 4.12 Location of ALDOT Truck Counts that Exceed 1,000 Trucks per Day.

The result of the analysis can be seen in the scatter plots shown in Figures 4.13 and 4.14. The scatter plots display the variation between the model assignment and the truck counts on specific roadways

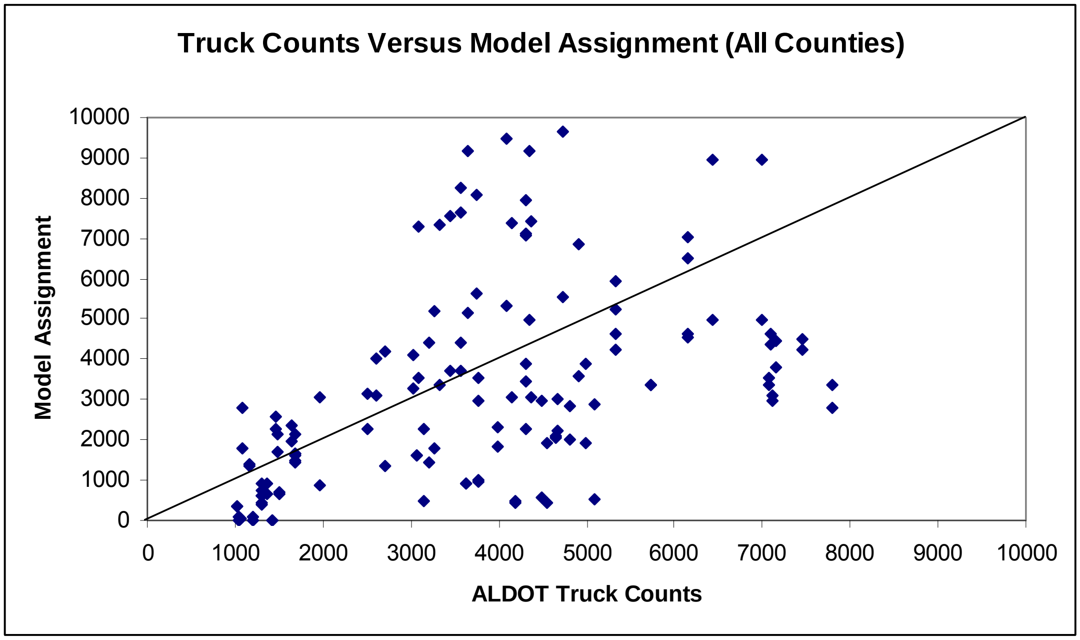

Figure 4.13 Scatter plot for the 67 County Model.

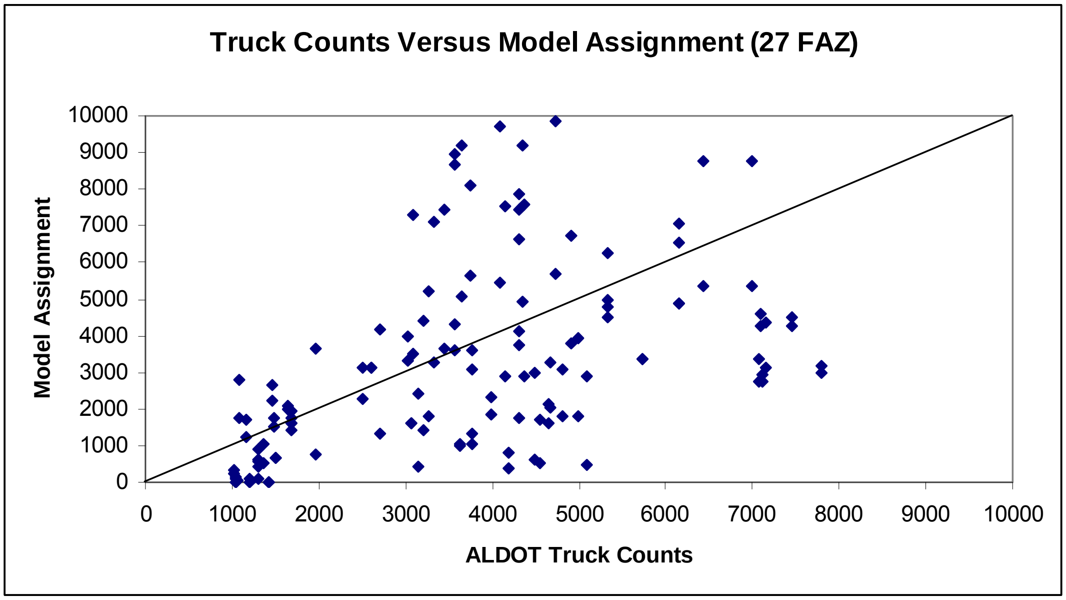

Figure 4.14 Scatter plot for the 27 FAZ Model.

The Nash Sutcliffe's (NS) coefficient was employed to measure the difference between the model assignments using the two input levels (all 67 counties or the 27 FAZs), [7]. The NS value can range from $-\infty$ to 1 with an efficiency of 1 (E=1) corresponding to *a* perfect match of forecasted counts to the ground counts. An efficiency of 0 (E=0) indicates that the forecasted values are as accurate as the mean of the ground counts, whereas an efficiency less than zero ($-\infty<E<0$) occurs when the forecasted mean is less than the ground values. The NS coefficient provides a measure of scatter variation from the 1:1 slope line of modeled truck counts vs. the ground counts. The more deviation of points from the slope line, the lower the coefficient. The greater the NS-value is the better the forecast. The formula for calculating the NS is shown in equation 10.

$$\text{NS-Coefficient} = 1-\frac{\sum_1^n (ModeledCounts - GroundCounts)^2}{\sum_1^n (GroundCounts - MeanGoundCounts)^2} \quad \text{(eq. 10)}$$

The NS statistic is considered the best measure of deviation between two data sets and used in many similar instances. Applying the NS test for the two input files results in a NS-coefficient of 0.689 for the model that uses all 67 counties and a NS-coefficient of 0.679 for the model with 27 FAZ, indicating that there is no statistical difference in the assignments obtained using the 67 county model or the 27 FAZ model. This result supports the hypothesis that FAZs can be used at the state level to limit the data collection needs for freight planning without a reducing the quality of the assignment output.

4.2.4. Conclusion

The initial use of counties as the disaggregation level for the freight data appeared promising and has easy initial understanding until the number of counties creates a data matrix that becomes excessively large and unwieldy. The research team believes that the ability to organize counties into Freight Analysis Zones provides a more efficient and effective way to organize the data into user-friendly form. The purpose of this research was to develop an initial methodology for developing Freight Analysis Zones at a State level. The results found indicate that the development and use of Freight Analysis Zones for including freight in the overall transportation plan provides value and can improve the planning process.

Future research into the concepts of Freight Analysis Zones needs to continue through the examination of freight data disaggregation methods and travel model results. The various methodologies to disaggregate freight to the FAZs will help identify the impact of using these larger measurement units and the modeling of freight data will provide a mechanism to validate the various FAZs options.

Appendix – 4.0 – References

4.0 Research Activity into Trip Generation of the Freight Planning Framework

4.1 Investigation of Freight Planning Factors

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4.2 The Development of Freight Analysis Zones

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5. Expansion and Enhancement of the Alabama Transportation Infrastructure Model (ATIM)

The Alabama Transportation Infrastructure Model (ATIM) has been very successful as a communication and educational tool for opening discussion to transportation infrastructure issues in Alabama. The ATIM is especially valuable in educating and greatly simplifying the complex issues of transportation systems for the transportation layperson. The enlightenment provided when a person observes the truck icons change from green (free flow speeds) to yellow (80% of FFS) to red (<60% FFS) simplifies the congestion issues into a common language that all persons can comprehend.

Unfortunately, the research team realized after two years of continued development of the multi-modal ATIM that the software used to create and run the discrete event simulation, ProModel, was essentially at the limits of its capabilities. The UAHuntsville research team had expanded the functionality of the ProModel program to such an extreme level that several software patches were developed by ProModel technical support technicians to fix problems encountered due to the demands of running the ATIM.

At the same time, the UAH research team was working with researchers from the University of Hamburg on a project involving discrete event simulation and education. The Hamburg team was working in the Java-based programming environment for discrete event simulation. The capability of Java expands the capabilities of discrete event modeling into "agent-based" simulation where each entity in the model is capable of using a logic framework to maneuver the simulated network. This capability overcomes many of the limitations the UAH research team had encountered with ProModel. The decision was then made to pursue an enhanced ATIM Version 2.0 built in a Java environment to continue the development of the capacity and capabilities of the ATIM discrete event simulation. The following section provides detailed descriptions of the Java approach.

5.1. The Alabama Transportation Infrastructure Model Version 2.0

The UAHuntsville research team has developed a highly flexible and extensible agent-based model of freight traffic on Alabama highways. Agent-based modeling works under the premise that entities in the model are somewhat "intelligent" and have a high level of autonomy. Each agent makes its own decisions as to how it will behave according to a set of internal characteristics and external stimuli. Internal characteristics may include knowledge-base, goals and pre-dispositions; external stimuli may include environmental conditions or "observation" of particular emergent events. Traditional examples of agents are entities like enemy soldiers inside computer games, but recently agents have been used much more broadly, even as system maintenance monitors in large simulation projects. Agent-based modeling has been used very successfully for research purposes in a host of different modeled scenarios, including excitable crowd vignettes, urban mass casualty events, and terrorist attacks on airports. In the ATIM V2.0, the agent is the driver of a vehicle; each vehicle has a unique driver agent. The logical distinction between the driver and the vehicle is currently under development and the code set supports such a distinction. The logic for each entity type will be developed in the next research effort.

5.1.1. Behaviors of the Agents

Agents generally have a set of behaviors, which they can choose from based on the various external stimuli and internal characteristics discussed above. For ATIM V2.0 purposes, the only behaviors of interest are described by speed and position of a vehicle, and the only current stimuli are the speed limit, and the position of the car ahead. The internal characteristics are all identical in the model currently. Namely, the driver simply maintains the highest speed possible that does not violate the posted speed limit, and does not position the car too close to the car in front.

5.1.2. Representation of the Roadways

The environment in this model is the Alabama highway network consisting of all interstates, most federal highways, and several state routes. No county highways or local surface streets are included. For the purpose of modeling, the roads are divided into individual links, which connect intersections or points of interest. There are 330 distinct links in the system. The intersections and points of interest are called nodes, of which there are 250. Names for the nodes might be Eufaula center, or I459×US280. The nodes and links together form a graph, in the discrete mathematics (or computer science) sense of the term. It should be noted here that currently it is assumed one lane of traffic in each direction, with the capability to expand to multi-lane roads in future work. Establishing the network and ensuring all links and nodes are functional was the priority during this period of performance.

For rendering purposes, each link has been augmented with rendering points that correspond to the geometry of the map provided to the research team by the Alabama Department of Transportation (see Figure 5.1). These rendering points were generated essentially by hand in an external data and graphics package called Interactive Data Language (IDL).

5.1.3. Route planning

Graphs form a significant field of study in discrete mathematics, which is fortunate for this research. The problem of route-planning on a road system can be very closely related to the problem of seeking the lowest cost path through a graph. This problem has been largely solved by the A* algorithm, due to Hart, Nilsson and Raphael [1]. This algorithm is regarded as “best first” as opposed to “depth first” or “breadth first” in that in generates the optimal path on its first pass through the network, rather than first searching the network and then identifying the best path. By “best,” the authors mean least cost, and leave it to the implementer to decide what cost is. For this research effort, shortest time was chosen. The best path is the one that takes the least time.

Each vehicle chooses its own route, and is free to change its route as conditions arise. However, agents are not currently empowered with sufficient knowledge of conditions to change their routes during the trip. Savvy commuters or truckers on CB radios would likely have such capability, and so the code is written to allow for route changes as an important future capability.

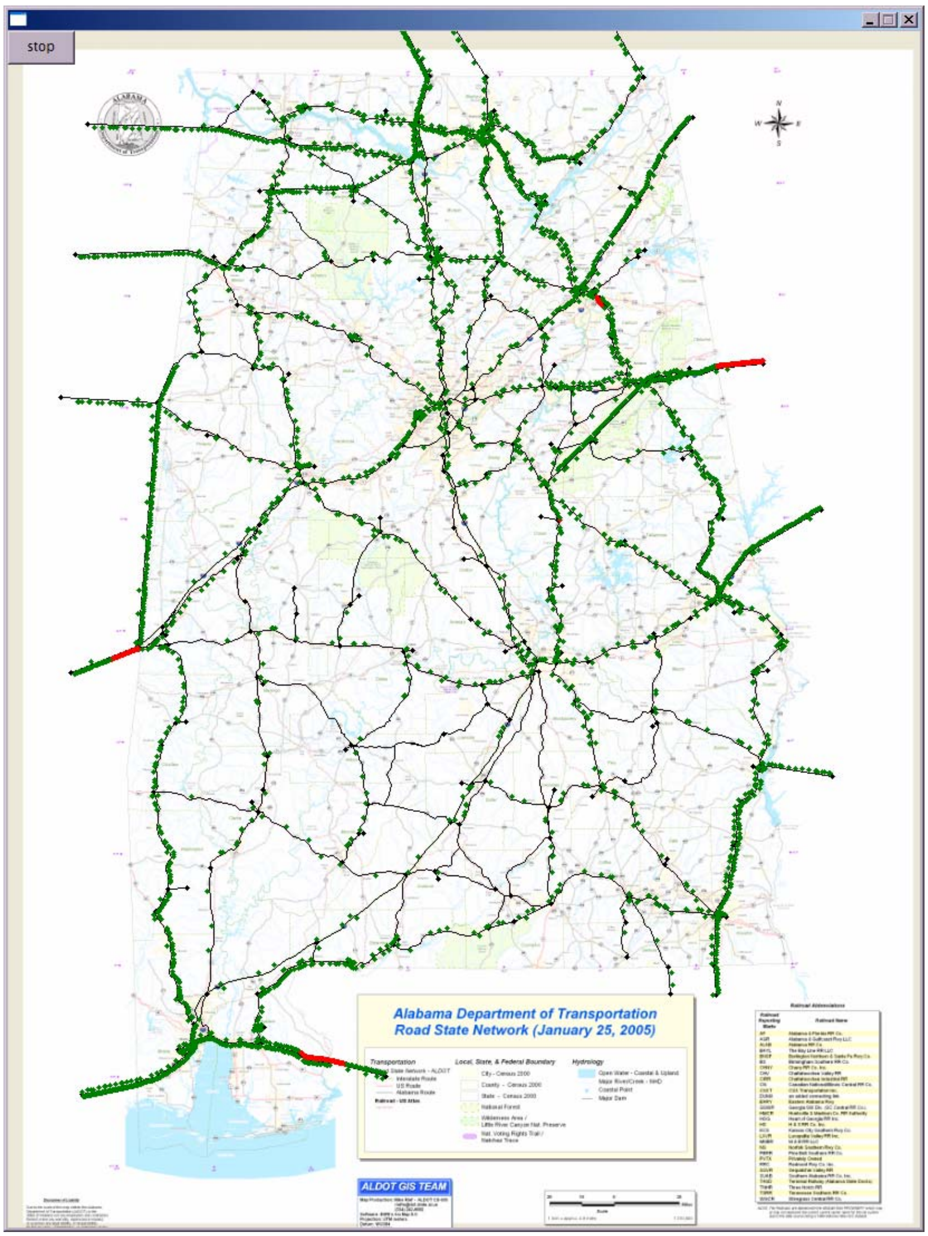


Figure 5.1 Screenshot from the simulation in progress.

5.1.4. Movement of Vehicles

The simulation, or execution of the model, occurs by uniform time-step advance. The state of each vehicle is defined by its location and speed, where location is the position on the link (and knowledge of which link the vehicle is on; the link knows about its own geometry); it is this state that is updated with each time-step advance.

In the simplest case, of a single open highway, a single vehicle would simply advance at the highway's posted speed limit. Of course, there are other vehicles on the road, and because it is assumed a single lane of traffic, the only additional information each vehicle needs is the position of the vehicle in front of it, but the question arises of *when* the next vehicle was in that position. Therefore, the updates are managed according to sorted position on the link. The front-most vehicle on the link is updated first, then the next vehicle, then the next. This ensures that each vehicle is updated in a logical and consistent way.

There are, however, some complications to address. During the course of a time-step, a vehicle may complete a link, complete its journey entirely, or encounter a pre-defined "incident." The model deals with each of these in event-based time, taking each event in chronological order (see Figure 5.2).

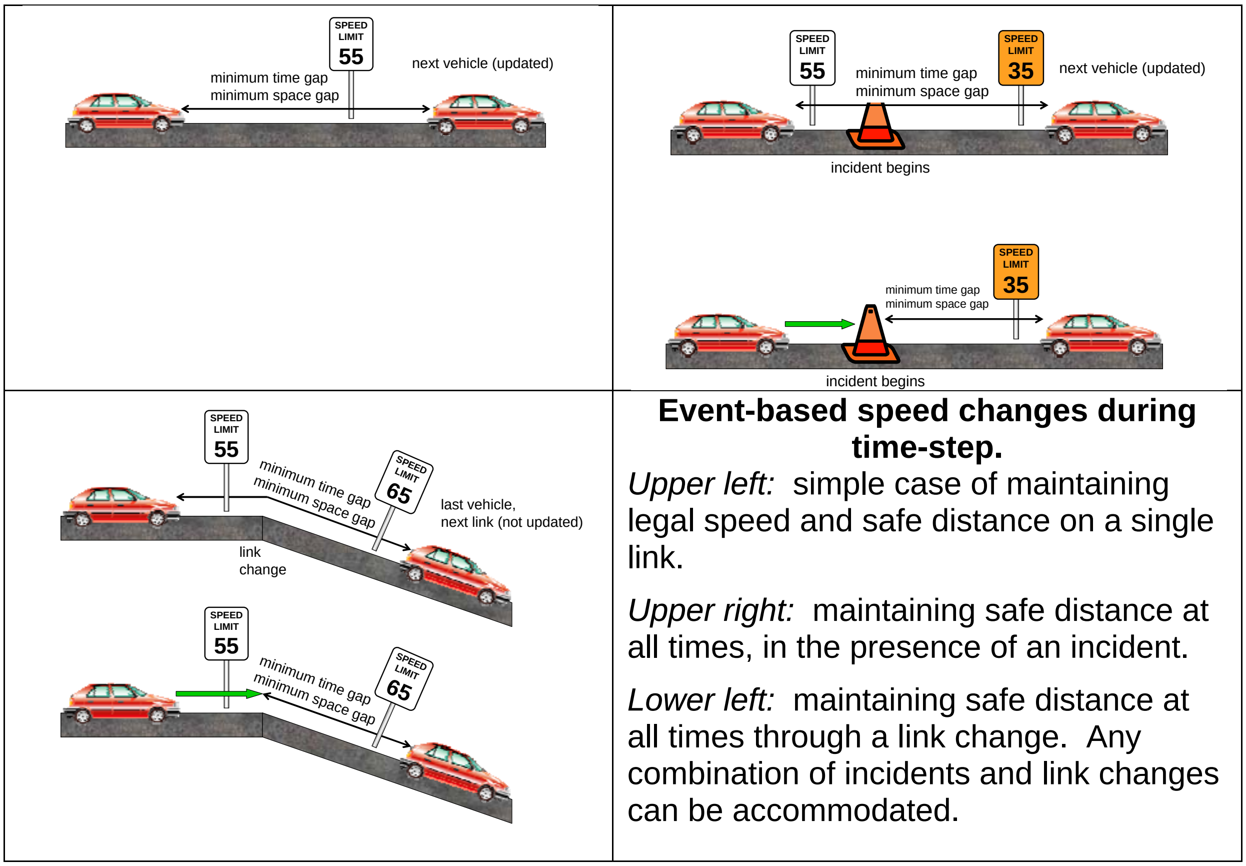
1. Find posted speed.
2. Find maximum position at end of step, given posted speed.
3. Determine if vehicle would change links before end of step. If necessary regard last vehicle on next link as next vehicle.
4. Given position of next car, find maximum safe speed, ensuring a minimum time-gap and a minimum space-gap at the end of the time-step.
5. Determine whether or not the car encounters an incident during this time-step. If so, adjust speed accordingly.
6. Determine whether a change of link occurs given adjusted speeds. If so, change links and obtain posted speeds and incident list for this link.
7. Repeat steps 4 through 6 until the time-step is complete.

Because each vehicle is calculated in order of position on the link, the model guarantees that no vehicles collide, the base condition. The only caveat is that when vehicles change links, the model cannot guarantee that the last vehicle on the next link has been calculated previously. As such, the model gathers the position of the last vehicle on the next link at the beginning of the time-step and ensures that the vehicle being calculated, when changing links, will not collide with that vehicle. This causes some slowdown at intersections, which is a realistic occurrence.

5.1.5. Implementation

The implementation environment for ATIM V2.0 is Java in the Eclipse Integrated Development Environment (version Ganymede). Java was chosen for several reasons: high platform portability, well-established reputation in discrete event simulation, well-documented graphical user interface (GUI) tools, and researcher experience with implementing an agent-based simulation in Java.

At the lowest level, most objects are stored in lists. For instance, the list of all vehicles in the simulation is an ArrayList<Vehicle> structure. No other special structures are used; though a custom sorted list structure was developed for storage of the rendering points on the links.



Event-based speed changes during time-step.

Upper left: simple case of maintaining legal speed and safe distance on a single link.

Upper right: maintaining safe distance at all times, in the presence of an incident.

Lower left: maintaining safe distance at all times through a link change. Any combination of incidents and link changes can be accommodated.

Figure 5.2 Vehicle Decisions.

GUI interactions come directly through the Standard Widget Toolkit (SWT), which has some advantages and some disadvantages vs. other GUI packages such as Swing. SWT is generally thought to generate better performance, although Swing is generally more portable. If portability becomes critical in the future, we may change to a Swing GUI implementation.

The broader question of why a general purpose programming language was used rather than a discrete event simulation environment has largely been addressed previously. The need for highly dynamic time-management with a fusion of time-step and event-based time management, and the ability to customize behaviors from the ground up are the principal drivers.

Just as important, however, is the high flexibility of the model. Few parameters are hard coded into the model. Nearly all model parameters, including the traffic loads, the node locations, the link locations, the background map and the rendering locations are file inputs to the model. Extensible mark-up language (XML) was chosen as the file format for all inputs (aside from the PNG or JPEG background map image). XML is a highly portable open-source format that provides maximum flexibility and ease of use.
The execution speed of the model is currently quite acceptable. With 8000 vehicles on the roadway, one hour of simulation time passes in less than one minute of clock time on a 4-year-old single-core Centrino laptop. As larger numbers of vehicles are introduced to the model, we may move to a more powerful machine, and consider some opportunities in coding for more efficient operation.

5.1.6. Current Status and Future Work

The core functionalities originally outlined for this initial development phase were:

- Fully dynamic movement of individual vehicles
- Dynamic route-planning
- High flexibility of inputs
- Graphical display of vehicles.

All of these original functionalities have currently been achieved. However, the model has just now become a scientific tool. As a science tool, the next and most important step of maturation is co-verification against the TRANPLAN traffic model. Because TRANPLAN solves for the traffic situation given various route loadings and link capacities in the continuous limit, comparison of that model to the fully dynamic and discrete agent-based model will be non-trivial. Special care must be taken to ensure that the scenarios and metrics are truly comparable. Because TRANPLAN is regarded as valid, our agent-based model, once verified against TRANPLAN becomes valid within reasonable parameters. Extension of the agent-based model into other scenarios and cases must be carried out with special emphasis on tying back to the behaviors known to be valid.

After verification and validation, the core capabilities in the tool can be extended rapidly to provide important future capabilities.

1. Multiple lanes—Virtually any primary or secondary road has multiple lanes of traffic, while generally any urban surface street likely has multiple lanes and/or turn lanes. Therefore, one of the first future developments will likely be incorporation of multiple lanes in the model and the logic for lane changes.

2. Local traffic—Interest has already developed in modeling local urban traffic, such as that of Birmingham or Mobile. Because of the flexibility of the model, the only real changes are the input files; however, pre-run data conditioning, the research team has found, is an important step to realistic modeling.

3. Multi-modal traffic—In freight, rail and ship traffic are just as important as truck traffic. As such, inclusion of these elements is a logical next step for our model development. Again, the model flexibility allows these networks and "vehicles" to be included fairly easily.

4. Additional routes—Substantial interest exists in how proposed roads, such as I-22 will improve freight mobility. Our model provides for rapid inclusion of new roadways. One simply needs to add the appropriate nodes and links to the input files, and the model takes care of the rest.

5.1.7. Conclusion

ATIM V2.0 is a powerful, flexible and extensible agent-based model of freight traffic on Alabama roadways. In a few short months, the research team has incorporated a large number of core functionalities ready for verification and validation study. The validated model will allow further development in exciting new areas and expand the capacity to communicate transportation systems and issues, and potential solutions, to decision makers.

5.2. Regionalization

The ATIM is built upon the same platform as the Mississippi VITS model. It was the desire of the research team at UAHuntsville to pursue uniting the two models to investigate the ability of a discrete event simulation to provide meaningful data and analysis capability across state lines. This effort would require coordination with researchers in Mississippi to obtain statewide origin/destination flows or the potential development of a Mississippi planning model.

Unfortunately the research team encountered technical and financial issues that simply could not be overcome to achieve this goal of linking the models in the ProModel discrete event environment. A few of the technical issues encountered were:

- Attempt to utilize the ProModel feature "Merge – Model/Submodel" to see if it could be used to link the two models together.
  - All attempts to link the existing models were unsuccessful.
  - The models are different sizes when merged (See Figure 5.3), thus the ability to merge is not viable without support from the Mississippi State research team.

- The technical resources at Mississippi State University were not available. The researchers that developed the VITS model had moved on to other opportunities and the positions were not refilled.

- Funding was not available to support the Mississippi State research team.

It is possible to develop a plan that will allow the joining of the models, but without funding for both teams, the work cannot be adequately coordinated. If funding can be defined, several actions could be taken to develop a truly regional model.

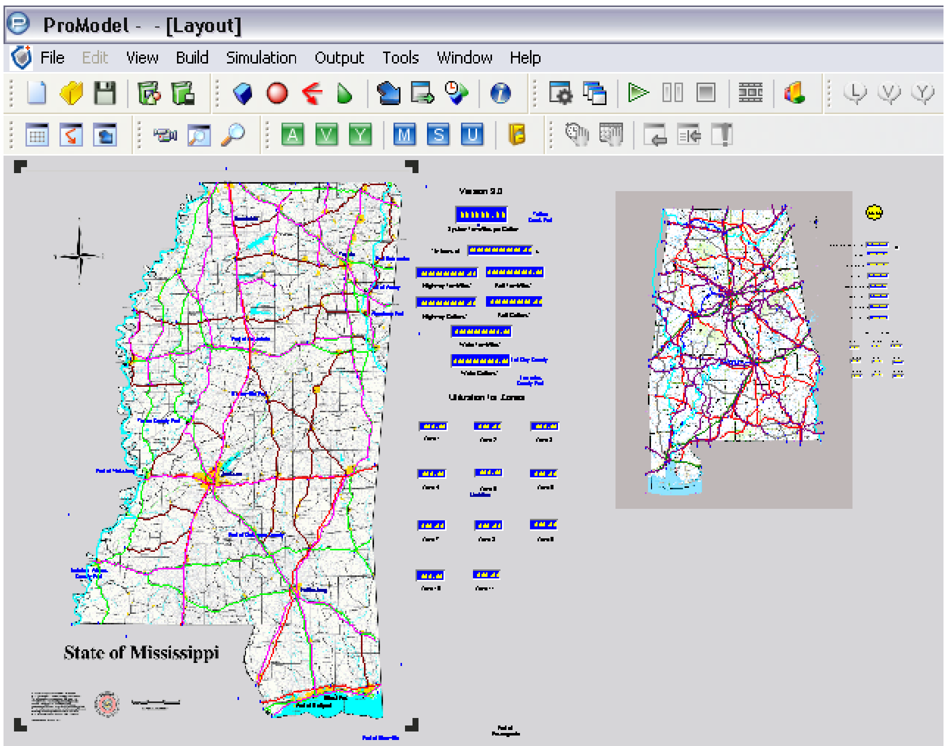


Figure 5.3 Model sizes.

The last item considered here is the reality that the ProModel discrete event simulation environment has been stretched to the limits, so the probability of building a regional model in ProModel is a stretch. The better opportunity may be to work with Mississippi to develop the VITS in Java to expand the capabilities of both state models.

5.3. Improving Graphics

After a significant level of effort, it was determined that the ProModel programming environment does not provide any opportunity to improve substantially the graphics of the icons. The fact that the ATIM had reached the limits of the ProModel programming environment made it obvious that continued investment into the ATIM in the ProModel simulation model was not the appropriate strategy. The ATIM V2.0 in a Java based application has the potential to achieve a more appealing graphic presentation. Improved graphics will be pursued with ATIM V2.0.

5.4. Application of Performance Measures

Over the last two decades, the development and execution of performance measures and performance-based management have been at the core of national and state transportation policy. Performance measures and management strategies have long been utilized by the private sector [1] and are being incorporated within the public sector to provide a means to assess the success or failure of projects/initiatives [2]. Performance measures are important, because they allow the users or owners of the transportation system to get more value from their investment, which takes special significance when considering the diverse nature of potential transportation stakeholders that have interest in the system performing well (commuters, state and local governments, trucking companies and associated customers, emergency response personnel, law enforcement, and environmental groups to name a few) [3].

The importance of performance measures have been studied by many researchers across a variety of disciplines. Most notably, the works of Pickrell and Neumann [3, 4, 5, 6] have been a frequently referenced guideline in describing the values and capabilities of performance measures. At a November 2000 conference, *Performance Measures to Improve Transportation Systems and Agency Operations*, Pickrell and Neumann listed six fundamental reasons for adopting performance measures [4], which include:

- **Accountability:** Performance measures can indicate how well an organization is meeting its planning goals. [5] Since funding is typically limited for transportation improvements and transportation projects can have significant environmental implications, data that can link performance to priorities is important.

- **Efficiency:** Performance measures can guide the allocation of resources to areas that need the most immediate attention as well as divert resources from failed programs [5]. Performance measures also provide for benefit/costs and other trade-off type analyses that can determine which projects have the highest return per dollar invested or which projects can provide a more timely response to transportation needs [7].

- **Effectiveness:** Performance measurement can provide a means to rate system performance against established benchmarks that define expected performance standards (such as 90% of all bridges should meet a certain structural condition) [8]. Effective programs allow for the allocations of funding resources and managerial decisions to be based on performance measurement [7].

- **Communications:** Performance measures allow for easier communication and potential support of transportation policy to the diverse audiences that exist both inside and outside the agency [5]. In addition, receiving feedback from the users of the transportation system can allow for refinement of performance measures in order to capture the most relevant information.

- **Clarity:** Performance measures can simplify existing programs by establishing clear links between goals and projects to see which methods best improve performance. Also, transparency of project selection when relying on performance measures can help to build trust among stakeholders.

- **Improvement:** Performance measures provide a decision-making tool that can help identify system deficiencies and opportunities for improvement [9]. Additionally, establishing of benchmarks amongst performance measures can help identify specific programs that may be successful in one state/region and easily adaptable to another.

Performance measurement is typically successful when meaningful measures are selected, the proper data needed for the measurement is obtained, and the measurement is incorporated into an overall planning process that guides decision-making based off the measurement. In many cases, agencies have collected performance data, such as vehicle collisions at an intersection or incident clearance times, but only recently has a push existed to link the collected data with programming to achieve established benchmarks. As public transportation agencies have moved forward with performance measures, the primary focus has been on passenger car-related performance, but recently other areas, such as freight movement, have become more important [10]. Performance measures allow for agencies to manage plans that have been selected due to their ability to achieve high-level performance in areas that the users/owners of the transportation system have deemed important [3].

Some aspects of performance measurement were outlined in the ALDOT's *Alabama Statewide Transportation Plan*, published in July 2008. This document presents long-range (2035) assessments of the state's transportation program. In the plan, four primary goals are identified that exist to drive the agency's long-range policies and decision-making. These goals are stated as follows:

- Provide safe and efficient transportation for people and goods.
- Protect the public and private investment in transportation.
- Provide an interconnected transportation system that supports economic development objectives.
- Provide a transportation system that preserves the quality of the environment and enhances the quality of life.

In addition, the plan identified certain “measures of condition” to gauge how well the transportation system is functioning in achieving these goals. Table 5.1 describes the specific measures of condition associated with the goal as well as any specified threshold values that the plan seeks to maintain.

Though the plan itself addresses all modes of transportation for which ALDOT has direct responsibility or participates cooperatively in support of other agencies, the only mention of “measures of condition” or performance measurement in the plan are in a highway context.

In developing performance measures for ALDOT, the research team consulted *NCHRP Report 446: A Guidebook for Performance-Based Transportation Planning* and *NCHRP Synthesis 311: Performance Measures of Operational Effectiveness for Highway Segments and Systems*. These comprehensive documents provide a wealth of information regarding the development of performance-based measurement programs and provide needed insight into the state of the practice and recommendations for the future. Though some overlap exists between these documents, *NCHRP Report 446* provides broad guidelines for instituting performance measures into existing planning programs while *NCHRP Synthesis 311* provides more tangible detail regarding the selection and usefulness of specific measures for highway applications. Both documents provided needed guidance in developing this report.

Table 5.1 Goals, Measures of Condition, and Thresholds from the ALDOT Statewide Plan

Goals	Measures of Condition	Recommended Threshold
Provide safe and efficient transportation for people and goods	Average congested roadway speed	n/a
	Average travel time	n/a
	Monitored crash rates (CARE data)	Routes with normalized crash and/or fatality rates one standard deviation above the study system average should be identified for future consideration
	Truck traffic volumes	n/a
Protect the public and private investment in transportation	HYDRA condition of pavement	Roadways with an ALDOT rating of marginal or less should be labeled as deficient, right shoulders less than 10 feet for rural arterial facilities, left shoulders less than 4 feet for 4-lane section
	Age of transit buses	n/a
	Bridge rating reviews	Replace bridges with a sufficiency rating below 50 or age greater than 50 years
Provide an interconnected transportation system that supports economic development objectives	Per capita vehicle miles traveled (VMT)	n/a
	Per capita vehicle hours traveled (VHT)	n/a
	Peak period volume to capacity (v/c) ratio	Rural: less than 0.75, Urban: less than 0.90
	Average congested roadway speed	n/a
	Average travel time (urban/rural)	n/a
Provide a transportation system that preserves the quality of the environment and enhances the quality of life	Wetland banks for mitigation	n/a
	Miles of sidewalks/bike trails	n/a
	Highway Beautification programs	n/a

5.4.1. NCHRP Report 446 & 311

Published in 2000, *NCHRP Report 446* addresses the incorporation of performance measures into a broader performance-based planning process. The purpose of the report is to offer flexible, widely applicable guidance for establishing performance-based planning that can be applied to diverse audiences (State DOT's, MPOs, county and local governments, transit agencies, special transportation commissions, policy boards or management agencies). *NCHRP Report 446* can be classified into two major components – the first of which describes an overarching framework and development process, and the second discusses data collection procedures (including freight) and analytical tools that may be useful for interpreting data.

NCHRP Report 446 also lists and describes the procedures needed to acquire performance data. Various types of survey methods (e.g., workplace, transit on-board, truck, and parking) are detailed as well as traffic data collection procedures, customer satisfaction polling, and national databases compiled by the Federal Highway Administration, such as the Highway Performance Monitoring System (HPMS).

Though *NCHRP Report 446* is written at a level high enough to provide guidelines for all modes of travel, most of the case studies and examples are oriented towards highway performance measurement. Appendix B, however, provides a list of many known performance measures and is not limited to a highway context. Appendix B was used as a preliminary resource for the research team when considering the potential performance measures relevant to ALDOT.

NCHRP Synthesis 311 was published in 2003 and seeks to summarize the current knowledge and practice of the use of performance measures for the monitoring and operational management of highways. The document has a narrower scope than *NCHRP Report 446* with most of the content focusing on the key factors for selecting performance measures and which measures have been successfully implemented in practice. *NCHRP Synthesis 311* presents a literature review of the seminal works on highway performance measures, summarizes the results of a nationwide survey, and lists highlights of federal, state, and local agency practices.

The literature review from *NCHRP Synthesis 311* contains many valuable insights about the selection of performance measures. In separate studies, Pratt and Lomax (1996) and Turner et al (1996) recommended similar key principles and guidelines for instituting performance measures, including matching performance measures with objectives, using common denominators to facilitate comparisons between multimodal systems, remembering the intended audience, and emphasizing the importance of quantification over subjective judgment. Additionally, Lomax et al (1997) in *NCHRP 398: Quantifying Urban Congestion* developed specific performance measures to gauge congestion that include:

- Travel rate in minutes per mile
- Delay rate in minutes per mile
- Total delay in person-hours
- Corridor mobility index (speed of person movement divided by a normalizing value)
- Accessibility, percent of destinations within *x* minutes
- Congested travel in person-miles, sum of congested lengths multiplied by number of persons

Additionally, the literature review indicated that more recent research on highway performance has emphasized a reliance on reliability measurement – namely, the accepted variability between expected travel time and the actual travel time that users of the system experience on a daily basis. Survey data and other research indicate that travel time reliability consistently ranks as one of the most important expectations from system users. *NCHRP Synthesis 311* outlines several research efforts to quantify travel time reliability, including the *Florida Reliability Manual* (2000) and the Texas Transportation Institute's *Urban Mobility Report*. The *Florida Reliability Manual* proposes to classify travel reliability by considering the median travel time across a corridor during a specific period of interest plus an additional amount of time estimated as a percent of the median travel time (such as 15%) that a traveler would find acceptable. Preference surveys are recommended to determine the acceptable additional time depending on the route and community. Additionally, the *Urban Mobility Report* uses a reliability "buffer index" that is defined as the difference in the average travel rate and the 95^{th} percentile travel rate divided by the average travel rate times 100%. This index is meant to illustrate the extra time that a traveler must budget when traveling during peak periods of the day. In any case, reliability measures are a very important component to any highway performance measurement system.

As mentioned, *NCHRP Synthesis 311* conducted a survey of state transportation agencies and MPOs to determine the state of the practice. The survey covered many aspects of performance measurement, including the agencies' history regarding performance measures, their intended audience, the data collection procedures, how the information is reported, and what measures are used for highway operations. Among the most notable findings were that the most important type of performance measures collected were those that described *quantity* and *quality* of service.

Quantity measures of volume, vehicle-miles traveled, and truck-miles traveled were important to agencies with stated goals of maximizing the movement of people/goods that can use the system. In addition, these basic measures allow for the derivation of important environmental measures, such as fuel consumption and noise and air quality impacts. Measures that describe the quality of travel were also identified by agencies as having a high importance. These measures include highway volume to capacity ratios, delay, speed, travel time, and highway segment level of service. Additionally, several agencies reported measures that relate more to agency output than system-related outcomes. These output measures include performance-based budgeting, percent of railroads with active crossing protection, and the number of signals retimed per year. These measures are less important to the users of the system, but can be very important to agencies in prioritizing goals and allocating funding.

Finally, *NCHRP Synthesis 311* provides a summary table (Table 5.2) that adapts evaluation criteria from various studies to assess the strengths and weaknesses of highway performance measures. The study then used these evaluation criteria to assess the relative value of the nearly 70 performance measures considered in this research. The assessment indicated that the following measures received favorable scores according to the criteria:

- Quantity of travel (user perspective): person-miles traveled, truck-miles traveled, vehicle-miles traveled, persons moved, trucks moved, vehicles moved.
- Quality of travel (user perspective): average speed weighted by person-miles traveled, average door-to-door travel time, travel time predictability, travel time reliability, average delay, and level of service.
- Utilization of the system (agency perspective): percent of system heavily congested, density, percentage of travel heavily congested, volume to capacity ratio, queuing, percent of miles operating in desired speed range, vehicle occupancy, duration of congestion.
- Safety: incident rate by severity or type
- Incidents: incident induced delay and evacuation clearance time
- Outputs (agency performance): incident response time by type, toll revenue, bridge condition, pavement condition, percent of ITS equipment operational.

Table 5.2 Summary of Performance Measures.

General Criteria	Specific Criteria
Clarity and simplicity	The measure is simple to present, analyze, and interpret
	The measure is unambiguous
	The measure's units are well defined and quantifiable
	The measure has professional credibility
Descriptive and predictive ability	Technical and nontechnical audiences understand the measure
	The measure describes existing conditions
	The measure can be used to identify problems
	The measure can be used to predict change and forecast condition
Analysis capability	The measure reflects changes in traffic flow conditions only
	The measure can be calculated easily
	The measure can be calculated with existing field data
	There are techniques available to estimate the measure
	The results are easy to analyze
Accuracy and precision	The measure achieves consistent results
	The accuracy level of the estimation techniques is acceptable
	The measure is sensitive to significant changes in assumptions
	The precision of the measure is consistent with planning applications
	The precision of the measure is consistent with an operation analysis
Flexibility	The measure applies to multiple modes
	The measure is meaningful at varying scales and settings

5.5 Freight Scenarios Using ATIM

The ability to make reasonable decisions regarding transportation investment is limited by the quality and quantity of information available on the transportation infrastructure. The ability to accurately model transportation infrastructure, identify congestion choke points, and define needed capacity shortfalls is vital to the planning decision-making needs on transportation systems for both people and goods.

The movement of freight in a timely and efficient manner is quickly becoming one of the critical components of the U.S. economy. Heavy vehicles, 18 wheel trucks, are the backbone of the logistics and economic success of industry in the United States. National projections are that freight shipments will double in the next ten years. The increase in freight will have a significant impact on the level of congestion along the national transportation infrastructure and will require innovative congestion mitigation solutions. A detailed understanding of the impact of the projected increase in truck traffic on the existing highway system is needed to examine in the potential outcomes and develop a focused plan to accommodate the anticipated increase.

To accomplish this task, the research team built upon the existing transportation analysis and planning tools developed at UAH. The first of these tools is the Alabama Transportation Infrastructure Model (ATIM). The second tool is a statewide highway, rail and waterway network developed in TRANPLAN, a generally accepted travel demand model, which has been enhanced to support a statewide freight analysis. The research team developed a seamless interface between the two models to allow for easy sharing of volume, route and Origin/Destination data. The integration of these models produced a tool capable of quickly analyzing scenarios and events on the transportation infrastructure and can be used to evaluate alternative solutions.

5.5.1 Updating the Networks

To begin the process of modeling the future truck growth using the two software packages in unison, the two highway networks needed to be amended to be reflective of each other. The differences in the networks was based on the fact that they were developed at different times and with the varied operation of the software packages, there were discrepancies that were initially entered to benefit each package. The TRANPLAN network was the network that required the updating as it was used for distributing the freight flow while the ATIM network was used for routing purposes. A careful process was undertaken to match roadways from the ATIM network to roadways in the original TRANPLAN network to ensure that the two networks were similar. This step was done manually with each roadway being correctly coded in the TRANPLAN environment. Upon completion, the TRANPLAN network contained the roughly 4,000 miles that the ATIM model contained.

After updating the TRANPLAN network, a process was developed to link the TRANPLAN network roadways to the roadways contained in data provided by the Alabama Department of Transportation (ALDOT). In this fashion, the roadways could be easily identified and the official data values such as capacity, lane miles, traffic volume and growth rates could be used for further analysis.

5.5.2 Model Validation

The use of freight data in transportation modeling requires confidence in the data being used for decision making. The method in transportation planning activities to gain confidence in the data is through a validation process, essentially, determining how well the freight data developed from the model matches the freight data observed through actual traffic counts. To perform this validation, a complete model for freight data was needed to generate freight at the county level, distribute freight between counties and assign freight to expected roadways in Alabama to determine if the assignment met closely with the actual volumes. Only after this preliminary validation of the freight volume, could the model be trusted to provide accurate future volumes when the various scenarios were developed. The procedure developed that resulted in a model assignment of trucks on the roadway is the “Freight Planning Framework” described in Section 3. The use of the FAF2 database and the disaggregation parameters outlined in the Freight Planning Framework were able to provide a quality freight forecast, and therefore should provide quality results in future scenarios.

5.5.3 Development of a Seamless Interface

A seamless interface was developed to provide a mechanism to pass data from the TRANPLAN into the Alabama Transportation Infrastructure Model (ATIM model). The program developed in this research was used to take the OD data output from TRANPLAN as a text file and update the Excel file which ATIM used as its input file. The process involved developing a program capable of editing existing Excel files and a file matching, search routine as the two networks, although similar in terms of roadways and capacities, were not attributed with the same classification schemes due to the differences in the two models being used, TRANPLAN and ProModel. The program developed was written in Visual Basic and operates as an executable file. The program reduces the time to update the ATIM data to a few hours and removes the possibility of human error.

5.5.4 Development of Freight Scenarios

The scenarios developed to explore the impact of increasing the number of trucks on the state's highway infrastructure were intended to provide a snap-shot of "what-ifs" to the current capacity available. It is important to note that the Alabama Department of Transportation is constantly adding capacity to the roadway infrastructure and the analysis performed assumes that the state's infrastructure is held constant, as a mechanism to identify potential choke-points and assist in focusing the scarce resources of the state.

Using the original ALDOT volumes and capacities provided and the freight data provided from the Freight Analysis Framework, Version 2, there were five growth scenarios examined in this work. The first scenario was a trend line projected growth using only the existing traffic count and growth percentage obtained from historical traffic counts to the year 2015. This scenario was the anticipation of what would happen if traffic volumes grew as traffic volumes had been growing in the past.

The next four scenarios all took different routes to forecast the amount of freight expected on the state's roadway infrastructure. However, the constant in the scenarios was that the number of passenger cars expected on the roadways was all based on the trend line projection of current passenger car level forecasted to 2015 using the historical growth factors.

The second scenario involved forecasting the freight using the projection for 2015 that was developed within the FAF2 database. The procedure for disaggregating the freight data to the county level identified in Section 3 was followed. Additionally, the passenger car volumes were added afterwards.

The third scenario involved a doubling of the 2002 FAF2 freight flow data. This doubling was performed such that each county's contribution of freight to the entire state was doubled. Additionally, the passenger car volumes were added afterwards.

The fourth scenario involved double selected counties in Alabama, not the state as a whole. The top sixteen counties, representing 25 percent of the state, was the model with a doubling of freight volumes. Additionally, the passenger car volumes were added afterwards.

The fifth scenario involved using the FAF2 database's forecast of 2035 freight volumes and making the assertion that the state would reach this level of freight activity by 2015, due to the tremendous growth in industry and freight movements. As with scenario 2, the procedure for disaggregating freight data to the county level identified in Section 3 was followed. Additionally, the passenger car volumes were added afterwards.

5.5.5 Run Scenarios and Identify Congestion Chokepoints

The data developed were forecasted in TRANPLAN and ATIM to identify congestion chokepoints. The advantage of operating the two models together is the ability to identify two different measures of congestion. TRANPLAN, which runs a static daily assignment, is used to determine the locations where the forecasted daily volumes are approaching the daily capacities. ATIM, which runs a discrete event simulation, is used to determine the travel times for vehicles on specific roadways segments during the peak period of the day. For the analysis, locations are defined as congested if the volume to capacity ratio exceeds 0.9 on a daily basis in TRANPLAN, and the travel time during the peak congested hour of the day exceeds 25 percent of the travel time that would be achieved if a vehicle could travel at the posted speed limit. Again, it is important to note that these identified chokepoints are based in existing capacity levels, and changes in capacity would alleviate the congestion and improve travel time at these locations. Additionally, varying the definition of congestion would identify different locations and amounts of congestion.

Initially, it is important to know what level of congestion is currently being experienced in Alabama. Using the definition of congestion mentioned above for the volume to capacity ratio of 0.9, the TRANPLAN model indicates that there are 329 miles total lane miles of congestion, shown in Figure 5.4. Using the increased travel time method of calculating congestion, there are 159 center line miles of roadway where actual travel time is 25% greater than travel time at free flow speeds. Based upon this starting point, several scenario based analyses were performed utilizing both the TRANPLAN model and ATIM.

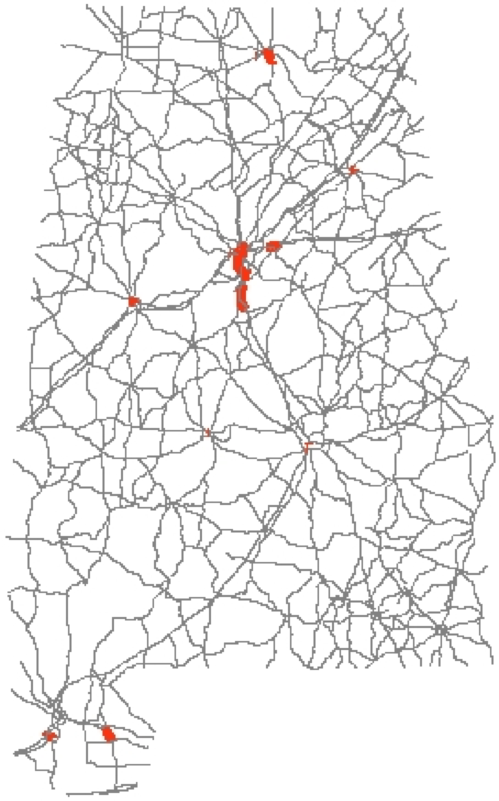


Figure 5.4 Current congestion locations.

5.5.5.1 First Scenario - ALDOT 2015 Forecast

The first scenario used only the ALDOT 2015 forecast based upon trend line analysis. This is to say that the traffic growth rate from historical traffic counts would be the method by which the future network demand would be determined. From the data, the total lane miles of congestion was determined to be 1,421 miles and the congested locations are shown in Figure 5.5. Based upon the current state of 329 congested lane miles, congestion is projected to grow by 332%.

