ESTIMATING FREIGHT COSTS OVER A MULTI-MODAL NETWORK: AN AUTO INDUSTRY SUPPLY CHAIN EXAMPLE

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SUMMARY

The objective of this research is to implement multi-modal cost calculations on a freight transportation network, in order to estimate the cost of freight shipments from parts suppliers to original equipment manufacturers (OEMs), and from OEMs to final consumers involved in the automobile manufacturing industry supply chain. The research will describe gaps in the current freight cost estimation literature, determine the strengths and weaknesses of current practices, and offer possible improvement strategies. The necessary components for this research include: a multi-modal (highway-rail-water-air) network database, the geocoded locations and activity levels of auto industry parts suppliers and OEMs; freight movement cost functions; information on the modes and vehicle/vessel types used for the shipment of certain commodity types; and distance-based travel costs per-mile for these modes. A product of this line of research will be a method that other industries, in other locations, might also use to determine overall freight transportation costs throughout an entire supply chain. The present research effort provides an example using data gathered on the automobile manufacturing industry centered in Georgia and Alabama. The network-based freight costs derived in this research should also be useful in other applications, including the estimation of origin-to-destination flows, as well as in the estimation of transportation costs used in regional and statewide freight planning models.

CHAPTER 1

INTRODUCTION

Knowing the costs of shipping an item from point A to point B is important for any company. It is especially important within the automobile manufacturing industry supply chain, which contains a complex network of suppliers, in order to manage overall costs and improve efficiency. Therefore, it is advantageous for companies within this industry to understand all of the costs involved in shipping various commodities to all locations associated with the supply chain, in order to make sound, financial decisions. Determination of all of the variables involved in the calculation of costs requires significant effort, and involves consideration of many factors that are dependent on the type of movement under consideration: including the mode and the vehicle type, the service type, and the class of commodity being shipped.

The modes of choice for shipping particular goods include: truck, rail, water, and air travel. The type of vehicle used depends on the class, commodity, and availability of network connectivity for that mode. Service type is dependent on many factors related to the items being shipped, including the trip origin and destination, whether items are being shipped a short distance or on a long haul, and the time sensitivity of the commodity being delivered. The class of commodity being shipped can vary a great deal, depending on the stage of the origin-destination movement within the overall product supply chain.

The costs of shipping an item from an origin to a destination are a function of time, distance, and the reliability of service. Variables that are crucial for determining costs of shipping items include: fuel costs; labor costs; and maintenance and operation costs. Fuel costs vary with the current price of oil, and with changes in international business relations, among other factors related to the current state of the economy. Labor costs vary due to factors that are specific to the vehicle and service type, or by regulations specified by workers' unions. Operation and maintenance costs, collectively, can include a number of factors, including: vehicle and driver insurance; vehicle maintenance (e.g. lubricating oil replacement), and parts replacement (e.g. tire replacement costs).

As noted in the Saratoga Springs Conference "Data Needs in the Changing World of Logistics and Freight Transportation" (Meyburg and Mbwana, 2002), and reiterated in the Transportation Research Board's Special Report 267 (TRB, 2003), obtaining detailed, and at the same time, representative and statistically-robust freight cost data from public domain sources is a well-known problem faced by transportation planners and researchers working in the public sector. There is also, as a result, a lack of consistency in the current research literature regarding freight cost calculations with differences in both which cost elements are included in the calculations, and in the level of detail used to derive specific cost elements. For example, some cost estimates disregard the time lost during shipment due to factors such as traffic congestion, while others fail to include the costs of empty backhauling. Furthermore, some freight movement studies rely on a standard published freight rate, with little regard for the specific parameters involved in rate selection.

An ideal cost model would have the ability to measure costs associated with moving any commodity, by any vehicle or mode type, any distance, at any time, from any origin to any destination on a network. One goal of this research is to examine the current literature regarding current cost estimation models, in an attempt to determine what is needed for a company or industry to make sound, financial decisions regarding the costs of shipping various commodities, by different modes of transport. Since such costs vary a great deal across different industries, a single industry is selected for further analysis. Specifically, the automobile manufacturing industry is selected, as an example in which many different modes of transport are used at many different stages, in order to move a very large and diverse set of raw, as well as pre-processed materials from their origination points to a common manufacturing site, and then transporting the finished product (e.g. a properly assembled, and functioning automobile) from the factory to the showroom.

The purpose of this research is to establish a model for calculating representative operational costs for freight movement within the automobile manufacturing industry supply chain. A freight planning model can provide large corporations, or even State departments of transportation, a basis for analysis. The model can also provide the State DOTs with an understanding of costs from a business perspective. Furthermore, measuring costs will help in effectively forecasting freight demand and traffic flows, which is a common goal for transportation planners.

Much of the current freight analysis literature uses statistical cost models as the basis for estimation. This research, however, will focus on engineering cost models as the basis for estimation. Also, because trucking is ubiquitous, this research will initially focus on the automobile manufacturing industry supply chain's reliance on trucks as the main mode of transport for its resource inputs.

The geographic area of focus for this research is the Southeastern United States (US); focusing on freight routes in Georgia and Alabama, specifically. The Kia Motor Company facility located in West Point, Georgia is selected as the basis for this supply chain study. This empirical study is meant to be illustrative only. While data limitations prevent the present study from being definitive of the actual costs incurred, the publicly available data sources used, allow for the reasonableness of the costs estimates produced to be evaluated against other literature and data sources on the subject. The purpose here it to determine: (a) what data sources are available and are needed to estimate freight supply chain costs, and (b) the necessary steps and level of effort required to do so. Following a review of the literature on freight movement cost components and appropriate cost estimation formulas (Chapter 2), selected cost formulas are used to derive a set of mode-specific line haul costs, which are in-turn, applied to an empirical study of an automobile manufacturing supply chain.

CHAPTER 2

LITERATURE REVIEW OF FREIGHT COST MODELS

Currently, there are numerous ways to calculate the costs of shipping various goods by different modes. However, the data used in these cost calculations can be difficult to obtain, and some modes have more readily-available data than others. Estimating truck shipping costs tends to be a more difficult feat than estimating rail or water shipping costs because, although many freight carriers provide overall shipping rates, the underlying costs of these rates are difficult to determine, and varies considerably in practice. Thus, several of the current methods typically take the form of regression analyses that rely on statistics related to shipping costs. These statistical methods, such as truck rate models, are generally used to determine the value of time when shipping a good from an origin to a destination.

2.1 Truck Freight Cost Models

It is a common theme for freight transportation researchers to develop cost models in order to aid in the development of sound transportation policy strategies. In a study by Hussein and Petering (2009), it was stated that: "good knowledge of shipping costs is vital to the formulation of effective public policy" (p. 3). Hussein and Petering (2009) evaluated several data sets in this particular study, including: the US Census Bureau Data Sets; the Commodity Flow Survey; the Vehicle Inventory and Use Survey; the Bureau of Transportation Statistics; the North American Trans-border Freight Database; and the Freight Analysis Framework (p. 2). Hussein and Petering (2009) considered the following variables for estimating costs in the model chosen for this particular study: fuel, labor, vehicle depreciation, maintenance, tire costs, loading and unloading costs, insurance, indirect (overhead) costs, and "extra" costs (such as fees associated with shipping hazardous materials). The authors used a set of formulas to estimate costs, and then compared these costs to actual reported costs. Studies comparing modeled to "observed" costs are common throughout the literature on the subject; where "observed" may refer to either costs reported as part of a government or industry-mandated data collection exercise, or reported in the form of responses to survey instruments.