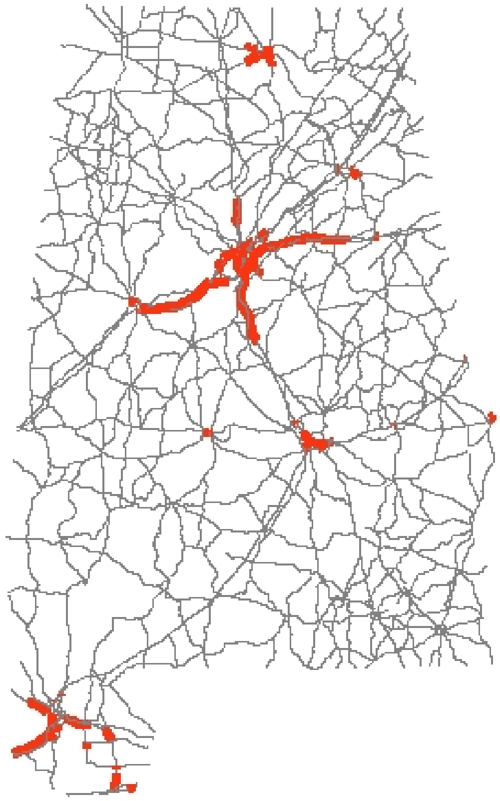


Figure 5.5 Congested locations using trend line analysis.

5.5.5.2 Second Scenario - FAF2 2015 Forecast

The second scenario used the 2015 projection from the FAF2 database. The origin/destination table for the trucks was obtained using the data disaggregating procedure identified previously in this report. The truck data was added to the passenger car projection for 2015 provided by ALDOT. Using the TRANPLAN model, this scenario resulted in 1,813 total lane miles of congestion. The congested locations are identified in Figure 5.6. ATIM was used to determine the maximum departure from free-flow travel speed to the travel speed the vehicle actual encounters during the worst period of the day. Figure 5-7 shows the locations where the actual travel time is 25 percent greater than the free-flow travel time.

These two figures clearly show the value in using the gravity distribution model (TRANPLAN) and a discrete event simulation (ATIM) concurrently to communicate transportation system issues. The TRANPLAN model communicates that the projected increase in congestion, based upon volume to capacity ratio is 451%. The ATIM model communicates that it will take at least 25% longer to travel than expected on 292 miles of roadways, an 84% increase. For freight, the expected travel time is probably the more important metric.

It would appear that there is discrepancy between the congestion calculations. In reality, the models are indicating that there are locations of congestion as defined by the volume to capacity ratio, where vehicles travel at times greater than free flow speed but less than the 25% threshold.

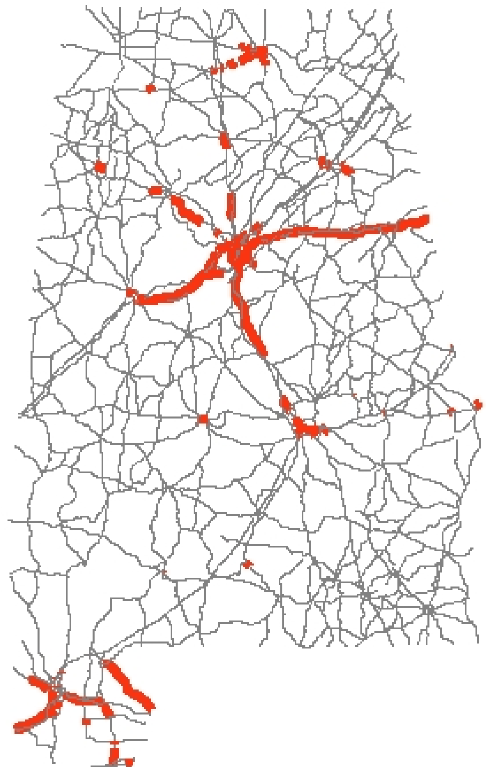


Figure 5.6 Congested locations using the FAF2 2015 projection.

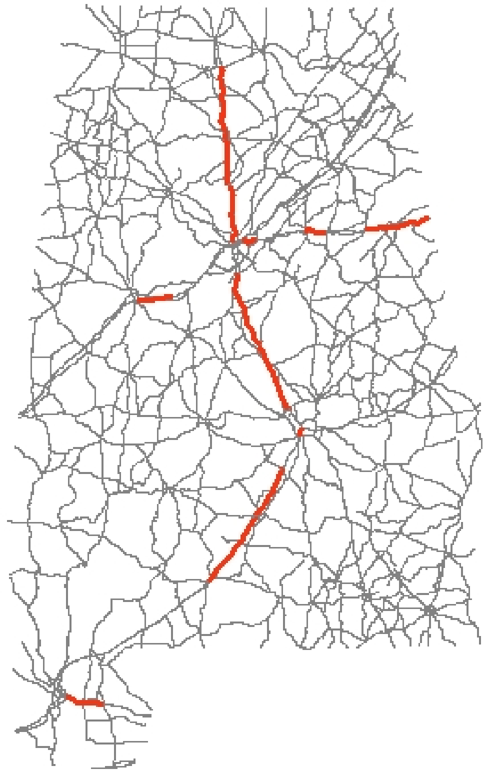


Figure 5.7 Locations Where Travel Time Exceeds 25% Using the FAF2 2015 Projection.

5.5.5.3 Third Scenario – Forecast Doubling the FAF2 2002 Truck Traffic Values

The third scenario used the 2002 truck data from the FAF2 database, but the values for each county in Alabama were doubled, which simulates the projection that freight traffic will double in the US by 2020. The truck origin/destination table for the trucks was obtained using the data disaggregating procedure identified previously in this report. The truck data was added to the passenger car projection for 2015 provided by ALDOT. This scenario resulted in 2,191 total lane miles of congestion and the congested locations are identified in Figure 5.8. The resulting growth in congestion, based upon the volume to capacity ration and the TRANPLAN model is 566%. It is important to state that this congestion metric assumes that capacity remains constant.

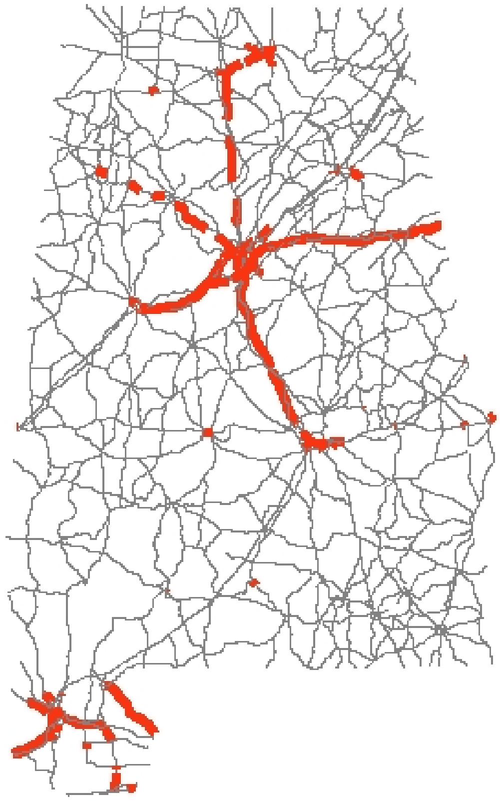


Figure 5.8 Congested Locations Doubling the FAF2 2002 Volumes.

ATIM was used to determine the maximum departure from free-flow travel speed to the travel speed the vehicle actual encounters during the worst period of the day. Figure 5-9 shows the locations where the actual travel time is 25 percent greater than the free-flow travel time. The resulting growth in congestion based upon travel time is 692 miles, or 335%.

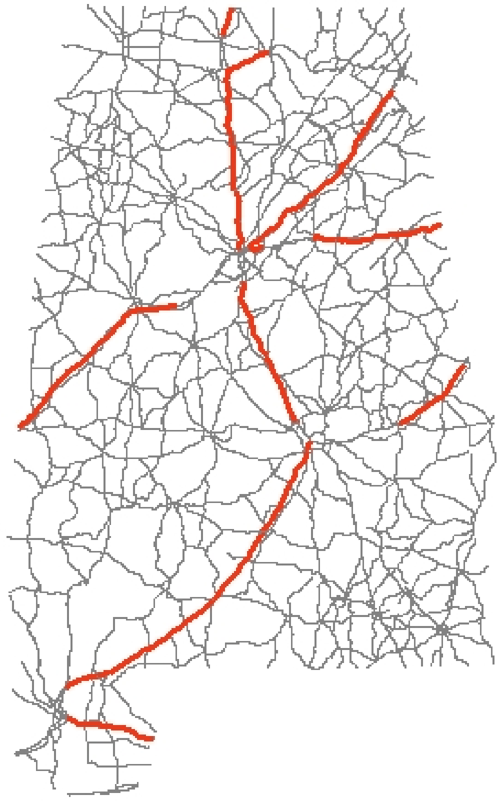


Figure 5.9 Locations Where Travel Time Exceeds 25% When Truck Traffic is Doubled From FAF2 2002 Volumes.

Figure 5-10 shows the locations where the actual travel time is greater than 100 percent of the free-flow travel time. This scenario describes a situation where it will take twice as long as to travel I-65 as one would expect at free flow speeds. The resulting impact of freight flow would be significant.

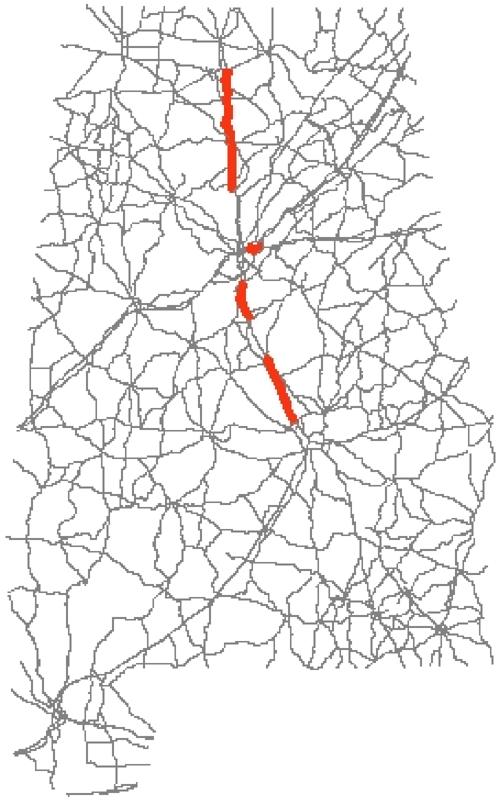


Figure 5.10 Locations Where Travel Time Exceeds 100% When FAF2 2002 Volumes are Doubled.

5.5.5.4 Fourth Scenario - FAF2 2002 Forecast Doubling Truck Traffic in Selected Counties

The fourth scenario used the 2002 truck data from the FAF2 database, but only the values for 16 counties with the most economic activity as measured by employment and value of shipments in Alabama were doubled, representing 25 percent of the state. The origin/destination table for trucks was obtained using the data disaggregating procedure identified previously in this report. The truck data was added to the passenger car projection for 2015 provided by ALDOT. This scenario resulted in 2,101 total lane miles of congestion. The congested locations are identified in Figure 5.11. The resulting growth in congestion, measured by volume to capacity ratio, is 538%. Note that this is not significantly different than scenario three where truck traffic in all counties was doubled, indicating that there are at least 71 counties where the capacity is available to absorb significant levels of growth before infrastructure improvements are required.

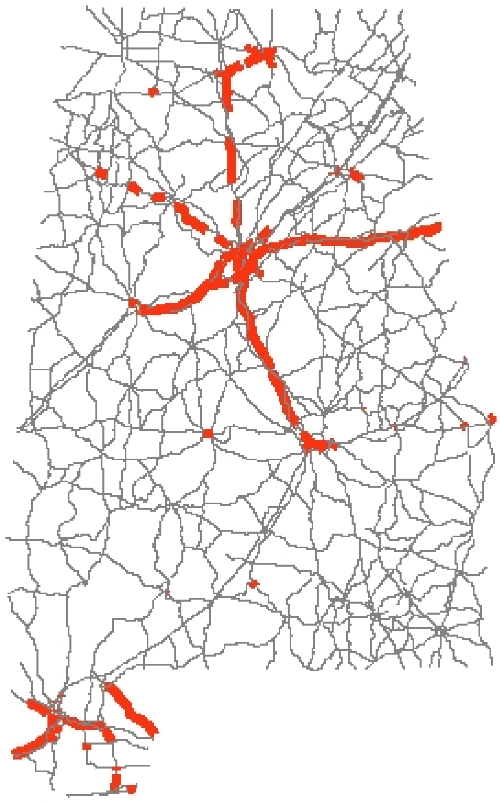


Figure 5.11 Congested Locations When Truck Traffic is Doubled in Selected Counties.

ATIM was used to determine the maximum departure from free-flow travel speed to the travel speed the vehicle actual encounter during the worst period of the day. Figure 5-12 shows the locations where the actual travel time is greater than 25 percent of the free-flow travel time. The resulting growth in congestion, measured by travel time exceeding the free flow time by more than 25 percent is 614 centerline miles or 286%.

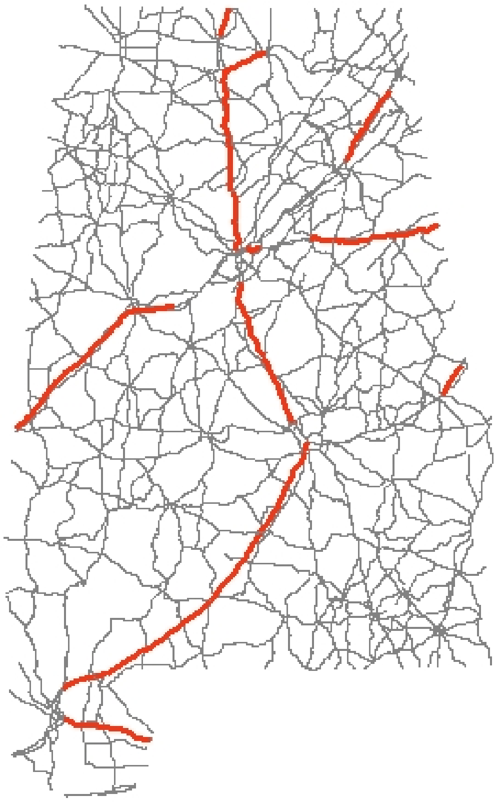


Figure 5.12 Locations Where Travel Time Exceeds 25% When Truck Traffic is Doubled for Selected Counties.

5.5.5.5 Fifth Scenario - FAF2 2035 Forecast

The fifth scenario tested used the 2035 truck data from the FAF2 database. The origin/destination table for trucks was obtained using the data disaggregating procedure identified previously in this report. The truck data was added to the passenger car projection for 2015 provided by ALDOT. This scenario resulted in 2,105 total lane miles of congestion and the congested locations are identified in Figure 5.13. The resulting growth in congestion, measured by volume to capacity ratio, is 539%.

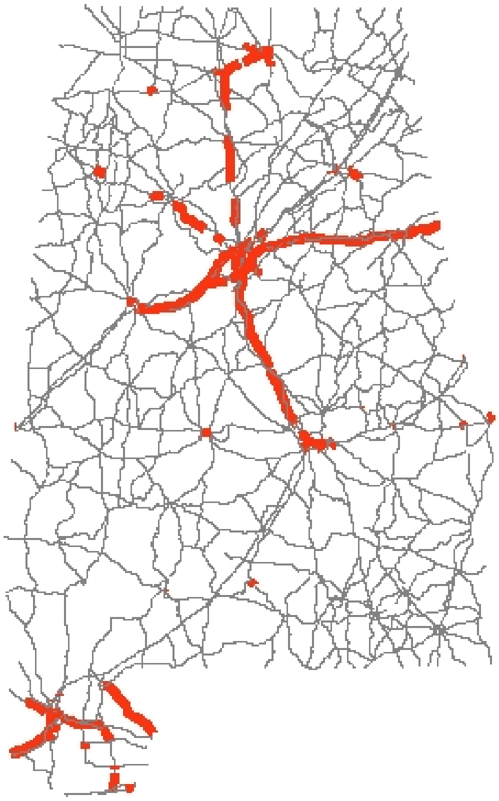


Figure 5.13 Congested Locations Using the 2035 FAF2 Projection.

ATIM was used to determine the maximum departure from free flow travel speed to the travel speed the vehicle actual encounters during the worst period of the day. Figure 5-14 shows the locations where the actual travel time is 25 percent greater than the free flow travel time. The resulting growth in congestion, measured by travel time exceeding the free flow time by more than 25 percent, is 694 centerline miles or 336%. Figure 5-15 shows the locations where the actual travel time is greater than 100 percent of the free-flow travel time.

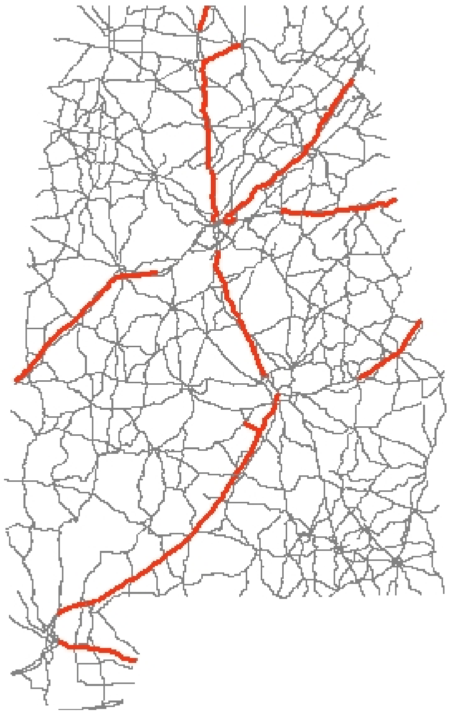


Figure 5.14 Locations Where Travel Time Exceeds 25% Using the 2035 FAF2 Projection.

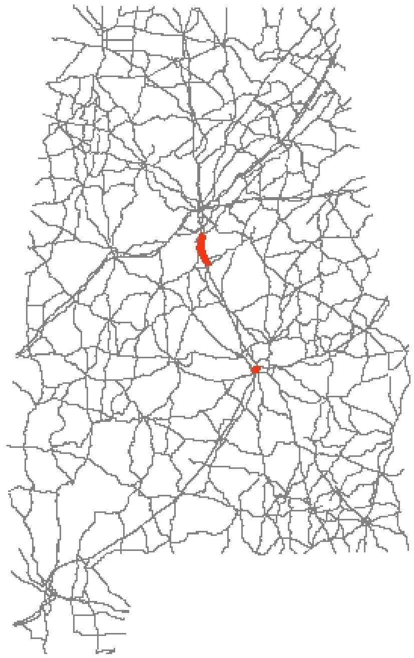


Figure 5.15 Locations Where Travel Time exceeds 100% Using the 2035 FAF2 Projection.

5.5.6 Conclusions

This ability to quickly develop and test scenarios in the two modeling packages represents a significant improvement, without reducing the accuracy of the models. The ability to identify congestion chokepoints/bottlenecks is important when considering that scarce resources are available for highway improvements and the cost for improvements continues to rise. The scenarios developed for this effort represent only possible growth options developed to test the development of the software packages and interface between them. The scenarios need not be limited after the development of the tools are established and multiple options could have been attempted. The scenarios are important to illustrate what conditions might occur due to funding limitations and other unforeseen situations.

5.6 Developing a Methodology to Apply Rural Time of Day

Presently, the ATIM creates traffic flows across a highway network for a twenty-four period using independently calculated daily volumes for trucks and passenger vehicles. These daily volumes were initially distributed in the ATIM using a basic 20/60/20 split over the course of the morning, midday, and night time periods of a day. This methodology was effective for simulating the cumulative traffic flow across the network, however, the model could be enhanced if additional information were known regarding hourly volume distributions for either vehicle type and if these distributions varied based on network location (urban vs. rural) or facility (arterial vs. interstate). Research was performed on these parameters to determine if the existing procedure could be improved.

5.6.1 ALDOT Count Stations

To determine hourly vehicle distributions, sample data was obtained from ALDOT permanent count stations for a typical weekday in April 2008. A select number of ALDOT permanent count stations offer publicly-available historic hourly count information for the total number of vehicles (trucks and passenger cars) traveling pass a facility. Twenty locations were chosen throughout the state – 5 urban interstate locations, 5 urban arterial locations, 5 rural interstate locations, and 5 rural arterial locations. Consideration was given to select locations in each of the four major urban areas (Birmingham, Huntsville, Mobile, and Montgomery) as well as to include rural locations from all regions of the state.

Figure 5.16 depicts the average hourly volume distribution for all rural and urban sampled locations. The profiles follow somewhat similar patterns with the peak period occurring between 5-6 PM for both urban and rural locations. The rural profile, however, rises steadily through the morning hours and does not have the morning peak period witnessed in the urban areas.

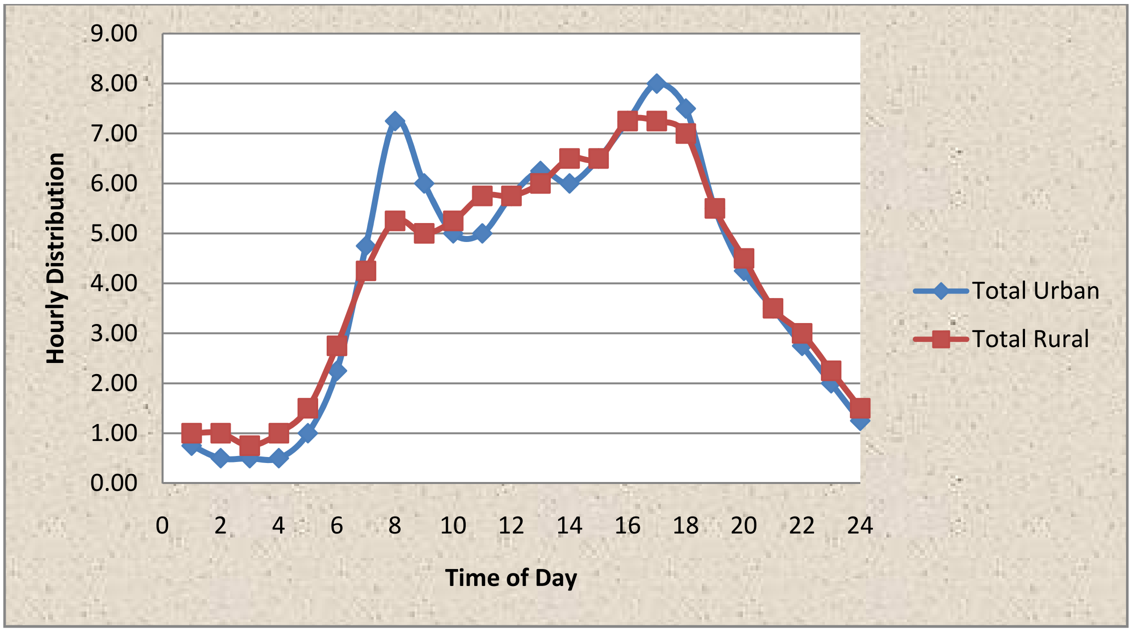


Figure 5.16 Urban vs. Rural Locations - Hourly Distribution from ALDOT Count Stations

Figure 5.17 depicts the average hourly volume profile for urban and rural freeways. Similar to the overall profile, the rural locations do not have volume peaks in the morning. The rural interstate profile is intuitive in that these locations are composed of a greater percentage of non-local through trips (trucks and traveling passenger cars), which are more likely to be driving during the afternoon hours.

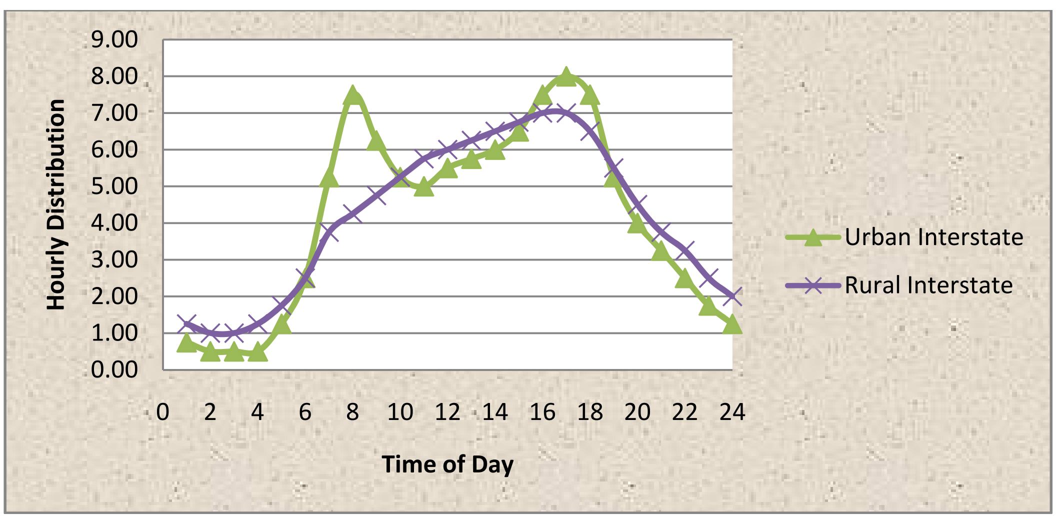


Figure 5.17 Urban vs. Rural Interstate - Hourly Distribution from ALDOT Count Stations

Figure 5.18 depicts the average hourly volume profile for urban arterials and rural arterials. As shown, the hourly distributions are much more similar for arterials than for interstates. The collected sample data indicates that rural arterials witness similar morning and afternoon peaking characteristics.

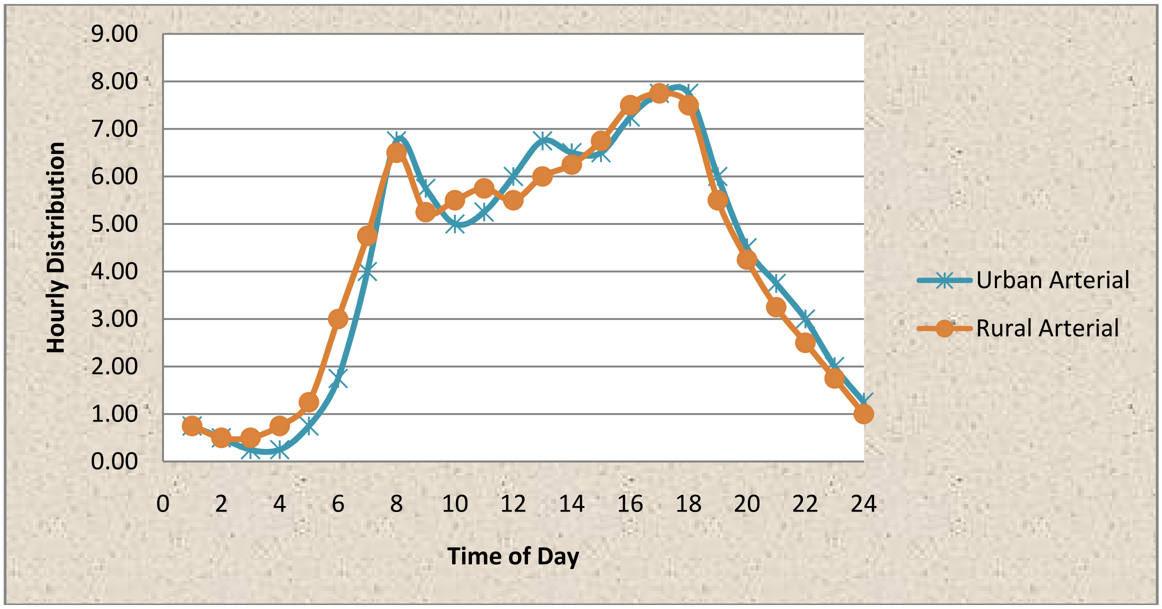


Figure 5.18 Urban vs. Rural Arterial - Hourly Distribution from ALDOT Count Stations

5.6.2 Other Data Sources

In addition to the local ALDOT count data, national hourly distributions from *NCHRP Report 365* were assessed. *NCHRP Report 365* contains hourly profiles for combined (trucks and passenger cars) volumes for a variety of urban area sizes (ranging from 50,000 to over 1,000,000 people). The *NCHRP* hourly percentages were averaged and are shown in Figure 6. As shown, the *NCHRP* profile is similar to the rural arterial and urban profiles with the exception of a slightly higher percentage of peak hour traffic occurring during the PM peak period (about 1% greater).

Truck-specific volumes by time of day were also assessed from the USDOT's *Quick Response Freight Manual (QRFM)*. The *QRFM* contained hourly distributions averaged from many urban areas across the country. As shown in Figure 5.19, the truck hourly profile differs significantly from the urban/rural profiles discussed previously as the typical evening peak period is not as heavy and the actual peak condition occurs around noon. Approximately 70% of the truck traffic shown in the truck profile occurs between 8 AM and 3 PM.

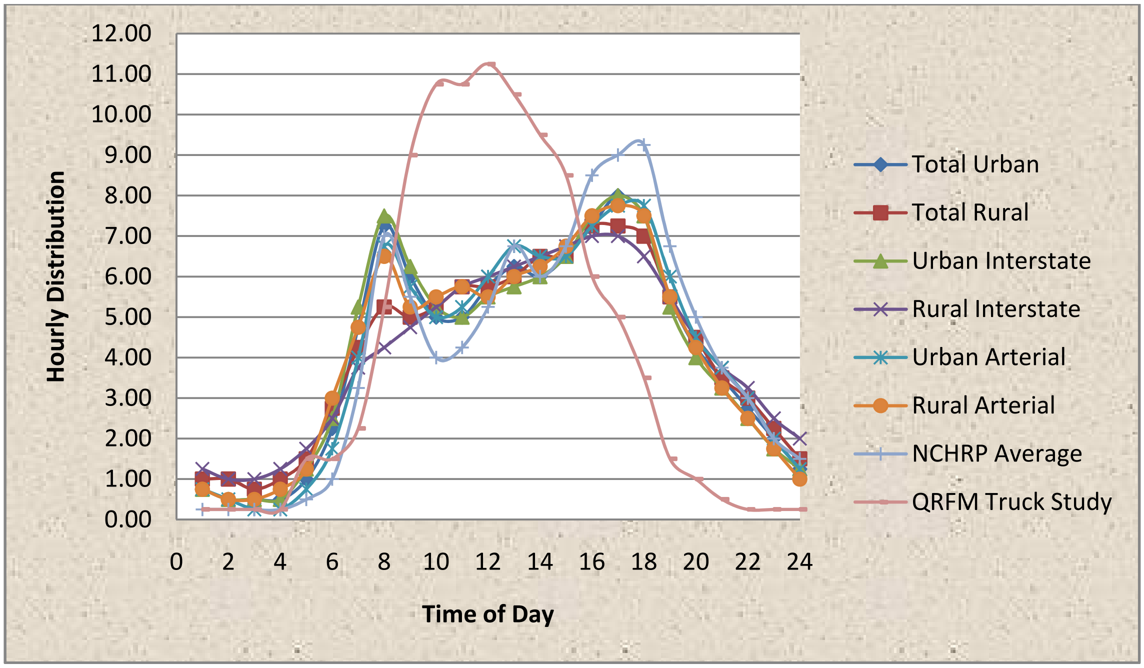


Figure 5.19 Hourly Profile Comparisons – ALDOT, NCHRP, QRFM

5.6.3 Conclusions

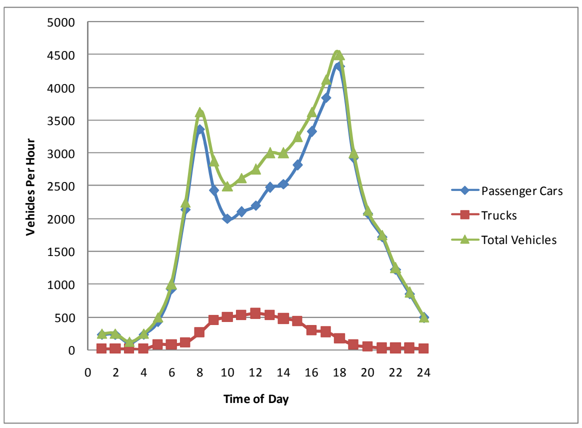
Research of the ALDOT hourly counts and other data sources indicated that enhancements could be made to the existing volume distribution for trucks and passenger cars into the ATIM. The ALDOT data revealed that the volume profile in urban locations was similar for both interstate and arterial routes with distinct morning and afternoon peaking characteristics. The ALDOT data for rural locations was similar to the urban results for arterial routes, but the rural interstate profiles lacked a morning peak. Data from the *NCHRP 365* confirmed the hourly profiles determined from the urban and rural arterial ALDOT data, with a slightly higher peaking characteristic in the afternoon. Truck-specific data found through the *QRFM* indicated that the hourly distribution of trucks differs significantly, resembling a bell-shaped curve with a peak around noon.

5.6.4 Recommendations

It is recommended that future generations of the ATIM use more defined time of day percentages when converting daily passenger car and truck volume into hourly flows. The recommended procedure is described below. For urban areas and rural arterial routes, the recommended hourly distributions for total vehicles and trucks are shown in Table 5.3. The distribution for total vehicles (passenger cars and trucks) is based on the ALDOT data and includes an adjustment to include a higher percentage in the PM peak period (9% from the *NCHRP* data). The distribution for trucks is based on the *QRFM* data. When entering the data to the ATIM, the total daily traffic volume and daily truck volume should be multiplied by the distributions to determine the hourly figures. The number of passenger cars per hour is the difference between the total number of vehicles and the number of trucks. A sample profile for a route with a daily traffic volume of 50,000 and 10% trucks is shown in Figure 5.20.   This method is viable as long as the vehicle mix is less than 50% trucks as the methodology would produce a negative number of passenger cars during the late morning hours when the trucks peak.

Table 5.3 Recommended Hourly Distributions for Urban Routes and Rural Arterials

Time of Day	Truck	Total Number of Vehicles	Time of Day	Truck	Total Number of Vehicles	Time of Day	Truck	Total Number of Vehicles
12 P - 1 AM	0.25	0.50	8 AM - 9 AM	9.00	5.75	4 PM - 5 PM	5.50	8.25
1 AM - 2 AM	0.25	0.50	9 AM - 10 AM	10.00	5.00	5 PM - 6 PM	3.50	9.00
2 AM - 3 AM	0.25	0.25	10 AM - 11 AM	10.50	5.25	6 PM - 7 PM	1.50	6.00
3 AM - 4 AM	0.25	0.50	11 AM - 12 PM	11.00	5.50	7 PM - 8 PM	1.00	4.25
4 AM - 5 AM	1.50	1.00	12 PM - 1 PM	10.50	6.00	8 PM - 9 PM	0.50	3.50
5 AM - 6 AM	1.50	2.00	1 PM - 2 PM	9.50	6.00	9 PM - 10 PM	0.50	2.50
6 AM - 7 AM	2.25	4.50	2 PM - 3 PM	8.75	6.50	10 PM - 11 PM	0.50	1.75
7 AM - 8 AM	5.25	7.25	3 PM - 4 PM	6.00	7.25	11 PM - 12 AM	0.25	1.00



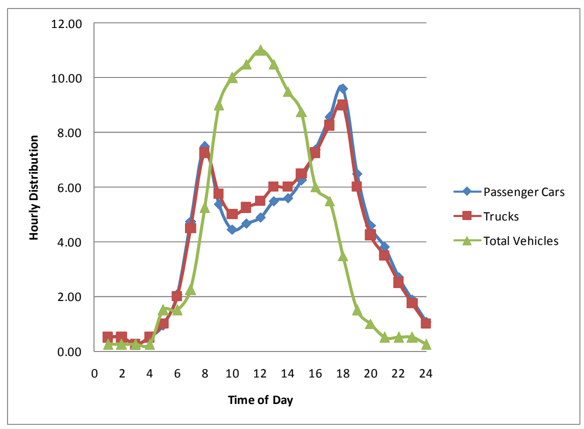
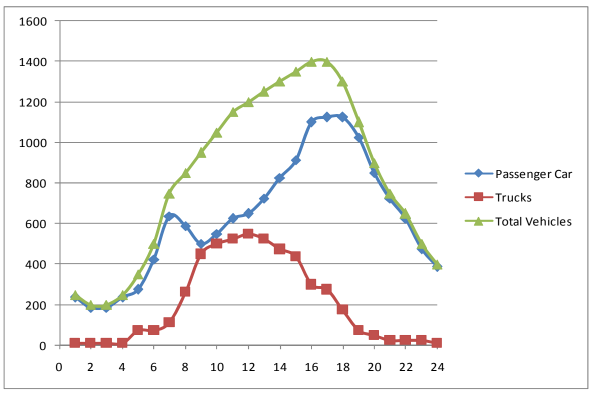


Figure 5.20 Sample Hourly Profiles for Urban Routes and Rural Collector

For rural interstate routes, the recommended hourly distribution for total vehicles and trucks is shown in Table 5.4. The distribution for total vehicles is based on the ALDOT data for rural interstates while the truck distribution is the same as that used for urban routes and rural arterials.   A sample profile for a route with a daily traffic volume of 20,000 with 25% trucks is shown in Figure 5.21.   As before, this methodology is accurate as long as the vehicle mix is less than approximately 50% trucks.

Table 5.4 Recommended Hourly Distributions for Rural Interstates

Time of Day	Truck	Total Number of Vehicles	Time of Day	Truck	Total Number of Vehicles	Time of Day	Truck	Total Number of Vehicles
12 P - 1 AM	0.25	1.25	8 AM - 9 AM	9.00	4.75	4 PM - 5 PM	5.50	7.00
1 AM - 2 AM	0.25	1.00	9 AM - 10 AM	10.00	5.25	5 PM - 6 PM	3.50	6.50
2 AM - 3 AM	0.25	1.00	10 AM - 11 AM	10.50	5.75	6 PM - 7 PM	1.50	5.50
3 AM - 4 AM	0.25	1.25	11 AM - 12 PM	11.00	6.00	7 PM - 8 PM	1.00	4.50
4 AM - 5 AM	1.50	1.75	12 PM - 1 PM	10.50	6.25	8 PM - 9 PM	0.50	3.75
5 AM - 6 AM	1.50	2.50	1 PM - 2 PM	9.50	6.50	9 PM - 10 PM	0.50	3.25
6 AM - 7 AM	2.25	3.75	2 PM - 3 PM	8.75	6.75	10 PM - 11 PM	0.50	2.50
7 AM - 8 AM	5.25	4.25	3 PM - 4 PM	6.00	7.00	11 PM - 12 AM	0.25	2.00



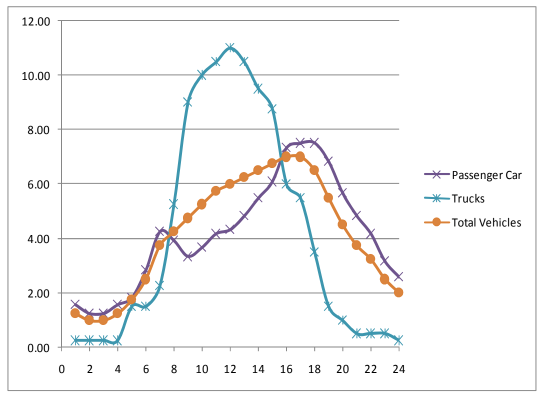


Figure 5.21Sample Hourly Profiles for Rural Interstates

5.6.4.1 Alternate Procedure

If time or modeling constraints prevent the ATIM volumes separating the total distribution based on urban/rural, a general distribution for all routes can be determined by averaging the two total vehicle approaches and maintaining the truck percentages. The recommended hourly distribution for total vehicles and trucks are shown in Table 5.5. A sample profile for a route with a daily traffic volume of 30,000 with 30% trucks is shown in Figure 5.22. As before, this methodology is accurate as long as the vehicle mix is less than approximately 50% trucks.

Table 5.5 Recommended Hourly Distributions for Alternate Procedure

Time of Day	Truck	Total Number of Vehicles	Time of Day	Truck	Total Number of Vehicles	Time of Day	Truck	Total Number of Vehicles
12 P - 1 AM	0.25	0.75	8 AM - 9 AM	9.00	5.25	4 PM - 5 PM	5.50	7.50
1 AM - 2 AM	0.25	0.50	9 AM - 10 AM	10.00	5.00	5 PM - 6 PM	3.50	8.00
2 AM - 3 AM	0.25	0.50	10 AM - 11 AM	10.50	5.25	6 PM - 7 PM	1.50	5.75
3 AM - 4 AM	0.25	1.25	11 AM - 12 PM	11.00	5.75	7 PM - 8 PM	1.00	4.50
4 AM - 5 AM	1.50	1.50	12 PM - 1 PM	10.50	6.25	8 PM - 9 PM	0.50	3.50
5 AM - 6 AM	1.50	2.25	1 PM - 2 PM	9.50	6.25	9 PM - 10 PM	0.50	3.00
6 AM - 7 AM	2.25	4.25	2 PM - 3 PM	8.75	6.25	10 PM - 11 PM	0.50	2.25
7 AM - 8 AM	5.25	6.50	3 PM - 4 PM	6.00	6.75	11 PM - 12 AM	0.25	1.25

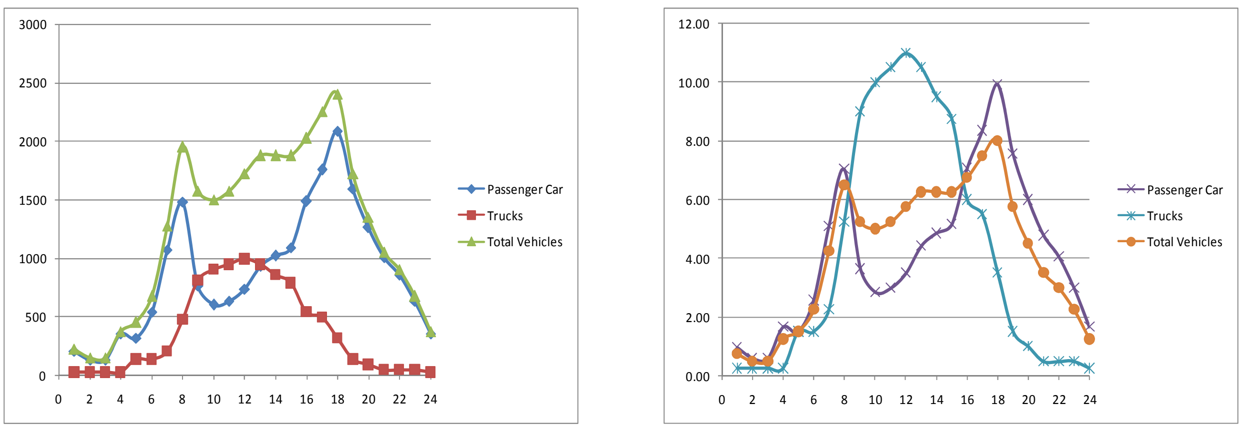


Figure 5.22 Sample Hourly Profile for Alternate Procedure

5.7 Evaluation of Commuter Rail Service in an Alabama Metropolitan Planning Organization

One reason for the noted increase in truck traffic is the globalization of international trade. The growth in commuter and truck traffic is significantly increasing the congestion at the I-10 tunnel crossing the Mobile River in Mobile, AL. In addition to the overall effects of growing international trade, area-specific growth of container shipments is occurring at the Mobile Container Terminal at the Port of Mobile, AL. The majority of containers at the recently expanded Port of Mobile are arriving and departing on trucks.

Figure 5.23 is a map portraying the Wallace tunnel on I-10 that crosses the Mobile River in downtown Mobile, AL. The Mobile Container Terminal is approximately two miles south of the tunnel and adjacent to I-10. Eastbound truck traffic exiting the tunnel continues on the Jubilee Parkway (I-10) across Mobile Bay. The Jubilee Parkway is a 7.5 mile girder bridge. Depending on the destination, westbound truck traffic exiting the tunnel will stay on I-10 towards Mississippi, take I-10 to I-65 North, or exit at Water Street and travel south to the Mobile Container Terminal or north to I-65 via I-165.

The increase in commuter and truck traffic is significantly increasing the congestion through the Mobile tunnel. A number of alternatives have been suggested to reduce this congestion. Some alternatives that have been proposed are 1) rerouting passenger traffic, 2) encouraging carpooling and 3) deploying passenger car ferries or transit (bus or rail).

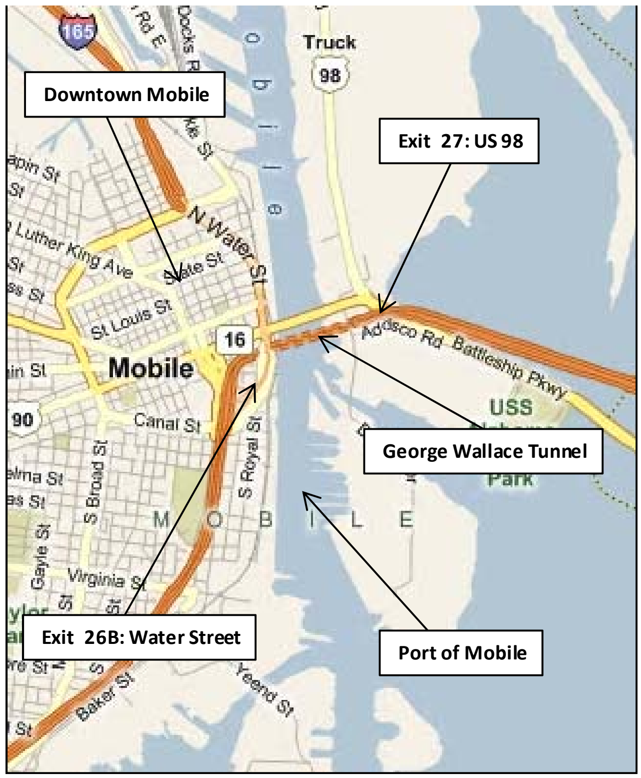


Figure 5.23 I-10 Through Downtown Mobile, AL.

5.7.1 The Simulation Model

Figure 5.24 presents the conceptual framework for the tunnel simulation model. Since traffic moves freely in the off-peak direction, the model constructed for this preliminary evaluation only simulates the traffic moving in one direction in the tunnel. The simulation model was written in ProcessModel [1].

5.7.2 Verification & Validation

Model validation is determining if the model is an accurate representation of the real world system (Harris et al. 2008). ProcessModel has a "Label" block that displays data generated by the global variables during the simulation (ProcessModel, 1999). By slowing the simulation down it is possible to observe these values as the entities move through the simulation. A group of transportation experts were placed in front of the computer to observe the model operation. The model simulated the peak hour traffic in one direction through the tunnel. A total of eleven percent of the daily traffic volume, or 6,560 vehicles, occurred during the peak hour. Fifty-five percent of the peak hour traffic, or 3,608 vehicles, moved in one direction. The simulation model was run for one hour to reach a steady state and then for another eight hours. The average hourly traffic volume was 3,610 vehicles and compares favorably to the actual volume of 3,608 vehicles.

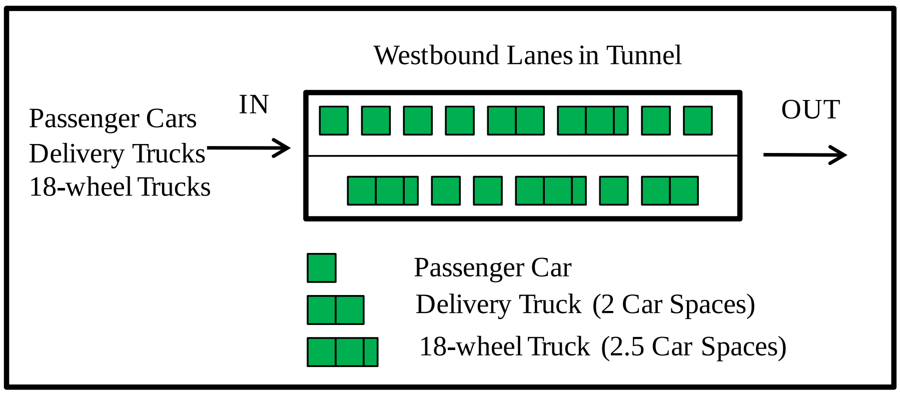


Figure 5.24 Conceptual Framework for Tunnel Simulation Model.

5.7.3 Design of the Experiment

Table 5.6 defines the experiment. Run1 was the baseline run to simulate existing traffic volumes during the peak hour. The second set of runs, Run2 & Run3, increased the directional traffic split from 55% to 60% and 65% while maintaining the 11% of the total daily traffic. The third set of runs, Run4 & Run5, increased truck traffic 5% and 10% while keeping other traffic volumes constant. The fourth set of runs, Run6 & Run7, decreased passenger car traffic by 5% and increased truck traffic by 5% and 10% respectively. Run8 & Run9 decreased passenger car traffic by 10% and increased truck traffic by 15% and 20%.

Table 5.6 Experimental design.

Run	Description
Run1 (Baseline)	Existing traffic volumes
Run2	Increase traffic volume to 60%
Run3	Increase traffic volume to 65%
Run4	Increase truck traffic 5%
Run5	Increase truck traffic 10%
Run6	Decrease car traffic 5% and increase truck traffic 5%
Run7	Decrease car traffic 5% and increase truck traffic 10%
Run8	Decrease car traffic 10% and increase truck traffic 15%
Run9	Decrease car traffic 10% and increase truck traffic 20%

5.7.4 Baseline Run

The input data for the Baseline Run1 consisted of:

- 1.2 miles tunnel length from US 90/98 exit 27, through the tunnel to Water Street exit 26B. The actual tunnel length is approximately one-half mile. However, once a vehicle passes one of the above exits, the vehicles are committed to proceed through the tunnel. Therefore, for modeling purposes the length of the tunnel is 1.2 miles.
- Four lanes of traffic in tunnel, two lanes in each direction.
- Assumed speed of 55 mph maximum speed though the tunnel.
- 59,630 daily volume of vehicles through tunnel.
- 11% of daily volume occurs during peak hour.
- 55%/45% directional split for peak hour traffic.
- Daily percentage of truck traffic is 15% of total traffic volume. During peak hour, the percentage of truck traffic is 11%.
- 10% of delivery truck traffic during peak hour.
- 79% of passenger traffic during peak hour.
- The *Highway Capacity Manual* lists the maximum density for a basic freeway section to be 45 passenger cars per mile per lane, which translates to 117-feet per passenger car per mile.
- Vehicle time in tunnel follows triangular distribution with parameters of 1.243, 1.309, and 1.374 minutes (based on 55 mph).

It should be noted that the model was run based on the peak hourly traffic and consequently models the worst case scenario. Traffic is less during the non-peak hours and congestion would also be less. The sources of the input data are the Alabama Department of Transportation and the South Alabama Regional Planning Commission.

The traffic volume to capacity ratio for the tunnel is defined as the number of vehicles in the tunnel divided by the tunnel capacity for vehicles. The volume to capacity ratio is a standard measure used to quantify congestion. A volume to capacity ratio of more than 90% indicates a deficient condition, or congestion, on that segment of highway according to the Alabama Department of Transportation specifications (UAH 2005).

The capacity of vehicles in the tunnel is defined as the number of car spaces, or car slots, in the tunnel. A car space is assumed to be 117 feet. Then a total of

$$\frac{\text{1.2 miles (length of tunnel) x 2 lanes per tunnel}}{\text{117 ft per car slot}} = \text{108 car slots}$$

The size and operating characteristics of trucks cause them to require more space than passenger cars. Since all vehicles must travel on up/down grades when using the tunnel, the assumption was made to treat one delivery truck space as equal to 2 passenger cars and one 18-wheel truck space as equal to 2.5 passenger cars (which is consistent with the *Highway Capacity Manual* for rolling terrain). The ProcessModel has a global variable named Capacity that is incremented as vehicle spaces are in use (that is as vehicles enter the tunnel) and decremented as vehicles exit the tunnel.

5.7.5 Simulation Results Baseline RUN1

The Baseline run had a two-hour warm-up and ran for eight hours. Table 5.7 gives the results of the Baseline Run1. A total of 77 vehicles were in the tunnel at the end of the simulation and occupied 97 car slots. As a result 89% of the car slots were occupied, or the traffic volume to capacity ratio was 89%. Most transportation planning organizations consider a volume to capacity ratio greater that 90% as congestion. Since the tunnel volume to capacity ratio was 89%, there were no time delays and no queue buildups of vehicles waiting to enter the tunnel. Consequently, there could be a small increase in tunnel traffic volume before experiencing delays.

Table 5.7 Baseline Run1 simulation results.

Output	Cars	Delivery Trucks	18-Wheel Trucks	Total
Vehicles in tunnel at end of simulation	61	8	8	77
Slots in use at end of simulation	61	16	20	97
Volume to capacity ratio				89%
Average delay entering tunnel (min)	0	0	0	
Average queue entering tunnel	0	0	0	
Hourly traffic	2,857	359	394	3,610

5.7.6 Increase in Directional Traffic Split

The Baseline Run1 indicated a volume to capacity ratio of 89%. Therefore, a small percentage increase in traffic is possible before reaching the congestion level of 90%. The input data was changed from a 55% directional traffic split to 60% and 65%, respectively.

Table 5.8 gives the simulation results for Runs2&3. The simulation model had a two-hour warm-up and ran for eight hours. The volume to capacity ratio for Run2 was 99% indicating congestion. The volume to capacity ratio for Run3 was 100%. Both runs had large buildups of traffic waiting to enter the tunnel. The ProcessModel for Run3 was only run for four hours because of the queue buildups. A volume to capacity ratio of less than 100% should result in no traffic buildup waiting to enter the tunnel. However, for Runs2&3 the system can be considered unstable because of the 100% volume to capacity ratio for Run3 and the delays beginning to occur for Run2. The longer the simulation for Runs2&3 the greater these traffic buildups will become.

Table 5.8 Simulation Results for Runs2&3.

Output	Run1	Run2	Run3
Directional traffic split	55%	60%	65%
Vehicles in tunnel at end of simulation:			
Passenger cars	61	67	69
Delivery trucks	8	8	8
18 wheel trucks	8	10	9
Slots in use at end of simulation	97	107	108
Volume to capacity ratio	89%	99%	100%
Average delay before entering tunnel (min):			
Passenger cars	0	2	17
Delivery trucks	0	2	17
18-wheel trucks	0	2	17
Queue length before entering tunnel at end of simulation:			
Passenger cars	0	295	1,455
Delivery trucks	0	37	185
18-wheel trucks	0	40	205
Average hourly traffic:			
Passenger cars	2,857	3,158	3,169
Delivery trucks	359	392	404
18-wheel trucks	394	431	445
Hourly traffic	3,610	3,943	4,018

5.7.7 Increase in Truck Traffic

The input data for Runs4&5 was modified to include an increase in truck traffic by 5% and 10% over the Baseline Run1, respectively. The simulation run had a two-hour warm-up and ran for eight hours. Table 5.9 gives the results for Run4&5. The volume to capacity ratio was 93% with a 5% increase in truck traffic and 94% with a 10% increase in truck traffic. These ratios suggest that both a 5% and a 10% increase in truck traffic result in congestion.

5.7.8 Decrease in Passenger Car Traffic and Increase in Truck Traffic

The input data for Runs6&7 was modified to include a 5% reduction in passenger car traffic and a continual increase in truck traffic of 5% and 10% respectively. The input data for Runs8&9 was modified to include a 10% reduction in passenger car traffic and a continued increase in truck traffic to 15% and 20% respectively. Table 5.10 gives the simulation results for Runs6 through 9. The volume to capacity ratio for Run6 was 89% and increased to 91% for Run7. The volume to capacity ratio for both Run8 and Run9 was 89%.

Table 5.9 Simulation results for Runs4&5.

Output	Run1	Run4	Run5
Directional traffic split	55%	55%	55%
Increase in 18-wheel traffic	0%	5%	10%
Vehicles in tunnel at end of simulation:			
Passenger cars	61	63	64
Delivery trucks	8	8	8
18 wheel trucks	8	9	9
Slots in use at end of simulation	97	101	102
Volume to capacity ratio	89%	93%	94%
Average delays before entering tunnel (min)	0	0	0
Queue length entering tunnel at end of simulation	0	0	0
Average hourly traffic:			
Passenger cars	2,857	2,857	2,856
Delivery trucks	359	359	359
18-wheel trucks	394	413	434
Hourly traffic	3,610	3,629	3,649

Table 5.10 Simulation results for Runs6 Through 9.

Output	Run6	Run7	Run8	Run9
Directional traffic split	55%	55%	55%	55%
Decrease in passenger car traffic	-5%	-5%	-10%	-10%
Increase in 18-wheel traffic	+5%	+10%	+15%	+20%
Vehicles in tunnel at end of simulation for:				
Passenger cars	60	59	56	57
Delivery trucks	7	8	7	7
18 wheel trucks	9	9	11	10
Slots in use at end of simulation	97	99	97	96
Volume to capacity ratio	89%	91%	89%	89%
Average delay entering tunnel (min)	0	0	0	0
Queue lengths entering tunnel at end of simulation for all vehicle types	0	0	0	0
Average hourly traffic:				
Passenger cars	2,727	2,727	2,608	2,609
Delivery trucks	359	359	359	359
18-wheel trucks	413	434	454	472
Hourly traffic	3,499	3,520	3,421	3,440

5.7.9 Conclusions

Figure 5.25 is a plot of the volume to capacity ratios for the simulation runs. In summary the following conclusions are made for peak hour traffic through the I-10 tunnel:

- The current traffic through the I-10 tunnel during the peak hour is close to congestion with a volume to capacity ratio of 89% (Run1).
- An increase in the directional traffic split from 55% to 60% (Run2) resulted in a volume to capacity ratio of 99% that is above the 90% congestion.
- An increase in the directional traffic split from 55% to 65% (Run3) resulted in a volume to capacity ratio of 100% that is above the 90% congestion. Also, a large number of vehicles were waiting to enter the tunnel. Runs2-3 can be considered unstable where the arrival rate exceeds service rate. Consequently, the queues and delay times will continue to increase.
- A small increase of 5% in truck traffic (Run4) resulted in a volume to capacity ratio of 93%, resulting in congestion.
- A 5% increase in truck traffic with a 5% decrease in passenger car traffic (Run6) is possible with a volume to capacity ratio of 89%. However, a 10% increase in truck traffic (Run7) resulted in a volume to capacity ratio of 91%.

- A 15% increase in truck traffic with a 10% decrease in passenger car traffic (Run8) resulted in a volume to capacity ratio of 89%. A further increase in truck traffic to 20% with a 10% decrease in passenger car traffic (Run9) also resulted in a volume to capacity ratio of 89%.

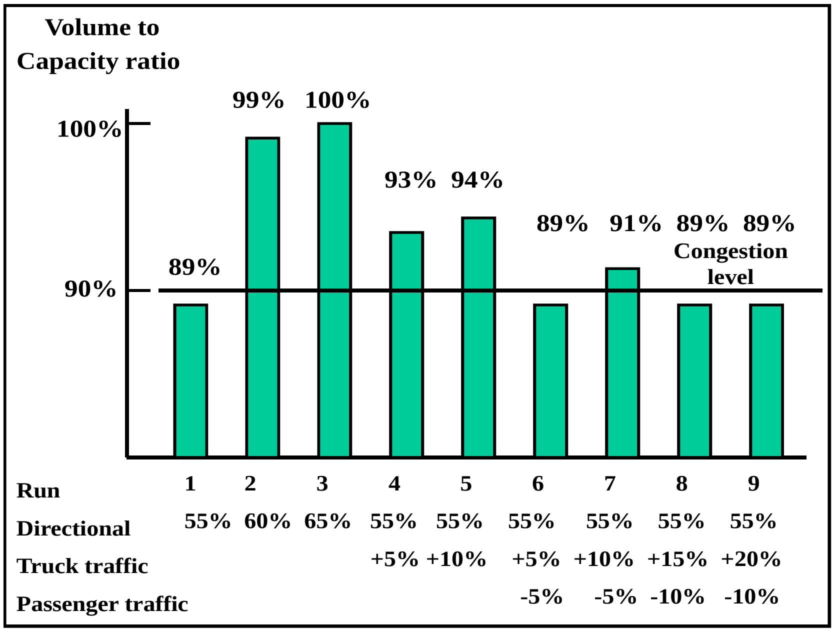


Figure 5.25 Volume to capacity ratios for simulation runs.

Once the Baseline Run1 had been made and the volume to capacity ratio determined, it was possible to compute the increase in truck traffic given a reduction in car traffic. For example, Run9 had a 10% decrease in car traffic, or 285 cars. A total of 285 cars/2.5 slots per truck or 114 trucks, can occupy these slots. Therefore, a total of 508 trucks (394 from baseline Run1 plus 114) is possible before the volume to capacity ratio exceeds 90%. In summary, the results for Run9 are:

Decrease in passenger car traffic per hour:	2,857 (Run1) to 2,608 (-10%)
Increase in truck traffic:	394 (Run1) to 508 (+29%)
Slots in use at end of simulation:	98
Volume to capacity ratio:	90%
Average delays and queues:	0
Hourly traffic through tunnel:	

Passenger cars	2,609
Delivery trucks	359
18-wheel trucks	508

5.7.10 Error Analysis

There is always a danger in using the absolute numbers from the simulation. For example, the volume to capacity ratios of 89, 90 and 91 percent may all represent congestion in the tunnel. Variability in the simulation can easily result in these differences. Therefore, it could be concluded that all these runs (See Figure 5.19) represent congestion.

Several runs were made with longer run times such as forty hours. These runs gave slightly different results especially the volume to capacity ratios. These differences may be due to the input variability in the times in the tunnel for different vehicle types.

5.8 Summary

The true value of combining a gravity distribution model, typical in transportation modeling, with a discrete event simulation becomes evident based upon the research performed during this grant. The gravity distribution model, familiar to transportation planners, can be used to understand loading of the network and the resulting locations of congestion so decisions can be made on the direction for infrastructure investment. The discrete event simulation communicates the issues that congestion and restricted capacity brings to the areas of economic development and growth, and the effect on the average citizen. Both models are valuable tools in communicating with stakeholders and developing consensus on infrastructure improvements needed to foster safety and economic growth.

An additional finding during this grant is that the original platform chosen for ATIM was not adequate to achieve the high goals of the model. The move to a Java, agent based discrete event simulation platform will provide flexibility and room for growth and expansion of the model capabilities.

Appendix – 5.0 – References

5.0 Expansion and Enhancement of the Alabama Transportation Infrastructure Model (ATIM)

5.1 The Alabama Transportation Infrastructure Model Version 2.0

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6. Modeling Intermodal Operations Using Discrete Event Simulation

Conceptual simulation models of intermodal facilities can be used to identify needed improvements and the potential benefits of continuous improvement activities. The use of simulation for intermodal operations at the International Intermodal Center at the Huntsville/Madison County International Airport and the Alabama State Docks in Mobile can be used to establish performance targets for planning future process improvement activities. UAH has focused on developing models that evaluate the effect of increasing freight volume on the immediate egresses to and from each facility and the resulting volumes on connector facilities in the region.

There have been three significant contributions to the research of modeling intermodal operations as a result of this effort. Research performed and presented in previous years have led the team to develop a broad reaching, conceptual framework for the development and operations of simulation models for ports and intermodal sites. This concept was written and presented at the Huntsville Simulation Conference in October, 2008. The peer reviewed paper was chosen for publication in the Society for Computer Simulation (SCS) sponsored conference proceedings. The essence of this paper is presented here in section 6.1.

Section 6.2 describes an investigation into the resources aspect of security inspections of containers in a port or intermodal terminal operation. This section provides the essence of a paper to be presented and published in the proceedings of the 88th Annual Transportation Research Board Meeting and the proceedings are under consideration for publication in the Transportation Research Record.

Section 6.3 of this report presents portions of papers that describe specific simulation results of actual ports and intermodal facilities modeled from the framework described in Section 6.1. This section includes detailed discussion of simulation efforts to maximize throughput at a container terminal. This concept was presented and published in the proceedings of the 2nd Annual National Urban Freight Conference. In addition, Section 6.3 presents synopses of additional specific modeling results for coal terminal simulation (summarized from a paper presented and published in the proceedings of the International Conference on Application of Advanced Technologies in Transportation) and intermodal container facility simulation (summarized from a paper submitted to the *Journal of Advanced Transportation*).

6.1. Conceptual Framework for Simulating Seaport Terminals

In nearly every context, a number of difficulties – insufficient data, time constraints, lack of model verification and validation – exist for the successful development and implementation of simulation models. The data needed for a successful simulation often does not exist or the data is simply not readily available. If available, much of the data is simply not credible, complete, or accurate. Often, there is not sufficient time to collect the data because of urgency from management for answers. Another constraint is model development time. Many models take considerably longer to develop than originally estimated and result in delays and cost overruns, infuriating management in the process. Additionally, model verification and validation (V&V) are frequently minimized or outright ignored due to the time and difficulty in performing this function. Model verification consists of determining if the model is correctly represented in the simulation code. Model validation consists of determining if the model is an accurate representation of the real world system. These difficulties often handicap the wider use of simulation, especially in obtaining management support, because of the perceived time and cost overruns of past simulation projects.

As with all domains, the modeling of seaports faces similar challenges. The focus of this research is on developing a conceptual framework that reduces the impact of many of the previously stated difficulties. When effectively done, simulations can be considered as inexpensive insurance against costly mistakes, especially when significant capital expansions are being considered, as is the case with the large capital investments at seaports (where a crane can cost millions of dollars).

6.1.1. Modeling Framework

A diagram of the conceptual framework used for the model development is shown in Figure 6.1. The model consists of a number of submodels that run independently with each model having its own data input and entities with specific attributes. For example, the data input can include arrival and service times, storage capacities, and available resources.

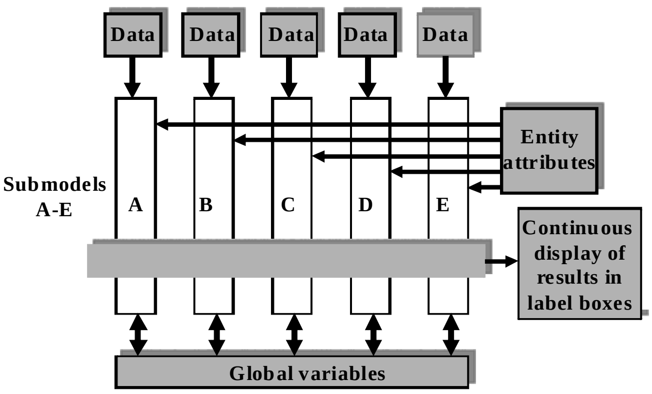

Figure 6.1 Conceptual Framework.

In the conceptual framework, data are shared between the submodels by the use of global variables. The content of global variables can be altered within any submodel with the new values immediately shared and used by any other submodel. These global variables not only pass data between the submodels, but they can also be used in logic statements to control the movement and routing of entities, branching logic, and updating entity attributes.

To aid in the verification and validation, the conceptual framework includes a set of output blocks displaying current values from the global variables during the running of the simulation. These values are generally overlaid on top of the simulation model so the user can observe the movement of entities as well as any bottlenecks.

ProcessModel [1] was selected to implement the conceptual framework. The building blocks in ProcessModel were ideal for constructing the submodels with each submodel having a “name specific” entity. Within each block and for each routing option (connecting line), there is the capability of adding very complex logic. Global variables and entity attributes can be easily defined.

The basic steps in constructing a ProcessModel that follows the conceptual framework are as follows:

- Define and name as many of the global variables, entity attributes, resources and output blocks as possible.
- Construct, debug, and verify and validate each submodel separately. (The use of constants for all data input greatly reduces the debugging time as well as model verification).
- Turn off the arrival of all entities before starting another submodel development. Once all the submodels have been constructed, add the arrival entities back into the submodels.
- Combine all submodels into one model and again verify and validate this time with distribution data.

6.1.2. Coal Terminal Model

A model of the McDuffie Coal Terminal at the Alabama State Docks in Mobile, Alabama is presented in Figure 6.2. The aim of the simulation was to increase the throughput of the existing coal operation (see section 6.3.2 for a detailed description). A perceived barrier to an increase in the capacity at the coal terminal was the number of tugs available for moving barges and ships throughout the terminal. This simulation model evaluated various tug alternatives for improving the velocity of coal through the terminal.

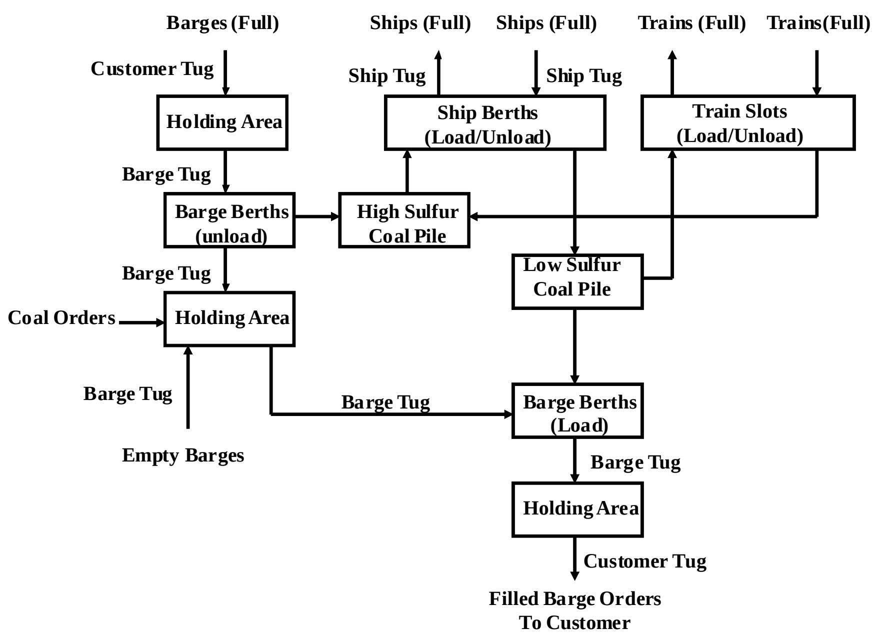

Figure 6.2 Coal Terminal Model.

As shown in Figure 6.2, the coal terminal handles high and low sulfur coal. Low sulfur coal arrives on ships and leaves on barges and trains. High sulfur coal arrives on barges and trains and leaves on ships. Translating this model into the conceptual framework resulted in the following submodels:

- Ships unloading low sulfur coal and loading high sulfur coal
- Barges unloading high sulfur coal loading low sulfur coal
- Trains unloading high sulfur coal and loading low sulfur coal

The labels that display selected global variables during the running of the simulation are:

- Cumulative unloaded high sulfur coal
- Cumulative unloaded low sulfur coal
- Cumulative loaded high sulfur coal
- Cumulative loaded low sulfur coal
- High sulfur coal pile
- Low sulfur coal pile

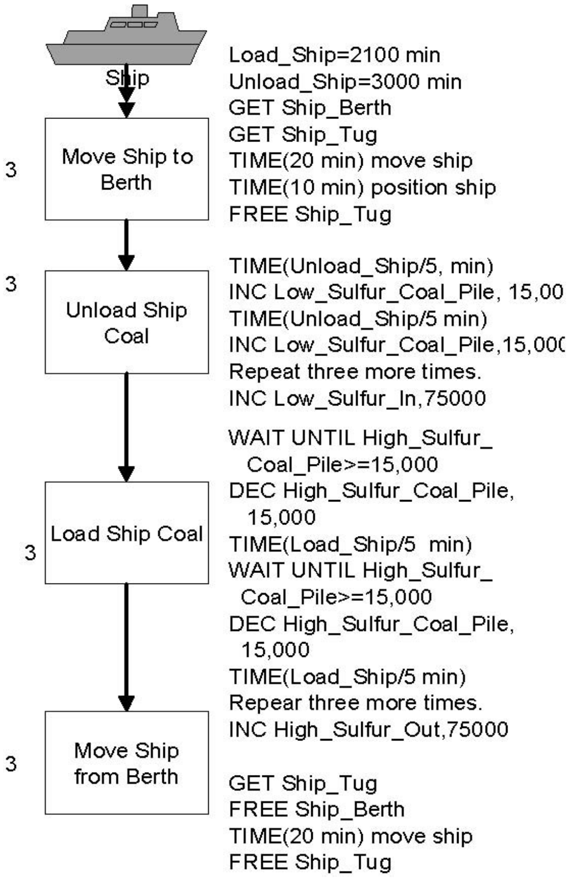

Figure 6.3 ProcessModel for Ship Submodel

The ProcessModel for the submodel named "ShipsUnloading_Low_Sulfur_Coal" and "Loading_High_Sulfur_Coal" is shown in Figure 6.3 [2]. The logic that is coded into the action section of each block is shown on the right. The numbers to the left of each block are the capacity of each activity. The entity is named "Ship."

For the "Move_Ship_to_Berth" activity, the logic contains two global variables, "Load_Ship" and "Unload_Ship", with capacities defined as shown and two resources, "Ship_Berth" and "Ship_Tug", which are responsible for moving and positioning the ship in a berth. In the case of the "Load_Ship_Coal" activity, there are three global variables – "High_Sulfur_Coal_Pile", "Load_Ship", and "High_Sulfur_Out." The logic consists of waiting until the high sulfur coal pile is greater than 15,000 tons, then decrementing the pile and loading the ship with the 15,000 tons and dividing the load ship variable by five, then repeating four more times for a total of 75,000 tons. After the ship is loaded, the "High_Sulfur_Out" variable is incremented by 75,000 tons.

One of the significant hurdles during the model development was the level of model fidelity. The decision was made to model at the "scoop" level, where a scoop is defined as the amount of coal that is moved at a time. Several more detailed ProcessModel applications have been written for a variable scoop size of as low as 15 tons. A ProcessModel scoop entity was drawn that is displayed and moved on the screen during coal unloading and loading. This definition of scoop and the subsequent development allowed stakeholders and process experts to verify the functionality of the model.

6.1.3. Container Terminal Model

A model of the container terminal at the Alabama State Docks in Mobile, Alabama is shown in Figure 6.4. The simulation aim was to establish a working model of the container operations to provide decision information for management at the newly expanded container facility (see section 6.3.1 for more detail). The model evaluated various entity arrivals (ships, trains, and trucks) to determine the potential capacity of the expanded facility. As shown in Figure 6.4, containers arriving on ships depart on trains and trucks and containers arriving on trains and trucks depart on ships.

Translating the model into the conceptual framework resulted in the following submodels:

- Ships unloading and loading of containers
- Trains unloading and loading of containers
- Trucks unloading and loading of containers
- Movement of containers from ship dock to container yard
- Movement of containers from container yard to ship dock

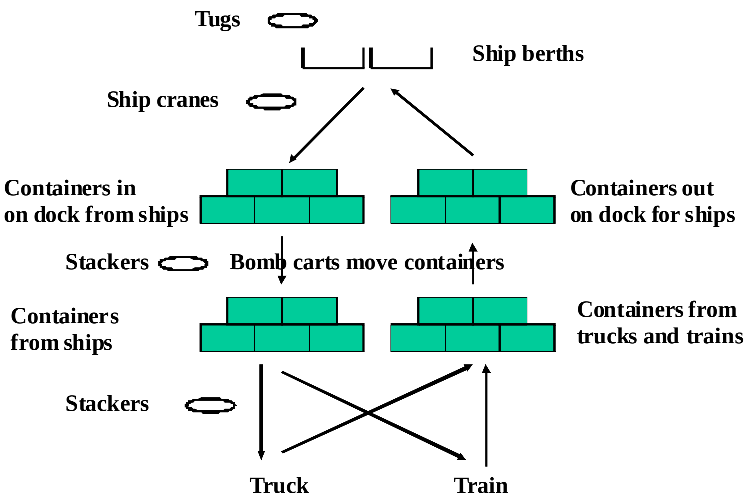

Figure 6.4 Container Terminal Model.

The labels that display selected global variables during the running of the simulation are:

- Cumulative containers unloaded from ship
- Cumulative containers unloaded from train
- Cumulative containers unloaded from truck
- Cumulative containers loaded onto ships
- Cumulative containers loaded onto trains

- Cumulative containers loaded onto trucks
- Containers on dock unloaded from ships
- Containers on dock waiting to be loaded onto ships
- Containers in container yard from ships
- Containers in container yard from trains and trucks

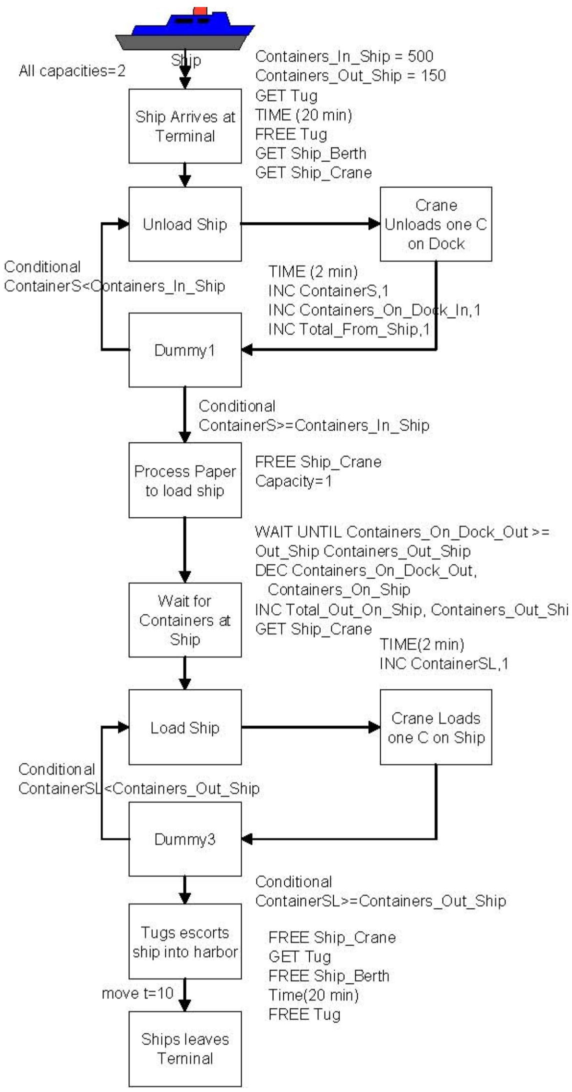

Figure 6.5 ProcessModel for Ship Submodel

Figure 6.5 is the ProcessModel for the submodel named "Ships Unloading" and "Loading_of_Containers" [3]. The comments to the right are the logic coded into the action section of each block. This model is slightly more complex than the coal simulation, but encompasses many of the same principles. One unique aspect of this submodel is the use of a "dummy" activity box that serves as a feedback loop as the crane resource unloads the container from the ship to the dock. When the number of containers on the dock is equal to or greater than the original number of containers in the ship, the ship has been unloaded and can move on to processing before being reloaded.

As with the coal model, a hurdle during the model development was the level of model fidelity. The decision was made to model at the container level. A ProcessModel container entity was drawn that is displayed and moved on the screen during any container movement such as unloading and loading.

6.1.4. Intermodal Center Model

A model of the intermodal terminal center at the Huntsville International Airport in Huntsville, AL is shown in Figure 6.6. The simulation was used to determine if throughput can satisfy anticipated demand and if sufficient resources are available to meet anticipated growth in demand (see section 6.3.3 for more detail). The model was similar to the Mobile Container Terminal except that it introduced an airplane entity rather than a ship entity. The entity arrival/departure relationship is as follows:

containers arriving on airplanes depart on trucks, containers arriving on trains depart on airplanes and trucks, and containers arriving on truck depart on airplanes and trains.

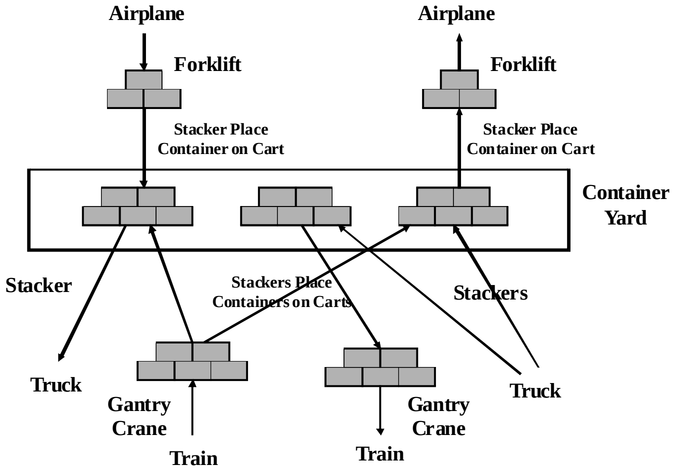

Figure 6.6 Intermodal Center Model

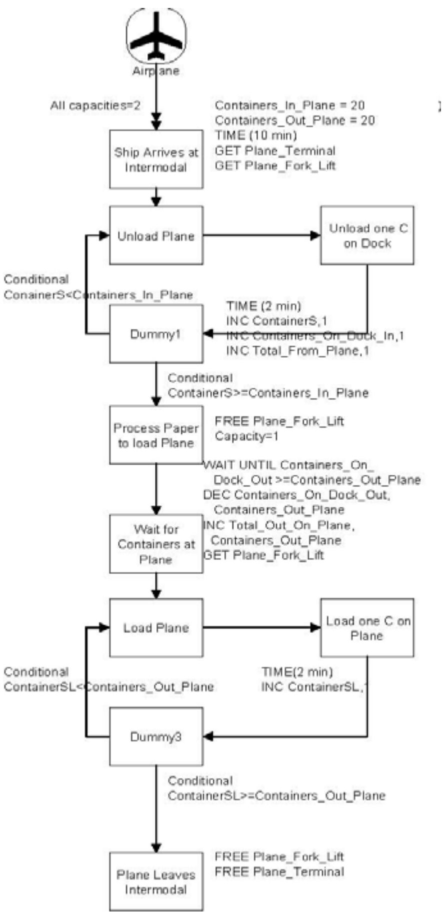

Figure 6.7 ProcessModel for Airplane Submodel.

Translating this model into the conceptual framework resulted in the following submodels:

- Planes unloading and loading of containers
- Trains unloading and loading of containers
- Trucks unloading and loading of containers
- Movement of containers from plane dock to container yard
- Movement of containers from container yard to plane dock
- Movement of containers from train dock to container yard
- Movement of containers from container yard to train dock

Figure 6.7 is the ProcessModel for the submodel named "Plane_Unloading_and_Loading_of_Containers". The comments to the right of each block are the logic coded into the action section of each block. This submodel for the plane is almost identical to the submodel "Ship_Unloading_and_Loading" in Figure 6.5.

6.1.5. Conclusions

Subsequent to the framework development, a number of model variations have been made to the models and are described in other sections of this document. For example, the impact of increased security inspection of containers was added to the container model and is discussed in Section 6.2. The impact of a number of continuous improvement events was also added to the coal model. This research was chosen for publication in the 2008 Transportation Research Record [4]. In addition, Section 6.3 discusses specific results of the models developed from the conceptual framework.

Table 6.1 presents a sequential comparison of the coal, container, and intermodal models developed using the conceptual framework. The time required to develop the models reduced each time the conceptual framework was applied. The purpose of the conceptual framework was to be able to quickly model the operations and provide information for managers to make better informed decisions. The coal model took forty hours, twenty-four hours for the container model, and sixteen hours for the intermodal model. The intermodal model was the most complex model, especially in terms of the logic; however, this model required the least development time, showing a learning effect and institutional knowledge from the use of previously defined models.

Table 6.1 Comparison of Various Models.

Model Attribute	Coal Model	Container Model	Intermodal Model
Submodels	3	5	7
Entities	5	7	9
Blocks	43	50	55
Attributes and Global Variables	10	23	28
Logic Statements	110	99	178
Development Time (hours)	40	24	16
V&V Time (hours)	16	12	12

In summary, the following conclusions are made:

- The conceptual framework provided an excellent template in the development of the coal terminal, container terminal and intermodal center models. This framework greatly reduced the time needed for development, model debugging, and verification and validation.
- The similarities of the submodels amongst the three simulations were such that similar variables and label blocks were called for. Branching logic was the only major deviation between the models.
- Data collection for the applications was done by interviewing the personnel at the Alabama State Docks and the Huntsville Intermodal Center. By asking the appropriate questions, most of the input data was collected through interviews. For example, a good assumption is that all service times follow triangular distributions. It is rather easy to ask knowledgeable personnel the

most frequent time, the smallest time and the largest time to obtain the parameters for the triangular distribution.
- Modifications to the models are simplified because of the submodel framework. Changes made to a submodel could be easily debugged without having to worry about the other submodels.
- Using the conceptual framework it is possible to construct the model in pieces or one submodel at a time. Consequently, each submodel can be debugged and verified separately, thus reducing development time.

6.2. Minimizing Disruption caused by Container Inspection at an Intermodal Terminal

Container terminal operations at the Alabama State Docks have recently undergone a major expansion [1] with new capacity to increase container throughput by 400 to 500%. The container terminal is intermodal with containers arriving and departing via ships, trains, and trucks. As a result of this expansion and increased security issues around the world, there is considerable interest in determining the impact increased container inspection will have on port operations and what resources may be needed to minimize this impact. The aim of this research effort was to use simulation as a tool to determine the resources to minimize the disruption of inspections at port terminals.

6.2.1. Simulation Model

The conceptual framework discussed in section 6.1 was used to construct this simulation model. The framework consists of a number of submodels that run independently. Translating the intermodal container terminal into the conceptual framework resulted in the following submodels:

- *Submodel A*: Ships - unloading and loading of containers (entity=ship) (Figure 6.8)
- *Submodel B*: Trains - unloading and loading of containers (entity=train) (Figure 6.9)
- *Submodel C*: Trucks - unloading and loading of containers (entities = truck, empty truck, and empty truck with container) (Figure 6.10)
- *Submodel D*: Movement of containers from ship dock to container yard (entity = move order1) (Figure 6.11)
- *Submodel E*: Movement of containers from container yard to ship dock (entity = move order2) (Figure 6.12)
- *Submodel F*: Movement of containers from train pavement to container yard (entity = move order3) (Figure 6.11)
- *Submodel G*: Movement of containers from container yard to train pavement (entity = move order4) (Figure 6.13)

Two types of inspections are simulated and shown in Figures 6.8 and 6.9. The first type is a quick tailgate inspection, which consists of opening the container to verify content. The second inspection consists of an intensive inspection where the container is opened, contents removed, inspected, and repacked. It is assumed that each of these inspections includes an inspector to conduct the inspection and operate any required equipment. Therefore, inspection equipment utilization is equivalent to inspector utilization. In addition, inspectors are assigned to check the paperwork of entity arrivals. These inspections occur before any containers are unloaded. Not all incoming containers are inspected. Some containers are designated C-TPAT (Customs Trade Partnership Against Terrorism) and certified safe by U.S. Customs and are transported directly by carts to the container yard.

The terminal simulation model utilizes ship berths, ship cranes, train slots, train cranes, truck slots, stackers, carts, inspectors, tailgate inspection stations and intensive inspection stations as resources. The inspectors check all paperwork on incoming ships, trains and trucks and inspect the containers arriving on trucks. It is assumed that an operator is placed at each tailgate inspection and intensive inspection station. The model has thirteen entity attributes, twenty global variables, seventy-eight activity blocks and eleven entity blocks. The simulation model is a modification to a ProcessModel used to evaluate the container traffic at the Intermodal Center in Huntsville, AL [2, 3]. Consequently, verification and validation had already been performed on the model.

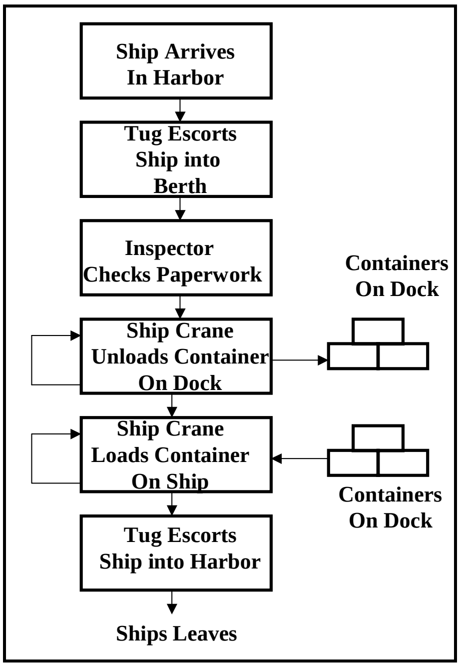

Figure 6.8 Simulation Logic for Unloading and Loading Ships (Submodel A).

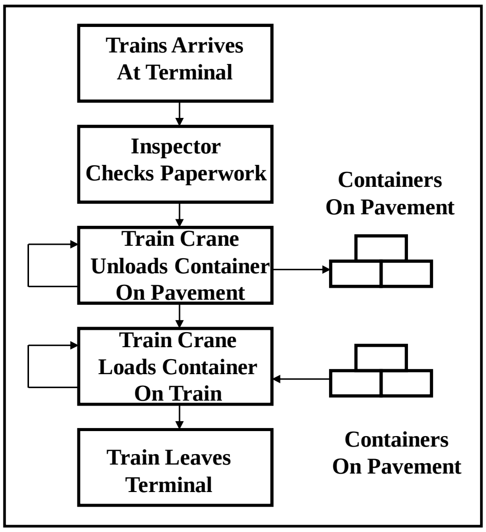

Figure 6.9 Simulation Logic for Unloading and Loading Ships (Submodel B).

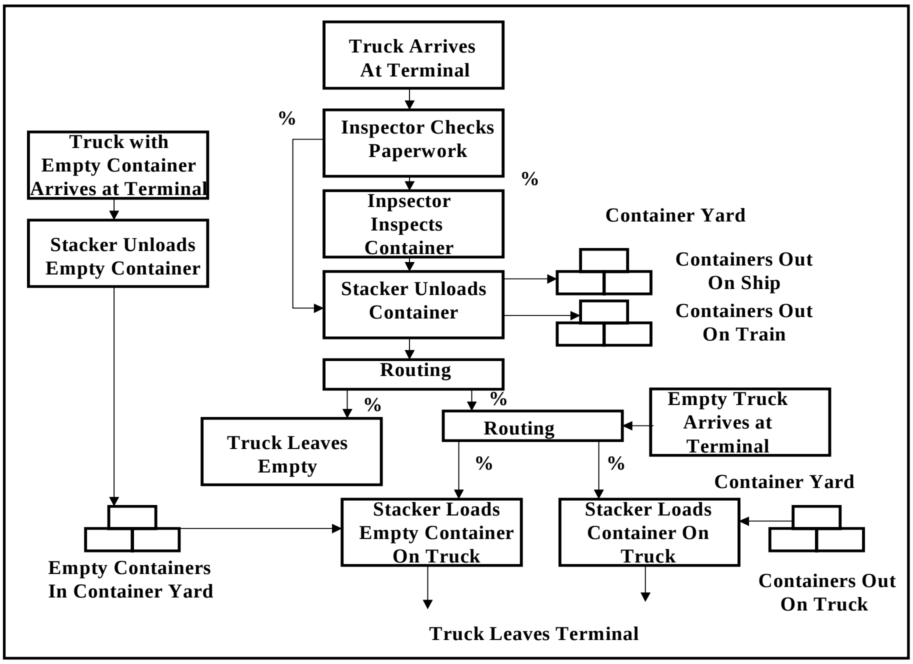

Figure 6.10 Simulation logic for unloading and loading trucks (Submodel C).

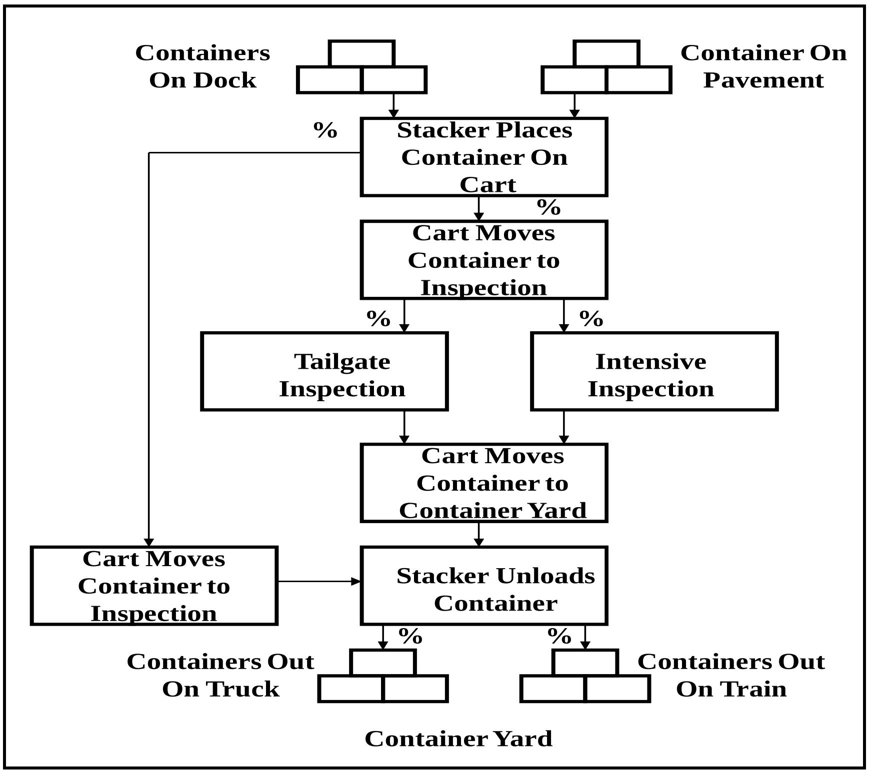

Figure 6.11 Simulation logic for moving containers from dock and pavement to container yard (Submodels D and F).

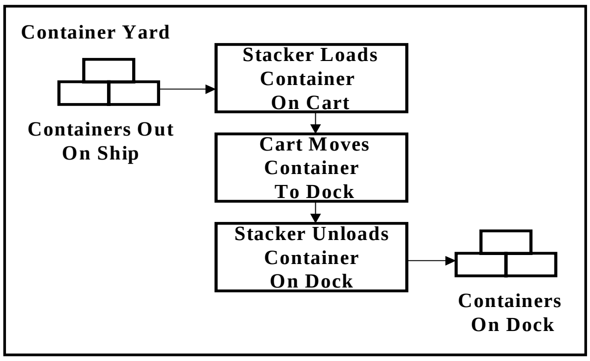

Figure 6.12 Simulation Logic for Moving Containers from Container Yard to Dock (Submodel E)

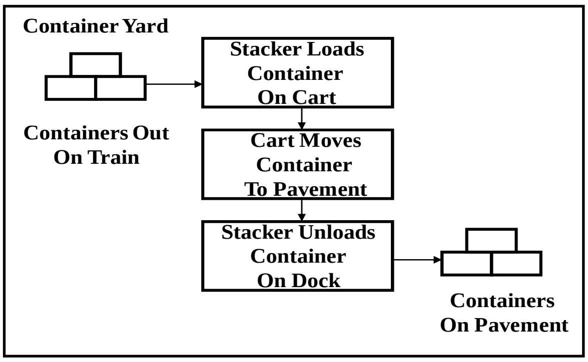

Figure 6.13 Simulation Logic for Moving Containers from Container Yard to Pavement (Submodel F)

6.2.2. Model Input

The input data for Run1 are shown in Tables 6.2 – 6.5. Table 6.2 presents the routing of containers within the terminal by percentage of activity. This data was from estimates by dock personnel and based on anticipated container arrival and departure patterns.

Table 6.2 - Movement of containers

	Containers out		
Containers in	Ship	Truck	Train
Ship		10%	90%
Truck	70%		30%
Train	80%	2%	18%

Table 6.3 provides the container inspection arrival data for each entity. The inspection times were derived from dock personnel and vendors of the inspection equipment. Eighty-five percent of containers on ships and trains are inspected. Of the containers that were inspected, ninety-eight percent go through the tailgate inspection station and two percent go through the intensive inspection station. Ninety percent of containers on trucks are inspected.

Table 6.3 Container Inspections.

Containers Arriving on	**% Inspected**	**Tailgate Inspection (of 85%)**	**Time of Tailgate Inspection (min)**	**Intensive Inspection (of 85%)**	**Time of Intensive Inspection (min)**
Ship	85%	98%	T(6,8,10)	2%	T(240,300,360)
Train	85%	98%	T(6,8,10)	2%	T(240,300,360)
Truck	90%	100%	3		

Table 6.4 provides the parameters for ship, train and empty train entities. The time between arrivals are based on estimated ship and train arrivals once the container facility is operational. The container arrivals and departures are also based on the capacities of these arrival entities. Likewise, the quantity of containers arriving and departing on ships and trains follow the triangular distributions.

Table 6.4 Entity Parameters.

Entity	Time between Arrivals (min)	Containers In	Containers Out
Ship	T(1320,1440,1560)	T(400,450,500)	T(200,250,300)
Train	T(420,480,540)	T(90,100,110)	T(90,100,110)
Empty Train	T(2080,2320,2560)		T(90,100,110)

Table 6.5 presents the parameters for the truck arrivals. Again, the time between arrivals are based on estimated truck arrivals once the container facility is operational. The container arrivals and departures are also based on the capacities of these arrival entities. Ten percent of the trucks that arrive with a full container, or that arrive with an empty container, leave with no container, nine percent leave with an empty container and the remaining eighty-one percent leave with another full container. One hundred percent of the empty truck arrivals leave with a full container.

Table 6.5 Additional Entity Parameters.

Entity	Time between Arrivals (min)	Qty. In	Truck Leaves w/o Container	Truck Leaves w/ Empty Container	Truck Leaves w/ Full Container
Truck with Full Container	T(54,60,66)	1	10%	9%	81%
Empty Truck	T(90,120,150)	0			100%
Truck with Empty Container	T(180,240,300)	1	10%	9%	81%

In addition to the data presented in Tables 6.2 - 6.5, the baseline input data for the model consisted of:

- Two ship berths for unloading and loading containers
- Two train terminals for unloading and loading containers
- Twenty truck slots (Maximum number of trucks in terminal at one time)
- Two ship cranes for unloading and loading containers from ships
- Two train cranes for unloading and loading containers from trains
- Twelve stackers for unloading and loading containers from trucks and onto and off of carts
- Thirty carts for moving containers throughout the terminal

- 2 minutes to unload or load a container from ship, train, or truck
- T(15,20,25) minutes to position a ship at a terminal
- T(15,20,25) minutes to position a train at a terminal
- T(4,5,6) minutes to position a truck for unloading or loading
- 2 minutes to process paperwork to load a ship, train or truck
- T(4,5,6) minutes for ship, train, or truck to exit terminal
- 2 minutes to unload and load a cart
- T(9,10,11) minutes for inspector to inspector to check paperwork for ship or train
- T(4,5,6) minutes to position truck in container yard
- T(2,3,4) minutes for inspector to inspect paperwork and container from truck
- T(2,3,4) minutes for cart to move container from dock or pavement to inspection area
- T(2,3,4) minutes for cart to move container from inspection area to container yard
- T(4,5,6) minutes for cart to move container directly from dock or pavement to container yard

6.2.3. Experimental Design

A previous simulation run with no container inspection [4] was modified to include the container inspection logic and is used as the baseline for this research. All the input data remained identical to the baseline run. Table 6.6 displays the experimental design. The basic concept of the design was to start the model with a large number of inspectors and inspection stations and then reduce these resources in subsequent runs until there is an impact on the operation of the intermodal center. This impact was measured in terms of the reduction in the number of ships and trains through the intermodal center. The simulation model was run for 1,440 hours, or 180 eight-hour days, which is six months.

Table 6.6 Experimental Design.

Runs	Inspectors	Tailgate Inspection Stations	Intensive Inspection Stations
Run1	5	10	10
Run2	3	10	10
Run3	1	10	10
Run4	1	8	10
Run5	1	8	6
Run6	1	8	5
Run7	1	6	5
Run8	1	6	4
Run9	1	6	3
Run10	1	5	3

6.2.4. Results

The results of the simulation runs are given in Tables 6.7–6.10. Table 6.7 shows the results for Runs1-3 where the number of inspectors was reduced from five to three and then to one. Note that a reduction in the number of inspectors did not impact entity throughput of the terminal.

Table 6.7 Simulation Results for Runs1-3.