Statistical methods are commonly used in cost calculation studies. In one study by Levinson, Corbett and Hashimi (2005), four different statistical models were used: a linear regression model, a Cobb-Douglas model, a Trans-log model, and the Box-Cox model. These models were used to determine if the results from a survey of Minnesota truck drivers' reactions to Spring Load Restrictions were perceived to increase shipping costs for freight companies, and to determine if these perceptions were comparable to the actual shipping costs incurred by those companies. The results from using the Cobb-Douglas model were closest to the results from the survey data (p. 10).

Survey data was used in a similar study where data availability was limited, and where data was compared with current cost data. In a study by Smalkoski and Levinson (2003), the costs of operating commercial freight lines was estimated based on survey data, and the results were then compared to estimations based on models. The survey data suggested that economies of scale exist within trucking, such that, as input increases, the per unit costs decrease. This survey was also used to determine if Spring Load Restriction laws in Minnesota were perceived to have an effect on costs for trucking companies. After obtaining the survey data, several models were run to estimate costs similar to the survey results. An operating costs model was created where "fuel, repair and maintenance, tire, depreciation, and labor cost are the most important costs that are considered in the estimation of operating cost per kilometer" (p. 4).

Engineering models are another way in which overall shipping costs can be calculated. The accuracy of this method relies on the variables chosen, and the weights associated with each variable. Engineering cost models are often used when rate data are unavailable, or when the data are unreliable, or lacking explanation. Within the literature in which engineering cost models were used, the variables chosen vary from one study to the next, depending, to a large extent, on the context of the study and the availability of particular data. In a study by Barnes and Langworthy (2003) overall truck shipping costs were estimated, to provide information for a benefit-cost analysis associated with the construction of a proposed highway. The components of costs were determined to be: fuel, maintenance (tires, oil, and routine work), unanticipated repairs, and vehicle depreciation costs (p. 2).

Several studies regarding cost calculation methods incorporate an economic-engineering approach, weighing the associated costs and benefits of engineering projects. A study by Berwick and Farooq (2003) used the economic-engineering approach to identify cost components for a new engineering firm. In this study, it was stated that: "a weakness of the economic-engineering approach is that results are based on average values of input prices and resource usage, and are accurate for a limited population" (p. 1).

In the Berwick and Farooq (2003) study, the variable costs that were outlined included: tire, fuel, maintenance and repair, labor and total variable costs. Fixed costs include: equipment costs, licensure and taxes, insurance and management, and overhead costs (p. 8). In terms of the fixed costs: "these values are based on annual costs [which are then converted to cost-per-mile]" (p. 16). Nine cents per mile was given as the default maintenance and repair costs (p. 26), which is slightly lower than maintenance and repair costs used in this study (Chapter 4).

In terms of fixed costs examined in the Berwick and Farooq (2003) study, equipment depreciation and return-on-investment were also considered. “The cost of using a capital asset results in depreciation. Salvage value depends on miles driven, and the equipment condition” (p. 27). Management costs are considered short-run, fixed costs and include: management and administration staff, and overhead costs, advertising and communications equipment costs, office space and equipment costs (p. 29).

There were many assumptions used in the Berwick and Farooq (2003) study, including an estimated working life of a truck of five years, and ten years of working life for a trailer. Tire costs were also adjusted based on the assumption that: “tire life decreases by about .7 percent for each one percent increase in weight” (p. 35). The authors conclude with the statement: “the shorter the trip, the greater the impact of loading and unloading time on cost” (p. 38). This study provided the basis for the development of appropriate cost calculation formulas used in this research, which will be discussed in further detail in the methodology section.

The cost functions in the literature vary based on the prospective usage, (e.g. engineering purposes, planning purposes, policy purposes). Much of the literature on engineering cost calculations for shipping goods by truck provides a generic cost, regardless of load-carrying capacity, or vehicle configuration. Barnes and Langworthy (2003) stated that “while there are obviously many different sizes and types of trucks, we estimate a single, composite value to account for all of them. There does not seem to be much information on how types of trucks differ from each other” (p. 8). Although this method of generalizing truck costs based on a lack of relevant data sources may be reasonable for some applications, it produces a method that does not take into account the often significant cost differences between mode and vehicle types.

Based on the current literature on estimating costs for shipping goods by truck, the main components of overall costs include, but are not limited to: fuel costs; labor costs and operations and maintenance costs. There are numerous variable costs inherent in these components, including: vehicle type: (body type, gross vehicle weight, and length); cargo type, distance: (long-haul or short-haul); fuel type: (mainly diesel, but gasoline and also natural gas, and electric vehicle alternatives are now available); tire costs, service type: (truckload versus less-than-truckload); private carriage, or for-hire; administrative costs: (insurance, taxes, tolls, and permits); and capital costs: (such as the depreciation of the vehicle). In a study by Fender and Pierce (2011), marginal costs were considered to be either "vehicle-based", made up of fuel and engine oil, lease payments, repair and maintenance, insurance, tires, permits and tolls; or "driver-based" costs, including: wages and benefits. (p. 4).

Levinson, Corbett and Hashimi (2005) found that some of the costs incurred by commercial freight lines included: licensure, insurance and interest (as fixed costs) and fuel, tires, labor, depreciation costs, and maintenance costs (as variable costs) (p.4). Levinson, Corbett and Hashimi (2005) also found that, for large fleets, the more truckloads delivered, resulted in economies of scale; while the more kilometers driven resulted in diseconomies of scale (p. 10). It was also noted that data regarding the number of backhauls (empty container trips), the amount of tons shipped, and the condition of roads used, were not considered, although these factors have been considered in other similar studies.

According to a study by Hussein and Petering (2009), truck cost estimate rates can vary between $10 and $200 per truck hour. Based on a survey of some 22,295 trucks operated by 20 different carriers, the American Transportation Research Institute (ATRI) estimated an average marginal truck operating cost of just under $60 per hour, or $1.49 per truck mile, with specialized carrier types having somewhat higher costs per mile, followed by less than truckload, and truckload carriers (Fender and Pierce, 2012). In their study, the following costs were considered: (vehicle-based): fuel-oil costs, truck/trailer costs, repairs and maintenance, fuel taxes, truck insurance premiums, tires, licensing, tolls; and (driver-based): driver pay, driver benefits, and driver bonus payments. After weighting for different types of trucking service (TL, LTL, Specialized) driver wages plus benefits accounted, on the average, for some 37% of these marginal operating costs, while rising fuel costs accounted for 31% of expenditures, and truck/trailer lease or purchase payments accounting for another 16% , in the first quarter of 2010.

Average cost figures can, however, be misleading in specific instances. For example, Wheeler (2010) provides a recent review of a number of truck freight value of time studies. The range of possible values reported is rather large, depending on study approach, as well as type of vehicle, type of carriage (e.g. private versus for-hire and truckload versus less-than truckload), and nature of the cargo/commodities being moved: from as low as $20 per hour on the lower end, to over $190 per hour associated with time delay cost in congested traffic conditions.