Resource	Run1		Run2		Run3	
	Qty.	Utilization	Qty.	Utilization	Qty.	Utilization
Tailgate Inspection Stations	10	35%	10	35%	10	35%
Intensive Inspection Stations	10	23%	10	23%	10	23%
Inspectors	5	1%	3	3%	1	7%
Carts	30	52%	30	52%	30	53%
Entities through Terminal	**Qty.**	**Time in Terminal (min)**	**Qty.**	**Time in Terminal (min)**	**Qty.**	**Time in Terminal (min)**
Ships	58	2,029	58	2,029	59	2,028
Trains	179	685	179	685	179	687
Empty Trains	38	418	38	418	38	415
Trucks	1,441	33	1,441	33	1,440	33
Empty Trucks	721	21	721	21	718	21

Table 6.8 gives the results for Runs4-6 where the number of tailgate inspection stations was reduced from ten for Run3 to eight for Runs4-6 and the number of intensive inspection stations was reduced from ten for Run4 to six for Run5 and five for Run6. Again, a reduction in the number of inspection stations did not impact the throughput quantity of entities at the terminal.

Table 6.8 Simulation Results for Runs 4-6.

Resource	Run4		Run5		Run6	
	Qty.	Utilization	Qty.	Utilization	Qty.	Utilization
Tailgate Inspection Stations	8	44%	8	44%	8	44%
Intensive Inspection Stations	10	26%	6	40%	5	48%
Inspectors	1	7%	1	7%	1	7%
Carts	30	54%	30	53%	30	53%
Entities through Terminal	**Qty.**	**Time in Terminal (min)**	**Qty.**	**Time in Terminal (min)**	**Qty.**	**Time in Terminal (min)**
Ships	59	2,034	59	1,996	59	2,032
Trains	178	692	178	690	179	690
Empty Trains	37	419	38	425	38	421
Trucks	1,438	33	1,442	33	1,441	33
Empty Trucks	714	21	720	21	716	21

Table 6.9 gives the results for Runs7-10 where the number of tailgate inspection stations was reduced from six for Runs7-9 to five for Run10 and the number of intensive inspection stations was reduced from five for Run7 to four for Run8 and to three for Runs9-10. The results again indicated that a reduction in the number of inspection stations did not impact entity throughput the terminal for Runs7-9. However, the number of ships through the terminal dropped significantly from 59 for Run9 to 41 for Run10, a reduction of 30%. The number of trains through the terminal dropped from 178 for Run9 to 123, a reduction of 30%, for Run10. The number of trucks through the terminal dropped from 1,441 for Run9 to 984 for Run10, a reduction of 31%.

For Run10, the utilization of the tailgate inspection stations dropped from 59% for Run9 to 49% for Run10 and the intensive inspection stations dropped from 83% for Run9 to 53% for Run10. On the other hand, the utilization of inspectors increased from 7% for Run9 to 37% for Run10 and carts from 60% for Run9 to 71% for Run10.

Table 6.9 Simulation Results for Runs7-10.

Resource	Run7		Run8		Run9		Run10	
	Qty	Utilization	Qty	Utilization	Qty	Utilization	Qty	Utilization
Tailgate Inspection Stations	6	60%	6	70%	6	59%	5	49%
Intensive Inspection Stations	5	47%	4	60%	3	83%	3	53%
Inspectors	1	8%	1	7%	1	7%	1	37%
Carts	30	53%	30	54%	30	60%	30	71%
Entities through Terminal	**Qty**	**Time in Terminal (min)**	**Qty**	**Time in Terminal (min)**	**Qty**	**Time in Terminal (min)**	**Qty**	**Time in Terminal (min)**
Ships	59	2,048	59	2,001	59	2,076	41	2,007
Trains	180	693	178	696	178	689	123	686
Empty Trains	38	423	37	443	38	411	37	423
Trucks	1,441	33	1,440	33	1,441	33	984	33
Empty Trucks	724	21	720	21	718	21	494	21

Table 6.10 shows the utilization of the remaining resources. Note that ship crane utilization dropped from 67% for Run9 to 46% for Run10 and train crane utilization decreased from 72% for Run9 to 51% for Run10. Truck slot utilization increased from 4% for Run9 to 34% for Run10 and stacker utilization increased from 35% for Run9 to 55% for Run10.

Table 6.10 Other Resource Utilizations.

Resources	Qty	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10
Ship Berths	2	68%	68%	68%	68%	67%	68%	69%	67%	70%	77%
Ship Cranes	2	67%	67%	67%	67%	66%	67%	67%	67%	67%	46%
Tugs	2	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Train Slots	2	71%	72%	71%	71%	71%	71%	72%	71%	71%	80%
Train Cranes	2	72%	72%	72%	72%	72%	72%	73%	72%	72%	51%
Truck Slots	20	4%	4%	4%	4%	4%	4%	4%	4%	4%	34%
Stackers	12	34%	34%	35%	35%	34%	35%	35%	35%	35%	55%

Figures 6.14-6.16 present information on the entities through the intermodal center. As previously stated, entity throughput remained constant until Run10. The number of tailgate inspection stations was reduced from six for Run9 to five for Run10. These results indicate that given the current entity arrival rates, inspection rates, and

inspection times, the optimum inspection resources are six tailgate inspection stations, three intensive inspection stations and one inspector.

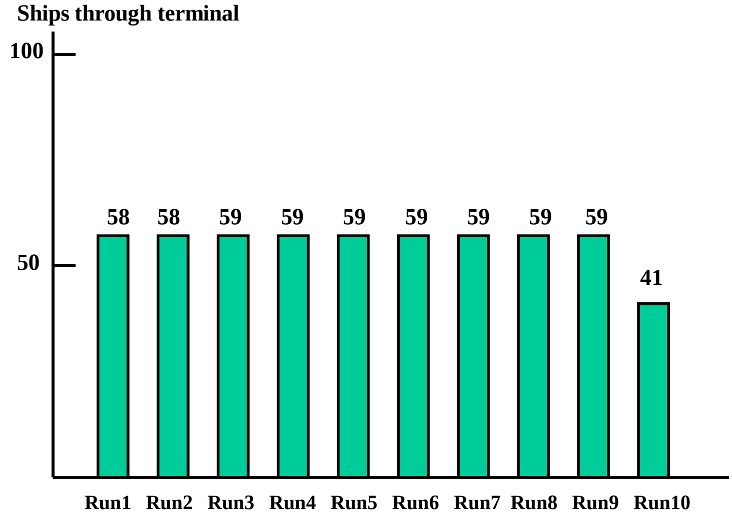

Figure 6.14 Number of Ships through Intermodal Center.

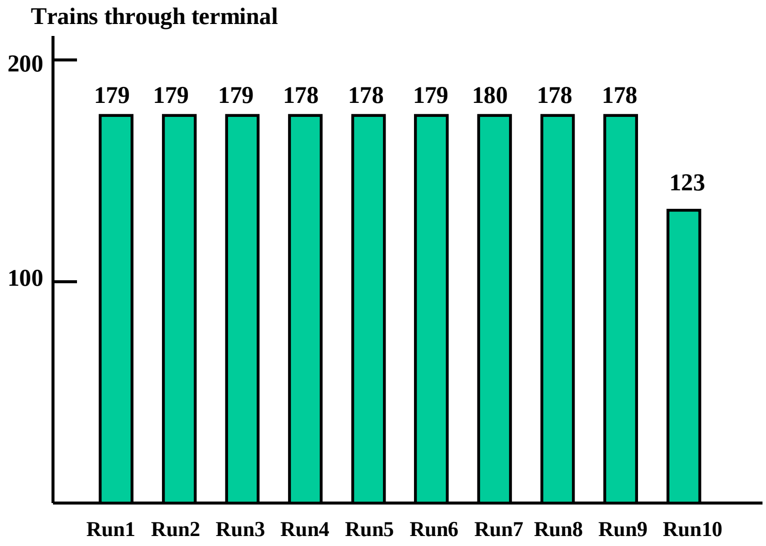

Figure 6.15 Number of trains through intermodal center.

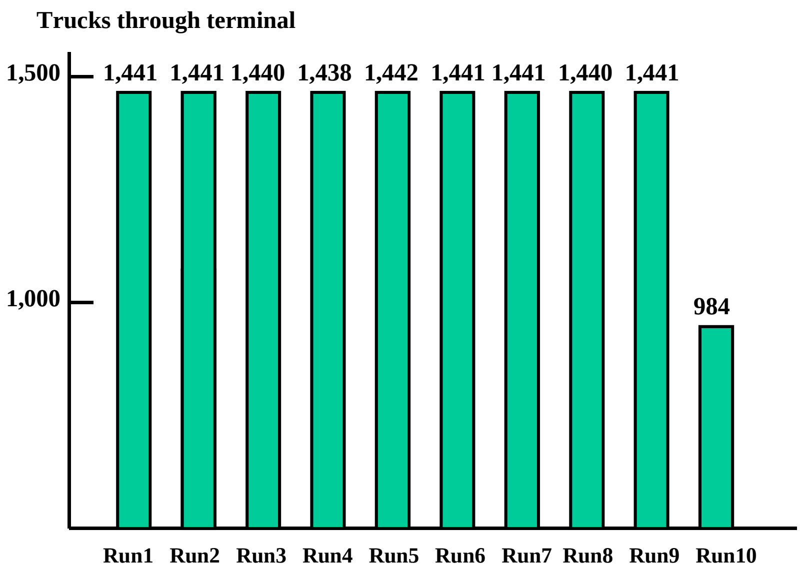

Figure 6.16 Number of trucks through intermodal center.

The simulation results suggest that the reduction to five tailgate inspection stations in Run10 resulted in a cascading effect on the utilization of various resources. For example, containers on the carts had to wait longer for service because of the fewer tailgate inspection stations. Therefore, the cart utilization increased to 71% for Run10 as compared to 60% for Run9. Since the cart utilization increased, the stackers had to wait until the carts became available. The stacker is captured before seizing a cart; therefore, the stacker utilization increased to 55% for Run10 as compared to 35% for Run9. Furthermore, the inspector for truck containers had to wait for a stacker. The inspector utilization increased to 37% for Run10 as compared to 7% for Run9.

The use of the ProcessModel commands of GET and FREE greatly impacted the interpretation of the resource utilizations. For example, the ProcessModel logic for loading and moving carts is to first GET a stacker and then GET a cart. Therefore, if a cart is not available the stacker waits. Since the stacker has already been seized (using GET) the utilization will increase. The ProcessModel logic for truck inspectors is to first GET the inspector and then GET a stacker. If the stacker is not available, then the inspector waits. Since the inspector has already been seized (using GET) the utilization will increase. The inspector wait time is then included in its utilization. For optimal performance, both resources must be available when the GET command is executed.

A reduction in the available empty carts resulted in fewer containers on the dock for loading onto ships and on the pavement for loading onto trains. As a result, the number of ships and trains through the terminal decreased. At the same time, the utilization of ship berths and train slots increased because the ships were not exiting the terminal. Since the ships and cranes were waiting for containers, the utilization of the ship and train cranes decreased. Ship crane utilization decreased to 46% for

Run10 as compared to 67% for Run9 and train crane utilization decreased to 51% for Run10 as compared to 72% for Run9.

6.2.5. Sensitivity Analysis

The objective of this project was to determine the resources necessary to minimize the disruptions to port terminal operations as a result of increased security inspection requirements for containers. Run 9 with six tailgate inspection stations and three intensive inspection stations met the stated objective. However, Run 10 with one less tailgate inspection station caused a significant reduction in ship, train and truck throughput.

An analysis of the data suggests that one of the primary factors impacting entity throughput may be the number of carts that move containers between the container yard and the ship and train docks. Therefore, Run11 was made with ten additional carts and the same number of inspection stations as Run10. The results of Run11 indicated similar results to Run9 in terms of throughput and utilization of resources. The average cart utilization dropped to 46% as compared to 71% for Run10. Therefore, it appears that there is an economic tradeoff between the number of carts and inspection resources. Less inspection resources may be needed if more carts are available at the terminal. However, there are limits between these two resources.

The results shown in Figures 6.15 and 6.16 suggest that the container terminal may be at capacity throughput when the inspection resources are reduced to the levels in Run 9. However, as shown by Run11 – with ten additional carts and the same number of inspection stations as Run10 – the same capacity as for Run9 can be achieved with one less inspection station resource.

There is significant sensitivity to the interdependency between entity arrivals (especially ship and train arrivals) and the number of containers arriving on these entities. For example, increased ship arrivals will obviously increase incoming containers but may not increase departing containers unless there are train and truck arrivals to take containers out of the facility. The dynamics of the situation become more complex when the availability of supporting resources, such as stackers and carts, are considered.

The resource utilization results are somewhat paradoxical for this container model. In most simulations, high utilizations can signify potential bottlenecks or that the system is near capacity. Most of these systems have very constant and steady arrival rates. However, with container terminal simulations, lower resource utilizations may indicate that the system is near capacity. For example, an arrival of a container ship requires a number of immediate resources such as a berth and crane to unload containers and stackers and carts to move containers from the container yard to the dock for loading. While the ship is in port, these resources are at 100% utilization. Then, after the ship leaves the terminal, these resources are idle. The unavailability of just one of these resources will significantly impact container throughput. For example, if a stacker is not available to load a cart or a cart is not available to move the container to the ship dock, then the supporting resources such as ship crane becomes idle and the time the ship is in the berth is extended. Therefore, the possibility exists to have an increase in resource utilizations, or an increase in entity arrivals while at the same time, have a decrease in container throughput. This coupling and interaction of resources and activities can result in misinterpretations and misunderstanding of the simulation results.

6.2.6. Conclusions

In summary, the following conclusions are made:

- Given the currently defined intermodal center operation, the minimum quantity of inspection resources that will not negatively impact entity throughput are six tailgate inspection stations, three intensive inspection stations and one general purpose inspector.
- Each of the inspection stations required one operator, or inspector. Therefore, a total of ten inspectors are necessary to minimize the impact of container inspections; six at tailgate inspection, three at intensive inspection and one general inspector.
- Any slight change in terminal operations for Run10 would have a definite negative impact on the required minimum inspection resources. For example, reducing the number of tailgate inspection stations by one in Run10 caused a 30% reduction in ship throughput, a 30% reduction in train throughput and a 31% reduction in truck throughput.
- The impact of increased container inspection can be minimized or even eliminated by an overabundance of inspectors and inspector stations. Therefore, tradeoffs between inspector and inspector station cost must be made with the time entities are at the terminal. The simulation results show that the adding of additional resources can basically eliminate any entity delays.
- The simulation model assumed that a small percentage (15%) of containers were not inspected because of C-TPAT designation and only a small percentage (2%) of containers required opening, stripping and an intensive inspection. A small change in these percentages would have a significant impact on entity throughput.
- The number of carts for moving containers within the intermodal terminal may be a limiting factor when the number of inspection resources is reduced. An increase in the number of carts resulted in the need for fewer inspection resources (Run11).

6.3. Simulation of Freight Activity – Container Ports, Coal Terminals, Intermodal Centers

Using the framework discussed in Section 6.1, specific models were developed to simulate container movement through a port and intermodal center as well as the volume of coal processed at a bulk handling facility. In all instances, the modeling was performed to serve as a tool to assist managers in improving operations at their facilities, which can include proper resource allocation, determination of existing/future capacities, and the impacts of process improvements or facility expansions. This section describes in detail the simulation process for the container port and also highlights the research efforts at the coal terminal and intermodal center.

6.3.1. Simulation of a Container Port

The Alabama State Port Authority is currently enhancing container and intermodal operations at the Alabama State Docks in Mobile, Alabama through the construction of a new container terminal. The container facility will encompass 57 acres and will accommodate container ships, trucks and trains that will deliver and pick-up containers from the terminal and from the warehousing and value-added areas [1]. In the last fiscal year, the Alabama State Docks processed approximately 60,000 TEU's (Twenty Foot Equivalent Units, a container). The new Mobile Container Terminal will be capable of handling 250,000 to 300,000 TEU's annually. The state docks are very interested in validating the design capacities of the container terminal and evaluating the potential of the expanded facility. The purpose of this project was to establish a working model of the container operations to provide decision information for the management team.

The model constructed for this facility was described in detail in Section 6.1.3 (see Figures 6.4-6.5). The model consisted of five sub-models that ran independently with global variables responsible for passing data between the models.

The terminal model has two container storage locations. One location is the inventory of containers delivered by ships that are to be loaded onto trains and trucks. The second location is the inventory of containers delivered by trains and trucks that are to be loaded onto ships. Entities in the model are ships, trains arriving full and empty and trucks arriving full and empty. Model resources are tugs, ship berths, ship cranes, bomb carts and stackers.

6.3.1.1. Baseline Run

The baseline simulation run consisted of the following inputs:

- Time between arrivals: 3 days for ships, 2 days for trains, and 2 hours for trucks
- Time between arrivals: 2 days for empty trains, 2 hours for empty trucks
- Arrival capacity: ship 500 containers, train 100 containers, and truck 1 container
- Departing capacity ship 150 containers, train 100 containers, and truck 1 container
- 20 minutes for tug to position or remove ship at berth
- 2 minutes for crane/stacker to unload/load a container from ship, train or truck
- 2 minutes for stacker to load or unload container at ship dock or container yard
- 5 minutes for bomb cart to move container from ship dock to container yard or from container yard to ship dock
- 2 ship berths, 2 tugs, 2 ship cranes
- 10 slots for trucks to load and unload, 2 slots for trains to load and unload
- 10 carts for loading and moving containers simultaneously from dock to container yard

- 10 carts for loading and moving containers simultaneously from container yard to dock
- 8 stackers shared for unloading and loading bomb carts, trains and trucks

At initiation, the simulation started empty and idle with no ships, trains or trucks at the terminal, and the container yard was empty. The baseline model ran for 1,440 hours. The baseline simulation results are shown in Table 6.11.

Table 6.11 Results of Baseline Model Run.

Utilization of Resources	
Tugs (2)	1%
Ship berths (2)	23%
Ship cranes (2)	22%
Bomb carts (20)	8%
Stackers (8)	14%
Ships through terminal	20
Trains through terminal	60
Trucks through terminal	1,440
Average time through the terminal	
Ship	2,088 minutes
Train	482 minutes
Truck	29 minutes
Average time through the terminal (value added time only)	
Ship	1,347 minutes
Train	308 minutes
Truck	13 minutes
Containers in from:	
Ship	10,000
Train	3,000
Truck	720
Containers out on:	
Ship	3,000
Train	6,000
Truck	1,440
Containers in yard:	
From ship	2,560
From train/truck	0
Containers on dock:	
In from ship	0
Out on ship	720

6.3.1.2. Verification & Validation

ProcessModel has a "Label" block that displays data generated by the global variables during the simulation [2]. By slowing the simulation down, it is possible to observe these values as the entities move through the simulation. The model ran for 1,440 hours, or sixty days. As part of the model verification, the containers unloaded from ships (10,000) minus the containers loaded onto trains and trucks (6,000+1,440) minus the containers on dock unloaded from ships (0) equals the containers in yard from ships (2,560). Likewise, the containers unloaded from trains and trucks (3,000+720) minus the containers loaded onto ships (720) minus the containers on the dock waiting to be loaded onto ships (3000) equals the containers in yard from trains and trucks (0). Model validation was not possible since the Mobile Container Terminal is under construction.

6.3.1.3. Experiment Design

The purpose behind the experiment design is to evaluate the interrelationships that the time between arrivals of ships, full trains, and empty trains have with the throughput of containers and the time each entity spends in the terminal facility. The experiment design is shown in Table 6.12. The independent variables for the experiment were the time between arrivals for ships, full trains, and empty trains. The time between arrivals for full trucks and empty trucks were left unchanged at two hours. All other data remained the same as the baseline.

Table 6.12 Experimental Design.

Entity	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10
Ship	3 days	2 days	1 day	2 days	2 days	2 days	1 day	1 day	1 day	12 hrs
Full Train	2 days	2 days	2 days	1 day	1 day	12 hrs	1 day	12 hrs	6 hrs	3 hrs
Empty Train	2 days	2 days	2 days	2 days	1 day	12 hrs	1 day	12 hrs	6 hrs	3 hrs

6.3.1.4. Analysis

Table 6.13 presents the container activity for each run. As expected, there is a building of containers in and out as the time between arrivals for ships and trains are decreased in the experiment. Interestingly, Runs 6, 9 and 10 result in similar results for containers in the yard from ships (low) but higher containers in the yard from trucks and trains. These relationships should be the subject of further investigation.

Table 6.13 Container Activity for Model Runs.

Container	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10
In from:										
Ship	10,000	13,000	13,000	15,000	15,000	15,000	23,000	29,972	29,973	44,090
Train	3,000	3,000	3,000	6,000	6,000	12,000	6000	12,000	24,000	24,000
Truck	720	720	720	720	720	720	720	720	720	720
Total	13,720	16,720	16,720	21,720	21,720	27,720	29,720	42,692	54,693	68,810
Out on:										
Ship	3000	3600	3600	4500	4500	4500	6600	8850	8850	13,200
Train	6000	6000	6000	9000	12000	13500	12,000	24,000	28,500	42,600
Truck	1440	1440	1440	1440	1440	1440	1440	1440	1440	1440
Total	10440	11040	11040	14,940	17,940	19,440	20,040	34,290	38,790	57,240
In Yard:										
From Ship	2560	5560	5560	4560	1560	60	9560	4529	29	45
From Train/ Truck	0	0	0	0	0	0	0	0	0	0
On Dock:										
From Ship	0	0	0	0	0	0	0	0	0	0
From Train/ Truck	720	120	120	2220	2220	8220	120	3870	15,870	11,520

Table 6.14 gives the entities that move through the terminal along with the average times the entities spent at the terminal (Note the large wait time for Runs 6 and 9). Additional investigation is warranted to determine what aspects of the relationships between the time between arrival settings for those runs and the unusual wait time documented in the model results for those particular runs.

Table 6.14 Entity Throughput and Average Times at Terminal.

Run	Ships Thru	Ship Time (min)	Trains Thru	Train Time (min)
1	20	2088	60	482
2	24	9864	60	482
3	24	26,424	60	482
4	30	2013	90	529
5	30	2013	120	480
6	30	2012	135	18,943
7	44	12,404	120	476
8	59	2012	240	477
9	59	2012	284	18,113
10	87	12,999	424	5496

Table 6.15 presents the average time for ships and trains in the terminal for model runs 4, 5 and 8. The table also presents the quantity of containers processed for each run and the extrapolated annual container throughput for those three runs. The model settings for Run8 obviously provide better container throughput by almost double the other two runs. Some explanation could be that the quantity of containers

per ship is best served by two trains during the same time period. This is another aspect of the port operations that warrants additional investigation.

Table 6.15 Summary Results for Selected Model Runs and Annual Throughput.

Run	Average Time		Containers		Annual Container Throughput	
	Ships	Trains	In	Out	In	Out
Run4	2013	529	21,720	14,940	130,320	89,640
Run5	2013	480	21,720	17,940	130,320	107,640
Run8	2012	477	42,692	34,290	256,152	205,740

Table 6.16 presents the utilizations of the resources associated with ship activities in the model. A utilization rate of 98% and 99%, as seen in Runs 3, 7, and 10 for Ship Berths indicates that there is inefficiency in the system and that ships are sitting at the dock for significant amounts of time without activity. This is an area of interest to the port operations management team and deserves additional investigation.

Table 6.16 Resource Utilizations for Model Runs (%).

Resource	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10
Ship berths (2)	23	93	99	34	34	33	98	67	67	99
Ship cranes (2)	22	28	28	33	33	33	51	67	67	99
Tugs (2)	1	1	1	1	1	1	1	1	1	2
Carts (20)	8	10	10	13	13	17	18	27	34	44
Stackers (8)	14	15	15	21	22	29	27	42	56	71

Decreasing the time between arrivals for ships from three days (Run1) to one day (Run3) had only a minimal increase on container activity. However, the time in the terminal for ships greatly increased from 2,088 minutes for Run1 to 26,424 minutes for Run3. The utilization of the ship berths increased to 99%. When the time between arrivals for ships is left fixed at two days and the time between arrivals for trains is decreased (Runs4-6), a large increase in the time in the terminal for train results, from 529 minutes for Run4 to 18,943 minutes for Run6.

Leaving the time between arrivals fixed for ships at one day (Runs7-9) and decreasing the time between arrivals for trains lead to a significant increase in the time in the terminal for ships in Run7 to 12,404 minutes and for trains in Run9 to 18,113 minutes. When the time between arrivals in Run10 was reduced to 12 hours for ships and 3 hours for trains, the time in the terminal increased to 12,999 for ships and 5496 for trains. The utilization of the ship berths increased to 99%.

The average times that entities were in the terminal were relatively low for Runs1, 4, 5, and 8 (See Table 6.14). The corresponding inventories at the terminal were also relatively low (See Table 6.13).

Cycle times were similar to the value added times, indicating minimal delays waiting on resources, activities or containers. For example, in Run8:

• Ship time in terminal	2,012 minutes
• Ship value added time	1,347 minutes
• Train time in terminal	477 minutes
• Train value added time	308 minutes
• Truck time in terminal	29 minutes
• Truck value added time	13 minutes

In Run8, the resource utilizations were 67% for ship berths and ship cranes, 27% for carts and 42% for stackers. The utilizations of the carts and stackers were relatively low, indicating that there may be an excess of these resources. Several additional runs should be made with fewer of these resources to understand the true relationships.

6.3.1.5. Conclusions

In summary, the model provides the needed insights for relationships that the management of the port desired. The model is very sensitive to the time between arrivals of ships, trains and truck. Due to the assumption that containers arriving on ships leave on trains and trucks and containers arriving on trains and trucks leave on ships, there is considerable dependency between entities. Simply reducing the time between arrivals of entities does not necessarily increase container activity. For example, decreasing the time between arrivals of ships requires an adequate arrival of containers from trains and trucks so ships can be loaded and exit the terminal.

Runs 4, 5 and 8 appear to provide lower times in the terminal for entities and also increased container throughput. There are possible other scenarios that may result in lower times and greater container activity.

Run 8 had an estimated annual unloading of 256,152 containers and an annual loading of 205,740 containers. Over 50,000 containers were in the container yard or on the dock waiting to be loaded. This scenario, along with some others with similar outcomes should be investigated further. The large number of containers in the terminal at the end of the simulation indicates that the system may not have achieved a stable state. This implies that the containers in the terminal will continue to increase over time. Additional research into the interrelationships of model entities and model resources is warranted. Refinements to the model can be made in the application of statistical distributions to the model variables.

6.3.2. Simulation of Coal Terminal – Synopsis

The Alabama State Port Authority wants to increase the volume of coal moving through the McDuffie Island Coal Terminal to 30,000,000 tons annually. A perceived barrier to an increase in capacity is the number of tugboats for moving barges throughout the terminal. The UAH research team developed a simulation model for evaluating the various tugboat alternatives for improving the velocity of coal through the terminal. Additionally, the simulation examined other potential constraints to the flow of coal and identified opportunities for productivity improvement.

The model constructed for this facility was described in detail in Section 6.1.2 (see Figures 6.2-6.3). The model consisted of five sub-models that ran independently with global variables responsible for passing data between the models.

The model employs three types of tugboats: ship tugboats, customer tugboats, and barge tugboats. Ship tugboats move incoming ships from the harbor to ship berths for unloading low sulfur coal. After unloading their low sulfur coal, and then loading with high sulfur coal, ship tugboats move the sea vessel back into the harbor. The model also includes customer tugboats for moving outgoing barge orders (six-packs) to the customer site and for moving incoming barges (six-packs) of high sulfur coal into the barge holding area. Full barges arrive in a group of six barges, called a six-pack, with each barge holding 1,500 tons of high sulfur coal. The full barges are relocated to a holding area by a customer tugboat. The barge tugboats then move the full barges to the barge berths for unloading. After unloading the high sulfur coal, the barge tugboats move the empty barges to the barge holding area.

The model has several barge holding areas: storage of empty barges, incoming full barges of high sulfur coal and outgoing full barges of low sulfur coal. Only when an order for low sulfur coal is received will an empty barge be moved into location for filling. Full barges are only moved for unloading when a barge birth is available at the unloading operation.

6.3.2.1. Experimental Design

Since the primary model objective was to evaluate tugboat utilization, several tugboat protocols for loading and unloading were defined. The baseline model contained the tugboat protocol below (Protocol A):

Ships

Get ship tugboat and move ship to berth
Get ship berth and position ship in berth
Free ship tugboat
Unload and load ship
Free ship tugboat

Full Barges

Get barge berth for unloading
Get Barge tugboat and move to berth
Free barge tugboat
Unload barge
Free barge berth for unloading

Coal Orders

Get barge berth for loading
Get barge tugboat and move barge to berth
Free barge tugboat
Load barge
Free barge berth for loading

The resources for the baseline model were:

- 1 ship tugboat
- 2 barge tugboats

- 10 customer tugboats
- 3 ship berths
- 2 barge berths for unloading
- 2 barge berths for loading
- 2 train slots for unloading
- 1 train slot for loading

Arrival and service times and coal capacities for the baseline model were:

- Time between arrivals for ships 2,160 minutes; 360 minutes for six full barges; 480 minutes for coal order of six barges; 1,440 minutes for trains; 2,880 minutes for six empty barges
- Coal capacity of ships incoming 75,000 tons and outgoing 75,000 tons
- Coal capacity of trains incoming 10,000 tons and outgoing 10,000 tons
- Coal capacity of barge incoming 1,500 tons (9,000 tons for group of 6 barges)
- Coal capacity of barge outgoing 1,500 tons (9,000 tons for 6 barges in a coal order)
- 3,000 minutes to unload ship, 2,100 minutes to load ship
- 100 minutes to unload one barge (600 minutes for a six-pack)
- 110 minutes to load one barge (660 minutes for a six-pack)
- 600 minutes to unload train, 200 minutes to load train
- 20 min. for movement of barges between holding areas and barge berths
- 20 minutes to move ship to berth and from berth
- 20 minutes for customer tugboat to move order (six barges) to customer (selected to reduce simulation time)

These times are based upon the implementation of the continuous improvements that have been performed at the terminal and validated by Harris, et.al. [3]. Actual times taken at the terminal for many of the activities are longer since all improvements have not been fully implemented or sustained. Again, to simplify the model all the time distributions were reduced to only the mean values.

The simulation started empty and idle, with no ships, barges or trains initially at the terminal; 25 empty barges were in the holding area; and both coal piles had 25,000 tons each. The experimental design for the remaining runs is shown in Table 6.17. All other data remained the same as the Baseline Run with the exception of the tugboat protocol.

The tugboat protocol (Protocol B) for Runs 1-5 was:

Ships (same as Protocol A)	**Full Barges**
Get ship tugboat and move ship to berth	Get barge tugboat and move barge to berth
Get ship berth and position ship in berth	Free barge tugboat
Free ship tugboat	Get barge berth for unloading
Unload and load ship	Unload barge
Free ship tugboat	Free barge berth for unloading

Coal Orders
Get barge tugboat and move barge to berth
Free barge tugboat
Get barge berth for loading
Load barge
Free barge berth for loading

Table 6.17 Experimental Design.

Run 1	Ship Tugboats	Barge Tugboats
Baseline (Protocol A)	1	2
Runs 1-5 (Protocol B)		
Run1	1	2
Run2	2	2
Run3	3	2
Run4	2	3
Run5	3	3

6.3.2.2. Results

The results of these runs indicated that the annual throughput can be estimated at approximately 29,800,000 tons if the facility is operating 24 hours/day. This capacity was close to the stated goal of the State Dock. Overall, the utilization ranged from 65% to 75% for ship tugboats and 38% to 58% for barge tugboats. The average time spent in the terminal dropped dramatically for each run as compared to the baseline with Runs 3 and 5 producing the shortest times.

After an initial analysis of the results, the authors modeled two additional scenarios, Runs3A and 3B. Run 3A was a modification of Run 3 and included faster arrival times for ships of low sulfur coal, barges and trains of high sulfur coal, and more frequent coal orders. The results of this run indicated that tonnage could be increased, but the barge unloading time increased dramatically with 99% utilization of ship and barge berths. Given these lengthy load times, a protocol modification was made to Run3A to produce Run3B. The modification consisted of making certain that there is an available ship berth prior to calling for a ship tugboat. Though this change reduced the tugboat utilization dramatically, the overall results were very similar.

6.3.2.3. Conclusions

The following conclusions can be drawn from this simulation exercise:

- The protocol for the use of tugboats is critical to increasing terminal throughput. Protocol A resulted in almost 100% utilization of the ship and barge tugboats with very little coal throughput.
- Protocol B for Run1 resulted in much lower utilizations of the ship and barge tugboats and very large coal throughput.
- Run1 (simulation run length of six months) with one ship tugboat and two barge tugboats achieved the loading of 8,200,000 tons of high sulfur coal and

6,700,000 tons of low sulfur coal. On an annual basis, this equates to 29,800,000 (assuming 24 hours/day operations).

- An increase in the number of ship tugboats and/or barge tugboats (Runs 2-5) slightly reduced average tugboat utilizations and did not significantly increase coal throughput.
- Run3 with three ship tugboats and two barge tugboats resulted in one of the lowest times for unloading and loading ships. The average time was 13,098 minutes as compared to 15,951 minutes for Run1. However, the average utilization of the three ship tugboats was only 65% and 58% for the two barge tugboats.
- A change in the ship protocol in Run3B and a reduction of the number of tugboats to one ship tugboat and two barge tugboats did not affect throughput. However, ship tugboat utilization dropped from 84% with three tugboats for Run3A to 2% with one tugboat for Run3B. Barge tugboat utilization remained constant at 68% for both runs.
- When entities (ships, barges and trains) arrive at the terminal, resources are needed immediately to unload and/or load coal. As a result, utilization of resources is high at that particular time. Once an entity leaves the terminal, the utilization of the model resources significantly drops. Consequently, looking at only average utilizations may be misleading. A look at peak need resources may be more revealing.
- Run3A reveals the interactions and constraints between the various submodels. Making a change in one submodel may or may not have a significant impact on another submodel due to the situation where each model was individually developed and then linked together, thus, the desired results may not be achieved.

In conclusion, the protocol used by State Docks' personnel is a very critical factor in ship tugboat and barge tugboat utilization. This protocol hinges on making certain the availability of a ship berth or a barge berth before calling for a corresponding tugboat. The protocol for Run3B along with one ship tugboat and two barge tugboats resulted in the largest coal throughput.

6.3.3. Simulation of Intermodal Container Center Served by Air, Rail, and Truck – Synopsis

This simulation model evaluates the operations of the container facility at the International Intermodal Center in Huntsville, Alabama. The simulation was used to determine if throughput can satisfy anticipated demand and if sufficient resources are available to meet anticipated growth in demand.

The model constructed for this facility was described in detail in Section 6.1.4 (see Figures 6.6-6.7). The model consisted of seven sub-models that ran independently with global variables responsible for passing data between the models. The intermodal terminal was modeled to include the following resources to support the movement of freight: plane terminals, train terminals, truck slots, plane lifts, train lifts, stackers, and carts. The model consists of freight moving from airplanes to trucks, trucks to airplanes, trucks to rail, rail to trucks, and from rail to airplane (in rare instances).

6.3.3.1. Experimental Design

A baseline run and fifteen additional experimental runs were conducted to test the intermodal center processes and capabilities. The input data for the baseline run was gathered from existing operations and are described below:

- Two plane terminals for unloading and loading containers
- Three train terminals for unloading and loading containers
- Maximum twenty trucks in intermodal center at one time
- Two lifts for unloading and loading containers from planes
- Two lifts for unloading and loading containers from trains
- Eight stackers for unloading and loading containers from trucks and onto carts
- Twenty carts for moving containers throughout the center
- 2 minutes to unload or load a container from plane, train, or truck
- 20 minutes to position a plane at a terminal
- 20 minutes to position a train at a terminal
- 5 minutes to position a truck for unloading or loading
- 2 minutes to process paperwork to load a plane, train or truck
- 5 minutes for plane, train, or truck to exit intermodal center
- 2 minutes to unload and load a cart
- 5 minutes to move a cart between a plane, train or truck and the container yard

Tables 6.18 and 6.19 describe the distribution of arriving and departing containers by mode as well as information about entity arrival rates, process time, and the contents of departing trucks.

Table 6.18 Movement of Containers.

	Containers Out		
Containers In	**Plane**	**Truck**	**Train**
Plane		100%	
Truck	40%		60%
Train	25%	55%	20%

Table 6.19 Intermodal Entities.

Entity	Time between Arrivals (min)	Average Containers In	Average Containers Out	Truck Leaves with no Containers	Truck leaves with container	Truck leaves with Full Container
Plane	480	10	10			
Train	960	50	40			
Truck with Full container	40	1	10%	10%	9%	81%
Empty Truck	240	0			100%	100%
Truck with Empty Container	120	1	10%	10%	9%	81%

The results of the baseline run indicated a yearly equivalent total of approximately 36,000 lifts (container load or unload), which compared favorably with the 34,410 annual lifts estimated by the Intermodal Center in 2005. Further analysis of the baseline run indicated relatively low wait times and low utilization of resources, which can be indicative of excess resources.

Runs2-10 was performed to evaluate how the model would react to a reduction in resources. These runs featured a reduction in the number of terminals for planes and trains, truck slots, plane lifts, stackers and carts. Run10 featured the most drastic of these reductions, cutting resources in half, and the results indicated similar quantities moving through the center as found in the baseline run. However, a moderate increase in wait time for the train entity was experienced.

Run11 added increased entity arrivals (such as a plane from Asia and the associated need for more trucks and trains) to the baseline run in order to assess how the Intermodal facility would react with their existing level of resources. The results of this run again indicated low average wait times and relatively low utilization rates while processing 28% more containers than the baseline run.

Similarly to Runs2-10, in Runs11-15 resources were stripped from the Run11 to see how the system would react in terms of wait time, utilization, and container throughput. Run15 featured the most drastic of the resource reductions, and the results indicated that identical throughput could be achieved with this run with about a 20% increase in wait time for airplanes (but similar times for other entities).

The results of these model runs indicated that the intermodal center has the capacity for additional container throughput, especially because of the low utilization of resources. Subsequently, Run16 was established to test the capacity of the center with the full amount of existing resources. As shown in Table 6.20, the arrival rate for all entities was significantly increased.

Table 6.20 Increase in Entity Arrivals for Run16.

Entity	Time between Arrivals (min.) (Run16)	Time between Arrivals (min.) (Run15)
Plane – Europe	360 (6 hours)	480
Plane – Asia	1,200 (20 hours)	2,400
Train	480 (8 hours)	720
Truck with Full Container	20	30
Empty Truck	240 (4 hours)	240
Truck with Empty Container	120 (2 hours)	120
Resources		
Plane Terminals	2	1
Train Terminals	3	2
Truck Slots	20	12
Plane Lifts	2	1
Train Lifts	2	2
Stackers	8	8
Carts	20	12

The results of Run16 indicated a substantial increase in throughput is possible with the existing resources without sacrificing entity wait time. Table 6.21 provides a summary of the results from Run16 in comparison to Runs1, 10, 11 and 15.

Table 6.21 Summary Results.

Annual container lifts (estimate)	Baseline Run1	Fewer Resources (Run10)	More Entity Arrivals (Run11)	Fewer Resources (Run15)	More Entity Arrivals (Run16)
Unloaded	18,360	18,360	23,520	23,520	34,060
Loaded	16,534	16,562	21,012	21,000	30,040
In Container Yard	1,826	1,798	2,508	2,520	4,018
Total Lifts	36,720	36,720	47,040	47,040	68,118
Annual entities through intermodal center (estimate)					
Planes - Europe	360	360	360	360	480
Planes -Asia	NA	NA	72	72	118
Trains	180	180	240	240	360
Trucks	4,320	4,320	5,758	5,758	8,638
Empty Trucks	720	720	720	720	720
Truck with Empty Container	1,440	1,440	1,440	1,440	1,440
Average time in intermodal center (min.)					
Planes –Europe	94	99	93	111	94
Planes –Asia	NA	NA	93	93	93
Trains	326	371	312	312	307
Trucks	43	28	29	32	28
Empty Trucks	36	21	21	24	21
Trucks with Empty Containers	39	27	27	30	27
Resources/ Utilization					
Plane Terminals	2/9%	1/20%	2/11%	1/23%	2/16%
Train Terminals	3/11%	1/36%	2/21%	2/21%	3/21%
Truck Slots	20/7%	12/5%	20/6%	12/7%	20/8%
Plane Lifts	2/6%	1/13%	2/8%	1/16%	2/11%
Train Lifts	2/14%	1/28%	2/18%	2/18%	2/28%
Stackers	8/13%	6/17%	8/16%	8/16%	8/24%
Carts	20/7%	10/15%	20/10%	12/16%	20/15%

In summary, the following conclusions are made:

- The current throughput (34,400 lifts in 2005) of the intermodal center can be met with considerably fewer resources than originally estimated for the Baseline Run1 and with no reduction in container throughput (Run10). The resources for Run10 were one plane terminal, one train terminal, twelve truck slots, one plane lift, one train lift, six stackers and ten carts. Annual lifts for Run10 were 36,720.

- The reduction in truck slots from twenty for the Baseline Run1 to 12 for Run10 indicates that only twelve trucks need to be inside the intermodal center at a time. This results in a considerably less space requirement and possibly fewer personnel.

- The container throughput can be increased considerably without any deterioration in entity times at the terminal. For Run15, the container throughput reached 47,040 lifts annually up from 36,720 for Run11. Consequently, entity times at the intermodal center remained relatively constant. For example, the average plane entity time was 93 minutes for Run11 and 111 minutes for Run15. The average train entity time was 312 minutes for Run11 and 312 minutes for Run15. The average truck entity time 29 minutes for Run11 and 32 minutes for Run15.

- Resource utilizations after reducing the number of resources were still relatively low. However, when resources, such as stackers, were reduced below eight, the average entity times increased significantly because of higher waiting times for either a resource or a container.

- Run16 indicates that considerably more container traffic is possible with the existing resources from the Baseline Run1. Run16 indicates that these resources can process 68,118 lifts annually. This is a 51% increase over the projected 2007 container traffic of 45,000 lifts.

- Resource utilization is not a good measure of the utilization of resources during the simulation. For example, when a train arrives at the train terminal the train lifts are 100% busy. Then after the train exits the intermodal center, these resources are idle. As a result, the average utilization is low.

- There is considerable interaction between the various submodels. Consequently, decreasing the time between arrivals of one entity might not increase container throughput. In fact, just the opposite might occur because the resources are now busy unloading an entity instead of loading another entity.

Appendix – 6.0 – References

6.0 Modeling Intermodal Operations Using Discrete Event Simulation

6.1 Conceptual Framework for Simulating Seaport Terminals

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6.2 Minimizing Disruption caused by Container Inspection at an Intermodal Terminal

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6.3 Simulation of Freight Activity – Container Ports, Coal Terminals, Intermodal Centers

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2. ProcessModel, 1999: Users Manual, ProcessModel Corp., Provo, UT.

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7. Continuous Improvement in Logistics and Transportation System

In the 2005 report on *Transportation Infrastructure In Alabama - Meeting the Needs for Economic Growth* to the USDOT, UAHuntsville researchers identified Logistics and Transportation Systems as one of the industry clusters with the most potential to provide vibrant economic growth for Alabama. The 2006 report *Transportation Infrastructure In Alabama – Bridging the Gap* to the USDOT, UAH researchers identified and explained the need for continuous improvement in our transportation and logistics operations to achieve the economic growth potential in this industry cluster.

In the research performed during this period of performance, two particular areas of interest were investigated. The first part of this research was to identify the best performing logistics companies, their characteristics and determine how these best performing companies consider continuous improvement in their operations.

The second part of this research was to relate how the concepts of continuous improvement that are considered part of the Lean Enterprise approach to continuous improvement, based upon the successful Toyota Production System, apply to logistics and transportation entities. In this portion of the research the UAH team provides a summary of the application of Lean principles over the past four years at the Port of Mobile, AL.

7.1. Best Performing Logistics and Transportation Operations

Many businesses, especially in the manufacturing sectors, are very familiar with the concept of continuous improvement. However, some industry sectors are less familiar with this concept. Even worse than a lack of understanding is thinking of continuous improvement as just another “quality fad” that will eventually be tossed aside for the next business salvation-of- the- day. Even though the concepts of LEAN, the Toyota Way, or simply continuous improvement, have now been proven in multiple industry sectors, there are companies within those sectors that have not yet learned the value-- much less experienced-- the benefits.

The logistics and transportation industry sector is no exception to the variety in levels of adoption of continuous improvement philosophies. There are companies that understand and embrace the concepts while others are still unable to distinguish continuous improvement philosophy from ‘quality circle’ fads of the 80’s. The purpose of this research is to address the question, “Are the best logistics and transportation companies utilizing continuous improvement activities in their regular conduct of business?”

The challenge in this task is multi-faceted. Choosing an approach to gain insight into continuous improvement activities in logistics and transportation companies must answer questions like –which ones are the best performing companies; what are the operational characteristics that set them apart; and how can ‘window-dressing’ be distinguished from cultural adoption?

The approach used to research this topic included using rankings and recognition by independent organizations which have little or nothing to gain in “proving” that continuous improvement or LEAN principles are beneficial. Specifically, the UAHuntsville research team identified organizations that recognize companies for profitability, employee culture, and admiration by the peers and/or the public.

Additionally, the research team identified the types of continuous improvement activities that logistics and transportation companies are using to produce great results. The findings presented include brief profiles of companies that rose to the top in these lists. These findings suggest that continuous improvement in logistics and transportation companies is alive and well … and is making a difference.

7.1.1 Financial Strength Acknowledgement

The UAH research team reviewed over various third party organizations’ lists ranking companies based on their financial strength. Fortune Magazine recognizes 1,000 of America’s largest companies each year. The list is ranked based on revenue growth between 2006 and 2007. The ranking of logistics/transportation companies by revenue performance per Fortune Magazine is shown in Table 7.1

Table 7.1 Ten highest ranking logistics/transportation companies by revenue performance for 2008 by Fortune Magazine

Fortune 2008 Ranking as Logistics/Transportation Company	Companies	Fortune 2008 Ranking Overall
1	C.H. Robinson Worldwide	#341
2	Caterpillar Logistics	#50
3	Con-way	#516
4	Expeditors International of Washington	#458
5	Federal Express	#68
6	J.B. Hunt Transport Services	#601
7	Ryder Systems	#371
8	Sirva	#552
9	United Parcel Service	#46
10	Wal-Mart Stores	#1

One significant benefit of continuous improvement practices is waste reduction. As waste is reduced, the company can become more profitable and more competitive which will be reflected in revenue growth – leading the UAHuntsville research team to select revenue growth as one measure of a successful logistics/transportation company that might be incorporating continuous improvement practices.

7.1.2. Culture & Customer Admiration

The second measure of company performance examined is a survey by Fortune Magazine and the Great Place to Work Institute. This survey obtained responses from nearly 100,000 employees in 407 companies. The companies were assigned a weighted score comprised of opinions of management credibility, job satisfaction, and camaraderie (2/3) plus the company's responses to the Institute's culture audit (1/3). The culture audit included demographic makeup, pay and benefit programs, open-ended questions about company's management philosophy, methods of internal communications, opportunities, compensation practices, and diversity efforts (1).

There is only one logistics/transportation company included in the Fortune 1000 list shown above and also in this "Best Places to Work". This company created the overnight delivery industry and is known today simply as FEDEX.

Another benefit of a culture of continuous improvement is employee empowerment to identify and correct problems. The Best Places to Work ranking elements of management credibility, job satisfaction, camaraderie, and methods of internal communications are used as proxies for positive employee empowerment.

Finally, a third independent ranking of *Best* companies is the list of “America’s Most Admired Companies”. The criteria used to rank this list of most admired companies include eight attributes:

1. Quality of management
2. Quality of products and services
3. Innovation
4. Long-term investment value
5. Financial soundness
6. People management
7. Social responsibility, and
8. Use of corporate assets (2).

The attributes of quality and innovation in this list are very similar to attributes of continuous improvement. Examining the list of the 2008 “America’s Most Admired Companies”, seven logistics/transportation companies appear. The companies are listed in Table 7.2.

Table 7.2 Top Listed Logistics/Transportation Companies in “America’s Most Admired Companies”

Ranking as Logistics/Transportation Company	Most Admired Companies	Score*
1	C.H. Robinson Worldwide	5.29
2	Caterpillar	7.58
3	Federal Express	7.86
4	J.B. Hunt	6.03
5	Ryder Systems	6.44
6	United Parcel Service	8.37
7	Wal-Mart Stores	6.22

* Lower score indicates higher rank

Of these companies, FedEx also appears in the Fortune 1000 and the Best Places to Work rankings.

7.1.3. Company Growth

The third area of assessment to evaluate successful logistic/transportation companies by the UAHuntsville Research team is in the area of company growth rates. Forbes magazine has a different ranking that recognizes top performing companies – its "Forbes 400 Best Big Companies" listing. Forbes Magazine uses Audit Integrity and the Accounting and Governance Review (AGR) to assist in evaluating the 400 Best Big Companies for inclusion in the ranking. The 400 Best Big Companies are selected based on growth rates over a 5 year time period.

A short review of how the 400 Best Big Companies are analyzed before selection is noted below.

Audit Integrity is a public accounting and governance analysis company that ranks the companies by comparing company metrics to prior periods, peer companies, and industry norms. Each company gets a score and a ranking in three different categories: accounting and governance, financial condition, and earnings quality.

AGR analyzes items that reflect potential deviations in a company's accounting records as well as rankings characterized as conservative, average, aggressive, or very aggressive**.**

Additionally, financial condition is assessed through a number of tests to determine financial strength such as quick ratio (current assets less inventory / current liabilities) and current ratio (current assets/current liabilities). Each company is ranked as strong, average, or weak.

Earnings quality is the third area of analysis in the Forbes 400 evaluation. Analysis is conducted to assess a firm's earnings sustainability using accounts receivable and intangible assets data from the balance sheet. The result is a rating of high, average, or low earnings quality. (3)

After the analysis is completed, Forbes announces the 400 Best Big Companies.

In reviewing the selection of both Forbes 400 for 2007 and Fortune's 1000 list for 2008 for top ranking logistics/transportation companies – the top six are listed below:

1. C.H. Robinson
2. Caterpillar Logistics
3. Expeditors Intl of Washington
4. FedEx
5. Ryder System
6. United Parcel Service (UPS)

A conclusion from analyzing these independent rankings of “best” companies is that continuous improvement activities can positively improve the utilization of a company’s assets in generating sustained revenue.

7.1.4. Industry/Peer Admiration

The recognition of top companies within an industry by professional associations or other industry-related organizations are additional criteria to evaluate to determine the best companies in an industry. Several groups within the logistics/transportation industry recognize excellence in the industry as noted in the listings cited below.

Inbound Logistics magazine publishes an annual list of the 100 Best 3PL (third party logistics) Providers to recognize third party logistics excellence as voted by their more than 5,000 readers. The 2007 list includes: (4)

1. C.H. Robinson
2. Caterpillar Logistics
3. FedEx
4. Ryder System
5. UPS

Logistics Quarter’s “Top North American 3PL Report” recognizes 36 3PL companies based on their growth in the 3PL sector. Companies are split into 3 tiers: [1] Global Supply Chain Managers, [2] Tier 2 3PLs, and [3] Tier 3 3PLs. Criteria for each of the 3 tiers are:

- Global Supply Chain Managers exceed $1 Billion in global gross revenues;
- Tier 2 companies serve North America and have annual revenues between $200 million and $1 billion; and
- Tier 3 companies usually have net revenues of less than $200 million and tend to specialize to excel. (5)

The logistics/transportation companies recognized for their growth by Logistics Quarterly in 2007 is listed in Table 7.3.

Table 7.3 Logistics Quarterly Ranking of 3PL Companies by Growth

2007 Ranking for Growth in 3PL sector	Companies	Logistics Quarterly Ranking Overall
1	C.H. Robinson Worldwide	#3
2	Caterpillar Logistics	#12
3	Expeditors International of Washington	#4
4	Federal Express	#15
5	J.B. Hunt Transport Services	#24
6	Ryder Systems	#10
7	United Parcel Service	#1

7.1.5 Return on Investment

Business Week Magazine also has a list of top performing companies. Business Week focuses on two core financial measures: average return on capital and revenue growth over the prior 36 months. Additionally, the companies are compared with others in their industry sectors and ranked separately on both measures. The top 50 companies in 2008 included two logistics/transportation companies: C.H. Robinson (#12), and Expeditors International of Washington (#32). (6)

Each of these independent rankings of top companies includes measures that are often used in tracking progress in companies practicing continuous improvement. Growth in revenue and return on assets are financial measures that can be noticeably impacted through a sustained continuous improvement philosophy.

7.1.6 Lean Principle Acknowledgements

Continuous improvement efforts can consist of a number of lean activities. The logistics industry has begun recognizing application of several lean principles and efforts in its sector.

- Just-in-time systems,
- Cross-docking systems,
- Sub-assembly and kitting,
- Kaizen (continuous improvement projects),
- Six sigma philosophies,
- ISO 9001 certifications.

A significant benefit which can be realized in the logistics industry from continuous improvement efforts is an increased velocity of operations. In addition to the direct measures of velocity like average processing time and average delivery times, business performance measures like revenue growth, volume growth, return on assets, and customer service quality can also be impacted.

7.1.7 Service Quality

Trade publication *Logistics Management*'s readers rate carriers and 3PL companies in all modes on the basis of service quality. Top performers are chosen in categories of motor carriers, railroad and intermodal services, ocean carriers, airlines, freight forwarders, and third party/contract logistics services. Readers, and presumably customers for 3PL services, rate transportation service providers and 3PLs differently.

Transportation service providers are rated on five key criteria:

(1) On-time Performance,
(2) Value,
(3) Customer Service,
(4) Information Technology, and
(5) Equipment & Operations.

3PLs are rated on:

(1) Carrier Selection and Negotiation,
(2) Order Fulfillment,
(3) Transportation & Distribution,
(4) Inventory Management, and
(5) Logistics Information Systems.

The companies that appear in one or more of the lists above and are rated on service quality by the *Logistics Management* survey are: (higher score indicates higher ranking) (7)

- Caterpillar Logistics (35.01 overall score)
- C.H. Robinson Worldwide (34.05 overall score)
- Expeditors Int'l of Washington (38.14 overall score)
- FedEx Supply Chain Services (36.10 overall score)

7.1.8 Customer Awards

Toyota Motor North America has also recognized logistics/transportation companies in two categories: Large Carrier of the Year Award and Top Supplier awards. The carriers are scored on their ability to embrace the "Toyota Way" and on their level culture for implementing kaizen. In 2006, Toyota Motor Sales USA recognized J.B. Hunt Transport Services, Inc. with Large Carrier Award. (8)

Top suppliers who exceed expectations are recognized by Toyota Motor Engineering & Manufacturing North America (TEMA). TEMA examines performance against their expectations for: Launch Performance, Technology, Supplier Diversity, Value Improvement, and Quality. Ryder Supply Chain Solutions was named by TEMA in 2008 as a top supplier. Ryder received a Superior Award in the area of Value Improvement. (9)

Customer recognition is practiced in many industries based on a wide variety of factors. From the awards described above, it is apparent that benefits and philosophies of continuous improvement are becoming significant award criteria in the logistics and transportation industry.

7.1.9 Logistics/Transportation Company Profiles

A brief look at some of the “best” companies appearing in one or more of the lists above shows that continuous improvement elements appear, if not touted, in the company profiles.

C.H. Robinson Worldwide (www.chrobinson.com)
C.H. Robinson Worldwide, now one of North America’s largest 3PL companies (341 on Fortune 1000), was started in 1905 as a produce company. It grew from a produce company to transportation services to logistics and sourcing. Today C.H. Robinson has operations in the United States, Canada, Mexico, South America, Europe, and Asia. Most of the revenues are generated from truck, rail, ocean and air transportation services worldwide. C.H. Robinson is a non-asset based transportation provider (they do not own the transportation equipment) which requires them to be highly effective in working with the equipment owners. The flow and management of information (and important continuous improvement element) is a key ability which enables their services to be considered among the best in the world.

Caterpillar Logistics (www.logistics.cat.com)
Caterpillar may be best known for the large, yellow equipment they manufacture. But, it is the support that they give their customers for this equipment around the world that was the genesis for the creation of Caterpillar Logistics, a subsidiary of Caterpillar, Inc. The mission of Caterpillar Logistics is to provide integrated solutions to clients in time-sensitive, service-critical businesses. This is the market segment that Caterpillar became very familiar with supporting the users of their machinery. The logistics subsidiary was formed in 1987 to build on the global distribution experience of its parent company. Their mission and business is to help other company’s lower distribution costs while improving customer service and brand loyalty…concepts central to continuous improvement culture. Caterpillar’s expertise in lean manufacturing, six sigma, sub-assembly kitting, and cross-docking is offered to clients. Caterpillar is a technology-based company that provides customized solutions that transform the process of product distribution to a source of competitive advantage. Their more than 60 clients are in an array of market sectors around the globe.

Expeditors International of Washington (www.expeditors.com)
This Seattle Washington based company was founded in 1979 with a mission to set the standard for excellence in global logistics through a total commitment to quality in people and customer service while maintaining superior financial results. Their services include vendor consolidation, air and ocean freight forwarding, customs brokerage, insurance, ocean consolidation, distribution, and value-added services. It is their philosophy that superior supply chain management can give their clients a competitive advantage. Expeditors International specializes in just-in-time delivery, [continuous] process improvement, cross-docking, and kitting for raw materials. They are ISO9001 certified and have been recognized with the Quest for Quality Award given by *Logistics Management*.

Federal Express (www.fedex.com)
Federal Express virtually created the overnight delivery business during the decade of the 1970's. Incorporated in June 1971, the company officially began operations on April 17, 1973. Today, Federal Express has an average daily volume of more than 7.5 million shipments for express, ground, freight, and expedited delivery services spanning more than 220 countries and territories including every address in the United States. Their stated mission is to produce superior financial returns for shareowners by providing high value-added supply chain, transportation, business, and related information services through focused operating companies. They commit to meet their customers' requirements in the highest quality manner appropriate to each market segment served. FedEx strives to develop mutually rewarding relationships with its employees, partners, and suppliers…all integral to continuous improvement…while considering safety in all operations. Corporate activities are conducted with the highest ethical and professional standards.

Federal Express Global Supply Chain Services provides solutions for its customers' most critical supply chain needs from spare parts to emergency deliveries to the integration of returns into the product life cycle. They also offer their customers a complete order fulfillment and transportation management solution backed by visibility, order, and event management technologies which provide peace of mind throughout the entire distribution cycle. Key to their ability to deliver this level of service are the practices of just-in-time and continuous improvement.

J.B. Hunt Transport Services (www.jbhunt.com)
J.B. Hunt was incorporated in 1961 and provides safe reliable transportation services to a diverse group of customers throughout the continental United States, Canada, and Mexico. Their services include transportation of full truckload containerized freight utilizing company, independent contract drivers in company-controlled equipment. J.B. Hunt also collaborates with most of the major North American rail carriers to transport truckload freight in containers and trailers.

J.B. Hunt has built their reputation of excellence by provided customized freight movement, revenue equipment, labor, and systems services tailored to individual customer requirements. Kaizen activities help the company to improve their service continually. They were recognized by Toyota Motor Sales USA as the 2006 Large Carrier Award.

Ryder System (www.ryder.com)
Ryder is a provider of leading-edge transportation, logistics, and supply chain management solutions worldwide. Founded in 1933, Ryder offers Fleet Management Solutions (FMS), Supply Chain Solutions (SCS), and Dedicated Contract Carriage (DCC). Fleet Management Solutions provides leasing, rental, and programmed maintenance of trucks, tractors, and trailers for commercial customers. Supply Chain Solutions manages the movement of materials and related information from the acquisition of raw materials to the delivery of finished products for end-users including value-added solutions such as kitting and light assembly. Dedicated Contract Carriage provides a turn-key transportation service that includes vehicles, drivers, routing, and scheduling.

Ryder serves customers throughout North America, Latin America, Europe, and Asia. They have been recognized by Toyota with a Top Supplier Award for Value Improvement and they have achieved ISO9001 certification. Continuous improvement, cross-docking, and just-in-time efforts are vital to their success.

United Parcel Service (www.ups.com)
UPS, a name now synonymous with parcel freight, was founded in 1907 as a messenger company in the United States. Today, UPS is the world's largest package delivery company and a leading global provider of specialized transportation and logistics services. Their service area spans more than 200 countries and territories including every address in North America and Europe.

UPS Supply Chain Solutions (www.ups-sc.com)
UPS Supply Chain Solutions Services include logistics and distribution, transportation and freight (air, sea, and ground), freight forwarding, international trade management and customs brokerage. They also have specialty services divisions of service parts logistics, technical repair and configuration, supply chain design and planning, and returns management. UPS-SC utilizes lean practices of just-in-time, benchmarking, pick-pack, and kitting.

Wal-Mart (www.walmartstores.com)
Wal-Mart was founded in 1962 and incorporated in 1969 as a retailer offering 'what their customers needed at a fair price'. Today's statement of their philosophy, *saving people money so they can live better,* carries on Sam Walton's business ideals. Wal-Mart now is recognized as a company with state-of-the-art logistics capabilities and has more than 40 regional distribution centers each over one million square feet in size. They operate the fleet of tractor trailers 24 hours per day, seven days per week to keep their retail stores stocked with the merchandise that their customers need … 'at the lowest price'. Inside each distribution center, more than five miles of conveyor belt move over 9,000 different lines of merchandise supporting stores usually within a 250-mile radius.

Wal-Mart has much invested in their very sophisticated just-in-time inventory management system and integrates the flow of information from each of their stores back to the suppliers/manufacturers to keep shelves stocked and cash registers ringing.

7.1.10. Conclusions

The application of continuous improvement techniques and lean principles are lauded as having positive impacts on company financial performance, morale, and customer satisfaction. These benefits have been demonstrated by companies like Toyota for many years. Other manufacturers have also embraced this culture and experienced the positive results of lean thinking. Logistics and transportation companies are now using continuous improvement principles to gain the improvements experienced in the manufacturing sectors. The answer to the question of whether continuous improvement works in service provider settings and specifically in logistics and transportation companies is simply yes.

Third party recognition of being a top company in measures like revenue growth, employee satisfaction, customer satisfaction, and application of lean principles is evident for logistics and transportation companies. The independent nature of multiple rankings of success like Fortune 1000, Forbes 400, Best Places to Work, and the Business Week Top 50 suggests that companies practicing continuous process improvement are doing very well. In conclusion, it is relatively easy to say that a philosophy of continuous improvement in logistics and transportation companies is alive and well … and is making a positive difference in their success.

7.2. Continuous Improvement at the Port of Mobile

The Port of Mobile, Alabama is one of only four deep water U.S. ports on the Gulf of Mexico. The port has both private and public operated terminals, with the public terminals owned and operated by the Alabama State Port Authority (ASPA). The public terminals handle containerized, bulk, break-bulk, roll-on/roll-off, and heavy lift cargoes and accounted for 26.9 million tons in 2007 [1]. A summary of the different divisions of the port are shown in Table 7.4.

Table 7.4 Summary of Alabama State Port Authority Divisions.

Division	Overview of Operation
McDuffie Coal Terminal	**Overview:** 240 employees; handles both import and export coal; **Capacity:** ground capacity = 2.3 million tons and annual throughput capacity = 22 million tons; **Resources:** 3 berths; 1 ship loader; 2 ship unloaders; 1 tandem rail dump, 1 single rail dump; 4 stacker/reclaimers, 2 double stackers; 2 barge loaders; 2 barge unloaders;
Bulk Material Handling Plant (BMHP)	**Overview:** 71 employees; in the past has handled any type of bulk material (pig iron, sand, etc) but currently only handles overflow import coal from McDuffie; **Capacity:** ground capacity = 400,000 tons; FY 2007 tonnage = 3 million **Resources:** 2 berths; 1 barge loader; 1 ship loader; 2 ship unloading towers
General Cargo/Intermodal (GCI)	**Overview:** 36 employees; handles both import and export break-bulk and containers, with major commodities being wood pulp, iron and steel, containers, aluminum, copper, lumber, linerboard and paper, and frozen poultry **Capacity and Resources:** 28 berths, rail ferry terminal, 21-acre container yard; freezer terminal; FY 2007 tonnage = 3.38 million
Terminal Railroad (TRR)	**Overview:** 116 employees; a Class-III railroad providing rail service and interchange to customers within the Port, adjacent industries, and other railroads; serves as an interchange hub for 5 Class-I railroads and 2 short line railroads **Capacity and Resources:** 8 locomotives, 247 freight cars, 75 miles of track; FY 2007 revenue generating moves = 111,782
Central Maintenance	**Overview:** 28 employees; provides maintenance services to facilities and non-rolling stock equipment for all of the Port's profit divisions except McDuffie, which handles this internally; Capabilities include millwrights, electricians, carpentry, plumbing, painting
Central Garage	**Overview:** 12 employees; provides mechanic and maintenance services to rolling stock equipment (vehicles, forklifts, rolling equipment, etc.) for all of the Port's profit divisions except McDuffie, which handles this internally;

The McDuffie Island Coal Terminal is the largest import coal terminal and second largest coal terminal overall in the U.S. with a designed capacity of 20 million tons per year. In 2003, one of McDuffie's major import customers informed the port that they were interested in the coal terminal doubling the amount of coal coming through the facility.

In addition to the coal terminal growth, the container terminal grew from handling 12,992 TEUs in 1997 to 63,480 TEUs in 2007, (a 389% increase) [2]. More growth has taken place in the Terminal Rail Road where the demand for revenue-producing car moves has almost doubled since 2005. Facing this level of growth, the port management team realized they needed to address inefficiencies existing in processes and equipment.

7.2.1. Lean Enterprise Implementation at the Port of Mobile

The implementation of Lean Enterprise at the port was strategically initiated from the executive management level. Realizing that a successful lean transformation is dependent on the education and empowerment of employees at all levels of the organization to identify and eliminate waste, the port invested in initial lean training for key management and developed a high-level strategy for integrating Lean Enterprise training and implementation into the organization's business activities. Each division of the port performed value stream mapping to establish the implementation plan prior to application of specific lean tools.

Port management began the transformation to a Lean Enterprise by prioritizing the order in which each of its operational divisions would rollout the lean improvement process. McDuffie was chosen to serve as the pilot division for implementation because of the huge opportunity to improve revenue and profitability. The coal terminal was already operating 7 days per week, 24 hours per day, 360 days per year and struggling with equipment issues.

The Lean Enterprise implementation strategy was as follows:

- Year 1 - Initiated lean training and implementation at McDuffie

- Year 2 - Continued work at the coal terminal, and begin lean training and implementation at the Terminal Rail Road (TRR)

- Year 3 - Continued at McDuffie and the TRR, and began lean training and implementation at the Bulk Material Handling Plant (BMHP) the port's corporate office

- Year 4 - Continued all previous implementations, and began lean training and implementation at the General Cargo division and various support functions (such as Human Resources, Technical Services, Central Maintenance, Central Garage, etc.)

- Year 5 - Continued all previous implementation efforts, growing and sustaining improvements

Prior to this initiative, strategic planning had been nonexistent at the port. Each major division began their Lean Enterprise rollout by conducting a strategic planning exercise to align clearly the objective of developing a lean continuous improvement program that supports the vision and mission statements.

Training at all levels of the organization is imperative to the success of a Lean Enterprise. A plan for training was developed for each division. Prior to beginning implementation at the coal terminal, an initial 40 hour Lean Enterprise Series (LES) training course was held on-site for 25 members of management. The training plan also provided for key members of each division's management to attend open enrollment, off-site installments of the LES course at later dates. All port employees participated in a 4 hour Lean Concepts overview course that included a live simulation, which provided first-hand understanding of the benefits of lean. Over 45 Lean Concepts courses have been delivered to more than 400 employees at the port. Additional training on specific lean tools, including training on Total Productive Maintenance, Lean Office Principles, leadership, and Kaizen Facilitation, were provided as needed.

7.2.2. Using Value Stream Mapping to Manage Lean Implementation

Value stream management is critical to a successful lean transformation. A value stream map consists of three deliverables-- a current state map, a future (or ideal) state map, and a detailed implementation plan [2]. The first step in the value stream mapping process is creating a current state map-- a one-page, visual representation of how the current process operates, integrating all the material and information flow steps involved in the operation. The purpose of the current state map is to provide a high-level, simplistic view of the value stream's present mode of operation, allowing the opportunity to see wastes that exist. The team constructing the value stream map then reviews the current state and brainstorms waste that is evident. Countermeasures are then developed to address as many of these wastes as possible and become the basis for the design of the future state map.

The future state value stream map is a visual representation of how the value stream's processes would ideally operate, with waste that was identified in the current state eliminated or greatly reduced, at the end of some designated time period for the planning horizon [2]. Typically future state maps are designed on a one year timeframe and reflect any process changes that are expected from the implementation of the desired improvements by showing countermeasures as "improvement bursts." The future state value stream map for the Port's TRR division is shown in Figure 7.1.

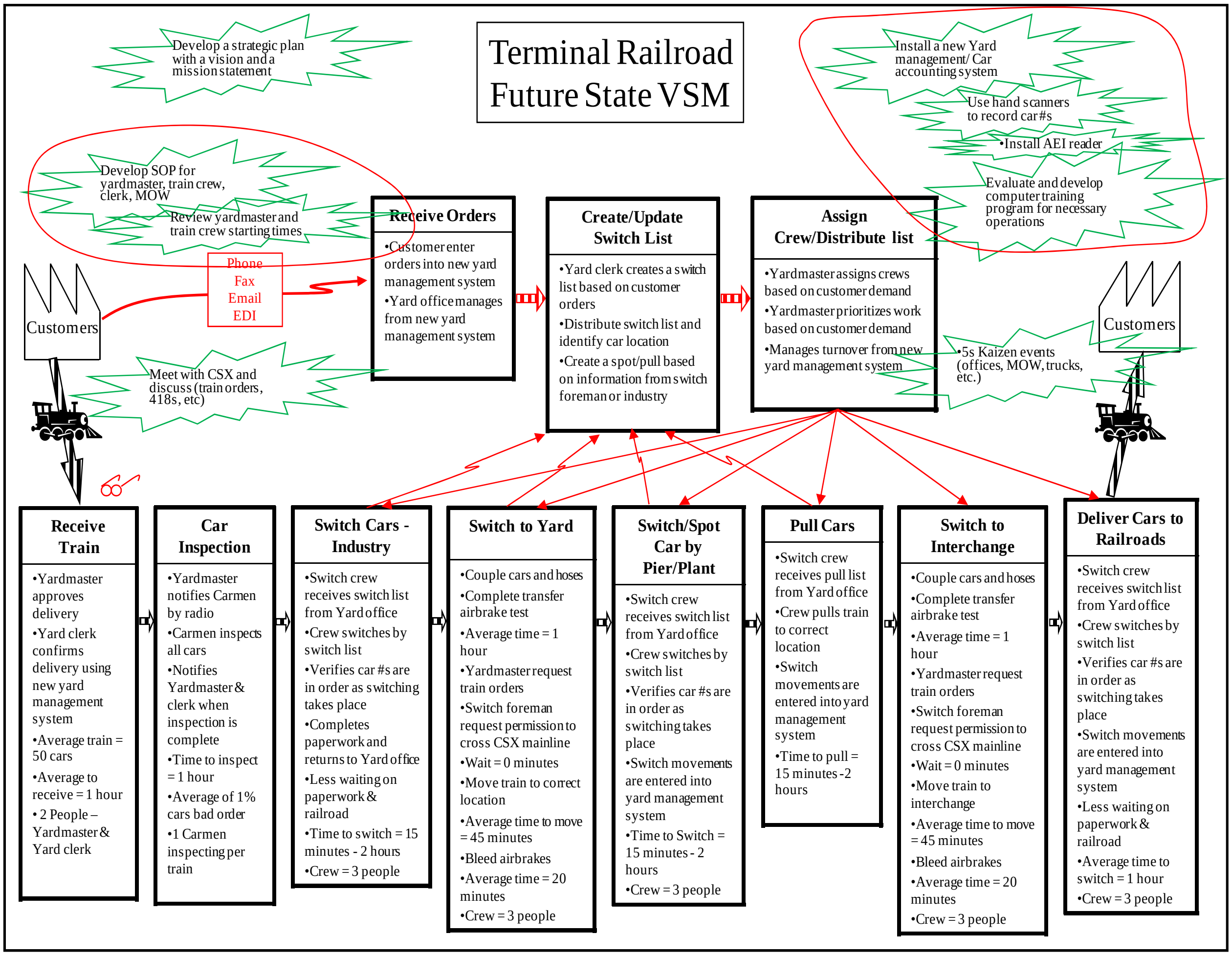

Figure 7.1 TRR Future State Map with Improvement Bursts.

The final component of a value stream map is the implementation plan. The implementation plan is a detailed roadmap of how to get from the current state to the future state [2]. Countermeasures that were developed are converted into detailed action items, prioritized, put into a timeline, and assigned to employees who will be responsible for completing each action item. Each value stream manager then manages to the plan, holds reviews on each action item, makes adjustments and decisions based on the reviews, and updates the value stream plan accordingly.

Value streams were identified and mapped at McDuffie, the Terminal Railroad, the General Cargo division, and many administrative and support functions. Each value stream mapping exercise was conducted with a team of key personnel and resulted in an implementation plan and the assignment of a value stream manager. Each value stream manager was then given the responsibility of implementing the plan.

Diligent management to the implementation plan is the key to the success of a Lean Enterprise transformation and an organization's overall performance. The TRR was handling less than 100,000 revenue cars (not including empty cars) in early 2006 at the beginning of Lean Enterprise implementation. In 2008, the TRR is handling in excess of 130,000 revenue cars (an increase of over 30%) in a more productive manner, with value stream management being an integral component to guide improvements and management decisions to increase capacity during this time of business growth.

7.2.3. Lean Implementation Tools for Seaports

Several tools exist to achieve the Lean Enterprise objectives of eliminating waste and creating customer value. The National Institute of Standards and Technology's (NIST) Manufacturing Extension Program (MEP) has developed a model demonstrating these tools, shown in Figure 7.2A [3]. An error that organizations often make in attempting to understand and implement a Lean Enterprise program is in trying to force the use of certain lean tools in situations where they do not fit. Lean is a business philosophy with a goal of eliminating waste to be responsive to customer demand; the tools are simply options of achieving this goal. Each company has the potential to construct their own lean implementation model featuring only the tools that are appropriate for their industry or organization. Based on tools that have been identified as applicable and successful during the implementation of Lean at the port, UAH has developed a modified Lean Enterprise implementation model for seaports. This model is exhibited in Figure 7.2B.

The Lean Enterprise implementation model for seaports is represented by a multi-tiered house. The foundation of the house consists of workplace organization tools which are necessary before upper level tools should be applied. The second and third levels of the house are composed of workplace analysis and workplace optimization tools. As previously mentioned, the value stream mapping is a management tool that serves as the stairway into the house of lean tools and provides a plan of how to best apply those tools to eliminate waste. All of the lean tools should be applied under the roof of a continuous improvement culture.

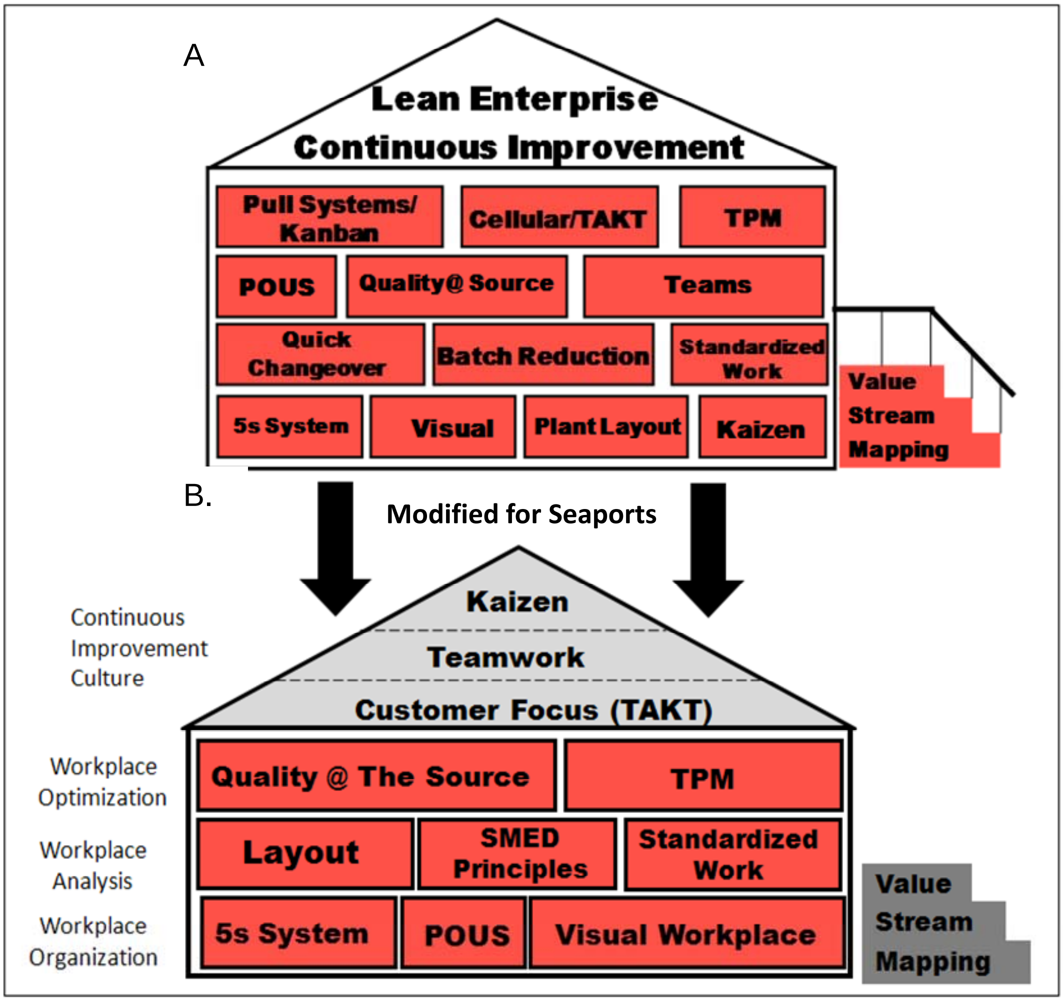

FIGURE 7.2 Lean Enterprise implementation model modified for seaports.

7.2.3.1. Continuous Improvement Culture

The continuous improvement culture section of the Lean Enterprise for the seaports model consists of the ideas of customer focus, teamwork and kaizen. Every improvement event or project should be linked to an action item on the value stream mapping implementation plan, which in turn should be designed to support customer demand. For example, McDuffie Coal Terminal's import coal customer expressed a desire to double the amount of coal processed. This was reflected in the value stream map for import coal. Because import coal arrives on ships and leaves on barges, the initial improvement efforts at McDuffie were focused on the ship unloading and barge loading processes, both determined to be constraining activities on the current state value stream map.

Many U.S. organizations have errantly applied the principles of Lean Enterprise by assigning a dedicated lean specialist to implement improvements without utilizing employee teams. This results in a process that is not optimally improved since the people actually performing the job were not involved. Even if the appropriate tools were applied and the process was technically ideal, the chances of success are minimized due to the lack of buy-in by the people actually performing the tasks. Teamwork is a vital component to the implementation of lean tools.

Cross-training of employees is another critical teamwork principle of Lean Enterprise and leads to greater flexibility when responding to customer demand. Cross-training was identified as a significant gap at the port. During the initial stages of lean implementation, the port had many employees with 20-40 years of experience that were on the verge of retirement. With no succession plans, cross-training, or documented procedures in place the organization was facing a massive loss of irreplaceable knowledge and competence. Several improvements were initiated at the Port to alleviate this gap, including:

- Revamping and utilizing "cubbing" development training and mentoring programs at the TRR for all categories of employees
- Creation of assistant foreman positions at McDuffie to allow more employees to learn under existing foreman and develop supervisory skills
- Development of standard operating procedures; every division and support function identified the need to document and train personnel on standard procedures in their value stream mapping implementation plans

Kaizen is the vehicle through which lean tools are implemented. Literally, kaizen is Japanese for "change for the good" and is a word that has become synonymous with improvement, not only at work but in everyday life [4]. When used in lean implementation, kaizen is a continuous improvement process that involves gathering a small team and performing an intensive, focused, waste elimination action on a specific process. Since beginning Lean Enterprise implementation in 2004, the port has performed over 40 kaizen events involving more than 350 employees and trained 8 internal employees as kaizen facilitators.

7.2.3.2. Workplace Organization Tools

The foundational tools of Lean Enterprise are those focused on workplace organization. Workplace organization is the concept of having a safe, clean, neat arrangement of the work area that provides a specific location for everything and purging anything not required [3]. Workplace organization tools are considered foundational to Lean Enterprise because, unlike other lean tools, they can be applied in every situation in every company wishing to implement lean. These tools can also be applied at a relatively low cost and low risk, which allows for quick, visible success while also applying the tools using kaizen to lay the groundwork for the continuous improvement culture necessary for the success of subsequent lean tools. The tools used to construct this foundational layer are the 5s system, visual workplace, and point-of-use storage (POUS).

The 5s system, when applied properly, creates an environment where all needed resources are located in a designated location, preventing the need to search for them. "5s" is the term used to describe a five point effort applied to the organization of any workspace. The five Ss are Sort, Set-in-order, Shine, Standardize, and Sustain. Clearly identified, designated locations also make it obvious when needed resources are not present. Visual workplace and point-of-use storage are most effective when incorporated in the set-in-order component of the 5s system, but can also be used individually.

The port used the workplace organization tools in the initial phases of lean implementation at all major divisions. McDuffie implemented the 5s system in the maintenance warehouse and electrical shop. The TRR applied 5s in the diesel shop and to the field trucks used by the maintenance-of-way track repair group. The Bulk Handling Facility utilized the 5s system in the maintenance shop. Both the Central Garage and Central Maintenance departments performed 5s kaizen events as their initial implementation efforts. A routine was established early on so that all workplace organization efforts at the port would be consistent. A 5s score sheet was developed to provide a standard for scoring the level of organization in each area. The same score sheet is used in rating the area before the initial 5s kaizen event, immediately after the kaizen event, and periodically thereafter. The 5s score sheet allows for a range of 0 (worst) to 100 (best) and gives each value stream manager a metric with which to manage in order to facilitate the sustainability of the workplace organization implementation.

As examples, the McDuffie electrical shop scored a zero on its initial 5s score, and scored a 70 at the end of the first 5s kaizen. The diesel shop at the TRR scored an 8 initially, and followed up with a 79 at the end of the kaizen. The Bulk Handling Facility's maintenance shop scored an 8 before applying the 5s system, and scored a 61 at the end of the kaizen event. These scores are typical because only the first 3 Ss are feasible to achieve on the short-term basis of a kaizen event. The last two Ss are long-term activities that take months to establish and scores should rise over time as efforts become standardized and sustained. Monthly audits are performed in each area and a new 5s score is issued.

The port has realized many benefits of workplace organization beyond the measurable gains of the 5s scores. All of the areas have experienced valuable gains in floor space utilization, improved lighting, and better visibility of spare parts. Consequently, it takes less time to perform repairs and other critical work vital to keeping the port's operations going. Finally, the visual effects of workplace organization have resulted in improved morale and give the facilities an impressive appearance as a world class seaport. The success of the initial workplace organization efforts created excitement at the port and the momentum spread quickly in the form of employees taking the initiative of performing internal 5s kaizen events at McDuffie in the fabrication shop and the TRR break room and yard office. This evidence of internal ownership exhibits signs of the continuous improvement culture needed for a Lean Enterprise to prosper. Before and after examples of 5s application is shown in Figure 7.3.

Figure 7.3 Before and after pictures of workplace organization at the Port.

7.2.3.3. Workplace Analysis Tools

Once a solid foundation of workplace organization is developed, specific process problems often become more obvious. The workplace analysis tools of the Lean Enterprise model for seaports provide methods for analyzing processes and identifying opportunities to abolish waste by reducing unnecessary activities. Tools for workplace analysis include layout improvement, Single-Minute-Exchange-of-Dies (SMED) principles, and standardized work.

Layout Analysis. While much of the equipment at the port is large and not moveable, there were several approaches that were applicable to layout improvement. One example of layout improvement is the Central Garage, a support division that performs maintenance activities on all rolling stock vehicles and equipment. A major activity performed at the garage is the maintenance of tires, including mounting and balancing. At the beginning of the kaizen event, the tire balancing machine was located at the opposite end of the garage from the mounting equipment, approximately 144 feet away. This resulted in the mechanics having to roll each tire being serviced (an average of 16 tires per day). A countermeasure implemented during the kaizen involved a redesign of the tire work area, relocating and hooking up the balancing machine next to the mounting machine so that tires could go immediately to the next step without being transported. The result of this was the reduction of over a half mile of travel each day, equating to over an hour of time, 365 hours per year or 6.5 man/weeks. This time savings could then be directly invested back into performing more value-added activities.

SMED Principles. Single Minute exchange of Die, or SMED, can be used to analyze activities within a process. This analysis can be performed using the principles of SMED which is to evaluate the activities that the piece of equipment must be a critical part of (internal) and those activities that take place outside of the machine (external). Without the application of SMED principles, these activities often are intermingled and result in inefficiency.

A SMED analysis of the barge loading process at the BMHP revealed many steps could be performed as external activities in parallel with the arrival of empty barges. A checklist was developed so that these activities could consistently be performed externally, as opposed to waiting until the empty barge arrives, allowing for faster loading time between the arrivals of empty barges.

Standardized Work. The final tool in workplace analysis is to document the improved process in a medium that can be used to train personnel effectively. This involves the development of standardized work, or standard operating procedures (SOPs). The Port had very little documentation of processes. SOPs have been implemented in numerous areas to both provide an institutionalization of knowledge, as well as to provide simple, visual, and effective training for personnel taking on new roles. SOPs were developed for all key operations at McDuffie including the unloading and loading of barges and ships, and the loading and dumping of train cars. The TRR has utilized SOPs in key areas as well, including all roles on the train crew, maintenance crews, and the yard office. Many other divisions, such as the BMHP, Central Garage, Central Maintenance, medical services, and human resources have identified the need to develop SOPs on their value stream plans.

Benefits of workplace analysis tools are often very obvious but difficult to measure. However, the port has experienced many measurable results from implementing and following SOPs. Table 7.5 demonstrates a sample of beneficial results at various operations at the port.

TABLE 7.5 Summary of SOP kaizen results at the Port.

Process	Metric Before	Metric After	% improvement
Barge Loading	**1 hr, 59 min** (avg. of month prior to kaizen)	**53 min** (measured 3 barges following SOP)	**125%**
Ship Unloading	**28000 Tons/day** (avg. of month prior to kaizen)	**35245 Tons/day** (measured following SOP at end of kaizen)	**26%**
Barge Unloading	**1 hr, 42 min**	**60 min**	**70%**
Ship Loading	**25000 Tons/day**	**36000 Tons/day**	**44%**
Train Car Dumping	Avg. Time to dump/train = **over 8 hrs**	Avg. Time to dump/train **= 4 hrs**	**100%**

7.2.3.4. Workplace Optimization Tools

The upper layer of the Lean Enterprise implementation model for seaports consists of tools to optimize processes that have already been organized and analyzed. These Lean tools are quality-at-the-source and total productive maintenance (TPM).

Quality at the Source. Quality-at-the-source describes the concept of being proactive about quality issues by having processes in place to catch the defects as they happen, or prevent them from happening at all [5]. The causes of quality problems can often be allocated into one of several categories. First, mistakes have the potential to occur due to a lack of, or inadequate, training of the operator. The port has taken strides to address this cause with a training development plan and the creation of visually documented SOPs for key operations.

Second, mistakes have the potential to occur if hiring or promotion practices do not allow for the people with appropriate knowledge, skills and abilities (KSAs) to perform a job to be placed in that job. In addition to Toyota's 7 deadly wastes, implementation of Lean concepts in the U.S. has resulted in the addition of an 8^{th} waste—not utilizing people's KSAs [3]. The Terminal Railroad held a kaizen event to determine critical KSAs relative to jobs for which they most frequently hire, such as carmen and train crew. After appropriate KSAs were identified, pre-employment tests were developed by the kaizen team to increase the likelihood of hiring individuals that possess those KSAs.

Finally, mistakes can also occur due to process problems. The Japanese concept of poka yoke, or mistake-proofing, provides inexpensive techniques to increase quality levels by mistake-proofing the process [6]. The ship unloading process at the BMHP loses an average of 2 hours per day because of downtime to replace hopper liners due to wear. A recent kaizen event at the BMHP yielded a design of a relatively inexpensive hydraulic-actuated system to adjust liner height, along with a move to vulcanizing conveyor belt splices instead of the current method of using metal fasteners, which cause the majority of liner wear. These improvements not only reduce wear but also mistake-proof the process because liner wear results in coal spillage. These improvements are projected to save almost 2 hours of capacity time per day at the BMHP, allowing the unloading of between 4-5 additional ships annually.

Total Productive Maintenance. For any port, the equipment that is necessary to perform the loading and unloading of materials and cargo is the lifeblood of the operation. Prior to Lean Enterprise implementation, equipment maintenance was mostly performed on a reactive basis after breakdowns occurred. Any preventative or predictive maintenance that was performed at the port was sporadic and inconsistent. The need to be proactive in the care of equipment was identified as a priority, and a systematic implementation of a TPM program began in the fourth year of Lean implementation at the port. TPM is a system of productive equipment maintenance performed on a company-wide basis involving all employees [7].

Similar to the rollout of the Lean program in general, the rollout of TPM began at McDuffie. UAHuntsville team trained all McDuffie employees in a 2 hour overview of TPM. Because no previous maintenance system or history existed, a paper work order system was then developed to manage maintenance activities. A kaizen event was held to develop critical spare parts lists for each of McDuffie's major pieces of equipment, reducing long periods of downtime due to waiting for ordered replacement parts to arrive. After getting personnel used to tracking maintenance activities with the paper system, a move was then made to utilize existing computerized maintenance management software (CMMS) system to help manage the system. McDuffie has recently invested in dedicated personnel to help facilitate the expansion of their TPM program. At present, McDuffie has a few items entered into the CMMS that are generating proactive maintenance work orders and are in the process of collecting and adding data to encompass more of their maintenance activities in the CMMS. Like

McDuffie, the BMHP had no existing proactive maintenance efforts. While only recently beginning improvements to equipment maintenance, the BMHP has already identified benefits to streamlining in that area.

The ultimate goal of TPM of zero unplanned downtime is far from being reached at the port, but steady improvement has been evident. A fully implemented TPM program can result in a 60% reduction in unplanned equipment downtime, an 80% reduction in breakdown cost, and a 30% reduction in spare part cost [3].

7.2.4. Lean Enterprise in the Office and Support Functions

Many companies have made great strides in implementing Lean and eliminating waste from the operations side of their business. However, an organization cannot be a true Lean Enterprise without also focusing on eliminating waste from the support functions that are in place to support (*15*). In the fourth year of Lean Enterprise implementation at the port, 13 training courses were held for all corporate administrative and support personnel (over 100 employees) on the topic of Lean Office. Seven value stream maps have been developed for administrative or support functions including Purchasing/Accounts Payable, Payroll, Central Garage, Central Maintenance, Medical Services, Harbor Master, and Human Resources. Additional Lean tools are scheduled to continue to be implemented in the administrative and support functions based on their respective value stream plans in an effort to eliminate waste at all levels of the port's organization.

7.2.5. Conclusion

The philosophy of Lean Enterprise can be successfully applied at seaports to address capacity issues relative to growth. The objective of Lean is to identify and eliminate non-value-waste in order to be more responsive to customers. A modified implementation model of Lean tools was developed specifically for seaports and deployed at the Port of Mobile. The port has experienced positive results that can directly provide additional capacity, including the ability to handle more revenue railcars (30% increase) and a reduction in barge loading times (125% improvement), barge unloading times (70% improvement), ship unloading times (26% improvement), ship loading times (44% improvement), and train car dumping times (100% improvement). A summary of the Lean activities at the port is shown in Table 7.3.

A systematic application of Lean Enterprise is imperative to achieving successful results in any arena. Lean should be integrated into the organization's business strategy, investment in training should be made at all levels, and critical value streams should be identified and managed. Lean tools should be implemented in phases via the kaizen process, choosing a highly visible pilot area and then spreading across the entire organization. The port has used this approach in their endeavor of becoming a Lean Enterprise seaport.

Lean Enterprise transformation is a journey, not a destination. The port has been implementing Lean for almost 5 years. While implementation has reached the majority of divisions at the port, opportunities for improvement still exist. As performance improves, it can be expected that customer demand and growth will continue to increase. Continuous improvement through investing in employees and focusing on establishing mature lean tools at the workplace optimization level is necessary to eliminate waste to accommodate this demand.

A paper written to validate several of the Lean implementation efforts at the port through simulation was published in the *2008 Transportation Research Record,* the journal of the Transportation Research Board [8].

Table 7.6 Summary of Continuous Improvement Activities at ASPA

• Alabama State Port Authority in General
o Strategically chose priorities for implementation per division o Established Lean Steering Committees at McDuffie Coal Terminal and the Terminal Railroad; these steering committees initially held meetings facilitated by UAH and the meetings were used to choose project areas and schedule improvement events; ASPA then began holding these meeting internally o Internal kaizen facilitators chosen by ASPA (2 from McDuffie, 2 from Terminal Railroad, 2 from Bulk Handling Plant) and participated in Kaizen Facilitator training o ASPA purchased their own Lean Concepts training kit in order to deliver additional training internally
• McDuffie Coal Terminal
o Initial Lean Enterprise Certificate Series for key management o Value Stream Mapping event o Establishment of Lean Steering committee o Over 20 kaizen events over 4 years on all major processes including barge loading, barge unloading, ship loading, ship unloading, train car loading and dumping, dozer pushing, and follow-up events on each area; 5S kaizen events in the warehouse and garage shop, and electrical shop; o Results- many of the kaizens resulted in capturing previously undocumented procedures for key processes, which improves training and reduces errors; some kaizen events yielded productivity improvements (50% reduction in barge loading time, 20% tonnage increase in ship unloading per day); however, many of the improvements haven't been realized to their fullest potential due to management not measuring key metrics to drive sustainment o Trained all employees in Total Productive Maintenance o Implemented manual PM activities (hand written work orders) o Implemented a Computerized Maintenance Management System (CMMS); McDuffie added two data clerks to input maintenance data to begin usage of the system

- Terminal Railroad
  - Trained all employees in Lean Concepts
  - Established steering committee to manage lean efforts
  - Value Stream Map was created and was initially managed well
  - 5s kaizen events in the diesel shop and the Maintenance of Way trucks generated much excitement had the results have been sustained well;
  - Standardized Work kaizen events on all areas- yard office, train crew, maintenance of way, Carmen, hiring/training procedures; these events each yielded great success and document procedures that have improved training and reduced the learning curve of new hires
  - Dramatic increase in volume of cars to be handles at the Terminal Railroad resulted in a loss of focus on lean activities in 2008 and all efforts seem to be put on hold
- Bulk Material Handling Plant
  - Trained all employees in Lean Concepts
  - 5s Maintenance shop kaizen
  - Barge loading kaizen event- resulting in various alternatives to reduce barge changeover time; limited follow-up on these alternatives
  - Ship unloading kaizen event- uncovered many issues related to conveyor belt capacity that are currently being worked on; resulted in proposal for alternative staffing at the Bulk Plant (no action has been taken by management on this)
  - Foreman/Supervisor Standard Operating procedure kaizen event
- Corporate Office
  - Trained all employees in Lean Office
  - Value Stream Maps
    - Purchasing/Accounts Payable
    - Payroll
    - Accounts Receivable
    - Human Resources
- General Cargo
  - Trained all employees in Lean Office
  - Value Stream map on GCI activities (break-bulk and containers)
- Central Maintenance
  - Trained all employees in Lean Concepts
  - Value Stream Map- very successful event; implementation plan includes projects for 5s and developing a worker order request system and improved visibility of work order status
  - 5s event- 5s event in one area of shop, generated excitement with plans to spread 5s to the electrical and welding shops as well as service trucks
- Central Garage
  - Trained all employees in Lean Concepts
  - Value Stream Map- has been managed to well by the division manager
  - 5s kaizen event- great immediate success, sustainment has been excellent 8 months later;
- Technical Services
  - Trained all employees in Lean Office
  - Value Stream Maps for activities involving the Harbor Master and Health Services

Appendix – 7.0 – References

7.1 Continuous Improvement in Logistics and Transportation System

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7.3. Continuous Improvement at the Port of Mobile

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8. Bridging the Data and Information Gap – A Repository for Transportation Related Data

The Office for Freight, Logistics, & Transportation (OFLT) at UAHuntsville developed the OFLT Online Information Warehouse in 2007 to manage transportation data used in research and to provide public access to research presentations and publications from the research team. The goal of this Online Information Warehouse was to facilitate the effective and efficient retrieval of data and information pertinent to the research process to UAHuntsville personnel and external researchers. As part of the 2007-2008 research, OFLT revised the Online Information Warehouse and made it accessible through the UAH College of Business Administration Research Centers website. The move from its original website will increase its exposure not only to UAH personnel and research staff but to outside researchers who visit the College of Business website.

The first step in developing the online information warehouse was to establish the boundaries of the project. OFLT determined the main categories for the project should follow the P-I-E interrelationship model (Population, Infrastructure, and Economic activity) presented in the 2005 report to the U.S. Department of Transportation entitled "*Transportation Infrastructure in Alabama – Meeting the Needs for Economic Growth.*" After establishing the categories, OFLT researchers began populating the warehouse with transportation related data, publications, reports, and presentations used and developed from transportation research at UAHuntsville.

8.1. OFLT Online Information Warehouse – Original Website

The original Online Information Warehouse website consisted of four pages. The first page displayed population, infrastructure, and economic data, while the second page displayed presentations, publications, and reports. Both pages contained a brief explanation of its contents and a list feature. The third and fourth pages provided a search feature for the population, infrastructure, and economic data and the presentations, publications and reports. Figures 8.1 – 8.4 show screen shots of the original Online Information Warehouse website.

8.2. OFLT Online Information Warehouse – Revised Website

The revised Online Information Warehouse is accessible through the UAH College of Business Administration Research Centers website (http://www.uahcmer.com/). From the home page the user accesses the Office for Freight, Logistics & Transportation Page (http://www.uahcmer.com/data_search/oflt). Figure 8.5 shows the homepage of the research centers website. From this page users can link to the Office for Freight, Logistics, & Transportation page, shown in Figure 8.6. On the OFLT homepage, a description of the online information warehouse is provided as well as a link to the main page. A search feature for locating presentations, publications, and reports written or developed by UAHuntsville researchers is also located on OFLT's homepage. Figure 8.7 displays an example of the search results.