2.2 Rail Freight Cost Models

Rail costing models also include both statistically estimated models of reported freight rates, and engineering cost models based on a summation of the costs associated with different cost elements (e.g. fuel, labor, etc). U.S. railroads collect and use a great deal of detailed data on component-specific costs. Public domain research studies that do not have access to this detailed data have often turned instead to statistical modeling, using a variety of data sources. The rail movement data used in most of these U.S. studies is the Surface Transportation Board's (STB) nationwide annual Railcar Waybill sample (STB, 2012).

“Railroad cost analysis has developed along two separate and distinct paths. Academic economists have analyzed aggregate cost functions to examine issues such as economies of scale, scope, and cost sub-additivity. At the same time, government regulators and the railroads have used railroad cost analysis in an attempt to measure variable costs associated with specific rail movements. The analysis of costs that aims to measure variable costs associated with specific rail movements is referred to as railroad costing” (Wilson and Bitzan, 2003). Wilson and Bitzan (2003) used data from the STB’s Annual Railcar Waybill Sample from 1983 to 2000 to obtain annual rates in terms of revenue per ton-mile. In another rail costing model study, Access Economics (2007), based out of Australia, determined rail cost components to be: insurance, overhead, capital costs, tariffs, safety accreditation fees for rail operators, excise taxes, rail user fees, fuel, maintenance and repairs, driver wages, and handling and unloading costs. Lastly, in a study by Troche (2009), rail cost components in this study included: energy, labor, capital costs, maintenance and repairs, insurance, and storage and handling costs. In this study, a socio-economic, incremental cost associated with rail usage was the “cost” of externalities on the environment (p. 55), which is of interest in many transportation studies.

In terms of the software tools used for modeling purposes, the methods for obtaining data for either a statistical or engineering model varies within the literature. GIS software was often used for mapping and analysis purposes. In a study by Southworth and Peterson (2000), a GIS was used for determining the location of connections and transfer points for multimodal and intermodal freight transportation. Impedance factors were developed to determine the best, least-cost scenarios for shipping. Data from the Commodity Flow Survey was used to determine origin-to-destination, zip code area-to-area movements for some 100,000 freight shippers. An intermodal network was created by linking rail, truck, and waterway transportation networks.

Notional links were created in the GIS in order for terminals to access the network. Two methods for creating links were used: notional links and shadow links. In this study, it was assumed that higher costs are the result of transfers: “indeed, it is often at these local access and transfer points that major delays, and hence, costs, occur in today’s freight movement system” (p. 159).

The Surface Transportation Research Board’s rail costing software program, which is part of the Uniform Railroad Costing System (URCS) was also used in this research. This software program uses input parameters to generate total costs for shipping a variety of commodities. The user is responsible for determining the rail line, rail car size and number, commodity type, mileage (origin-to-destination), among other parameters. The model then generates costs based on the rail type, tonnage, mileage, and shipping costs. Terminal costs, terminal switching costs, and intermodal costs are also calculated by the program. “Special service costs” are also considered for certain shipping scenarios, including the shipment of automobiles (Surface Transportation Research Board, 2004). ITIC-ST (Intermodal Transportation and Inventory Costing Model State Tool), which examines shipment details between origins and destinations, also considered intermodal transfers between truck and rail (ITIC-ST, 2011). In this research, the focus will primarily be on truck and rail modes, however, water and air transfers could also be considered to further estimate shipping costs on the network.

The following tables contain a summary of the sources used in this research. The tables are separated into two sections: truck costs, rail costs. The cost components found in each source can be found in the last column of the table.

Table One: Summary Table of Sources and Cost Components for Truck Costs

Article Title	Author(s)	Year Published	Costs Considered in the Research
An Analysis of the Operational Costs of Trucking: 2011 Update	American Transportation Research Institute	2011	fuel, lease or purchase payments, maintenance and repair, wages, insurance, tires, tolls, permits and licensure
The Per-Mile Costs of Operating Automobiles and Trucks	Barnes and Langworthy	2003	fuel, maintenance (tires, oil, and routine work), unanticipated repairs, and depreciation costs
Truck Costing Model for Transportation Managers	Berwick and Farooq	2003	tire, fuel, maintenance and repair, labor and total variable costs; fixed costs: equipment costs, licensure and taxes, insurance and management and overhead costs
Intermodal Transfer and Inventory Costing Model State Tool (ITIC-ST)	Federal Highway Administration	2011	Intermodal transfer costs
An Analysis of the Operational Costs of Trucking	Fender and Pierce	2011	"vehicle-based" (fuel and engine oil, lease payments, repair and maintenance, insurance, tires, permits and tolls) and "driver-based" (wages and benefits)
A Policy-Oriented Cost Model for Shipping Commodites by Truck	Hussein and Petering	2009	fuel, labor, depreciation, maintenance, tire costs, loading and unloading costs, insurance, indirect (overhead) costs, and "extra" costs (such as shipping hazardous materials)

Table Two: Summary Table of Sources and Cost Components for Rail Costs

Article Title	Author(s)	Year Published	Costs Considered in the Research
Intermodal Transfer and Inventory Costing Model State Tool (ITIC-ST)	Federal Highway Administration	2011	Intermodal transfer costs
Activity-Based Rail Freight Costing	Troche	2009	energy, labor, capital costs, maintenance and repairs, insurance, and storage and handling costs
Cost Functions for Australia's Railways	Wilson and Bitzan	2003	insurance, overhead, capital costs, tariffs, safety accreditation fees for rail operators in Australia, excise taxes, rail user fees, fuel, maintenance and repairs, driver wages and handling and unloading costs

CHAPTER 3

ESTIMATING O-D FREIGHT COSTS ON A MULTIMODAL/INTERMODAL NETWORK

3.1 Introduction

Once a set of freight cost formulas have been developed, in which the various components of the costs of movement have been included, then the next step for freight flow modeling purposes is to associate these costs with specific origin-to-destination (O-D) pairs, and to derive the resulting per vehicle, per cargo unit, and/or per shipment cost for each O-D movement. This means assigning such freight movements over specific multi-link paths, or routes, through a state's, or region's, or if necessary, over an entire nation's transportation network. This usually means applying a shortest, or more generally, a least-cost, path-finding algorithm to a suitable node-link defined network database in order to estimate the expected mileage and travel time associated with any O-D specific trip. Where more than one mode of transportation is used to move cargo between an O-D pair, this means accounting for not only the line-haul costs associated with each mode, but also with any intermodal transfer costs, and inventory holding fees along the way. For example, automobiles are often shipped by a combination of truck and rail transport between the auto manufacturing plant and a vehicle storage and distribution center located close to a city's auto dealer showrooms.

Where traffic congestion enters the picture, this often leads to the use of congestion-sensitive route selection, or "traffic assignment" routines that may spread traffic volumes over two or more roughly parallel routes between any O-D pair, while taking into account all O-D traffic volumes simultaneously. In the context of the current research, it is assumed that such route-specific traffic volumes are known, or have been estimated, producing (what are mixed passenger-plus-freight) traffic volume-based, “congestion-sensitive”, and link-specific, average travel times. These route-specific times (and distances) can then become the starting point for the trip-specific cost estimates associated with the individual freight movements that support the empirical analysis of a company’s freight movement costs.

The consideration of congestion in cost calculation studies varies. For example, Barnes and Langworthy (2003) considered congestion in a study to determine whether the construction of a proposed highway was necessary (p. 2). A future component of this study is to consider the impact of congestion around the Southeast. Traffic congestion was also taken into account by Alam (2011) in developing the nationwide truck traffic flow maps as part of the Federal Highway Administration’s (FHWA) Freight Analysis Framework (or FAF) database. In FAF Version 3, these flows are routed between some 48,000 origin-destination pairs of places using a congestion-sensitive route assignment algorithm that computes travel speeds over each link as a function of the ratio of total mixed (e.g. truck plus passenger auto) traffic volumes (V) and the traffic design capabilities (C) of each highway link in the national network (e.g. the higher the V/C ratio, the lower the average link speed).

One objective for this research is in combining the use of cost functions with a freight network. In terms of the method used to calculate costs, freight network models are typically used for the purpose of projecting estimated routes and generating costs based on shortest paths. Florian and Crainic (1990), considered network models to “enable the prediction of multi-commodity flows over a multimodal network, where the physical network is modeled at a level of detail appropriate for a nation or a large region, and represents the physical facilities with relatively little abstraction” (p. 25).

3.2 Alternative Multi-modal Network Data Models

To date, only a handful of multi-modal freight network models have been developed. Among these, each of the models reviewed below has been applied to a broad regional and/or fully national study of freight movements.

STAN

Florian and Crainic (1990) developed STAN (Strategic Planning of National and Regional Freight Transportation), modeling and planning software that uses a proprietary, multi-modal network model of highway, rail, and water links. Cost assignment can be performed using STAN, in a similar fashion to the methods used in this study, where costs can be calculated using algebraic formulas, which can then be applied to particular links within the network. “The primary role of STAN is the comparison and evaluation of alternatives. The contemplated alternatives normally represent major changes to the transportation infrastructure or important modifications to the operating policies and cost structures. The simulation of freight flows is carried out on these scenarios as well. Subsequently, flows, link costs, delay and congestion, intermodal shipments, infrastructure utilization and other performance factors may be compared between different scenarios. The network optimization model that is used to simulate network flows in STAN is a non linear multimode-multiproduct assignment formulation that minimizes the total generalized system cost. The generalized cost is computed for each link and transfer of the network, as a weighted sum of an operating cost function, a delay function and an energy consumption function” (Lubis, et al, 2003).

Florian and Crainic (1990) considered network models to “enable the prediction of multi-commodity flows over a multimodal network, where the physical network is modeled at a level of detail appropriate for a nation or a large region, and represents the physical facilities with relatively little abstraction" (p. 25). In their study, it was stated that "demand and mode choice are exogenous and assumed to specify, for each product, a set of O/D demand matrices, each of which may be assigned on the sub-network corresponding to a permitted subset of modes only. The choice of the paths used through a permitted sub-network is determined by the congestion conditions present and the particular form of the generalized cost structure" (p. 27). For this study, a similar action will be performed. Using the network and shortest path model, origin/destination matrices will be created based on network links and mode assignment in order to calculate costs for specific routes.

Intermodal transfer and storage costs will be considered in this research, but calculations will not be included in truck shipping scenarios. In Florian and Crainic's study (1990), "once the network representation is chosen, it is necessary, in order to model intermodal shipments, to permit and associate the appropriate costs and delays for mode transfers at certain nodes of the network" (p. 28).

Another similarity between this research and the Florian and Crainic (1990) study is with the usage of transfer links. In the Florian and Crainic (1990) study, "a mode change is only possible at a transfer node. This representation also permits one to restrict the flows of certain commodities to subsets of modes and thus capture the mode captivity and restrictions that occur in the operation of freight networks, as well as the trans-shipments at transfer nodes" (p. 28). In this present research, transfer links that connect the links on two different modal sub-networks are used to carry the costs of transfers between modes and can be used to further restrict route designations for such reasons as the shipping of incompatible loads.

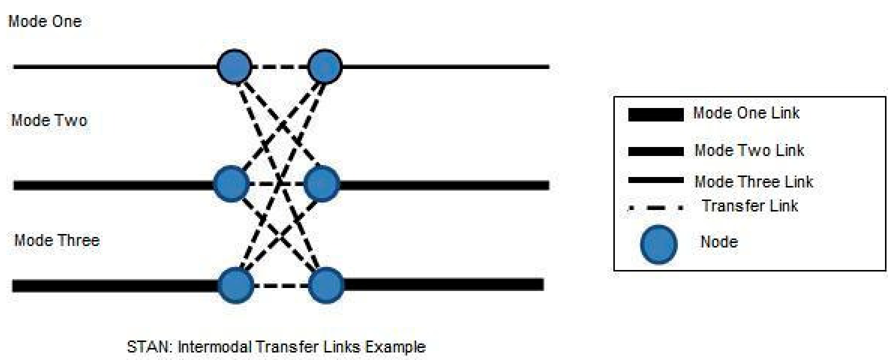
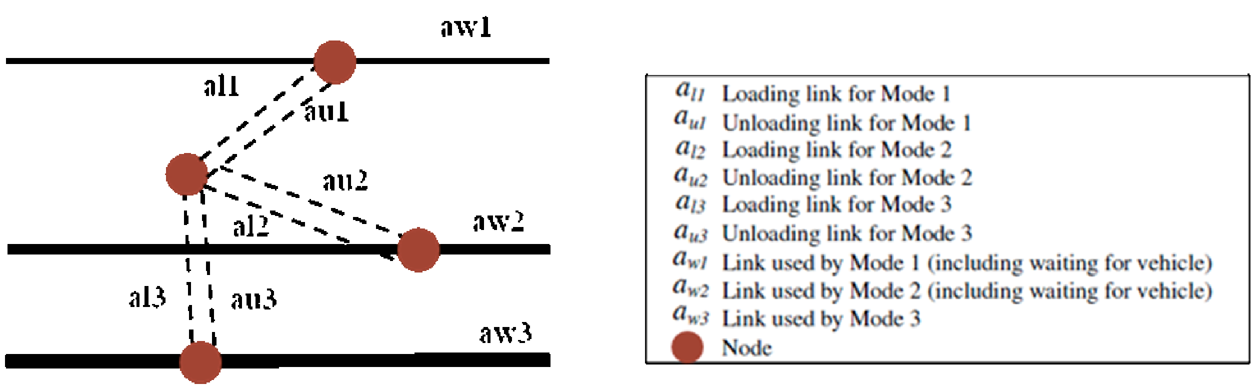


Figure One: STAN-like Intermodal Transfer Links Example

Russ et al. and Yamada et al

Russ et al (2005) examined the freight network in Indonesia to determine route assignment patterns in order to create a planning model for determining the locations of future expressway projects. Yamada et al (2009) examined the transport network within the Philippines, where there is a need to develop a comprehensive multimodal freight network, and used the Genetic Local Search optimization algorithm to determine the optimal locations for multimodal freight development and expansion within the country.



Intermodal transfers modeled after Russ et al, 2005, and Yamada et al 2007

Figure Two: Russ et al (2005) and Yamada et al (2007) Intermodal Transfers Example

NODUS

Another example of a multimodal network model used in international studies is NODUS. NODUS is a geographic information system, developed at the University of Mons (Belgium), and has been used to model freight movement in European countries using the European freight network. NODUS is typically used in studies involving multimodal freight flows and freight mode determination. “NODUS encompasses the concept of ‘generalized cost’ which allows for the integration of all factors relevant to transport decision making in terms of monetary units. The virtual network requires the development of four types of cost functions, which are associated with specific virtual links: (un) loading, transit, transshipping, and moving virtual links” (Geerts and Jourquin, 2000).