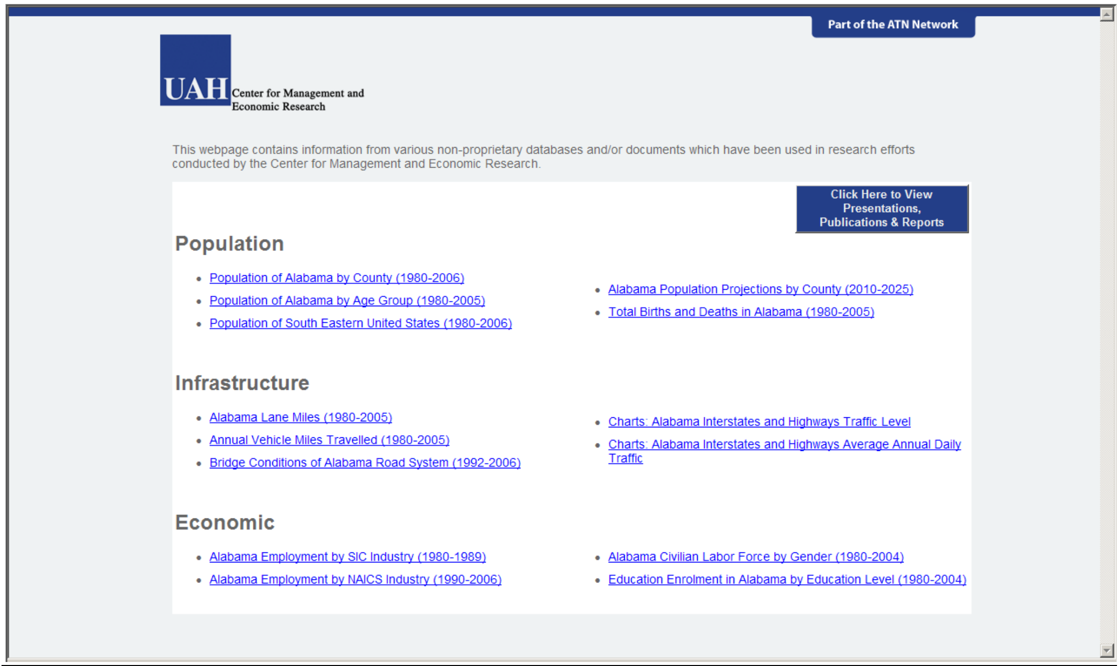

Figure 8.1 Population, Infrastructure, and Economic Activity (P-I-E) Webpage.

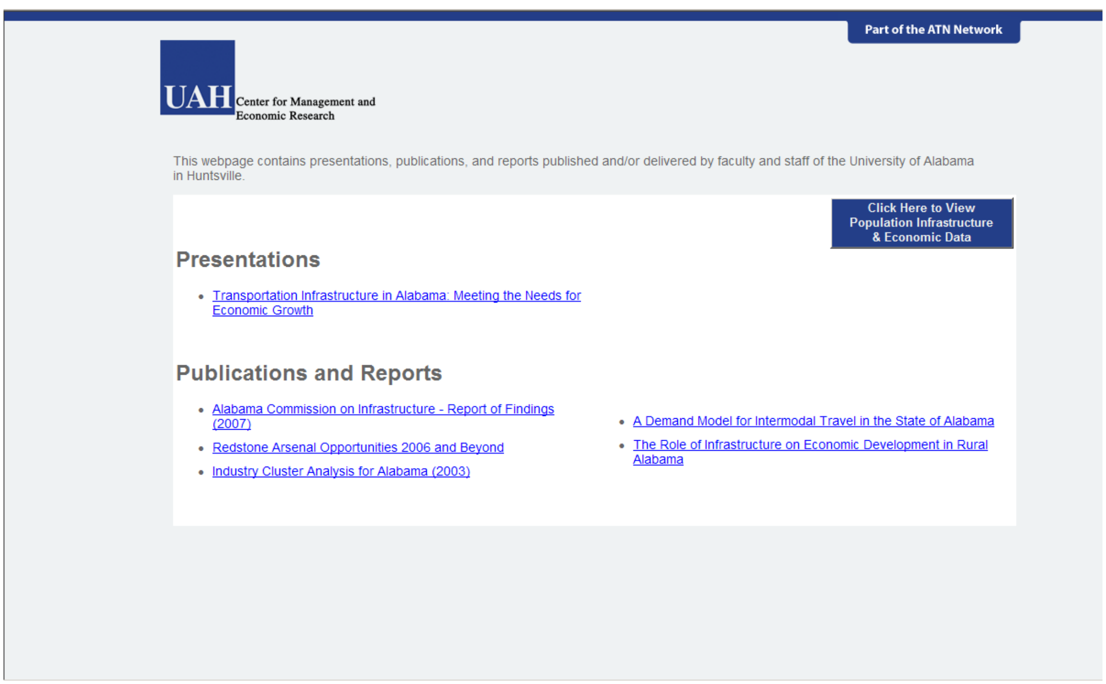

Figure 8.2 Presentations, Publications, and Reports Webpage.

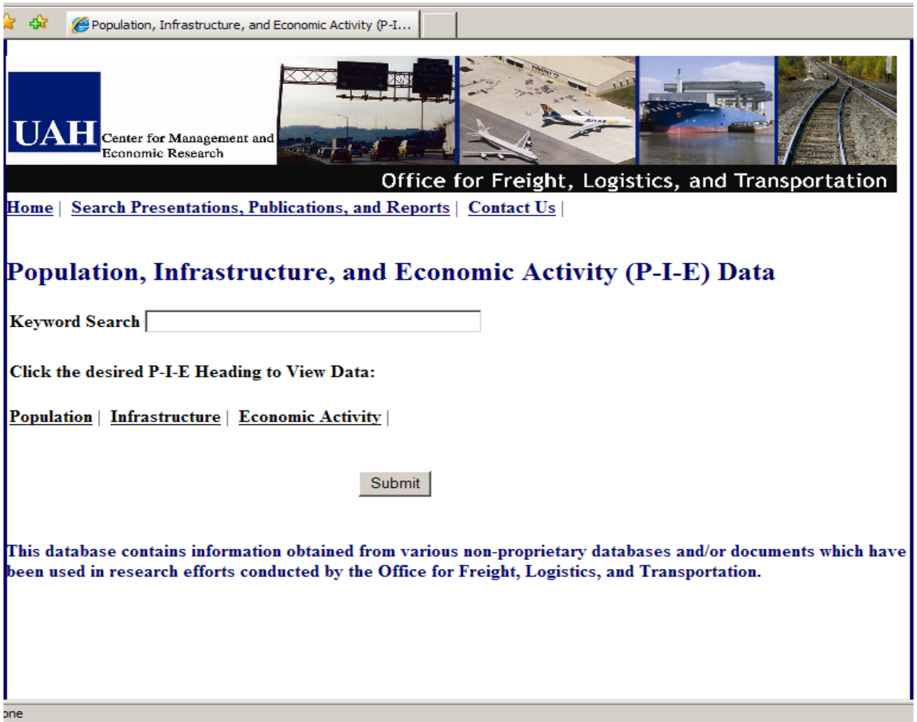

Figure 8.3 Population, Infrastructure, and Economic Activity Search Webpage.

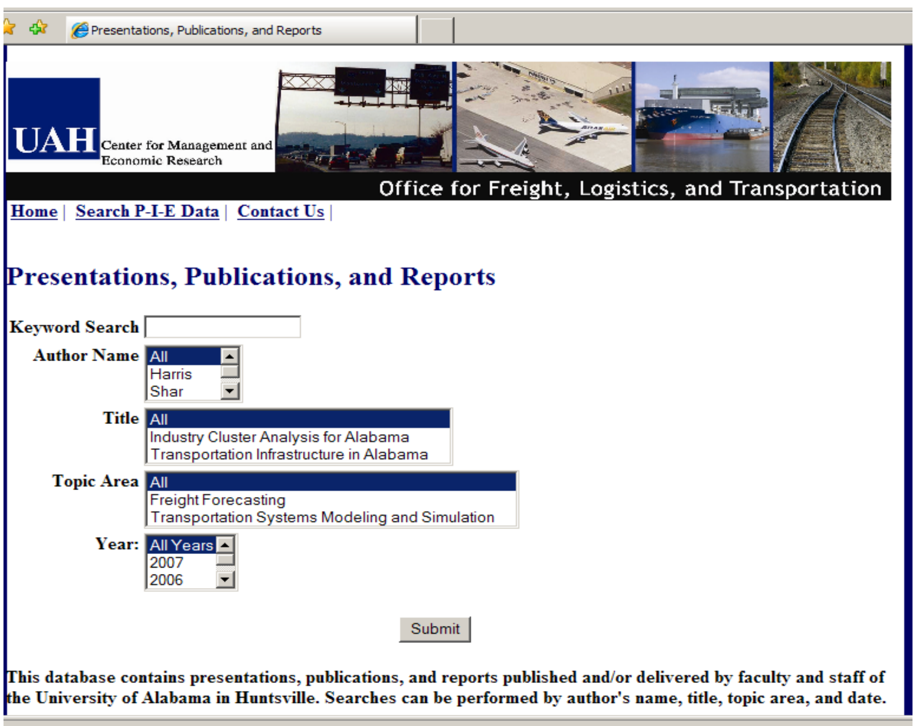

Figure 8.4 Presentations, Publications, and Reports Search Webpage.

Figure 8.5 College of Business Administration Research Centers Website.

Figure 8.6 Office for Freight, Logistics & Transportation Homepage.

The online information warehouse main page shows the headings for the categories established for the original website: Population, Infrastructure, Economic Activity, Presentations, and Publications and Reports. Under each heading is a list of all the available data for a particular category. Figure 8.8 shows the main page of the OFLT Online Information Warehouse.

Figure 8.7 Presentations, Publications, and Reports Search Results.

OFLT Online Information Warehouse

Population Data
- Population of Alabama by County (1980-2006)
- Population of Alabama by Age Group (1980-2006)
- Alabama Population Projections by County (2010-2025)
- Total Births and Deaths in Alabama (1980-2005)

Infrastructure Data
- Alabama Lane Mines (1980-2005)
- Alabama Vehicle Miles Travelled (1980-2005)
- Bridge Conditions of Alabama Road Systems (1982-2006)
- Charts: Interstate 65 (1980-2005)
- Charts: Interstate 59
- Charts: Interstate 20
- Charts: Interstate 10

Economic Data
- Alabama Civilian Labor Force by Gender (1980-2004)
- Education Enrollment in Alabama by Education Level (1980-2005)

Presentations
- Transportation Infrastructure in Alabama: Meeting the Needs for Economic Growth (2005)

Publications and Reports
- Transportation Infrastructure in Alabama:Bridging to the Future (2006)
- Redstone Opportunities 2006 and Beyond
- Alabama Cluster Report (2003)
- A Demand Model for Intermodal Travel in the State of Alabama
- The Role of Infrastructure on Economic Development in Rural Alabama

Figure 8.8 OFLT Online Information Warehouse Main Page.

8.3. OFLT Online Information Warehouse - Sample Data

The online information warehouse contains three types of data sets: population related data, infrastructure related data, and economic related data.

Population related data was obtained from the US Census Bureau, population division. The population division provides annual population estimates at the national, state, and local level, and conducts a population census each decade. An example of the population related data that can be found in the online information warehouse can be seen in Figure 8.9. This figure contains total population data from 1980 – 2006 for counties in Alabama.

Population of Alabama by County 1980 - 2006							
	Census 1980	1985	Census 1990	1995	Census 2000	2005	2006
United States	226,545,805	237,923,795	248,790,925	262,803,276	281,421,906	296,507,061	299,398,484
Alabama	3,893,888	3,972,523	4,040,389	4,262,731	4,447,100	4,548,327	4,599,030
Autauga	32,259	32,245	34,222	39,112	43,671	48,454	49,730
Baldwin	78,556	89,401	98,280	120,896	140,415	162,749	169,162
Barbour	24,756	25,002	25,417	27,854	29,038	28,291	28,171
Bibb	15,723	16,157	16,598	18,507	20,826	21,454	21,482
Blount	36,459	37,417	39,248	44,060	51,024	55,572	56,436
Bullock	10,596	10,777	11,042	11,431	11,714	11,011	10,906
Butler	21,680	22,427	21,892	21,824	21,399	20,642	20,520
Calhoun	119,761	118,644	116,032	116,790	112,249	112,242	112,903
Chambers	39,191	38,614	36,876	37,179	36,583	35,373	35,176
Cherokee	18,760	18,890	19,543	21,871	23,988	24,592	24,863
Chilton	30,612	31,560	32,458	35,537	39,593	41,648	41,953
Choctaw	16,839	16,710	16,018	16,195	15,922	14,727	14,656
Clarke	27,702	27,419	27,240	27,455	27,867	27,082	27,248
Clay	13,703	13,700	13,252	13,590	14,254	13,920	13,829
Cleburne	12,595	12,659	12,730	13,080	14,123	14,521	14,700
Coffee	38,533	40,386	40,240	43,174	43,615	45,448	46,027
Colbert	54,519	52,858	51,666	53,702	54,984	54,597	54,766
Conecuh	15,884	15,029	14,054	14,322	14,089	13,227	13,403
Coosa	11,377	11,033	11,063	11,952	12,202	11,133	11,044
Covington	36,850	37,152	36,478	37,489	37,631	36,969	37,234
Crenshaw	14,110	13,899	13,635	13,585	13,665	13,598	13,719
Cullman	61,642	65,039	67,613	73,037	77,483	79,747	80,187
Source: U.S Census Bureau, Population Division							

Figure 8.9 Population of Alabama by County 1980 – 2006.

Infrastructure related data found in the online information warehouse was gathered from the US Department of Transportation, Federal Highway Administration, The Bureau of Transportation Statistics, The Army Corps of Engineers, and The Alabama Department of Transportation. The information under this heading includes data such as vehicle miles traveled, Alabama lane miles, and traffic count charts for Alabama interstates.

The following figures are examples of infrastructure related data. Figure 8.10 displays Alabama lane miles between 1980 and 2005. Figure 8.11 illustrates the annual average daily traffic by mile marker on Interstate 65 for 1985 – 2004.

Alabama: Lane Miles 1980-2005		
	Interstate Lane Miles	**Total Lane Miles**
1980	3,250	180,870
1985	3,654	181,485
1990	3,775	187,597
1995	3,854	193,124
2000	3,873	195,298
2001	3,875	195,652
2002	3,889	195,680
2003	3,890	195,683
2004	3,894	197,892
2005	3,930	199,093
Source: U.S. Department of Transportation, Federal Highway Administration Highway Statistics		

Figure 8.10 Alabama Lane Miles 1980 – 2005.

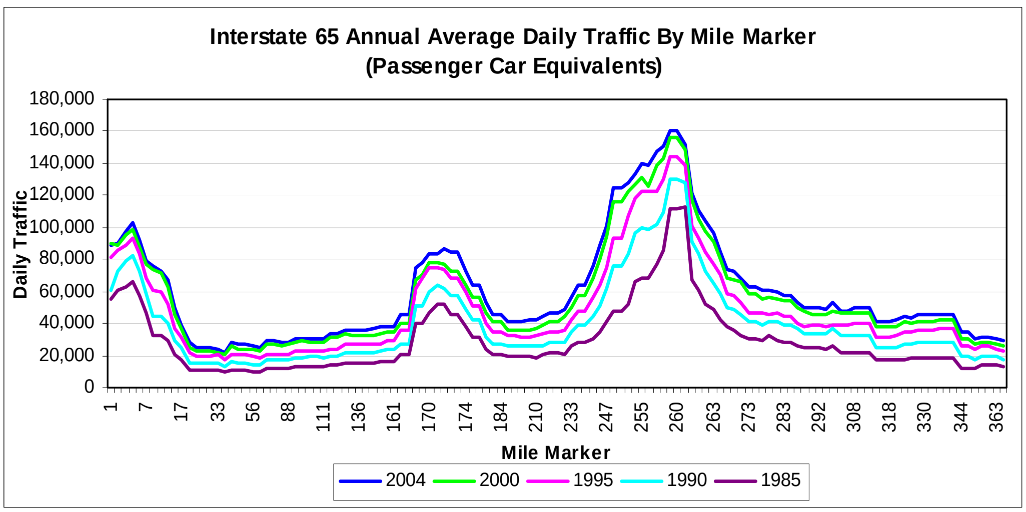

Figure 8.11 Annual Average Daily Traffic Interstate 65, 1985 – 2004.

Economic related data currently found in the online information warehouse includes Industry employment data, Alabama labor force charts, as well as Alabama School Enrollment data. Economic data was obtained from the Bureau of Economic Analysis, the Bureau of Labor Statistics, the Alabama Department of Industrial Relations, and the National Center for Education Statistics. Examples of the economic related data that can be found in the online information warehouse can be seen in Figures 8.12 and 8.13. Figure 8.12 contains data on Alabama's civilian labor force by gender for the years 1980 to 2004. Figure 8.13 shows the total enrollment for Alabama's elementary, secondary, and post-secondary schools between 1980 and 2005.

Alabama: Civilian Labor Force by Gender 1980-2004							
	Men in Civilian Labor Force				Women in Civilian Labor Force		
Year	Employed	Unemployed	Total		Employed	Unemployed	Total
1980	882	72	954		616	71	687
1981	855	91	946		632	87	719
1982	834	136	970		632	111	743
1983	858	136	994		663	104	767
1984	911	99	1,010		683	101	784
1985	927	84	1,011		716	76	792
1986	927	94	1,021		771	91	862
1987	972	73	1,045		774	74	848
1988	983	66	1,049		768	70	838
1989	993	64	1,057		780	70	850
1990	986	66	1,052		775	64	839
1991	975	72	1,047		794	67	861
1992	995	69	1,064		822	76	898
1993	1,012	79	1,091		833	73	906
1994	1,043	51	1,094		870	70	940
1995	1,034	71	1,105		898	58	956
1996	1,047	54	1,101		938	54	992
1997	1,116	51	1,167		948	59	1,007
1998	1,119	40	1,159		943	51	994
1999	1,088	51	1,139		955	51	1,006
2000	1,074	50	1,124		981	49	1,030
2001	1,069	59	1,128		964	56	1,020
2002	1,040	63	1,103		938	61	999
2003	1,064	60	1,124		958	64	1,022
2004	1,096	61	1,157		957	66	1,023
Source: Bureau of Labor Statistics, Current Population Survey							

Figure 8.12 Alabama Civilian Labor Force by Gender 1980 – 2004

Alabama: Enrollment by Education Level 1980-2005							
	1980	1985	1990	1995	2000	2004	2005
Elementary	492,176	463,766	473,030	470,246	472,686	466,920	466,164
Secondary	230,968	213,099	194,709	206,840	201,358	205,907	212,414
Post Secondary	328,612	358,686	437,178	451,224	467,924	511,652	
Source: National Center for Education Statistics (NCES)							

Figure 8.13 Alabama Enrollment by Education Level 1980 – 2005.

Publications, presentations, and reports are listed on the Online Information Warehouse main page and can also be found using a keyword search located on the Office for Freight, Logistics, and Transportation home page. The keyword search allows the user to search presentations, publications or reports independently. An advanced search option is available and allows users to search by research center, author, topic, and year. Figure 8.14 is a screenshot of the advanced search option page.

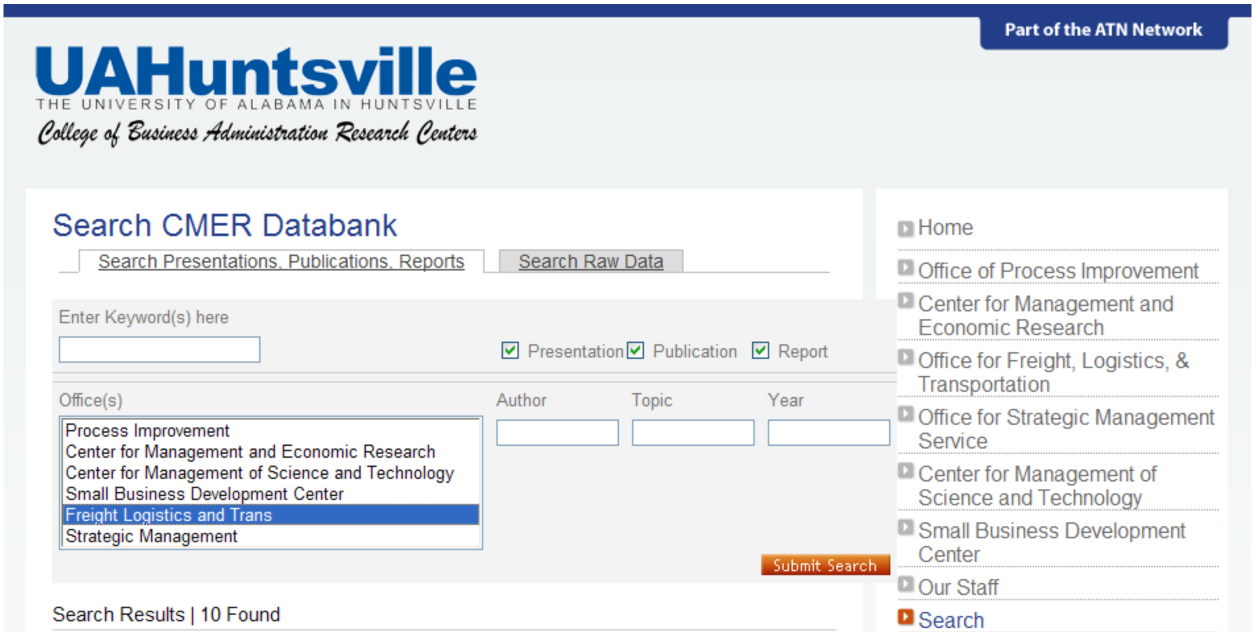

Figure 8.14 Advanced Search Option.

8.4. Conclusion

Access to data gathered by the OFLT research team, presentations, publications, and reports is pertinent to the research process. The Online Information Warehouse provides a benefit to UAH researchers, many of whom work on multiple contracts that utilize data sets developed during previous projects and allowing researchers to find the data, information, reports and presentations used and developed from previous transportation research at UAH.

9. Student Research Initiatives

Doctoral and Masters Students bring fresh ideas and concepts to research. The research performed during this period of performance provided several opportunities for students to not only participate, but take lead positions in performing and managing the projects. These student research initiatives have the potential to encourage the development of new ideas that can be expanded into further research efforts in the coming years. Three student research projects are listed below. Each of the projects has either been published in conference proceedings or they are in the process of being submitted for publication. Other than formatting of report section titles, no changes have been made to the submitted student research presented here.

9.1. A Methodology to Use FAF2 Data to Forecast Statewide External-External Trips

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This research was presented at the Tools of the Trade Conference of the Transportation Research Board in Portland, OR, 2008. The paper was published as part of the proceedings and was awarded one of the Best Paper identifications.

9.1.1. Abstract

Simulating freight activity in a statewide model requires the development of an origin/destination matrix containing internal-internal trips, internal-external and external-internal trips, and external-external trips. The external-external trips are often difficult to obtain as data for these trips cannot be surveyed through traditional travel surveying techniques. This paper presents a methodology to use the Freight Analysis Framework Version 2 Database (FAF2) to determine the volume of pass through freight for a statewide transportation model in either tons of freight or value of freight. The

methodology is presented using a statewide case study, but is applicable to any region from the database. The paper concludes that the ability to obtain accurate pass-through freight data from a federal database for use in transportation modeling is vital to successful planning.

9.1.2. Introduction

The efficient and effective movement of freight is a critical component in the transformation and growth of the economy. The ability to predict freight transportation requirements is vital to planning the necessary infrastructure improvements that can ensure congestion along a state's highways does not lead to a reduction in economic development (1). Transportation models must include predictions of freight movements. The freight predictions include those internal to the study area, those that either are attracted to or originate from the study area and those external to the study area that are a result of the freight passing through. The trips that have either the origination or destination in the study area are easier to model because the industries or retail outlets responsible for the freight activity are located in the study area and can be surveyed to determine the volume of freight flows produced or attracted. The freight trips that are external to the study are more difficult to model because the planner is not able to survey industries or retail outlets that produce or attract the freight. The difficulty with obtaining this critical data has been identified in research performed on other statewide models and guides that indicate a trip exchange table for external-external freight transportation is necessary, but no clear guidance is provided to develop the trip table (2).

The goal of this paper is to present a methodology for the development of a forecast of statewide external-external values for use in modeling. The methodology uses a federally developed freight database and is intended to be applied at the state, or major regional level (those included in the federal database) (3). This paper presents a review of the database, then a systematic methodology to extract the external-external values, by commodity and mode, for use in transportation modeling. Finally, the paper presents a pilot application of the methodology using the state of Alabama as the case study. The paper concludes that correct application of this methodology can develop external-external origin/destination tables that can be incorporated, and add significant value, into statewide or major regional transportation models.

9.1.3. Data

The accuracy of any modeling activity is based on the quality of data entered into the process. For freight applications, the best data that is currently available is the Federal Highway Administration's Freight Analysis Framework (FAF) database. The second generation of the Freight Analysis Framework (FAF) known as FAF2 is a continuation of the original Freight Analysis Framework developed by the U.S. Department of Transportation, Federal Highway Administration (FHWA) (4). Whereas the original FAF provided the public with generalized freight movement and highway congestion maps without disclosing the underlying data, FAF2 provides a commodity flow origin-destination (O-D) and freight movement data on all highways within the FAF2 highway network. The FAF2 Commodity Origin-Destination Database estimates tonnage and value of goods shipped by type of commodity (see Table 1) and mode of transportation (see Table 2) for 114 FAF2 zones (shown in Figure 1), 7 international trading regions and 17 additional international gateways, (3). The 2002 estimate is primarily derived from the Commodity Flow Survey (CFS) with some of the data voids in the CFS filled in by analysis of the Economic Census and other data sources. Forecasts are included for 2010 to 2035 in 5-year increments (3). The data are available in Microsoft Access format and contain values in millions of dollars of value and thousands of short tons.

TABLE 1 Listing of commodities on FAF2 database (5).

BTS/Census Full Commodity Name	FAF Abbreviation
Live animals and live fish	Live animals/fish
Cereal grains	Cereal grains
Other agricultural products	Other ag prods.
Animal feed and products of animal origin, n.e.c.1	Animal feed
Meat, fish, seafood, and their preparations	Meat/seafood
Milled grain products and preparations, bakery products	Milled grain prods.
Other prepared foodstuffs and fats and oils	Other foodstuffs
Alcoholic beverages	Alcoholic beverages
Tobacco products	Tobacco prods.
Monumental or building stone	Building stone
Natural sands	Natural sands
Gravel and crushed stone	Gravel
Nonmetallic minerals n.e.c.1	Nonmetallic minerals
Metallic ores and concentrates	Metallic ores
Coal	Coal
Crude Petroleum	Crude petroleum
Gasoline and aviation turbine fuel	Gasoline
Fuel oils	Fuel oils
Coal and petroleum products, n.e.c.1 (Note: primarily natural gas, selected coal products, and products of petroleum refining, excluding gasoline, aviation fuel, and fuel oil.)	Coal-n.e.c.1
Basic chemicals	Basic chemicals
Pharmaceutical products	Pharmaceuticals
Fertilizers	Fertilizers
Chemical products and preparations, n.e.c.1	Chemical prods.

Plastics and rubber	Plastics/rubber
Logs and other wood in the rough	Logs
Wood products	Wood prods.
Pulp, newsprint, paper, and paperboard	Newsprint/paper
Paper or paperboard articles	Paper articles
Printed products	Printed prods.
Textiles, leather, and articles of textiles or leather	Textiles/leather
Nonmetallic mineral products	Nonmetal min. prods.
Base metal in primary or semi-finished forms and in finished basic shapes	Base metals
Articles of base metal	Articles-base metal
Machinery	Machinery
Electronic and other electrical equipment and components and office equipment	Electronics
Motorized and other vehicles (including parts)	Motorized vehicles
Transportation equipment, n.e.c.1	Transport equip.
Precision instruments and apparatus	Precision instruments
Furniture, mattresses and mattress supports, lamps, lighting fittings	Furniture
Miscellaneous manufactured products	Misc. mfg. prods.
Waste and scrap	Waste/scrap
Mixed freight	Mixed freight
Commodity unknown	Unknown

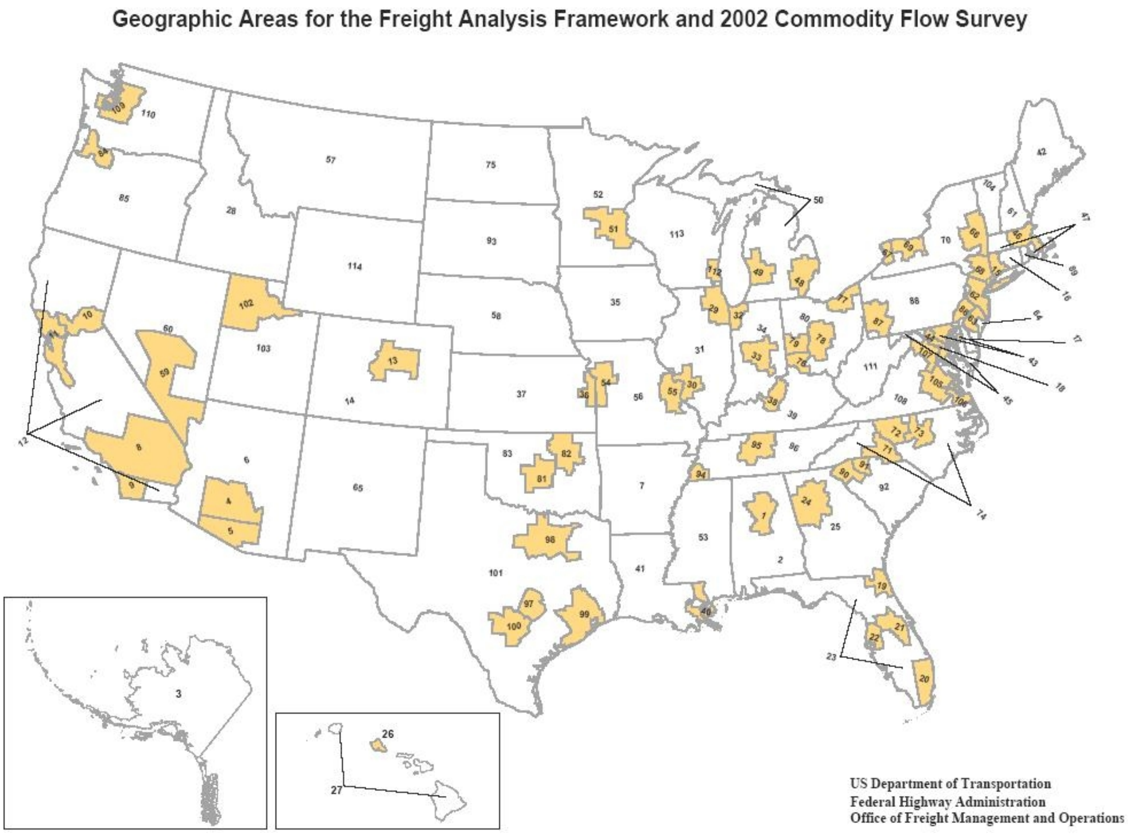

FIGURE 1 Geographic locations for FAF2 data (6).

TABLE 2 Listing of Transportation Modes from FAF2 (6).

Truck. Includes private and for-hire truck. Private trucks are operated by a temporary or permanent employee of an establishment or the buyer/receiver of the shipment. For-hire trucks carry freight for a fee collected from the shipper, recipient of the shipment, or an arranger of the transportation.
Rail. Any common carrier or private railroad.
Water. Includes shallow draft, deep draft and Great Lakes shipments. FAF2 uses definitions by the U.S. Army Corps of Engineers. Shallow draft includes barges, ships, or ferries operating primarily on rivers and canals; in harbors; the Saint Lawrence Seaway; the Intra-coastal Waterway; the Inside Passage to Alaska; major bays and inlets; or in the ocean close to the shoreline. Deep draft includes barges, ships, or ferries operating primarily in the open ocean.
Air (includes truck-air). Includes shipments by air or a combination of truck and air. Commercial or private aircraft and all air service for shipments that typically weigh more than 100 pounds. Includes air freight and air express.
Truck-Rail Intermodal. Includes shipments by a combination of truck and rail.
Other Multiple Modes. Includes shipments typically weighing less than 100 pounds by Parcel, U.S. Postal Service, or Courier, as well as shipments of all sizes by truck-water, water-rail, and other intermodal combinations.
Pipeline and Unknown. Pipeline is included with unknown because region-to-region flows by pipeline are subject to large uncertainty.

9.1.4. Methodology

The methodology to develop the external-external table from the FAF2 database is comprised of the following steps:

1. Develop a national travel demand network that includes all 114 zones defined by the FAF2 database.
2. Perform a select link analysis technique in a commonly used travel demand model to determine which origin/destination pairs use roadways in the desired study area or state.
3. Extract the relevant data from the FAF2 database based on the O/D pairs obtained in step 2, either in dollar value of shipment or tons shipped,.
4. Use the O/D pairs and data in a travel forecasting model to determine external-external trips.

The steps listed above are explained in further detail in the following sections.

9.1.4.1. Task 1: Create a National Network

The national network is designed to provide a basis for using a travel demand software package to determine the external-external traffic flows. The creation of the network involves the development of zones and roadway infrastructure similar to what would be performed to develop a traditional urban planning model. Any travel demand software can be used to create the network and run the model.

The FAF2 data structure defining the 114 zones (see Figure 1) of freight origin and destination should serve as the base zone structure for the travel demand model network. To improve the analysis, a geographic file that contains the 114 regions can be downloaded from the FAF2 website (3). This geographic data is intended to be the starting point for the analysis.

The roadway network developed serves as the connection between the zones. The travel demand network should include roadway distances, travel speeds and capacities. To assist in the analysis, a geographic file containing transportation infrastructure is available for download from the FAF2 website (3).

9.1.4.2. Task 2: Perform Flow Analysis

After the national infrastructure network has been developed, a flow analysis is performed to determine the travel patterns and identify which O/D pairs utilize the roadways in the area or state of interest. This can be accomplished through various methods based upon the travel demand model being employed for the study. Traffic must be assigned from each zone independently and the path to the other 113 destination zones can be determined. The O/D pairs that use roadways in the area or state of interest can then be identified. The O/D pairs that use the roadways in the study area or state can then be used in the analysis.

9.1.4.3. Task 3: Run Computer Program to Extract Data

After the O/D pairs that traverse the area or state of interest are determined in task 2, the FAF2 database must be reduced to contain only data for the O/D pairs of interest. To assist this step, researchers at the University of Alabama in Huntsville, Office for Freight, Logistics and Transportation developed a computer program in C++ that allows the user to input the relevant O/D pairs in a text file. The program generates an external-external table for the area or state in either the value of shipment in dollars or tons shipped.

9.1.4.4. Task 4: Assign Data to National Network

Once the external-external data is developed, the user must assign the data to the national network. The assignment should be performed using the travel demand model and the user defined assignment procedure. This will allow for the analysis of external-external value of shipment or tons shipped to be assigned to the travel demand network. The assignment must be converted to the number of vehicles to be used for modeling purpose. The conversion factors for turning value of shipments or tons shipped into an accurate number of vehicles for each commodity and mode are critical to the freight planning process, and are of great concern, but is the subject for a future research paper.

The development of the external-external data and assignment can be accomplished by performing the steps of the methodology presented above. Planners can use the process described to create the data for the base level of freight traffic on the transportation facilities in their area of concern, whether local or statewide.

9.1.5. Case Study: Alabama

To demonstrate the application of the methodology, an analysis of the external-external data was performed for the state of Alabama. Included in the case study description is increased detail and documentation of specific steps when using TRANPLAN, which is the travel demand model used in Alabama.

9.1.5.1. Task 1: Create a National Network

The first task was the development of the national network. The FAF2 website provides a starting point by providing a national infrastructure. The infrastructure, in ArcGIS format, was downloaded and is shown in Figure 2. From this data, the Interstate routes were highlighted and used to create a national network to connect the zones defined in the FAF2 database (see Figure 3). The national network was developed using CUBE-TRANPLAN, the travel demand model currently being used in Alabama for transportation forecasting. The national network was comprised of 114 zones (as defined by the FAF2 regions), nodes to reflect intersections and links to serve as roadways. The roadway was manually developed and the nodes and links were drawn using a “heads-up” digitizing technique with the ArcGIS file serving as an image layer to ensure the roadways were spatially accurate. Attributes were applied to the network such as roadway distances, speed limits and capacities. However, as the use of the network was to determine shortest path between zones, flows were not constrained by capacity.

9.1.5.2. Task 2: Perform Flow Analysis

A variety of CUBE-TRANPLAN modules were used to develop the flow analysis and define the shortest path through the national network between zones. Initially, the network was input to the Highway Selected Summation module to determine the skims, or the shortest path between all 114 zones. Then, the skims were entered into a gravity distribution model, Gravity Model, with a fictitious production and attraction file. The production and attraction file was established with 100,000 productions and attractions for each zone – essentially a large value to ensure some trips would be distributed between each zone pair. Next, a fictitious assignment was performed to utilize the roadway network and place traffic on the roadways utilizing Load Highway Network. The assignment was performed using a shortest path methodology directing all traffic on to the shortest route, regardless of congestion. Finally, the Load Highway Selected Links module was used to extract specific route information.

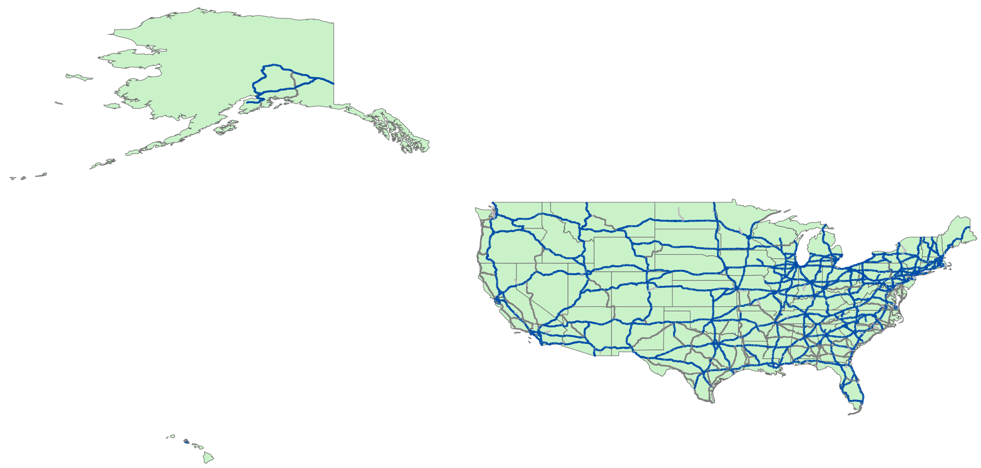

FIGURE 2 Roadway infrastructure from FAF2.

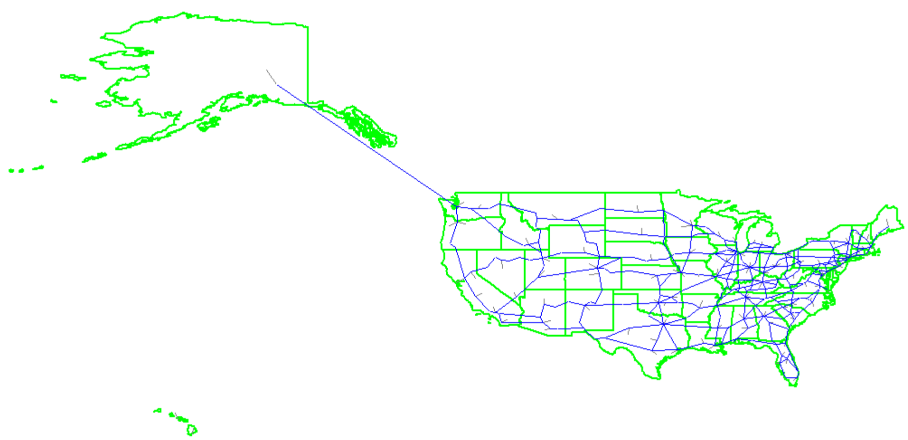

FIGURE 3 National Network in CUBE-TRANPLAN format.

Using the Load Highway Selected Links module, it was possible to identify selected roadways where only the traffic using the selected roadways would be included in the output. It is possible to identify a collection of links where the travelers have to use all the links identified or only one of the links identified. For Alabama, seven roadways that represented interstates crossing state lines were identified as the selected links. The rule was established that the traffic only needed to use one of the links to be included in the results. In addition, the module allows for the identification of origin locations, destinations locations or a combination of both be identified to limit the amount of traffic stored. In the analysis, as the values external to Alabama were of interest, the origin zones were varied individually from zone 3 – Alaska to zone 114 – Wyoming. Zone 1 and 2 were excluded from the study because they are internal to Alabama. Figure 4 presents the shortest paths from Zone 21 – Orlando, FL to all other zones, if the shortest path crosses through Alabama.

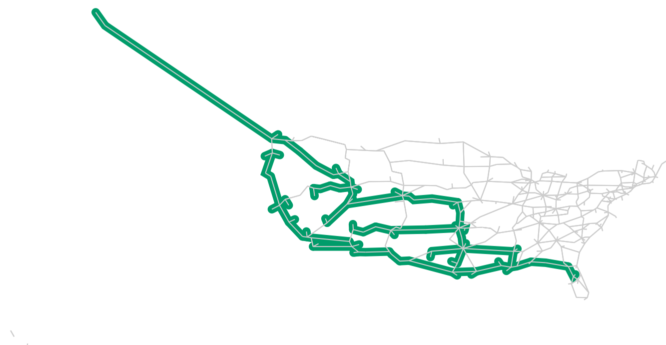

FIGURE 4 Shortest path from Zone 21 through Alabama.

During the process of running the Load Highway Selected Links for each origin, the output network containing the paths that pass through Alabama were exported to ArcGIS for further analysis. A query was developed to show the destination zones that were on the path through Alabama. The main interest in this step was the development of paths from a single origin to multiple destinations. These values were recorded in a spreadsheet and saved as tab delimited text file. The values, formatted to show the origin zone number, destination A zone number, destination B zone number, destination C zone number, etc., were saved for input into the computer program written to extract the FAF2 data.

9.1.5.3. Task 3: Run Computer Program to Extract Data

After developing the origin destination pairs traffic passing through Alabama would use, the next step was to extract the FAF2 data from its native Microsoft Access Database format into a text file. The FAF2 data for either ‘Kilotons’ or ‘Millions of Dollar Shipped’ could be used by the planner. The two text files serve as input to the computer program written to extract the data. The flowchart for the program developed at UAH is shown in Figure 5. The FAF2 Data Extraction Program creates a text file containing origin, destination and FAF2 value for each commodity listed in the database. In addition, as a parameter input into the program, a search is performed during the operation of the program to extract only data for which “truck” is listed as the mode of transportation. It is important to note, that if the infrastructure were developed for alternative modes, the program could be easily modified to extract rail or water shipment data if the origin destination zones were also adjusted to reflect the alternate mode.

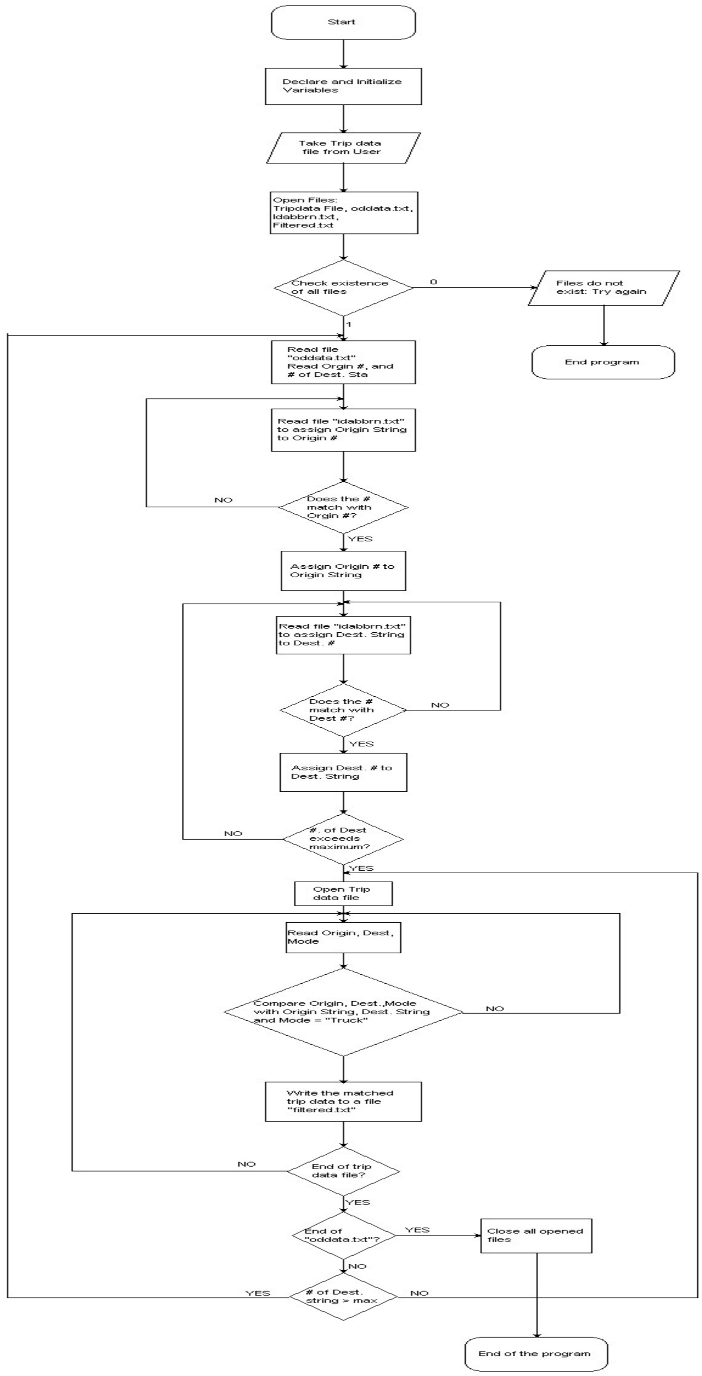

FIGURE 5 Flowchart of the FAF2 Data Extraction Program.

9.1.5.4. Task 4: Assign Data to National Network

The output from the program is a text file that contains origin zone number, destination zone number, and FAF2 data value, either ‘Kilotons’ or ‘Millions of Dollar Shipped’, for each commodity in the FAF2 database. Once developed, a TRANPLAN routine was employed to convert the text file into a trip table for entry into CUBE-TRANPLAN. The trip table file is then input to the Load Highway Network module with the national network, to assign the ‘Kilotons’ or ‘Millions of Dollar Shipped’. Figure 6 illustrates two commodities assigned to the national network that pass through Alabama.

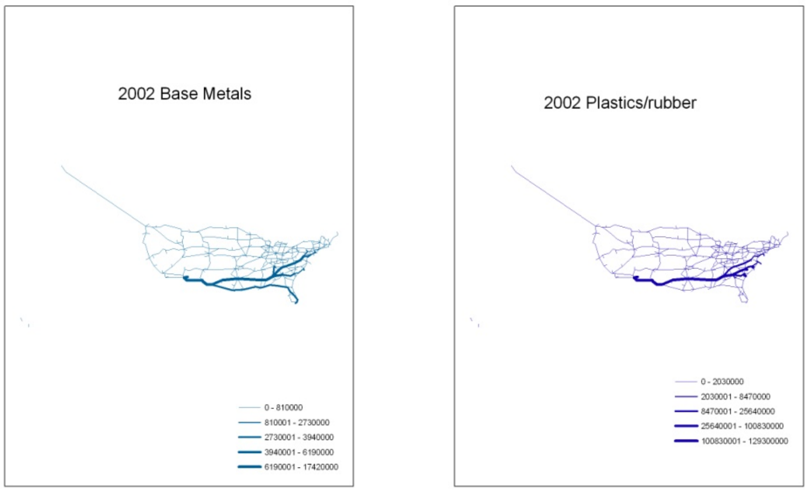

FIGURE 6 Assigned value of kilotons passing through Alabama.

9.1.6. Methodology Validation

The validation of the methodology is difficult because the FAF2 data does not contain vehicle traffic. However, it is possible to perform a limited validation of the methodology. The validation technique involves comparing the tons of freight passing in and out of Alabama to the truck traffic crossing the state line to determine if the values violate truck weight laws, or not.

The assignment by commodity of the external kilotons to the national network is intended to provide a measure of the pass through traffic. However, it is still necessary to collect the internal-external and external-internal traffic for Alabama since these trips also pass across the state line. The values of kilotons that have either the origin or destination in Alabama are obtained from a direct export from the FAF2 database. The data exported can be sorted and purged such that only those that have their origin or destination in Zone 1 or Zone 2 (Alabama) and sorted by individual commodities to remove all the values that are not moved by “truck”. The TRANPLAN routine can be run to create a trip table for entry into the CUBE-TRANPLAN Load Highway Network module. Figure 7 shows the flow from the FAF2 database of all kilotons moved across the Alabama state lines.

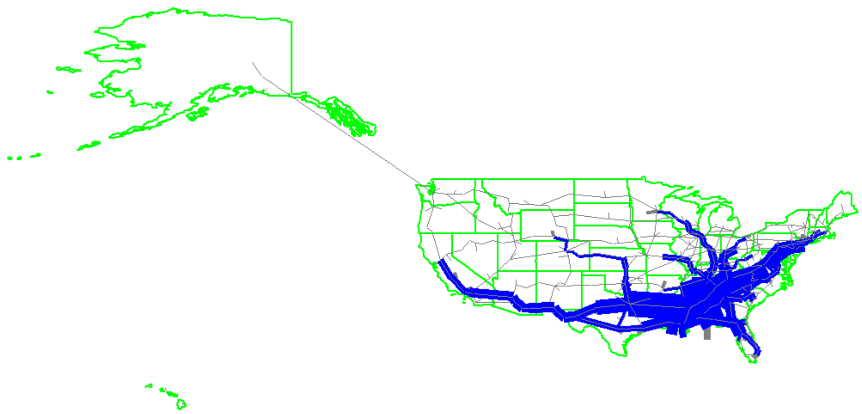

FIGURE 7 Kilotons of freight moved from, destine to, or through Alabama.

A collection of the Kilotons crossing the state lines was then compared to the total truck count at the state line interstate locations. The Alabama Department of Transportation (ALDOT) provided the data related to truck counts. Table 3 presents the number of trucks per day reported by ALDOT crossing the Alabama state line. Table 3 also contains the tons of freight per year obtained from the FAF2 database that the methodology suggests crosses the Alabama state line. A comparison of the results indicates that the values obtained by calculating the weight per truck are realistic. The differences in truck weight are associated with the wide variety of commodities shipped via truck across the state lines and the distribution of destinations for those specific commodities.

TABLE 3 Method Validation.