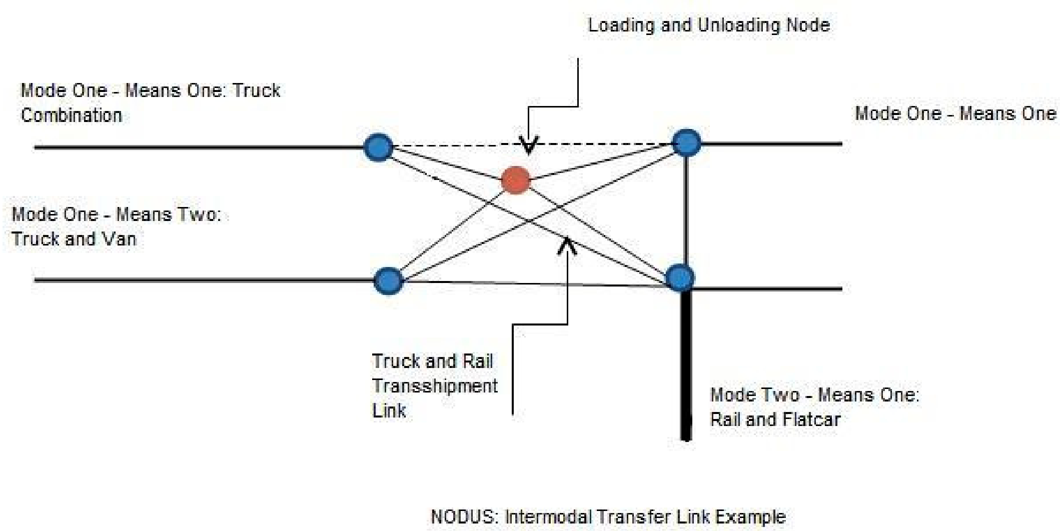


Figure Three: NODUS-like Intermodal Transfer Link Example

Another network model used in similar freight studies is the SMILE (Strategic Model for Integrated Logistics and Evaluation) network model, developed by the Institute for Road Safety Research, in the Netherlands (1996). This model can be used as a tool to predict future development, using Economy and Transport modules for the purpose of forecasting. A “chain structure" is used to depict supply chain O-D travel. The model can then be evaluated to determine if the predicted development has an impact on freight travel and the freight network (Transportation Research Board, 2013).

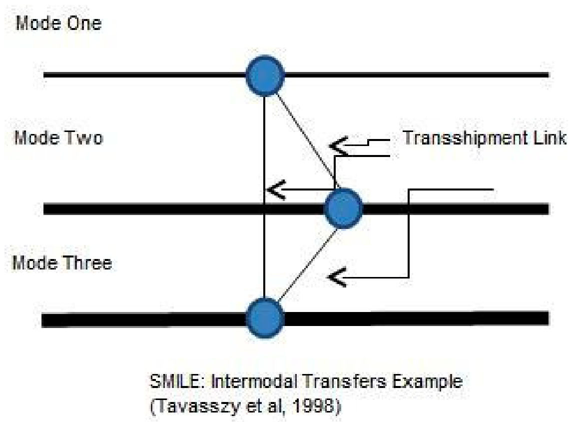


Figure Four: SMILE-like Intermodal Transfers Example

ORNL

The Oak Ridge National Laboratory's multi-modal freight network contains highway, rail, air, and waterway links. Each link contains information necessary for estimating freight flows. Notional links are established in the network to route vehicles to desired destinations. Nodes represent access points and locations of terminals where transfers within and between modes take place. The ORNL multi-modal freight network was chosen for this thesis study because the information is available in the public domain, it has been extensively used in similar research, it is focused on the U.S., and the level of detail in the ORNL network is comparable with the other frequently used network models: STAN and NODUS.

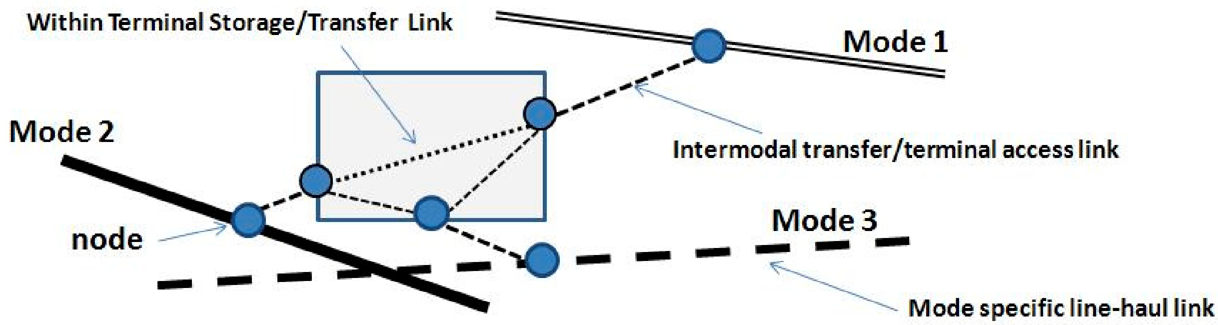


Figure Five: ORNL Modeled Intermodal

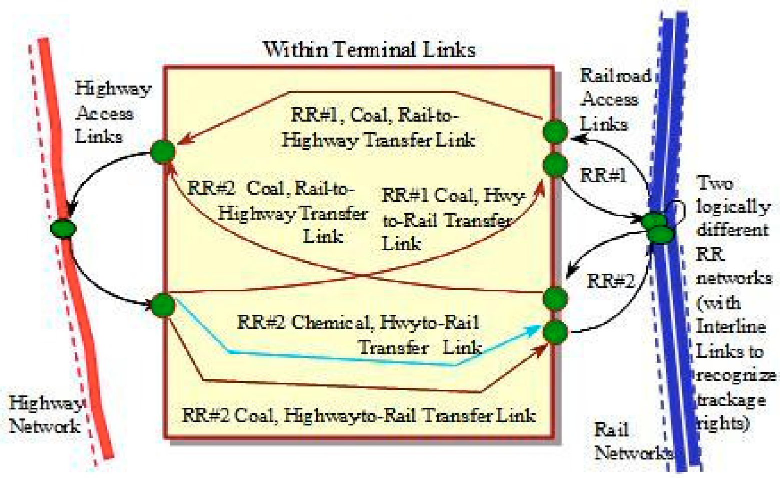


Figure Six: ORNL Within Terminal Transfers

Table Three: Summary table of network models

Article Title	Author(s)	Year Published	Costs Considered in the Research
STAN (Strategic Planning of National and Regional Freight Transportation)	Florian and Crainic	1990	congestion costs and intermodal transfer costs
SMILE (Strategic Model for Integrated Logistics and Evaluation)	Institute for Road Safety Research (Netherlands)	1996	future transporatation development costs
Transport Network in Indonesia	Smalkoski and Levinson	2003	fuel, repair and maintenance, tire, depreciation, and labor cost
Intermodal and International Freight Network Modeling	Southworth and Peterson	2000	transfer costs, costs associated with border-crossings, line-haul costs
NODUS	University of Mons (Belgium)	2000	loading/unloading, storage and intermodal transfer costs
Designing Multimodal Freight Transport Networks: A Heuristic Approach and Applications	Yamada, et al	2009	operational costs, handling and storage

CHAPTER 4

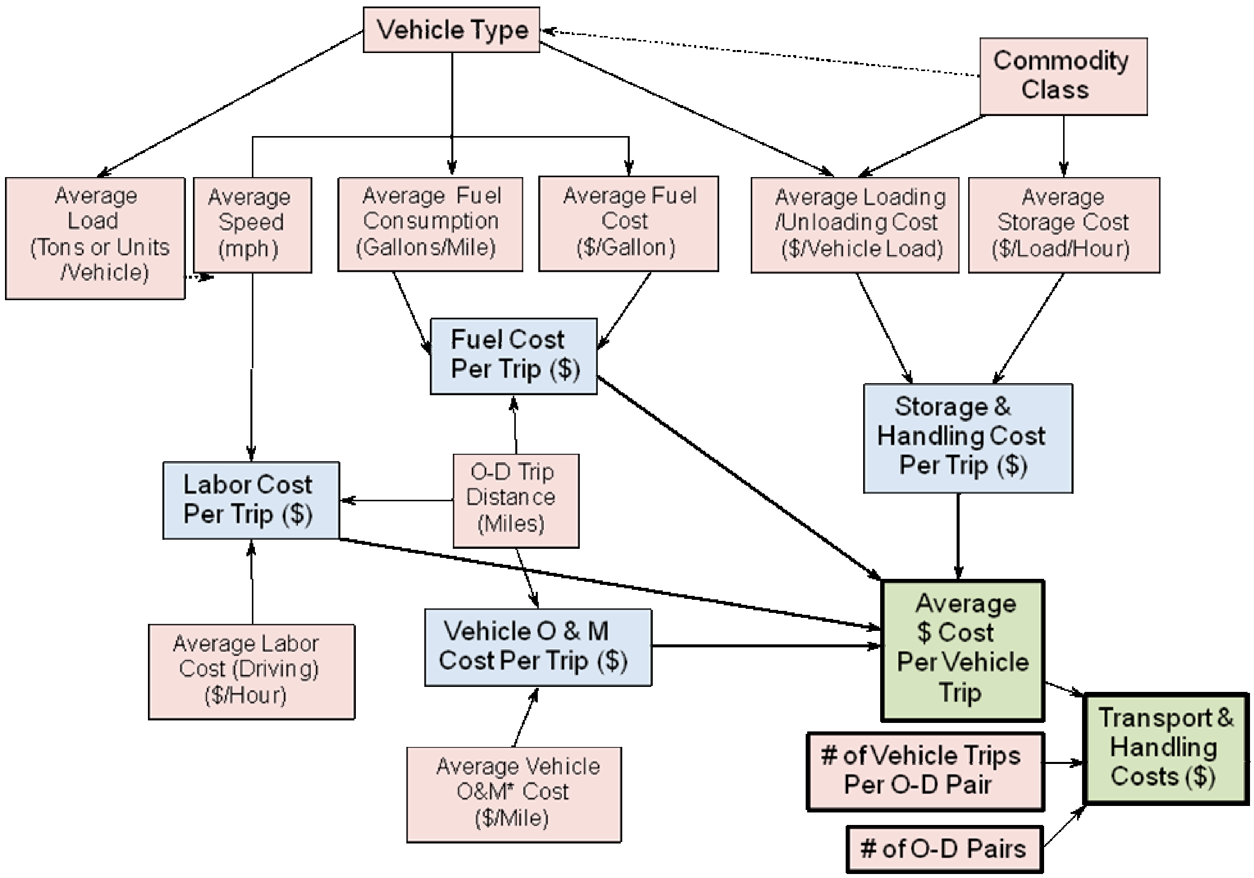
MODELING FRAMEWORK AND EXAMPLES OF COST MODELING APPLICATION

4.1 Introduction

For this study, the automobile manufacturing industry supply chain for Georgia and Alabama was used as an example for modeling cost calculation applications, and specifically the parts suppliers to the Kia and Hyundai Motor Companies. The geographic locations of all parts suppliers and original equipment manufacturers (OEMs) were obtained to map the locations in a GIS. The Oak Ridge National Laboratory's (ORNL) multi-modal freight network was used to route specific freight movements, using a shortest path routing algorithm. Using cost calculation formulas derived from the literature, specific parameters for calculating fuel, labor, and operation and maintenance costs were used as input for the model (along with other variables). The model generates individual link distances and costs, and aggregate link costs and distances using the formulas specified for particular model runs. The results from each model run are then entered in the GIS software to create a visual representation of the routes specified by each model run.

Freight Routing Supply Chain (FRSC) Model Structure

As displayed in Figure Seven, the FRSC model components, as outlined in Chapter 2 are: fuel, labor, and operation and maintenance costs. Each major cost component then involves specific input parameters based on the weight, speed, fuel consumption, average fuel cost, average labor cost, and average operation and maintenance costs. Although loading/unloading and storage costs were not a focus in this study, these costs can later be used as input for the model to further estimate overall shipping costs.



*Vehicle O&M cost includes costs associated with tires, oil, parts maintenance and replacement, insurance and licenses

Figure Seven: Flow Chart of Cost Components

4.2 Data Sources

Oak Ridge National Laboratory Multi-Modal Network

The Oak Ridge National Laboratory (ORNL) multi-modal network was chosen for this study to assign freight to designated routes throughout the country (ORNL.gov, 2013). This freight network contains the ORNL national highway, railway, and waterway link connections, as well as major truck-rail, truck-waterway and rail-waterway intermodal terminals, and ports, and was chosen to represent line haul routes for each mode, as well as terminal transfers between modes.

For this study, an updated, 2011 version of the ORNL multi-modal network was obtained. This network database is in the public domain. The link attribute data within the network was used in origin-destination distance estimation in the shortest path routine. The file was uploaded into the GIS to access attribute data and display results from the model runs.

Kia and Hyundai Facilities

The locations of 470 parts suppliers and the two original equipment manufacturers (OEMs): the Kia Motor Company located in West Point, Georgia, and the Hyundai manufacturing facility in Selma, Alabama were geocoded based on the addresses for each location. The locations for all parts suppliers were obtained from Southern Company (Southern Company, 2011) and the Alabama Development Office (Alabama Department of Commerce, 2012). Manual geocoding of the parts suppliers and OEMs was performed using Microsoft Excel software, and Caliper's Maptitude GIS software. The database contains the following information for each facility location: an arbitrary identification number, geographic coordinates, the corresponding nearest node on the ORNL network and the node number within the facilities database, the Standard Industrial Classification (SIC) code for each facility type, number of employees, arbitrary tier number (based on products manufactured on-site), address information (street, city, county, and zip code), the product classification for products manufactured at that particular facility, and the firm's name.

Trucking Cost Calculation Data

Cost calculation components and formulas were gathered from the literature. For the purpose of calculating costs for this study, it was determined that the formula used for calculating cost per mile consisted of: fuel costs, labor costs, and operation and maintenance costs (Chapter 2).

Determination of overall fuel costs is based on a number of different factors. The weight of the items being shipped, or "payload", affects fuel consumption. Therefore, the weight of the empty tractor and trailer, or "tare weight", needs to be determined. The gross vehicle weight then consists of the payload and the tare weight combined (in pounds). The average truck speed for interstate highways, as outlined in Berwick and Farooq (2003), is 65 mph, although 50 mph was used in this reasearch. A table from Berwick and Farooq (2003) was also used to determine fuel consumption based on type of truck and trailer, and also to determine the fixed and variable co-efficients used in fuel cost calculations (for details, see Appendix A).