	Trucks/day (7)	Tons/year model	Tons/day	Tons/truck	Pounds/ truck
I65	7,768	52,071,250	142,661	18.37	36,730
I59	4,758	47,408,170	129,885	27.30	54,601
I20	14,531	38,163,040	104,556	7.20	14,390
I85	6,070	42,259,400	115,779	19.07	38,149
I10E	6,334	13,234,480	36,259	5.72	11,450
I10W	9,979	22,101,760	60,553	6.07	12,136
I59W	8,875	107,198,800	293,695	33.09	66,188

9.1.7. Conclusions and Recommendations

The methodology presented in this paper focuses on a means to utilize FAF2 data to estimate statewide external traffic levels. The results of using the methodology produce a reasonable value of weight per truck for each interstate route as it crosses the Alabama state line. Additional use of this methodology would be a forecast of future years freight tonnage provided in the FAF2 database. Then, the application of a reasonable number of trucks to transport the total tonnage of freight could be ascertained to develop a future freight external flow value.

This methodology has been developed to be applicable to any state, or region identified in the FAF2 zone structure. Future improvements of the methodology would include developing truck weight factors for specific commodities and advancements in disaggregating the FAF2 database to a sub-state level. The method presented here improves the ability of transportation planners to quantify the base level of freight traffic in their area of concern. The base level of freight traffic contributes to total roadway congestion, but is difficult to ascertain because traditional sampling techniques are only available within the study area. The methodology presented in this paper can be used to determine the freight movements that occur simply because the study area is along the travel path between unrelated origins and destinations. Overall, this methodology is intended to serve as a starting point for statewide freight flow models interested in using the FAF2 database, but facing the difficulty in understanding the methods to obtain the data and extract the data that is appropriate.

9.1.8. Acknowledgement

This research was sponsored by the U.S. Department of Transportation, Federal Highway Administration, "The Freight Analysis Framework Pilot Project, DTFH61-070G-00007 Amendment 1" and the Alabama Department of Transportation, “FAF2 Pilot Project: Utilization of FAF2 Data by State and Local Governmental Agencies, 03-428 Mod Project 930-682.”

9.1.9. References

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2. Horowitz, Alan. *Statewide Travel Forecasting Models.* NCHRP Synthesis 358. Transportation Research Board of the National Academies. Washington D.C. 2006.

3. FAF2 Internet Page. http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

4. Harris, G.A. and Anderson, M.D. “A Freight Planning Framework” Submitted for presentation at the 2008 Transportation Research Board Annual Meeting and publication in the Journal of the Transportation Research Record.

5. FAF2 Internet Page. http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2userguide/index.htm

6. FAF2 Internet Page. http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/cfs_faf_areas.htm

7. ALDOT Traffic Count Maps. http://aldotgis.dot.state.al.us/trafficvolume/viewer.htm

9.2. Final Report The Impact of BRAC on Freight Movement Within North Alabama

Prepared for:
Dr. Michael Anderson

Author:
Earlan Dujon

9.2.1. Introduction

9.2.1.1. Problem Statement

The Base Realignment and Closure (BRAC) panel approved moving the headquarters of the Army Material Command (AMC) to Redstone Arsenal (RSA) and Space and Missile Defense Command (SMDC) to the Tennessee valley. Business owners were very pleased with the move. Businesses such as Northrop Grumman Corporation and Raytheon Integrated Defense Systems have been making preparations for such a move. The Huntsville Times reported in an article dated August 25th 2005 that moving the headquarters of AMC and SMDC to Huntsville, which has long been the headquarters for the Army Aviation and Missile Command, would elevate Redstone's stature as a key site for the Army. It could also make Huntsville home to several more Army generals. The BRAC commission has recommended moving approximately 4700 jobs to the valley[1]. In addition it is expected to have at least 1,755 new federal jobs, and an estimated 2,500 contractor jobs. This would allow for a cumulated total of just under 9000 jobs. For a more conservative refection of the model, 12,000 jobs were used as the expected number of employees due to the BRAC relocation [2]. With such projections we can expect changes to the infrastructure, school districts and land use for urban development.

The objective of this report is to determine traffic conditions and its impact on freight movement through the Tennessee Valley due to the BRAC relocation. A brief study using ARCGIS in conjunction with Cube software package will be used to determine possible impacts of traffic and population densities within the Tennessee Valley.

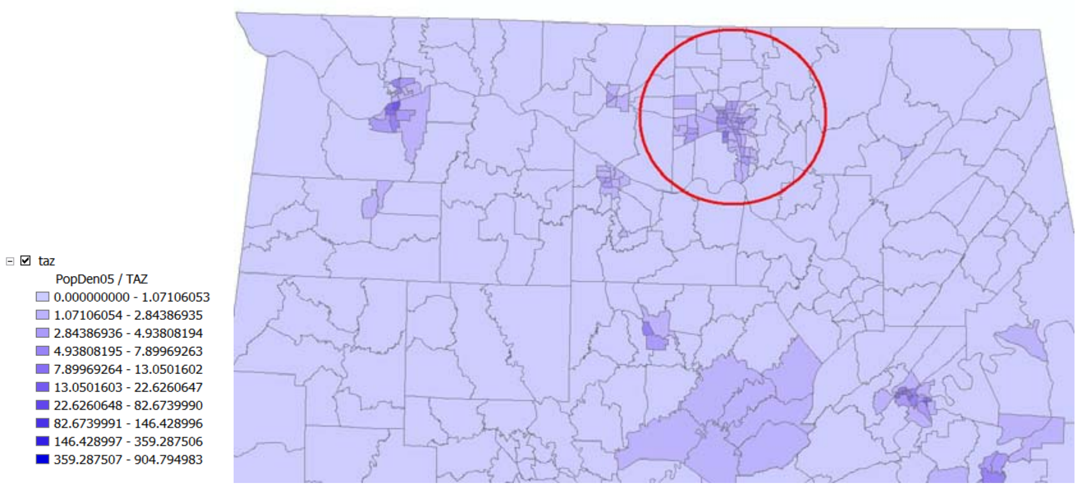
9.2.1.2. Data Source

The initial data source for this report was obtained from traffic counts generated by a statewide travel demand model maintained by the Alabama Department of Transportation (ALDOT). The model included a shape file for the state of Alabama identifying the various counties which were further divided into several Traffic Analysis Zones (TAZs). Each TAZ was attributed with population and employment for 2005 (the baseline) and 2035 (the proposed thirty year projection). Additional Census data was used to execute the above mentioned task and was downloaded from the following website: arcdata.esri.com. The data included a base map for Madison County and the North Alabama region (Tennessee Valley). A road network for the state of Alabama generated in CUBE and sourced from the DOT was also employed. This CUBE file contained roadway conditions, such as capacity and speed of roadways and the resulting volume from the travel demand model to locate potential congestion. From the

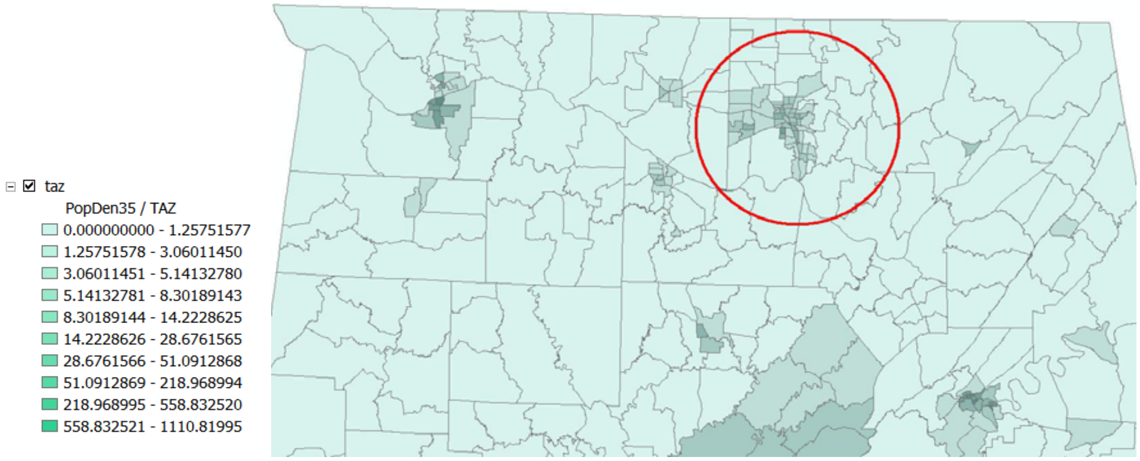
CUBE model, the number of trips generated for 2005 will be compared to that of the possible trips to be generated as a result of the BRAC relocation for an additional 30 years beyond 2005. This study will be conducted using household trips that are broken into three categories; Home Base Work (HBW), Home Base Other (HBO) and Non Home Base (NHB) trips.

9.2.1.3. Purpose

The purpose of this report was to determine the congestion impact on the road network within North Alabama and its effect on freight movement. Primary focus was given to major roads within Madison County and surrounding areas. It would be necessary to obtain a geo-spatial representation of all the congested roadways relative to the Traffic Analysis Zones served by the considered network. In addition, the need to determine the population density of the region and the projected population density with the next thirty years could also be represented. Figures 1 and 2 show the population density for the base year (2005), and the thirty year projection (2035). From the two images it can be seen that the population density with Madison County is expected to increase significantly. In a recent study performed by the city officials it was determined that the population is expected to increase by sixteen percent (16%) within thirty years from the base year [3]. It should further be noted that the expected traffic conditions would also show some increase in congestion.



Legend **Figure 1 – Population Density for 2005**



Legend **Figure 2 – Population Density for 2035**

9.2.2. Background – Statewide Models

9.2.2.1. General

With the increase in the demand for commercial goods and services there has been an increase in the amount of freight movement within the continental United States. According to the report on Statewide Travel Forecasting Model published by the National Cooperative Highway Research Program (NCHRP), travel forecasting has become a common activity in transportation planning. There has recently being an increase in the number of states with transportation models. Most state models are created to address the planning needs associated with specific large projects or for general planning needs. These models have been essential for intercity corridor and statewide system planning.

For an effective travel demand model to exist the four step travel demand forecasting process should be employed. The steps include; Trip Generation, Trip Distribution, Mode Choice, and Traffic Assignment [9]. Most statewide models are similar in structure to this four-step transportation planning model. The only difference may be relative to a typical urban model would be the format or scale in which the four steps are configured. The NCHRP manual on Statewide Travel Forecasting suggests that there is no well accepted definition for optimum results in statewide models. As with the implementation of any policy or practice, most models are determined greatly on cost, available man-power, research, development period, and capabilities. As statewide models are developed, several trends have been noticed. There has been significant use and reliance of geographic information systems to manage and acquire data required for the model. With regards to traffic assignment, newer models are less likely to use an “all or nothing” assignment procedure as the need for equilibrium in the model has grown to be a significant factor for efficiency. In addition these newer models allow for networking detail that provides the same level of precision, validation of accuracy, and standards as urban models. Finally, statewide models allow for more freight components that are commodity-based as compared to being truck related only. There is also a greater emphasis on multiclass traffic assignment for combining freight and passenger traffic forecasts.

9.2.2.2. Statewide Models - Alabama

The Alabama Department of Transportation has recently developed a statewide model based on socio-economic data collected within the state. The model was based on number of households obtained in each traffic analysis zone, the average income within the households, the number of retail, and non-retail employment. The expected productions and attractions were determined using HBW, HBO, NHB, and truck trips. Due the complexity of the model, there may be a few deficiencies with the data and the algorithm. For instance there is the possibility that creation and use of transferable parameters within any of the model steps appeared to be a key deficiency. In addition there may have been little progress in integrating Freight Analysis Framework (FAF) data into the model [9]. As mentioned previously the effect of freight movement due to BRAC will be the final objective of the model and this process will be analyzed manually.

9.2.3. Methodology

9.2.3.1. Application of the Model

The data used for this study was provided by the (DOT) and operates as an excel model and a CUBE model. The excel model converts socio-economic data into productions and attraction trips generated from existing households and businesses. Based population and employment expected due to BRAC, it was necessary to generate two production/attraction (P/A) output files. These two outputs were considered as alternative 1 and 2 respectively. These P/A files were manually generated as some difficulties aroused during the file conversion from the initial excel spread sheet provided by the DOT. The congestion levels on the road network were determined using three levels of congestion. The first option was determined by analyzing congestion when the allowed volume of the network was twenty percent (20%) greater that the capacity. The other two options were performed when traffic volume was greater than the capacity of the network at 50%, 80% and 100%. For effective analysis of the congestions levels within the network, it was necessary to generate five different layers of files within the ARCGIS software. Figure 3 to the right illustrates all the layers used. The congestions of the original layer (base) would be compared to the two alternatives *(Alt1 and Alt2)* at the three capacity options mention previously.

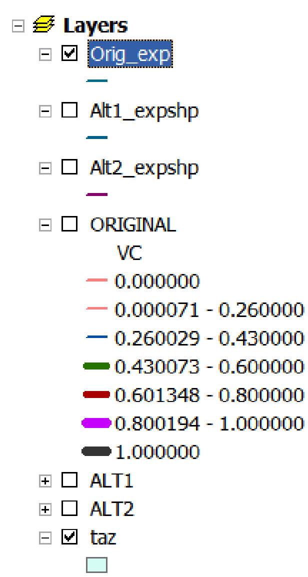


Figure 3 – Layers used during analysis

The bulk of the study would be performed using the ARCGIS software; as a result a few queries had to be pre-established so as to obtain the relevant information that could be necessary to perform the analysis. The following are some of the queries that were applied in order to obtain some geo-spatial representation of the congestion conditions generated;

- Determine all traffic analysis zones (TAZ) that are within 45 miles of the RedStone Arsenal (TAZ 663)
- Determine the three congestion levels for the base file.
- Using the P/A files generated for alternatives 1 & 2, determine which road ways have the highest traffic congestion.
- Using the volume capacity ratios, determine the traffic congestion generated within the considered network (option 1 & 2).
- Determine which distribution had the least traffic congestion

As indicated earlier all the shape files contained information for the entire state of Alabama. Since this study was specific to the North Alabama and Madison county region it was necessary to narrow the area of concern. In order to determine a concise area it was assumed that the average commuter would travel no more than 45 miles to their place of work. As a result all the TAZ's within a 45 mile radius were selected during preliminary studies. Figure 4 illustrates a visual representation of the proposed area to be affect by the BRAC move, while Figure 5 illustrates a summary of all the counties and the number of TAZ's that would be affected. The TAZ highlighted in red *(TAZ 663)* is that of the RedStone Arsenal (RSA). It should be noted that the areas of the network that would be affected by freight movement would be Interstate 65 and 565 and any other major arterial roads. The initial freight movement due to congestion would be determined and compared to that of population distribution of option 1 and 2.

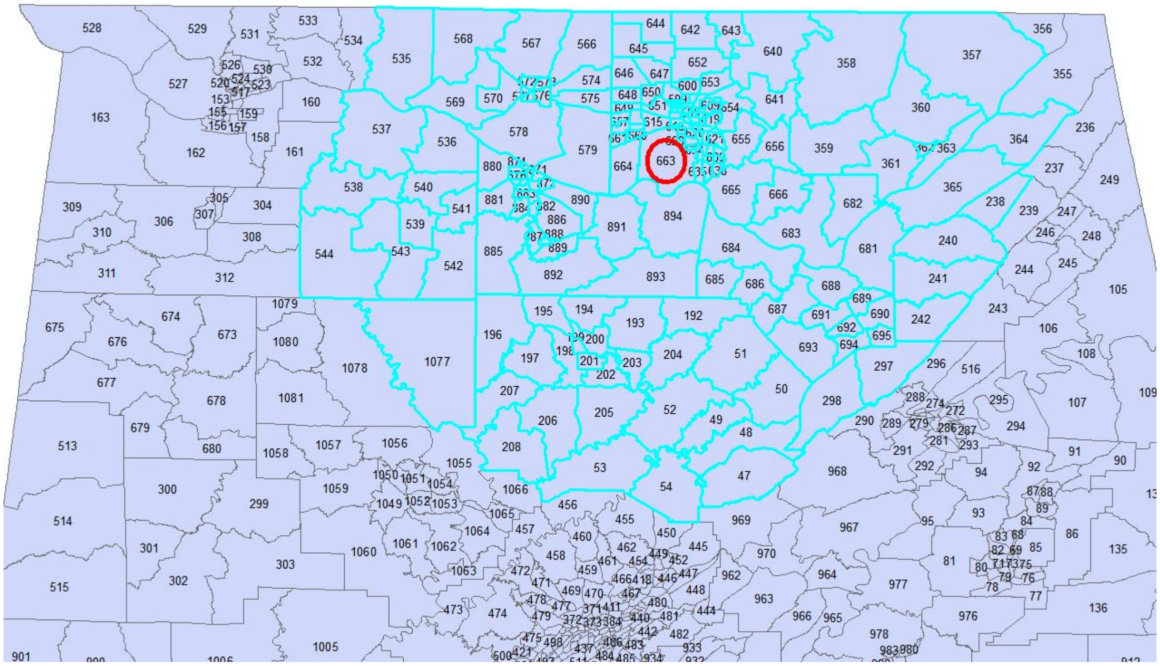


Figure 4 – TAZ's with a 45 mile Radius from RSA.

OID	COUNTY_NAM	Count_COUNTY_NAM	Sum_2005EMP	Sum_2005POP	Sum_2035EMP	Sum_2035POP
0	BLOUNT	8	9983	57324	15467	97559
1	CULLMAN	17	29451	82338	45629	108384
2	DEKALB	4	6044	25759	9364	38495
3	ETOWAH	2	1331	14096	1726	14873
4	JACKSON	9	16920	46064	26213	64914
5	LAUDERDALE	1	988	8433	1266	10075
6	LAWRENCE	9	7434	36173	11518	41534
7	LIMESTONE	14	21391	64575	33262	95729
8	MADISON	73	143879	284170	316907	436178
9	MARSHALL	15	40152	88255	60217	130981
10	MORGAN	24	59827	116612	79888	161875
11	WINSTON	1	2280	7931	2922	10046

Figure 5 – Expected Counties to be affected and Number of TAZ's

9.2.3.2. Existing Conditions

Presently, the major roadways within the North Alabama region do not show much congestion when compared to neighboring cities like Birmingham, Alabama or Atlanta, Georgia. Table 1 illustrates the level of service based on the volume/capacity ratio. The average daily traffic and level of service for the major arterial roads within Madison County are listed below in Table 2. These highways were singled out of the network as they are the ones most used for freight movement. Figure 6 illustrates the level of service of all the roads within the Madison and North Alabama Region.

Table #1 – Level of Service and V/C Ratios

LOS	V/C Ratio
A	< 0.26
B	0.26 - 0.43
C	0.43 - 0.60
D	0.60 - 0.80
E	0.80 - 1.00
F	> 1.00

Source: Montgomery Study Area, 2030 Long range Transportation Plan [8]

Table #2 – Level of Service and V/C Ratios of Key Highways

Highway Code	Average Daily Traffic	Average VC Ratio	Initial LOS
20	22,000	0.273	B
53	20,000	0.803	E
72	33,200	0.671	C
231	44,500	0.934	E
255	36,000	0.410	B
431	23,500	1.156	F
565	9,000	0.355	B
	18,000	0.952	B
	34,000	0.495	C
	51,000	o.414	B
	68,000	0.349	B
	85,000	0.381	B

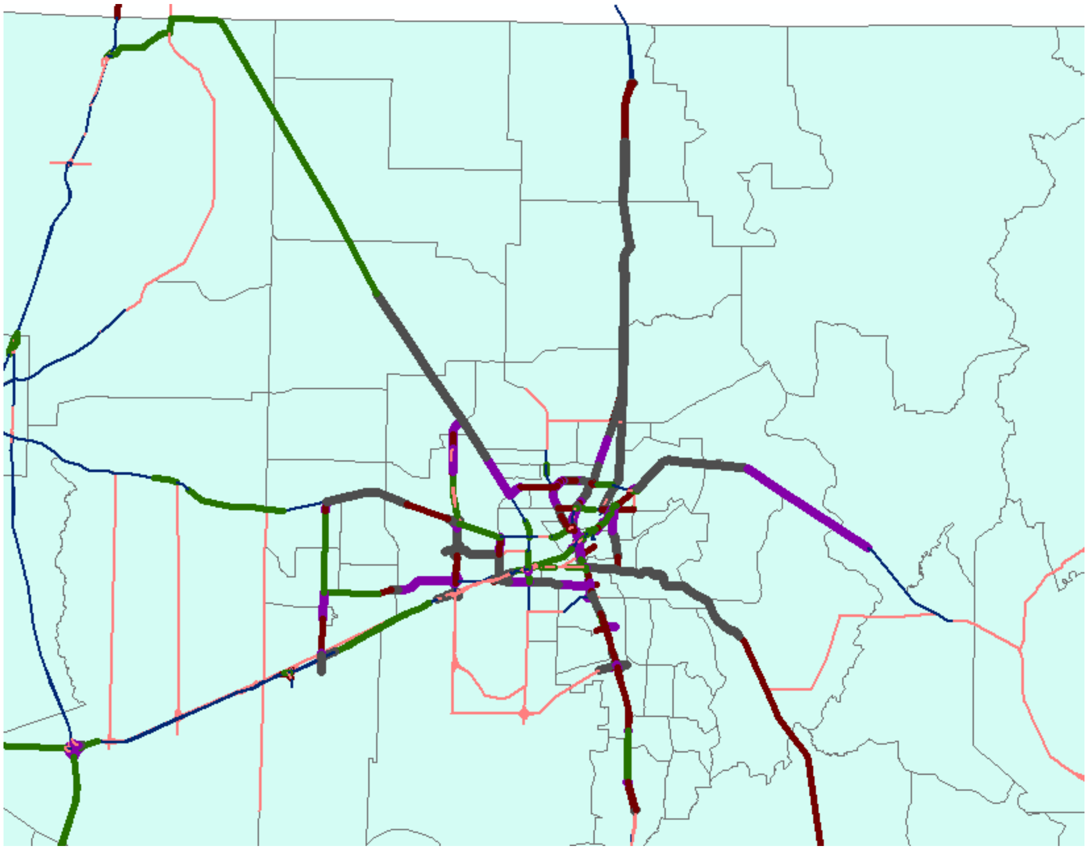
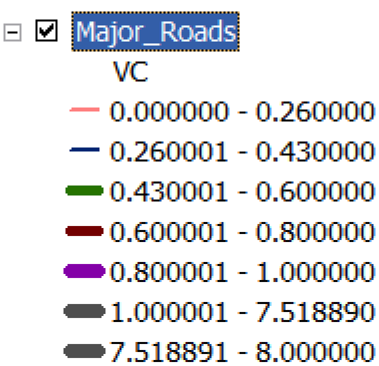


Figure 6 – Initial Level of Service Conditions

Legend



9.2.3.3. Options Considered

As indicated previously, two options were considered for this study, option 1 contained a housing distribution based on a bubble diagram (see Figure 7) obtained from a previous economic impact study conducted for the Madison County area. Option 2 was determined by allocating all the houses towards the western side on the county and into Limestone and Morgan County. This option was considered as the population densities within these counties were relatively low *(5 – 10 persons per square mile).* Based on the previous economic impact study by the Alabama DOT it was determined that a total of 30,000 households would result from the BRAC move. This value was used as the expected growth and distributed as necessary for options 1 and 2. Figures 10 and 11 show a spatial representation of the TAZ's that would be of concern for the two options. The general road network within the Tennessee Valley is shown in Figure A-1, while the network affected by option 1 is shown in Figure A-2, these two figures can be seen in Appendix A. The traffic congestions and level of service impacts for option 1 and 2 were compared to the base option without the BRAC move. The results from the model relevant to option 1 can be seen in figures 8 and 9 on the following page. The remaining figures are illustrating travel time increase at 50%, and 80% increase for option two can be seen in Appendix A.

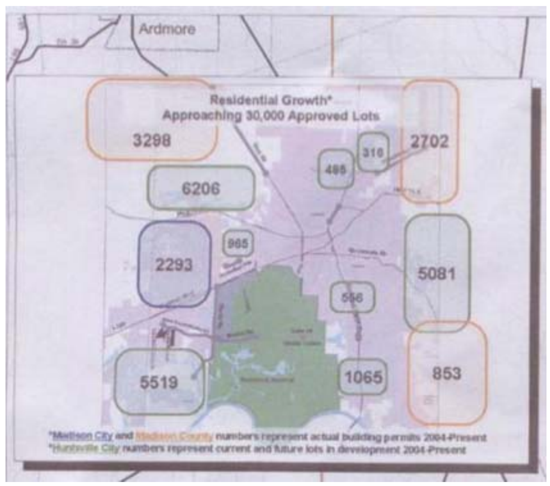


Figure 6 – Housing Distribution for option one

The following figures illustrate the increase in travel time by 50% and 80% respectively. The red highlights indicate the area of the next work that would result with such an increase in travel time. This increase is based on the initial travel time within the network and that of option 1. Of the two outputs the only part of the network that was different was highway 231 between I-565 and its merge with highway 431.

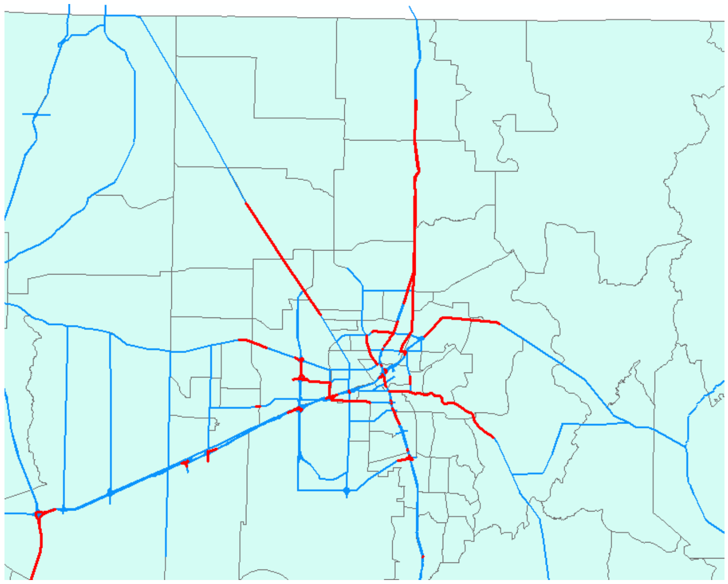


Figure 8 – Road Network with an increased travel time of 50% that Base Model

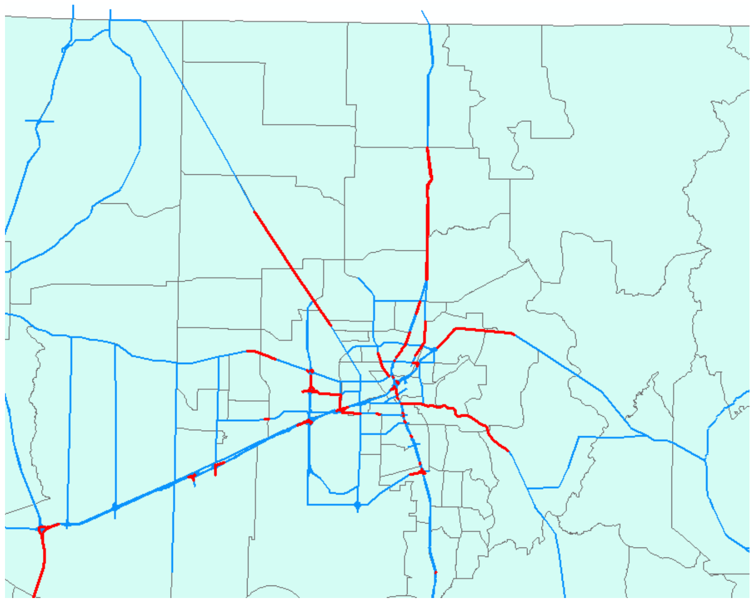


Figure 9 – Road Network with an increased travel time of 80% that Base Model

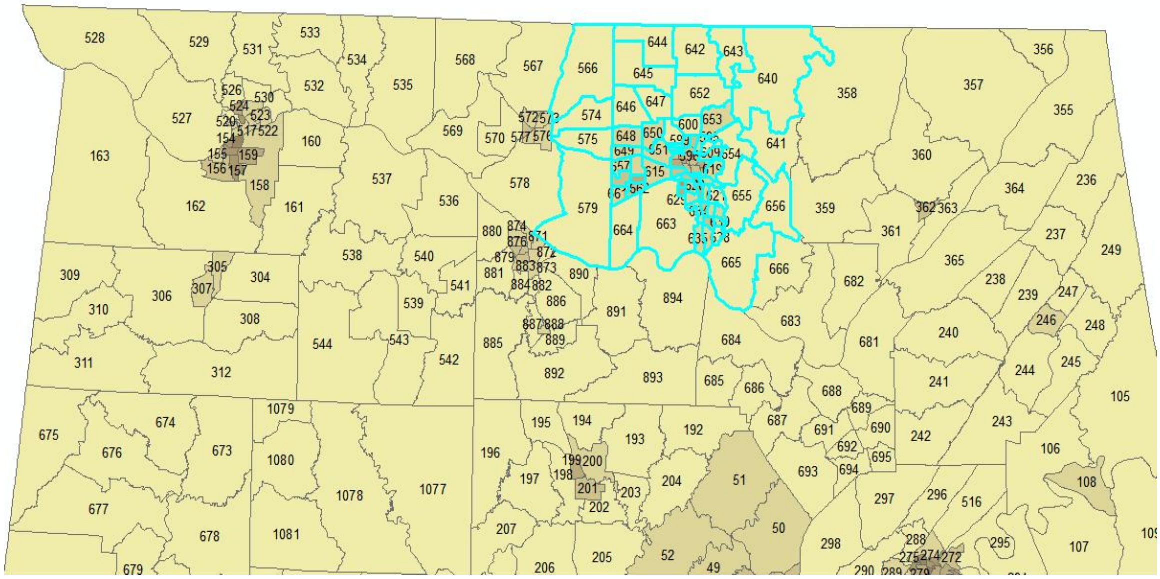


Figure 10 – TAZ's affected by Option 1

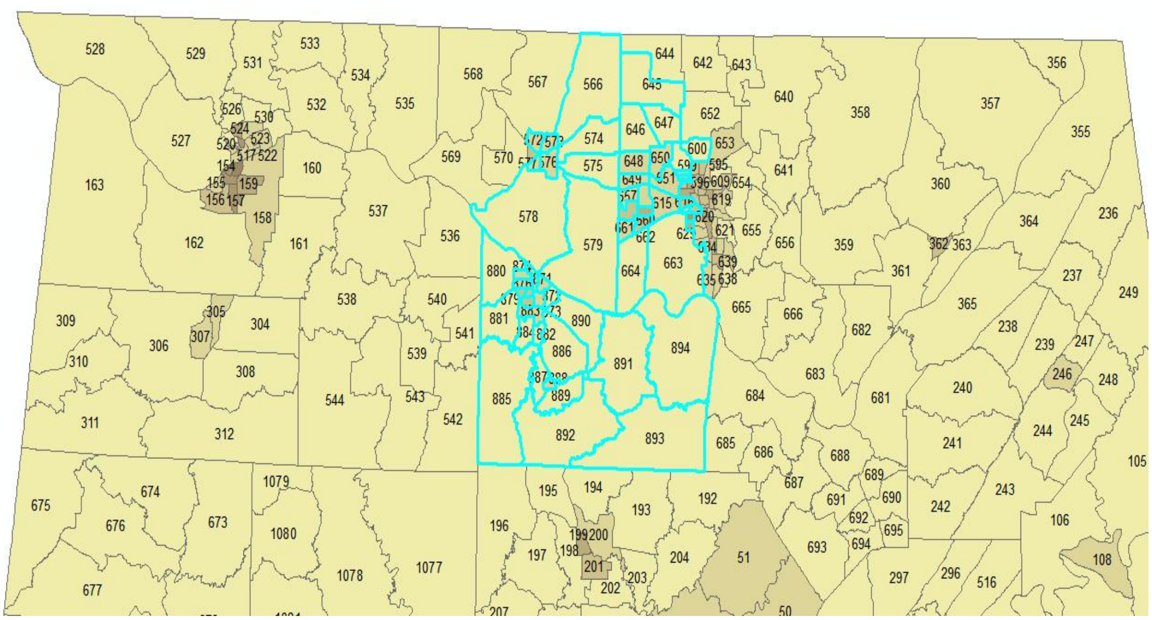


Figure 11 – TAZ's affected by Option 2

9.2.4. Analysis and Results

As indicated previously, the analysis of the TAZ's and road network was done by comparing the two options with that of the Base option. In addition, the results from the model were analyzed in two capacities. The first approach was based on the change in level of service from the base model to that of the two alternatives considered. The second approach compared the change in travel time from the base model to the other two alternatives. Table 3 below illustrates the initial travel time of the network and the expected travel time for option one and two. Primary concern was give to the major highways as they would be the expected routes for freight movement. The table highlights the highways with an increase in travel time greater than 80% of the initial travel time. Figure A-3 in Appendix A shows a spatial representation of the areas within the next work with such an increase in travel time. A total of 88.01 highway miles will be affected by option 1 while 36.59 miles will be affected by option 2.

Table #3 – Travel time Delay for option 1 and 2 at 80% Increase

Highway	Avg. Initial TT	Avg. TT Option 1	Length of Road	Avg. Initial TT	Avg. TT Option 2	Length of Road
20	N/A	N/A	N/A	N/A	N/A	N/A
53	232.75	3417.87	13.49	189.40	6713.50	13.46
72	42.46	143.94	11.41	32.27	78.37	11.01
231	54.40	121.63	18.40	13.40	25.13	1.64
255	12.14	35.57	3.11	9.78	53.57	0.89
431	20.10	58.34	30.31	8.00	19.24	5.95
565	32.84	96.61	11.29	16.58	237.64	3.39

9.2.5. Congestion Effects

From the proposed area of the network to be affected by option 1 and 2, it was necessary to determine freight effects at three levels of congestions. This will be executed using the following equation

$$TT = TT_0(1 + \alpha(Vol/Cap)^{\beta}) \text{ [10].}$$

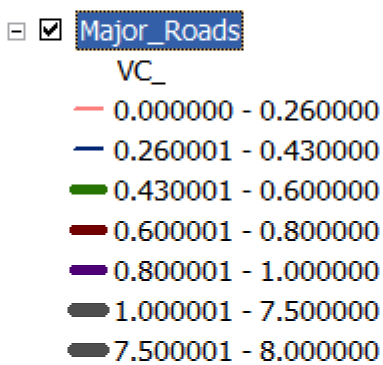
Where:
TT = Congested link travel time
TT_0 = Initial travel time of the link (roadway)
Vol = the assigned roadway traffic volume
Cap = Roadway capacity
α, β = volume and delay coefficients

As stated earlier the level of congestion was compared at 20%, 50%, and 80% increase to the initial travel time. These percentages were applied to each of the two options considered. The travel time along the major highways were compared to the initial travel time of the network before the BRAC options are applied. At a travel time increase greater than 80%, highway 53 showed the highest increase while highway 431 showed the lowest increase in travel time.

According to the NCHRP Report 365, the standard volume and delay coefficients for α and β are 0.15 and 4.0. Other coefficients are recommended for different freeway and multilane highway speeds, however when plotted to scale these coefficients show a much higher speed at a volume/capacity ratio equal to one.

9.2.6. Level of Service Option

Figure 5 on showed the initial level of service within the base model. The following two figures, 11 and 12, indicate the expected level of service for option 1 and 2 respectively. The results indicate a significant increase from the base model to that of the two options.



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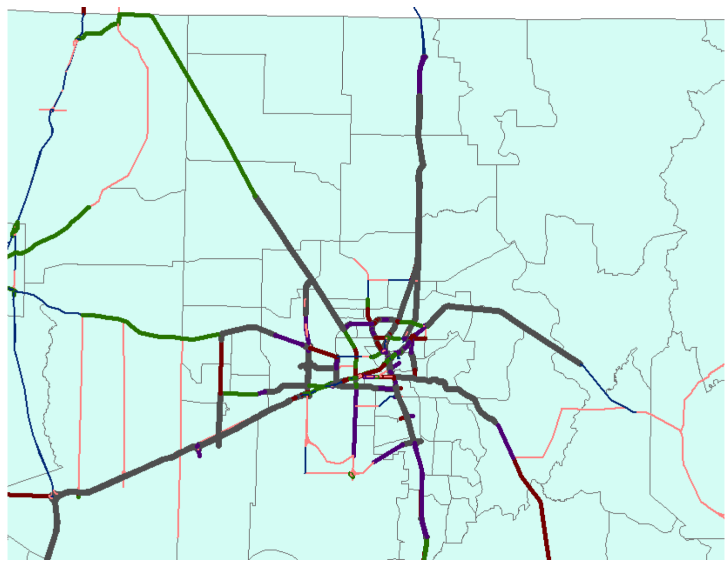

Figure 11 – Expected LOS conditions for option 1.

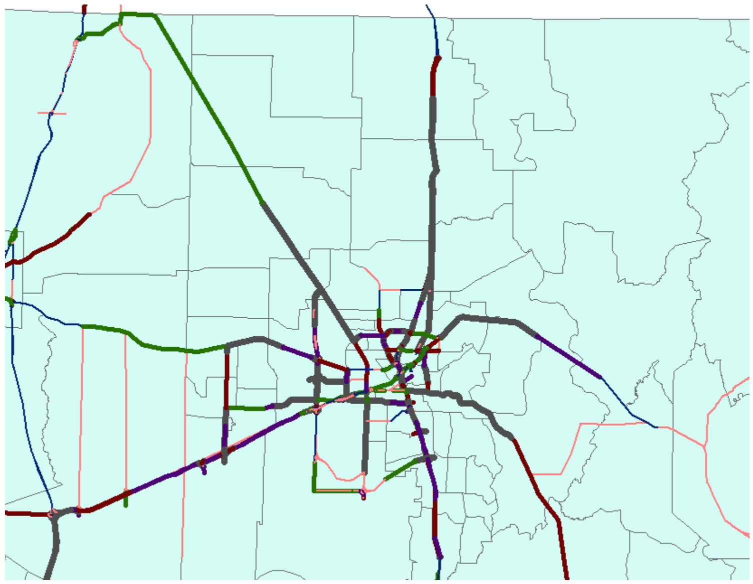

Figure 12 – Expected LOS conditions for option 2.

9.2.7. Conclusions

With the increase in travel time it is expected that the overall level of service of the network will also increase. With a decreased level of service it can be expected that freight movement will be affected. The expected delivery of goods to consumers would be increased significantly and indirectly affect customer satisfaction and delivery reliability. Of the two options considered, option two proved the most suited so as to ensure minimal effect to freight movement. At 20% increase in travel time option two showed less of a burden to the network. For instance, Interstate 565 showed a minimal increase in travel time delay when options 1 and 2 were compared. See Appendix A.4 for a spatial representation of the output provided by ARCGIS. The same result was obtained at 80% and 100% increases in travel time. The level of service for most of the highways within the network dropped significantly when the model was applied. In most cases it dropped by two letter grades. In some parts of Interstate 565 the LOS grade dropped from B to F. It was noticed that most of the significant LOS decreases occurred at on and off ramps on Interstate 565. As per the major highways significant decreases in the LOS rating occurred at merging lanes. Highway 255 / Research Park Boulevard showed most of its delay between Highway 70 and Bradford Avenue and the ramps attached to these intersections.

After careful analysis of options one and two, alone with the three levels of travel time delay it was determined that option two would be the best development plan to ensure the least increase in travel time along major highways. This in turn would have minimal effect on freight movement within the Madison County and North Alabama region.

9.2.8. References

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9. Horowitz, Alan J., Statewide Travel Forecasting Models, National Cooperative Highway Research Program, American Association of State Highway and Transportation Officials, Transportation Research Board, 2006.

Acronyms

ALDOT – Alabama Department of Transportation
AMC – Army Material Command
BRAC – Base Realignment and Closure
DOT – Department of Transportation
FHA – Federal Highway Administration
HBW – Home Base Work
HBO – Home Base Other
NHB – Non Home Base
RSA – Red Stone Arsenal
SMDC – Space and Missile Defense Command
TAZ – Traffic Analysis Zones