Example of fuel cost per mile formula components: ⚜⚜F

Empty truck: using default 65 mph and constant $\alpha = 0.02$ (based on a reduction in fuel consumption efficiency as vehicle speed exceeds 55 mph):

$$[\alpha \text{ x } (mph - 55)] = [\alpha \text{ x } (65 - 55)] = [\alpha \text{ x } 10] = 0.2$$

Loaded truck:

$$[5\ (1 - 0.2)] \text{ miles/gallon} = 5\ (0.8) = 4 \text{ miles/gallon (average)}$$

Empty truck:

$$[6\ (1 - 0.2)] \text{ miles/gallon} = 6\ (0.8) = 4.8 \text{ miles/gallon (average)}$$

Cost per mile:
Loaded truck:

Current fuel price / 4

Empty truck:

Current fuel price / 4.8

Average fuel cost (◎◎F) per mile using default 50/50 time split for loaded and empty:

$$[(\text{loaded cost x } 0.5) + (\text{empty cost x } 0.5)] = \text{average cost per mile}$$

Driver labor costs were computed as follows: ◎◎L
***Labor Costs** (Bureau of Labor Statistics, 2010) using (constant) $\beta = 19.15$(in dollars per hour) and an average speed of 65 miles per hour:*

$$[\beta / 65] = 0.3 \text{ labor cost per mile based on average truck wage rate}$$

(This estimate is low compared to the 2013 average hourly salary for truck drivers according to the National Salary Trend from Indeed.com, estimated at approximately $27.00 per hour).

Operation and Maintenance Costs were computed as follows: ⚜⚜OM
Maintenance and Repairs:
Base cost using defaults from Berwick and Farooq (2003):

$0.09 per mile for 58,000 pounds Gross Vehicle Weight (GVW)

Weight Adjustment:

0.00097 for each 1000 pounds above or below base

Loaded:

[(loaded GVW – 58,000) / 1000] x 0.00097 x percent of time loaded (typically 50%)

Empty:

[(empty weight – 58,000) / 1000] x 0.00097 x percent of time empty (typically 50%)

Average Operation and Maintenance Cost per mile:

[0.09 + loaded – empty]

[Fuel Cost + Labor Cost + Operation and Maintenance Cost]

Average dollar cost per mile:

These costs are computed as the sum of the above fuel, labor, and operations and maintenance costs:

Average dollar cost per mile = ◎◎F + ◎◎L + ◎◎OM

In this study, the speeds on individual links are computed within the shortest path algorithm. These speeds can be converted into average-speed based fuel costs, using the above formulas, or using published relationships between average vehicle (link) speeds, and per mile fuel consumption rates. In this manner, network congestion costs, as well as temporary loss of a parts supply route's capacity can also be evaluated for its effects on supply costs.

URCS-Based Rail Cost Data and Formulas

The Surface Transportation Board's Rail Costing Software (RCS) program uses average wage rates from the annually collected Railcar Waybill Sample (STB Railroad Cost Program User Manual, 2011), which provides information regarding the shipment of goods by-rail. "It is a stratified sample of carload waybills for all U.S. rail traffic submitted by those rail carriers terminating 4,500 or more revenue carloads annually" (STB, 2011). Using the information from the Railcar Waybills, the software calculates the cost based on distance shipped, number and type of railcar (including whether or not the railcars are privately-owned), the type of freight being shipped (e.g. automobiles) , and what type of backhauls (returning of empty or loaded railcars) will take place (refer to Figure Eight for input parameters). Default settings can also be used to determine the circuity of the route in which the railcars will travel, the empty (e.g. unloaded), or tare weight of the specific type of railcar (e.g. a flatbed) , and a general overhead ratio which allocates administrative and other indirect expenses to variable car-mile and car-day costs for the specific railroad service in question (refer to Figure Nine for input parameters).

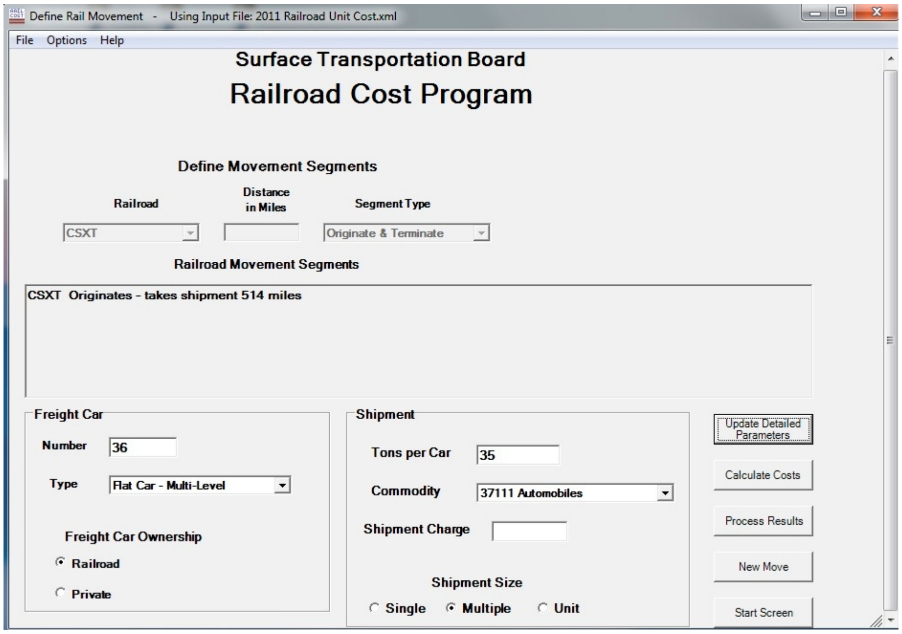


Figure Eight: Input parameters for rail costing program

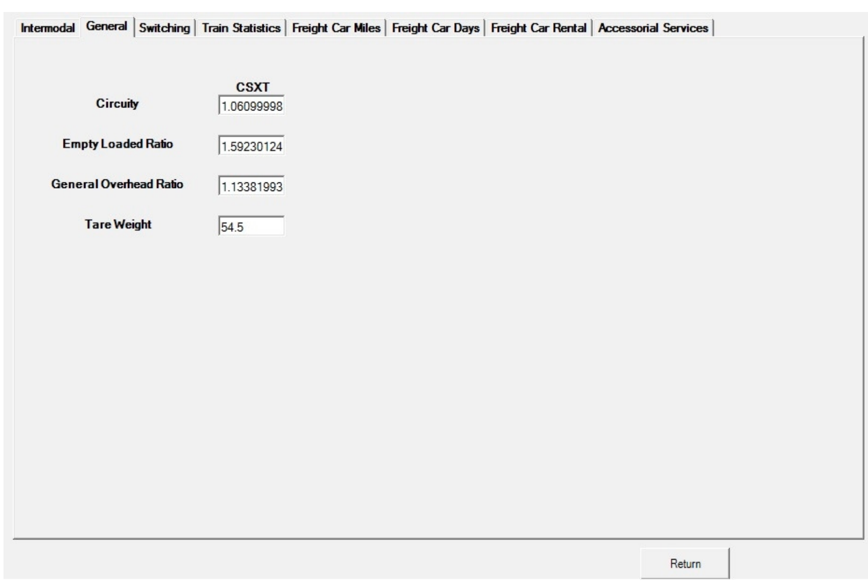


Figure Nine: Additional default parameter settings for rail costing program

4.3 Routing Algorithm

A shortest path routing algorithm was needed in order to generate origin-to-destination routes along the ORNL network. The shortest path routine used for this study is a Fortran code similar to that used by ORNL to route freight for the U.S. Commodity Flow Surveys of 1993, 1997, and 2002. It is based on Moore's label correcting algorithm (Moore, 1959), adapted to handle multiple transportation modes, including mixtures of the long and short distance links (e.g. a short highway connector and trans-oceanic shipping lane link), (Southworth and Peterson, 2000). The routine was then run as a macro in Microsoft Excel. Input parameters for running the model consisted of a variety of different variables to create specific outputs based on the desired mode used in a run, and any desired impedance factors that are expected to hinder the performance of the run.