APPENDIX A

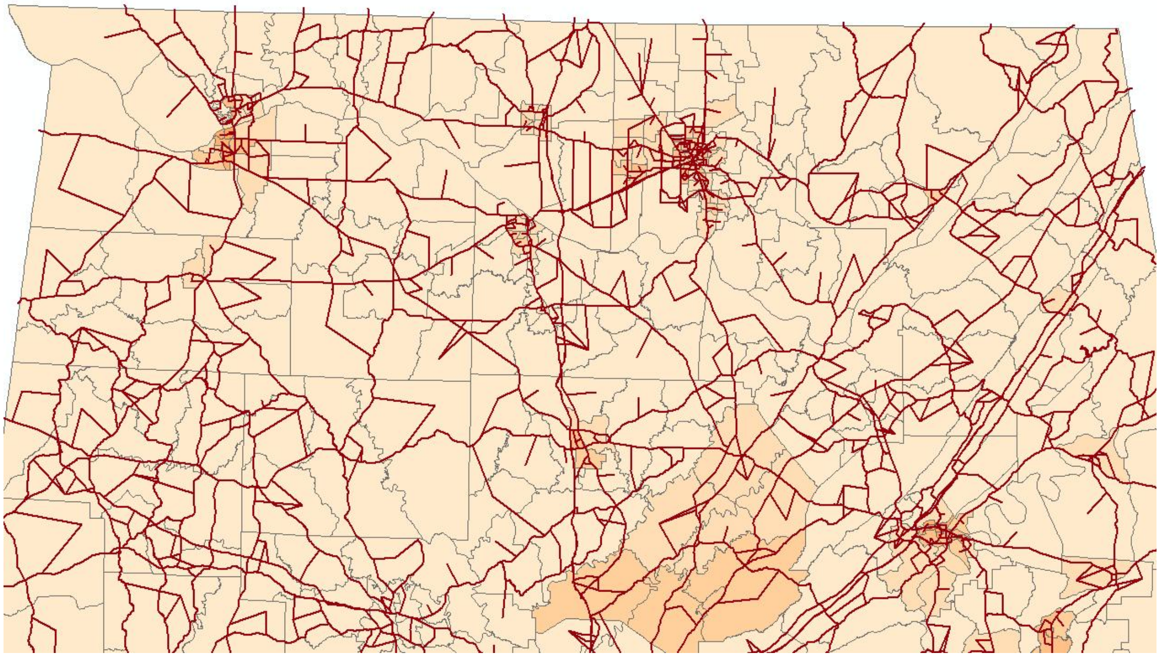

Figure A.1 – General Road Network within Tennessee Valley

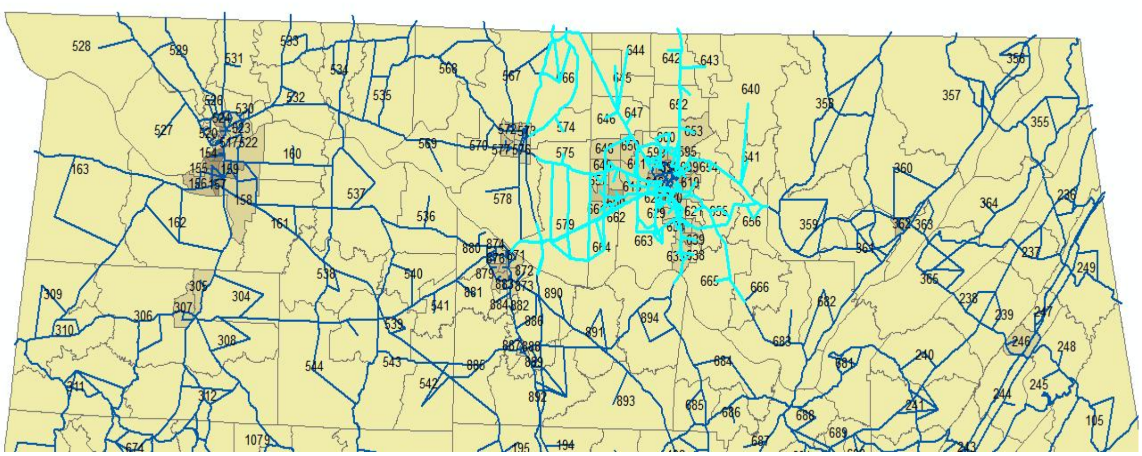

Figure A.2 – Proposed Road Network to be affected by option 1

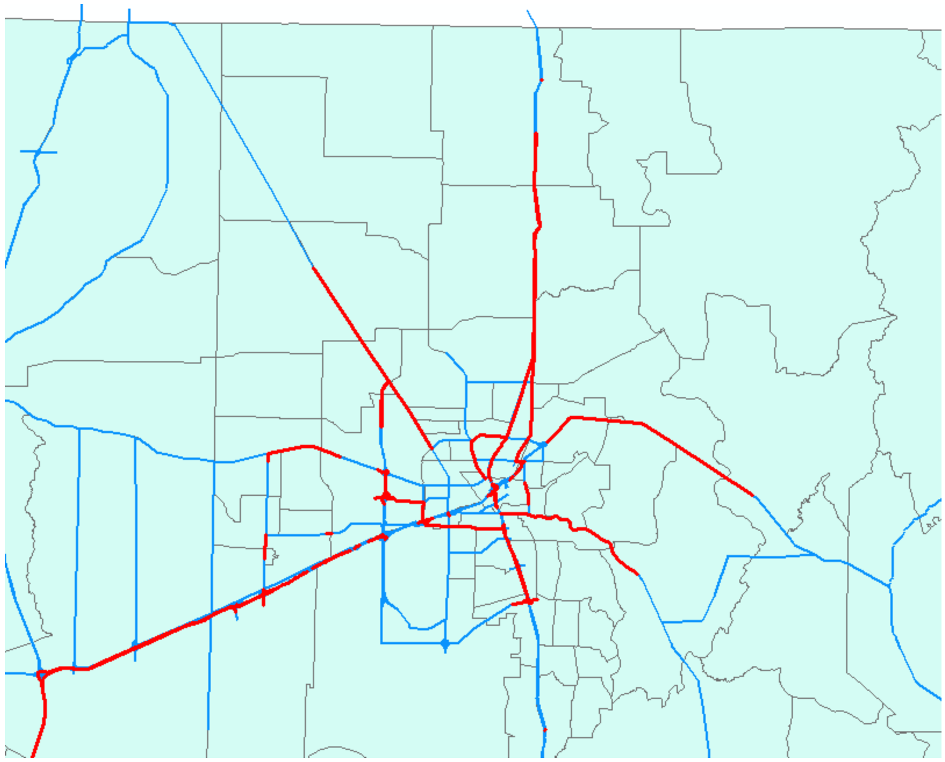

Figure A.3 – Road Network with an increased travel time of 20% Option 1

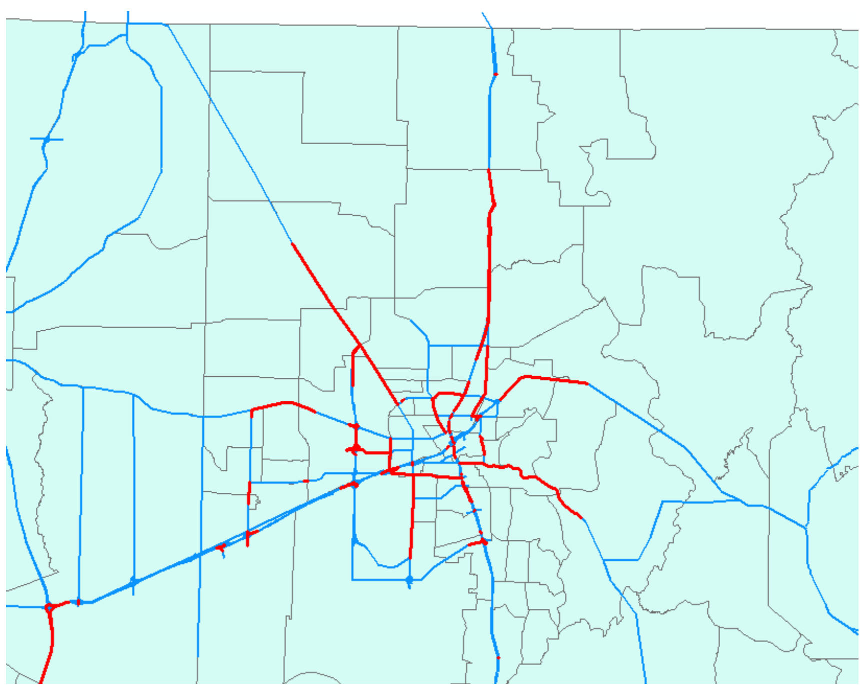

Figure A.4 – Road Network with an increased travel time of 20% Option 2

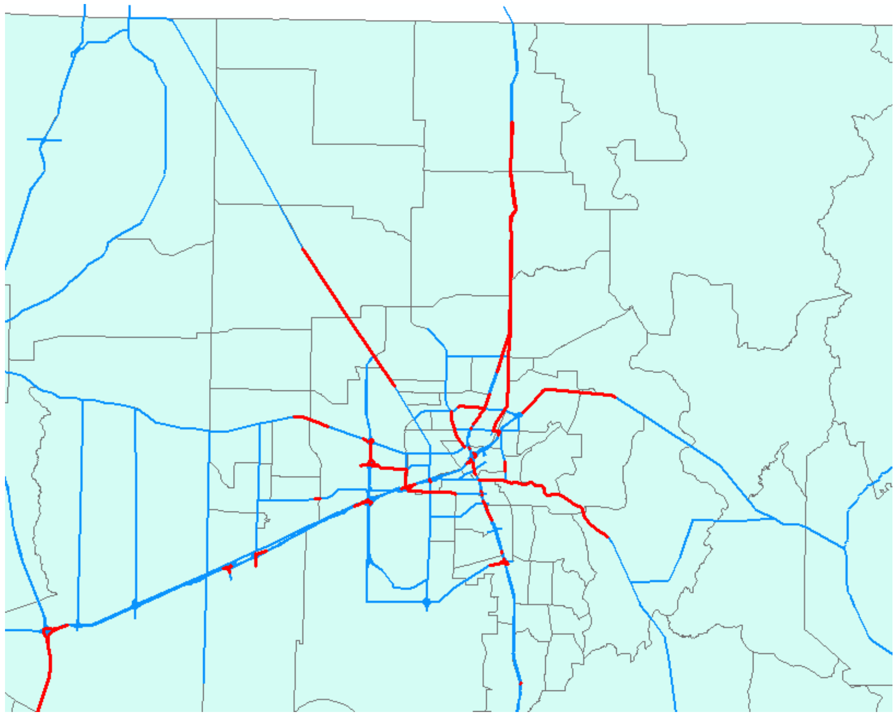

Figure A.5 – Road Network with an increased travel time of 50% Option 1

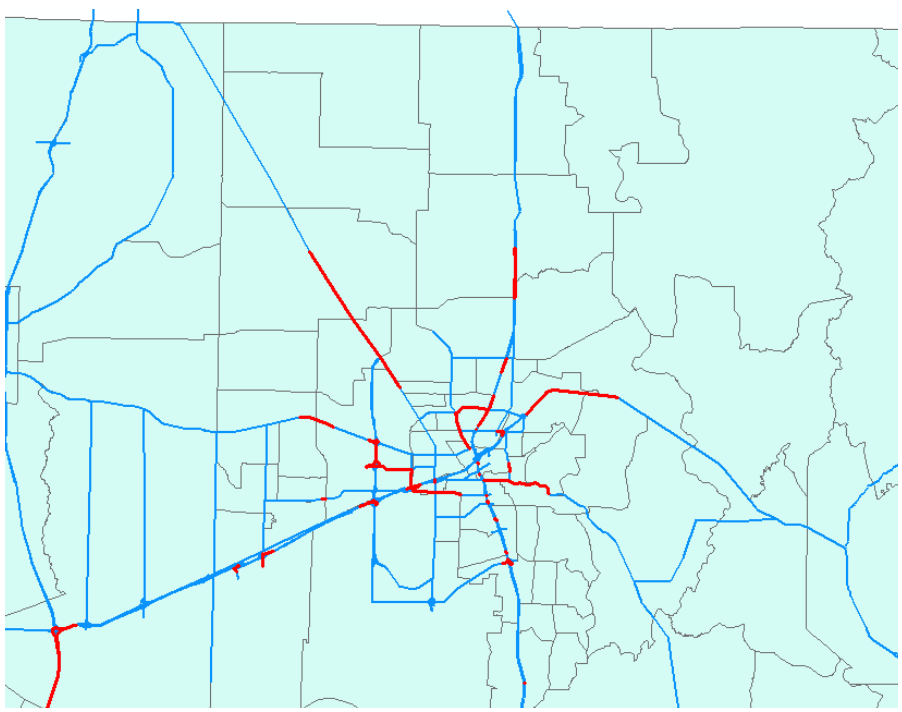

Figure A.6 – Road Network with an increased travel time of 50% Option 2

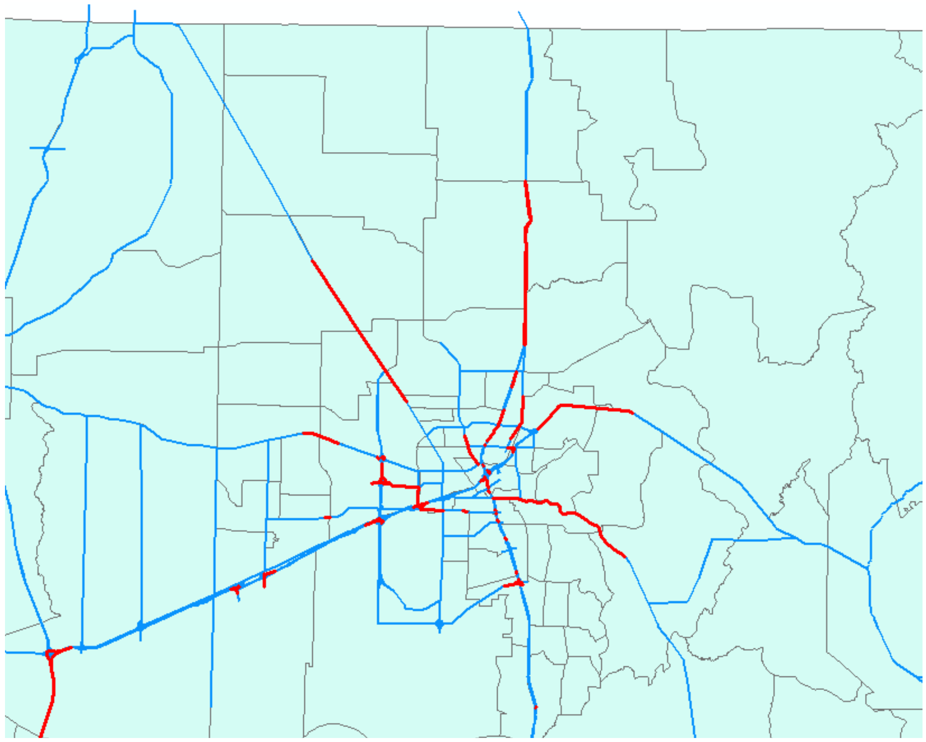

Figure A.7 – Road Network with an increased travel time of 80% Option 1

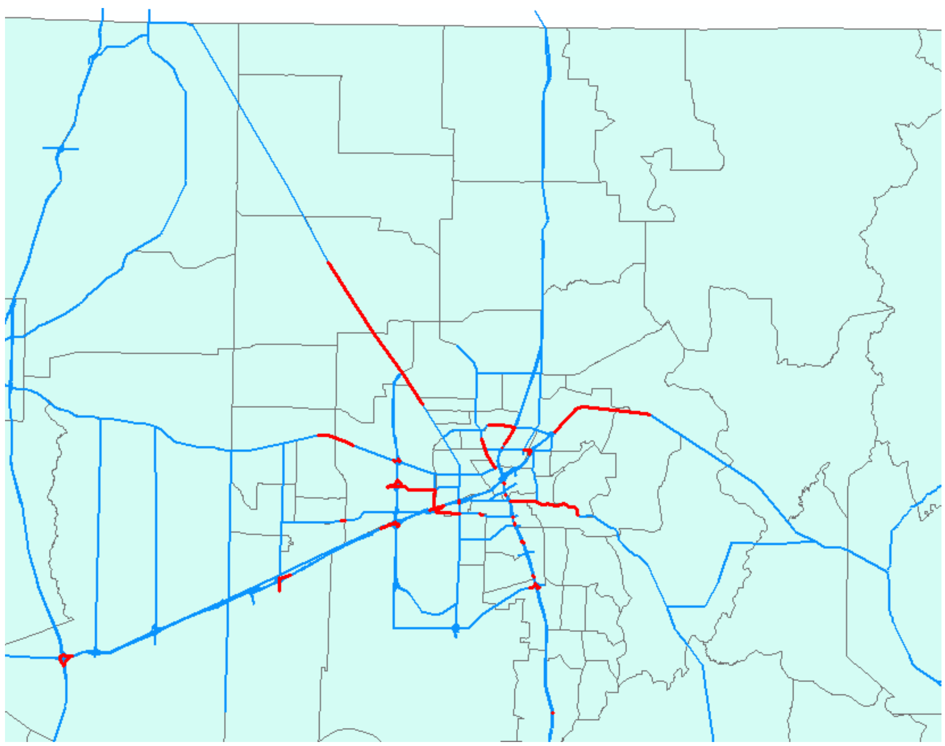

Figure A.8 – Road Network with an increased travel time of 80% Option 2

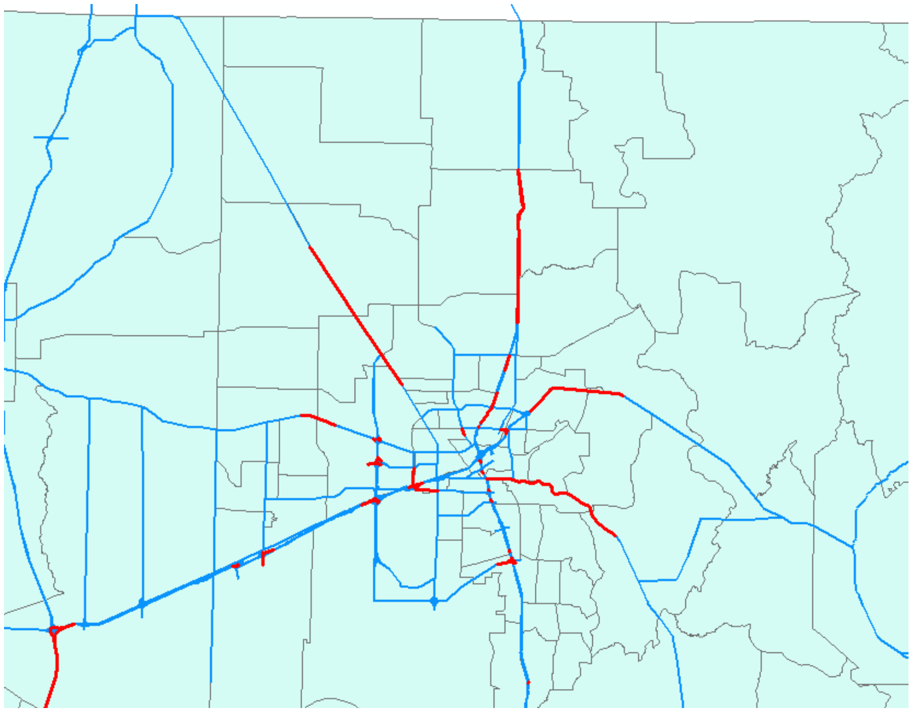

Figure A.9 – Road Network with an increased travel time of 100% Option 1

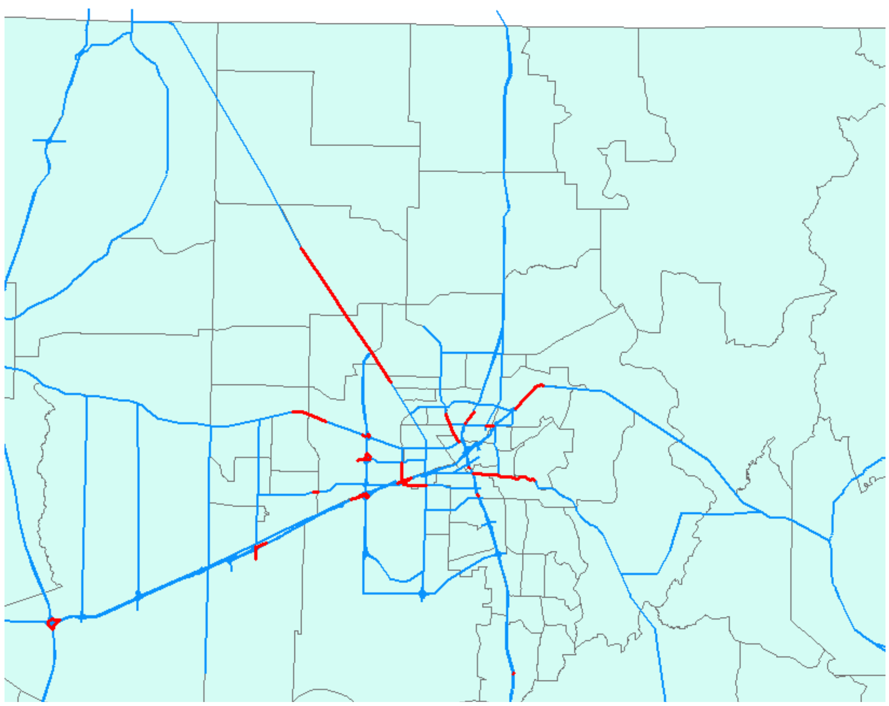

Figure A.10 – Road Network with an increased travel time of 100% Option 2

9.3. Effectively Using the QRFM to Model Truck Trips in Medium-Sized Urban Communities

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9.3.1. Abstract

The goal of this paper is to analyze the application of the Quick Response Freight Manual (QRFM) to model freight transportation in a medium sized urban community. Typically, freight transportation needs are often not included in the travel demand models developed and maintained for small and medium sized urban communities, or if freight is included in the model, it is often incorporated through rudimentary means or as an after-thought. Previously, the neglect of freight was justifiable as passenger car transportation was the primary focus of roadway improvements. However, the ever-increasing volume of freight movements, coupled with manufacturers implementing cost saving strategies such as just-in-time delivery systems, have resulted in community infrastructure needs and investment decisions tools that should include freight volumes. This paper contains a case study using a medium sized urban area travel model and the QRFM trip generation methodology to provide a framework for freight planning in small communities that can be used to improve resource allocation decisions.

9.3.2. Introduction

The efficient and effective movement of freight is a critical component in the transformation and growth of the economy. Often, transportation planners use urban transportation planning models, which are representations of the existing transportation infrastructure in order to determine the impacts of future changes [*1*]. These planning models are developed and validated to reflect existing traffic volumes and patterns. After validation, these models are used to forecast daily traffic volumes on primary arterials and freeways to evaluate changes in roadway infrastructure and socio-economic characteristics. In small and medium sized urban communities, proper roadway infrastructure resource allocation decisions based on data obtained from the community's travel demand model and long-range transportation planning process could potentially be the determining factor between the continued community growth or stagnation.

With this level of importance being based on the modeling process, it is critical that models provide the best forecast of future conditions. Unfortunately, freight transportation requirements are often not included in travel demand models developed and maintained in small communities, or else, freight trips are included in these models through very simplified methodologies.

This paper examines the potential to use available freight trip generation factors and a distribution scheme to determine freight transportation demand appropriate for incorporation into a small community travel demand model. First, the paper presents background into travel demand forecasting and the Quick Response Freight Manual (QRFM) trip generation equations [*2*, *3*]. Next, the paper applies the model through a case study of Huntsville, AL, a small community in the north-central portion of the state. A statistical analysis of the QRFM technique applied to the network using a variety of distribution schemes improves the forecasting ability. The paper concludes that the proper application of freight transportation needs into the travel demand modeling process can produce improved model results, which should lead to improved investment decisions for the community.

9.3.3. Transportation Planning Background and Freight Specifics

The background for this paper focuses on the traditional four step modeling process used in most small and medium sized urban areas and specifics of the process that deal with freight. The traditional transportation planning process follows the sequential four-step methodology: trip generation, trip distribution, mode split, and traffic assignment.

The first step in the process, trip generation, uses the socio-economic data, aggregated to traffic analysis zones within the study area, to determine the number of trips produced by and attracted to each zone in the study area [*1*]. For passenger transportation, factors that can influence trips produced from or attracted to a zone are: household income and size, automobile ownership, type of businesses, and trip purpose [*4*]. The trip generation step then converts these zonal data values into trip purposes. However, in most small and medium sized urban communities, there is no model developed for freight productions or attractions as it is time consuming and costly to survey businesses and manufacturers on their specific freight requirements.

Trip distribution connects the trip origins and destinations to develop a trip exchange matrix. Trip length and the travel direction or orientation, are the two main factors to consider. The most common method used for trip distribution is a gravity model, which is based on Newton’s law [*1*]. The gravity model predicts that trip interchanges between zones are directly proportional to the productions and attractions in the zones and inversely proportional to the spatial separation between zones [*4*]. In other words, zones with more activity or businesses are more likely to exchange more trips, and zones with greater distances between them are likely to exchange fewer trips. For freight, it is expected that the trip distribution would be similarly performed.

Modal split is used to estimate how many trips will use public transit and how many trips will use private vehicles, typically using a logit model [*4*]. However, this step of the process is generally ignored in small and medium sized communities, as transit ridership is not significant. With freight however, this step would contrast truck versus alternative mode of shipment (rail, water, and air). As limited availability for alternate freight shipping models often exists in medium sized communities, this step is not usually included.

Traffic is then assigned to available roadways or transit routes, typically following Waldrop's equilibrium theorem, or some approximation of equilibrium, determining the amount of traffic to allocate to each route. Under equilibrium conditions traffic arranges itself in congested networks in such a way that no individual trip maker can reduce his path costs by switching routes [*4*]. Regarding freight, it is not necessarily logical to assume freight shipments will likely change their route due to congestion effects, at least not off the major roadways within the communities.

To overcome the absence of freight in transportation models, the original Quick Response Freight Manual (QRFM) and updated version QRFM II, were prepared for the Federal Highway Administration [*2*], [*3*]. The objective of the reports were to provide background information on the freight transportation system and factors affecting freight demand to planners who may be relatively new to this area and to provide simple techniques and transferable parameters that can be used to develop commercial vehicle trip tables which can then be merged with passenger vehicle trip tables developed through the conventional four-step planning process. The QRFM report identifies trip generation factors that define production and attraction values manageable within a small community. To support trip distribution, the QRFM provides a series of friction factors that can be incorporated into the gravity model to specify the expected length of freight movements. Figure 1 provides the trip generation equations and Figure 2 presents the friction factor equations.

Generator	Commercial Vehicle Trip Destinations (or Origins) per Unit per Day			
	Four-Tire Vehicles	Single Unit Trucks (6+ Tires)	Combinations	TOTAL
Employment *				
• Agriculture, Mining and Construction	1.110	0.289	0.174	1.573
• Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	0.938	0.242	0.104	1.284
• Retail Trade	0.888	0.253	0.065	1.206
• Office and Services	0.437	0.068	0.009	0.514
Households	0.251	0.099	0.038	0.388

* If employment data is available only in terms of retail and non-retail employment, the trip generation rates shown above for non-retail employment should be weighted by the following national employment average percentages: (1) Agriculture, Mining and Construction - 10.9%; (2) Manufacturing, Transportation, Communications, Utilities and Wholesale Trade - 29.5%, (3) Office and Services - 59.6%.

FIGURE 1 Trip Generation rates from the original QRFM [*2*].

Four-tire commercial vehicles:

$$F_{ij} = e^{-0.08 * t_{ij}}$$

Single unit trucks (6+tires):

$$F_{ij} = e^{-0.1 * t_{ij}}$$

Combinations:

$$F_{ij} = e^{-0.03 * t_{ij}}$$

FIGURE 2 Friction factors from the original QRFM [*2*].

9.3.4. Case Study: Huntsville, Alabama

Huntsville, Alabama (area population approximately 300,000) was the case study location selected to analyze the incorporation of freight into the modeling process. For this research, the transportation network for the City of Huntsville was acquired from the Huntsville Metropolitan Planning Organization (MPO) (Figure 3) [5].

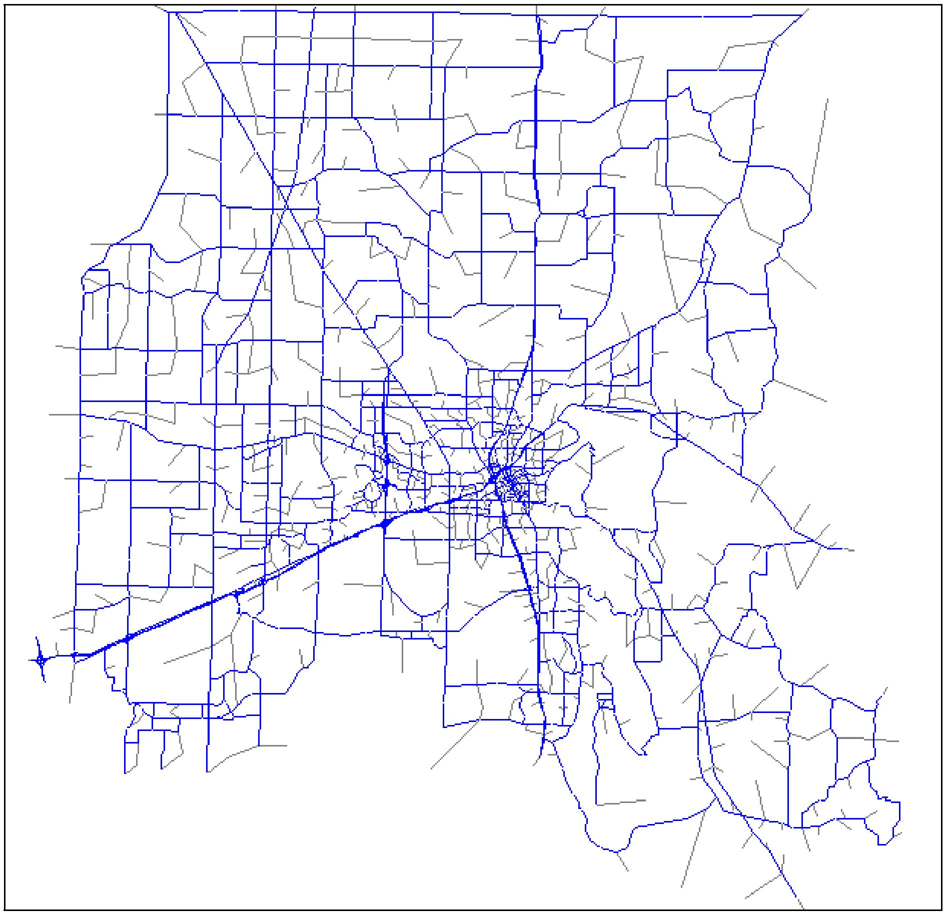

FIGURE 3 Huntsville, AL planning model.

The research was performed by applying the trip generation rates obtained from the QRFM to the socio-economic data collected by the Huntsville MPO. For each zone, the socio-economic data were converted into freight trips using the rates provided from the QRFM. To validate the application of the trip generation model, a thematic map showing the amount of non-retail employment within each traffic analysis zone combined with a dot density plot of the freight trips (see Figure 4).

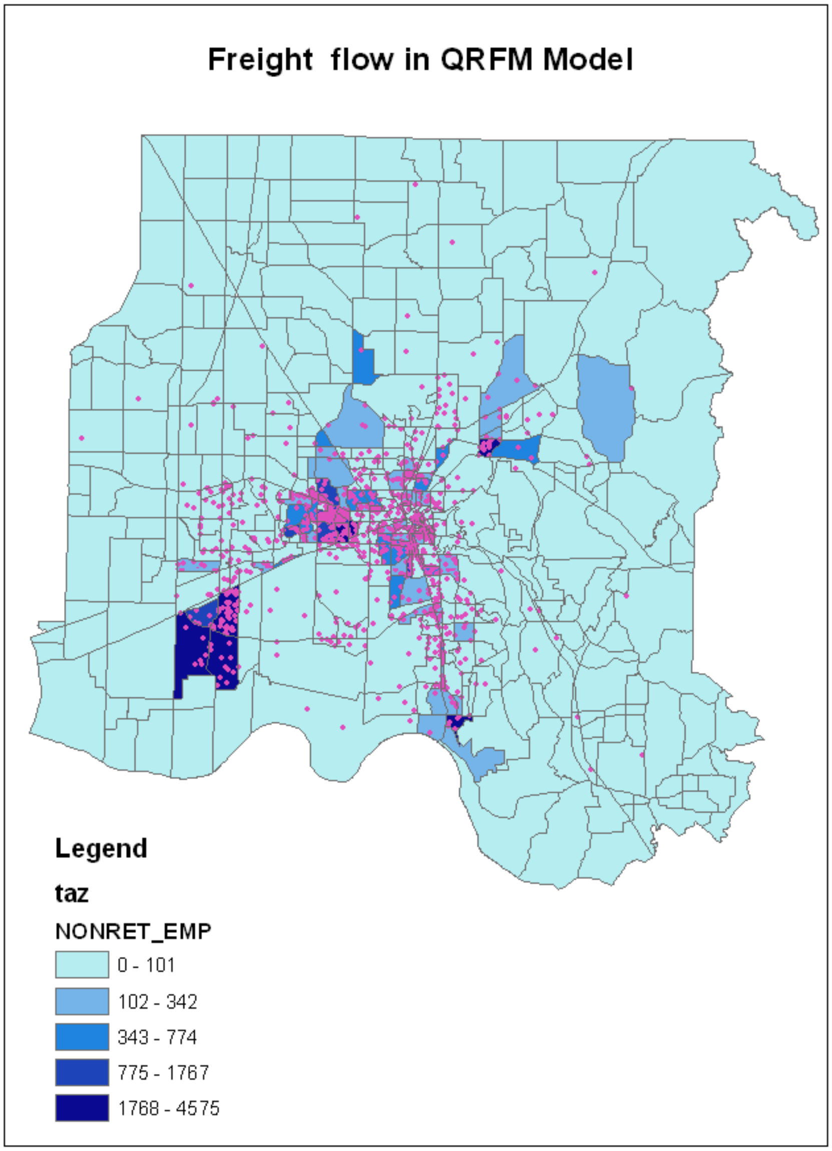

FIGURE 4 Freight trips versus non-retail employment.

9.3.5. Statistical Analysis

The analysis of the model for calculating truck trips was performed by developing a freight trip purpose and designing a series of travel modules to perform trip distribution and assign the freight trips to roadways in the model network.

Initially, the trips produced and attracted were distributed using a gravity model approach that treats the trips similar to other passenger related trip purposes in the model. Essentially, the freight trips produced in the study area are distributed to zones within the study area. Truck counts at external stations in the model were included as a separate trip purpose and distributed between themselves. Regarding assignment, the freight trips were assigned to the network without the passenger cars, ensuring that the freight trips would not be assigned to minor roadways in the community that would not be expected to serve commercial movements.

Accuracy of the assignment of truck volumes was established by the analysis of the model assignment to actual truck volumes as reported by the Alabama Department of Transportation (ALDOT). The first examination included the development of scatter plot with actual volume of trucks versus the QRFM assigned model volumes. The scatter plot is shown in figure 5.

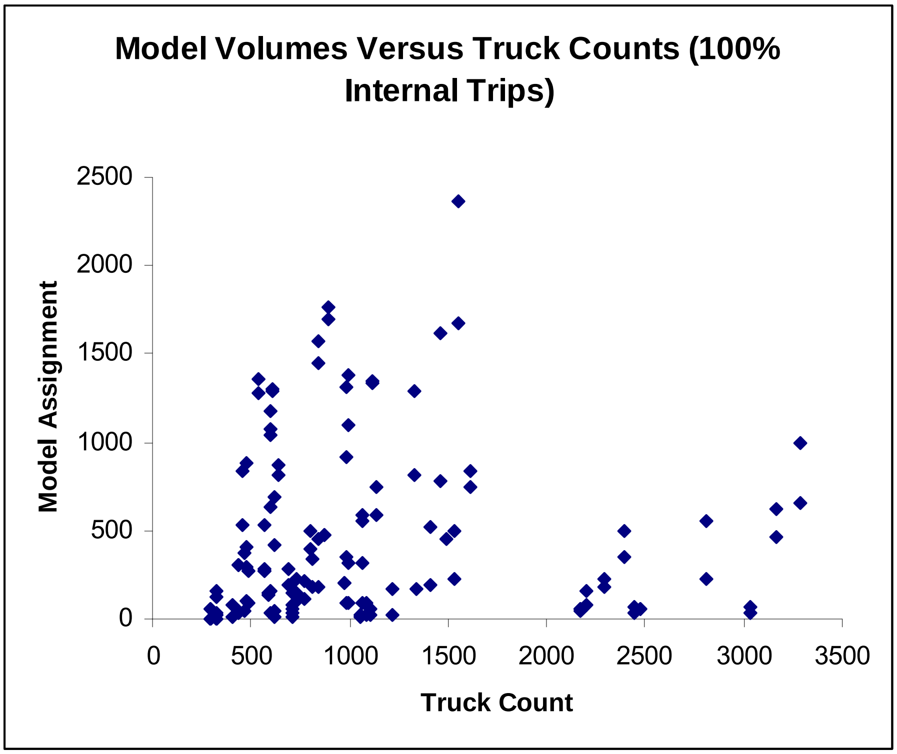

FIGURE 5 Scatter plot of truck traffic.

To statistically measure the difference between the model assignments using the QRFM trip generation methodology and the actual truck counts, the Nash Sutcliffe's (NS) coefficient was employed [*6*]. The Nash-Sutcliffe value can range from $-\infty$ to 1. An efficiency of 1 (*E*=1) corresponds to a perfect match of forecasted counts to the ground counts. An efficiency of 0 (*E*=0) indicates that the forecasted values are as accurate as the mean of the ground counts, whereas an efficiency coefficient less than zero ($-\infty<E<0$) occurs when the forecasted mean is less than the ground values. In other words, this coefficient gives us a measure of scatter variation from the 1:1 slope line of modeled truck counts vs. the ground counts. The more deviation of points from the 1:1 slope line, the lower the coefficient. The greater the NS-value is the better the forecast. It can be calculated using the formula:

$$\textbf{NS-COEFFICIENT} = 1 - \frac{\sum_1^n (ModeledCounts - GroundCounts)^2}{\sum_1^n (GroundCounts - MeanGoundCounts)^2}$$

The result of applying the Nash-Sutcliffe test to the data from the Huntsville, Alabama case study generated an efficiency coefficient of -1.45. The negative value indicates that taking an average value of the truck counts from ALDOT would actually be a better prediction of the truck flows than the travel demand model.

Further statistical tests were performed to determine whether the data obtained from the travel demand model were similar to the actual truck counts. MINITAB™ statistical software was used to analyze the data employing the analysis of variance (ANOVA) test and resulted in the conclusion that there is statistical evidence to suggest that actual truck volumes are different from the model assigned volumes.

In an effort to improve the results, an alternate trip distribution scheme was employed. The alternate distribution scheme was developed from the results of a study being performed in the Mobile, Alabama community. The flow patterns collected from the Mobile area are shown in Table 1.

TABLE 1 Freight locations for Mobile area.

Freight Origin/Destination Location	Origins	Destinations
Within Mobile County	14.5%	16.4%
Outside Mobile County	84.5%	80.7%
Local Port	1.0%	2.8%

From Table 1, it can be seen that the External-Internal (E-I) truck trips and Internal-External (I-E) truck trips represent over 80 percent of the total truck volume in Mobile, while the Internal–Internal (I-I) truck trips accounted for less than 20 percent. This implies that approximately 80 percent of the raw materials for the manufacturing of the finished goods are generated outside the area and approximately 80 percent of the finished products are exported outside the area.

To account for the distribution changes in the model, the modules used to run the Huntsville MPO travel demand model were adjusted to account for freight trips distributed into the community from outside, and outward from the community to points beyond the study area. An experiment was designed to include the adjustments made at four different distribution levels:

- 90 percent (E-I and I-E) and 10 percent (I-I)
- 80 percent (E-I and I-E) and 20 percent (I-I)
- 70 percent (E-I and I-E) and 30 percent (I-I)
- 60 percent (E-I and I-E) and 40 percent (I-I)

The reason for not using the 80 percent (E-I and I-E) found in the Mobile project was that the research team was unsure if Huntsville would perform similar to Mobile due to the socio-economic differences in the communities and the influence of the Port of Mobile.

The E-I and I-E truck trip implementation was developed using the total number of trucks crossing the study area boundary. The total number of trucks at the boundaries was split by percentage into the number of trucks expected to enter and leave the community (E-I and I-E) and the number of trucks passing through the community. Parameters in the gravity model were derived to constrain the E-I and I-E truck numbers such that the total number of trucks at the external stations did not exceed boundary conditions. A separate gravity model was performed for the internal truck trips, but with a reduction factor used to limit the number of trips. As before, mode split was not included in the model and the truck trips were assigned to the Huntsville network without passenger cars to allow truck access to the major roadways.

A scatter plot was developed to compare actual truck count versus the trucks assigned from the model for each percentage split. A scatter plot for the 80 percent E-I and I-E with 20 percent internal trips is shown in figure 6. As can be seen, the results appear to align much closer to the 1:1 slope with the trip distribution adjustment.

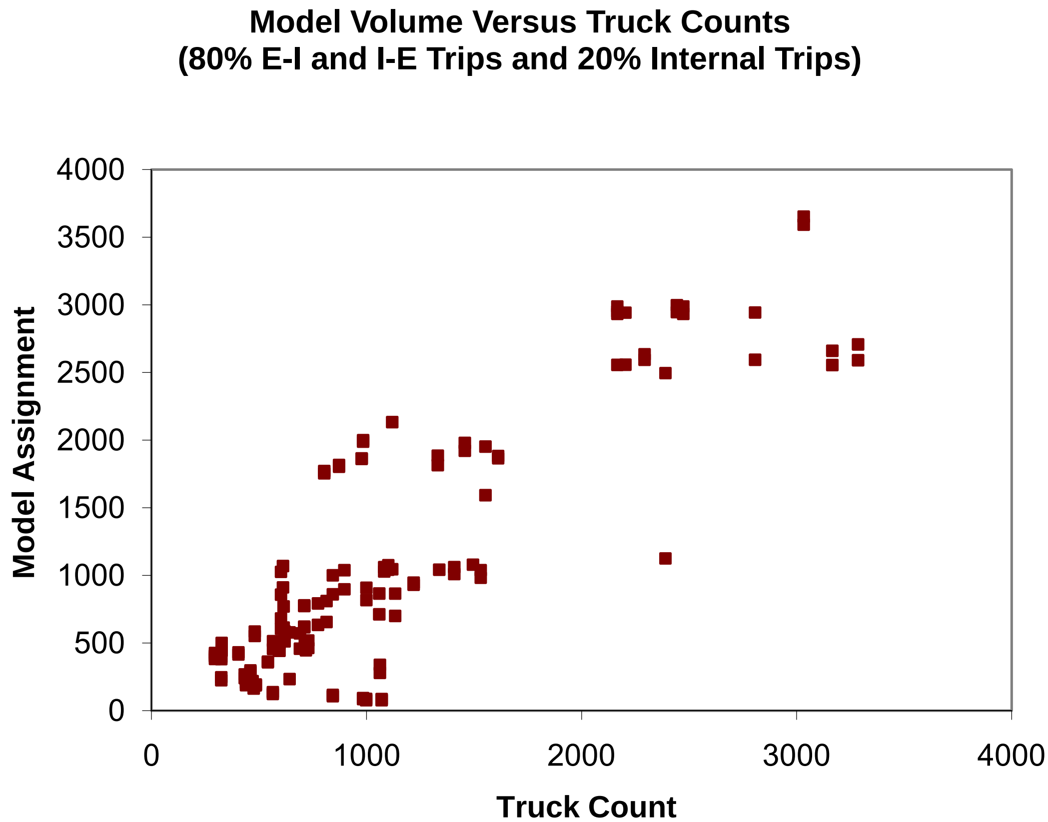

FIGURE 6 Scatter plot of truck traffic with distribution modification.

For comparison purposes, the Nash-Sutcliffe efficiency coefficient was developed for each trip distribution split. The results calculated from the model output were as followed:

- NS Coefficient=0.59 for the 90 percent (E-I and I-E) and 10 percent (I-I)
- NS Coefficient=0.61 for the 80 percent (E-I and I-E) and 20 percent (I-I)
- NS Coefficient=0.62 for the 70 percent (E-I and I-E) and 30 percent (I-I)
- NS Coefficient=0.61 for the 60 percent (E-I and I-E) and 40 percent (I-I)

As the results show, there is little difference between the models. To improve the analysis, additional distributions could be incorporated, but the current level of accuracy would be sufficient to justify incorporation. However, all models performed significantly better than using the 100 percent internal distribution.

Further statistical tests were performed to know whether the data obtained from the travel demand model were similar to the actual truck counts. MINITAB™ was used to analyze the new data using an analysis of variance (ANOVA) test resulted in the conclusion that there is no statistical evidence to suggest that actual truck volumes are different from the model assigned volumes. Further, performing a Mann-Whitney non-parametric test shows that it is likely that the QRFM data comes from the same population as the actual data.

9.3.6. Conclusion and Recommendations

The purpose of this paper was to examine the use of the QRFM parameters for trip generation and a distribution scheme to effectively incorporate freight trips into a medium sized travel demand model. Based on the case study and analyses performed, the methodology was found to be effective in replicating actual truck traffic, especially when the distribution of truck trips into and out of the study community was explicitly modeled. The statistical comparison of the actual truck counts versus the assigned truck volumes from the travel demand model concluded there was no statistical difference between the two values.

Overall, this paper examined the application of trip generation parameters from the QRFM and a distribution scheme designed to allow for freight to be incorporated into a medium sized travel demand model. Appropriate use of the QRFM parameters coupled with the distribution of trips into and out of the community can provide a mechanism to support urban freight modeling.

9.3.7. References

1. Dickey, J. *Metropolitan Transportation Planning.* Second Edition. Hemisphere Publishing Corporation, Bristol, PA. 1983.

2. Cambridge Systematics, Inc. Quick Response Freight Manual. Federal Highway Administration. DTFH61-93-C-00075, DTFH61-93-C-00216. September 1996.

3. Cambridge Systematics, Inc. Quick Response Freight Manual II. Federal Highway Administration. Publication No. FHWA-HOP-08-010. September 2007.

4. J.de D. Ortuzar and L. G. Willumsen. *Modeling Transport.* Second Edition. John Wiley and Sons, New York, NY. 1994.

5. Information provided by Mr. James Moore, Transportation Planner for Huntsville, AL Metropolitan Planning Organization. April 22, 2007.

6. Nash, J. E. and J.V. Sutcliffe. River flow forecasting through conceptual models. Part I: A discussion of principles. *Journal of Hydrology*. 10, 282-290, 1970.

10. Conclusions and Next Steps

There were two main topics to be considered when this research began, the development of freight analysis zones and the continued development of ATIM. As the research progressed, it became obvious that there was something larger than simply disaggregating national data through freight analysis zones and that the ProModel platform for ATIM was restricting the development of the simulation into the decision analysis tool that all thought it could be.

The freight analysis zone research led to the development of a methodology for integrating freight into the transportation models and plans at the state level and at the Metropolitan Planning Organization (MPO) level. It is believed that this Freight Planning Framework (FPF) is a significant step forward in freight planning and modeling. There is also a significant amount of research to do to refine each individual part of the FPF process. This will be a main focus as the UAH research team continues on the path to improve the ability of states, regional planning offices (RPOs) and MPOs to integrate freight considerations into plans and activities.

The limitations encountered in the discrete event simulation of the Alabama transportation network led to a breakthrough in the overall development of the tool. The step made to revise the ATIM and develop Version 2.0 in a Java based environment provides significant opportunities for tool enhancement. An agent-based system will provide significantly upgraded capabilities to communicate transportation issues to stakeholders at all levels. There will be significant resources applied to the refinement and continued development of the ATIM V2.0 tool.

Specific items the UAH research team will pursue in the FY2008 research will include:

Research & Development of the Freight Planning Framework (FPF)
The Freight Planning Framework (FPF) builds upon the traditional four-step transportation planning process by creating a forward looking approach to the trip generation issues described previously. The following subtasks present the approach and methodology proposed to overcome the problems with the traditional four-step process, and the interrelationships of the systems approach.

<u>Trip Generation - Development of Freight Data and Analysis Methodologies and Tools</u>
The FPF methodology takes freight flow data at the national level and structures it in a format usable for freight planning purposes at a variety of levels. This methodology is expected to be a valuable piece of the overall transportation planning toolbox in the future. As with all new ideas, significant research is needed within each component of the FPF to ensure the final product provides value added information and data to transportation planners in Alabama and throughout the nation.

The UAH research team will focus on the development of data collection, manipulation and analysis to provide input to the transportation planning process. New freight planning factors will be developed and utilized to provide more accurate input to the state and Metropolitan Planning Organization (MPO) Transportation Planner. Emphasis will be placed on data gathering methodologies utilizing public databases and industry surveys, approaches to disaggregation and clustering of data, and preparing the data for input to the transportation planning process.

Trip Distribution – Integration of Freight and Transit System Loads

Traffic Analysis Zones (TAZs) are a key component to transportation planning at all levels. Freight is not as applicable at the TAZ level. Therefore, the concept of Freight Analysis Zones (FAZs) needs to be developed to allow for the integration of the freight component into state and MPO transportation plans. The UAH research team will focus on developing appropriate planning levels for freight and how they relate to traditional TAZs. Once the planning level is determined, it is important to integrate and distribute the load on the transportation network. A second focus is the development of integration methods and techniques of freight, transit and passenger travel loads.

Modal Split and Assignment – State and Local Simulations

To overcome the limitations of the previous ProModel platform on which ATIM operated, the modeling platform must be transferred to a micro-simulation that uses an open-source programming language. The alternative chosen for development of ATIM V2.0 is a JAVA based platform, using the Discrete Event Simulation Module. This allows ATIM to overcome many of the limitations the tools are currently experiencing -- including the incorporation of infrastructure alternatives, improved graphics capabilities, the ability to model incidents, and queues and recovery time permitting a greater understanding of the traffic flow. This research will focus on the continued development of Version 2.0 of the ATIM model in a more flexible and expandable software.

Analysis – System Performance Measures

The final piece of the FPF is the ability to measure the performance of the transportation system. The FPF is proposed as a tool to use for continuously improving the transportation system's ability to efficiently, effectively and safely move people and freight. Improvement cannot occur if a measurement system is not in place to quantify the performance. An optimal set of metrics for use in evaluating the performance of multimodal transportation systems is needed to direct the application of resources in addressing problems in the transportation system that best serves the users. The multimodal transportation system includes the roadway network used by passenger cars, mass transit systems, freight vehicles, the railway network used for passenger and freight movement, and the navigable inland waterways.

Access to an efficient transportation system is a key element to the promotion of economic growth and development within a region. It is essential that the performance measures used by Alabama be chosen with that goal in mind. It is also important to choose metrics appropriate to the needs of the intended audience: the state government, the state legislature, DOT management and staff, other agencies, elected officials, and the public at large. An optimal set of performance metrics will provide the ability to determine the impact of improvements to the transportation system performance over time, and compare the results to short-term and long-term goals and objectives. This research focus is on the development and evaluation of transportation system performance measures at the state and MPO level.

Evaluation of Alternative Transportation Modes for Improving Transportation and Freight Flow

Freight and passenger traffic are both users of the same transportation networks. If analyzed and optimized individually, the overall system will more than likely be sub-optimized. Therefore, it is important to consider the effects of transportation infrastructure decisions and the decisions made by users on the performance of the entire system.

Evaluation of Commuter Rail Service Application Between Birmingham, AL and Montgomery, AL.

I-65 from Birmingham to Montgomery is one of the most congested facilities in Alabama. Research is needed on the analysis of a potential commuter rail application between the two MPOs. Additional analysis will evaluate the potential improvements to the flow of freight and passenger traffic as a result of the new travel option.

Evaluation of the Utilization of the International Intermodal Center in Huntsville, AL as an Inland Container Facility for the Port of Mobile.

The opening of the container port operations in Mobile, AL will have a profound impact on traffic on Alabama roadways. There should be research performed to understand the issues associated with an idea for utilizing Huntsville as an inland port in much the same way Front Royal, VA is used as a portal for the Port of Norfolk. The research team will work to bring in experts and assistance from the Port of Huntsville and the Port of Mobile, along with resources from the major rail lines servicing Alabama and the Southeast.

Enhancement and expansion of the application of continuous improvement principles for port operations

Since 2003 UAHuntsville has worked with the Alabama State Port Authority (ASPA) to apply continuous improvement concepts, primarily Lean Enterprise, to improve overall port operations. The application of these continuous improvement concepts have included strategic planning, training, and implementation in a wide range of port operations such as coal terminal operations, short-line railroad operations, general cargo operations, and support functions such as maintenance, garage, and corporate accounting and payroll.

In FY 07, the successes and lessons learned from this extensive experience were integrated into an 8-hour Lean Principles for Port Operations training course. Container terminals are a vital part of many of the nation's port operations. An enhancement of the current Lean Principles for Port Operations training course to include experience and examples relative to container terminal operations would make the training more beneficial and applicable for all ports. The current 8-hour training course provides an excellent overview of the benefits of applying continuous improvement concepts at port operations; however, expanding the training offerings to include more detailed instruction on the "how-to" aspect of implementation would allow ports to develop internal resources to assure the sustainment of improvements.

To enhance and expand the continuous improvement training for port operations, the following items should be undertaken:

<u>Enhancement of Lean Principles in Port Operations Training Class to Include Container Terminal Operations</u>

- Research and data gathering through literature surveys and visits to container terminals for observation
- Participation in lean improvement events at a container terminal
- Documentation and integration of knowledge and experience gained through observation and participation at container terminals to make the Lean Principles at Port Operations training class more comprehensive.

<u>Expand Lean Training Offerings Customized for Port Operations.</u>

The current 8-hour training course provides an excellent education on Lean Enterprise principles. Expanding the training to include modules on how to implement Lean tools specifically beneficial to port operations is imperative to developing the internal resources necessary to sustain the long-term benefits of a true Lean transformation. Topics included in the expanded training include value stream mapping, workplace organization (5S), standardized work, total productive maintenance, and quick changeover principles.

Student Research Initiatives

Significant research is being performed by graduate students at UAH in multiple disciplines. This has generated excitement in the study of transportation issues. It is important to continue this wave of enthusiasm.

Appendix I – Papers and Presentations

1. Published Journal Articles

1.1. "A Simulation Approach to Evaluating Productivity Improvement at a Seaport Coal Terminal," Harris, G. A, A. Holden, B. Schroer, and D.P.F. Moeller; *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 2062/2008, pp. 19-24.

2. Published Conference Proceedings

2.1. *Huntsville Simulation Conference*

2.1.1. "Simulating the Impact of Increased Truck Traffic through Tunnel Crossing Mobile River," Gregory Harris, Mike Spayd, Michael Anderson and Bernard Schroer, University of Alabama in Huntsville, Huntsville, AL USA, and Dietmar P.F. Moeller University of Hamburg, Hamburg, Germany

2.1.2. "Container Security Inspection: Simulation to Evaluate Various Container Sampling Plans on Port Operations," Gregory Harris, Maruf Rahman and Bernard Schroer, University of Alabama in Huntsville, Huntsville, AL USA, and Dietmar P.F. Moeller University of Hamburg, Hamburg, Germany

2.1.3. "Conceptual Framework for Simulating Seaport Terminals," Bernard Schroer, Maruf Rahman, and Gregory Harris, University of Alabama in Huntsville, Huntsville, AL USA, and Dietmar P.F. Moeller University of Hamburg, Hamburg, Germany

2.1.4. "Container Terminal Simulation," Gregory A. Harris, Lauren Jennings and Bernard J. Schroer, University of Alabama in Huntsville; Huntsville, AL, and Dietmar P.F. Moeller, University of Hamburg; Hamburg, Germany

2.2. *2nd Annual National Urban Freight Conference*

2.2.1. "Using Simulation to Evaluate and Improve the Operations of a Seaport Container Terminal," Gregory A. Harris, Lauren Jennings and Bernard J. Schroer, University of Alabama in Huntsville; Huntsville, AL, and Dietmar P.F. Moeller, University of Hamburg; Hamburg, Germany

2.3. *10th International Conference on Application of Advanced Technologies in Transportation*

2.3.1. "Application of Simulation to Improve Volume through a Seaport Coal Terminal," Harris, Gregory A., Anthony Holden, Bernard Schroer and Dietmar P.F. Möeller. *Proceedings of the 10th International Conference* *on Application of Advanced Technologies in Transportation,* Athens, Greece, May 2008.

2.3.2. "Using a Gravity Distribution Model and Discrete Event Simulation to Enhance Freight Planning," Harris, Gregory A., Michael D. Anderson and Heather R. Shar. *Proceedings of the 10th International Conference on Application of Advanced Technologies in Transportation,* Athens, Greece, May 2008.

2.3.3. "Using a Federal Database and New Factors for Disaggregation of Freight to a Local Level," Anderson, Michael D., Gregory A. Harris and Niles Schoening. *Proceedings of the 10th International Conference on Application of Advanced Technologies in Transportation,* Athens, Greece, May 2008.

2.4. *Transportation Research Forum Annual Conference*

2.4.1. "Developing Freight Analysis Zones at a State Level: A Cluster Analysis Approach." Harris, G.A., Farrington, P.A., Anderson, M.D., Schoening, N., Swain, J., *Proceedings of the Transportation Research Forum Annual Conference*, Fort Worth, TX., March 17-19, 2008.

2.4.2. "Cost Analysis of Proposed Truck-Only Highway Segments in Alabama." Anderson, M.D., Youngblood, A.D., Harris, G.A., *Proceedings of the Transportation Research Forum Annual Conference*, Fort Worth, TX., March 17-19, 2008.

3. Submitted Journal Papers

3.1. "Simulation of an Intermodal Container Center Served by Air, Rail and Truck," Bernard J. Schroer, Gregory A. Harris and William Killingsworth, University of Alabama in Huntsville, Huntsville, AL USA, and Dietmar P.F. Moeller, University of Hamburg, Hamburg, Germany
SUBMITTED to the JOURNAL of ADVANCED TRANSPORTATION

3.2. "Using FAF2 Data to Analyze Freight Impact of Interstate 22," Michael D. Anderson, Mary Catherine Dondapati, and Gregory A. Harris, The University of Alabama in Huntsville, Huntsville, AL, USA
SUBMITTED to the JOURNAL of TRANSPORTATION RESEARCH FORUM

3.3. "A Freight Planning Framework," Gregory A. Harris and Michael D. Anderson, University of Alabama in Huntsville, Huntsville, AL, USA
SUBMITTED to TRANSPORT POLICY

4. Accepted Conference Papers

4.1. "Developing Freight Analysis Zones at a State Level: A Cluster Analysis Approach," Gregory A. Harris, Phillip A. Farrington, Michael D. Anderson, Niles Schoening, James Swain, and Nitin Sharma, University of Alabama in Huntsville, Huntsville, Alabama, USA
Transportation Research Board Annual Meeting, January 2009

4.2. "Resources to Minimize Disruption Caused by Increased Security Inspection of Containers at an Intermodal Terminal: Application of Simulation," Gregory A. Harris, Bernard J. Schroer, Michael D. Anderson, University of Alabama in Huntsville, Huntsville, AL, USA, and D.P.F. Moëller, University of Hamburg, Hamburg, Germany
Transportation Research Board Annual Meeting, January 2009

4.3. "The Application of Lean Enterprise to Improve Seaport Operations," Nicholas Loyd, Lauren C. Jennings, Jeff Siniard, Michael L. Spayd, Anthony Holden, and George Rittenhouse, University of Alabama in Huntsville, Huntsville, AL
Transportation Research Board Annual Meeting, January 2009