4.4 Model Run Set-Up

The mode-specific routing impedance factors include the following modes: highway, rail, inland water, Great Lakes, deep sea, and air. Based on the desired mode for a run, the model allows the user to make adjustments to either hinder or allow the usage of a particular mode (e.g. entering a "1" for the highway mode, and entering "1000" for all other modes would force the model to choose highway for its desired mode). The intermodal terminal transfer and throughput impedances can then be entered into the model.

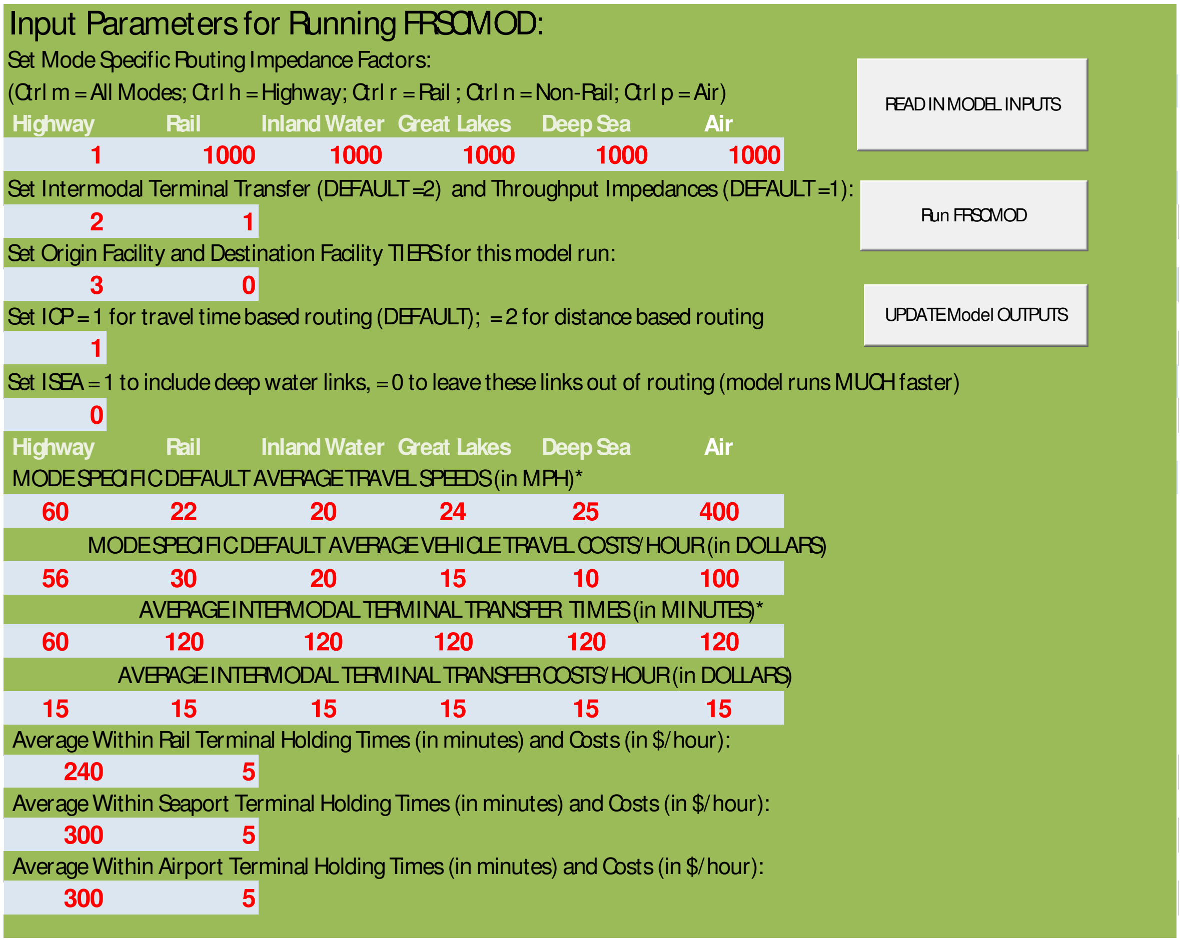


Figure Ten: Model Input Parameters from Excel Macro

In the table consisting of the geocoded locations of parts suppliers and OEMs (Chapter 3), specific supplier facilities can be selected for routing to the OEM site based on their industry type or other considerations. Similarly, a column with an arbitrary tier number can be assigned, based on the estimated location of the facility within the automobile manufacturing industry supply chain. In the model, the origin and destination facility tiers could be chosen for a particular model run, based on the user's decision to consider certain facilities within the supply chain.

Prior to routing a set of one or more O-D specific traffic flows, the user can select between routes based on travel time or distance. This is called the ICP value for the model, using a "1" for travel time-based routing and "2" for distance-based routing. The ISEA value for the model can be chosen to determine whether deep water links are included in the model run: a value of "1" is chosen if deep water links will be included, and a "0" is chosen if these links are not considered for the model run, a condition that typically results in much shorter run times.

Different parameters for each mode can then be set to determine speeds, costs, transfer times, terminal transfer costs, and terminal holding costs. Default settings are typically used and based on assumptions and reports from the literature on the subject, including the sources reviewed in Chapter 2 of this research. The specified cost calculations can be determined and input into separate Excel pages and run in the macro. The output from the model is shown in an Excel spreadsheet that is linked with the model. The results in Excel contain the geographic locations of the links, the origin and destination tiers, distance, time, cost, and mph (based on link attribute data).

4.5 GIS

Geographic information software was needed to generate and display the ORNL multi-modal highway link connections and origin to destination routes, as assigned by the shortest path algorithm. The geographic information software chosen for this study was Caliper's Maptitude software program. It was chosen based on its routing capabilities and similar interface with that of Caliper's TransCAD software. The GIS was linked with the routing algorithm, and each link chosen for a model run is highlighted in the GIS.

Summary of Research Methods

As displayed in Figure Eleven, there are four main components to this research. The first component involving truck costs requires information from the literature on truck cost components and cost calculations, as well as information regarding fuel prices, average labor costs, and operation and maintenance costs. This part of the research is responsible for providing cost estimates as input for the model, and, in-turn, the model will generate the distances and travel times needed to complete the cost calculations (represented by reciprocating arrows). The Freight Supply Chain (FRSC) model is then responsible for estimating distances for both truck and rail scenarios. Once the distance is calculated in the FRSC model, the estimated distance can then be used as input for the URCS model to calculate costs. Lastly, the GIS is responsible for generating visual representations of routing schemes for both truck and rail scenarios.

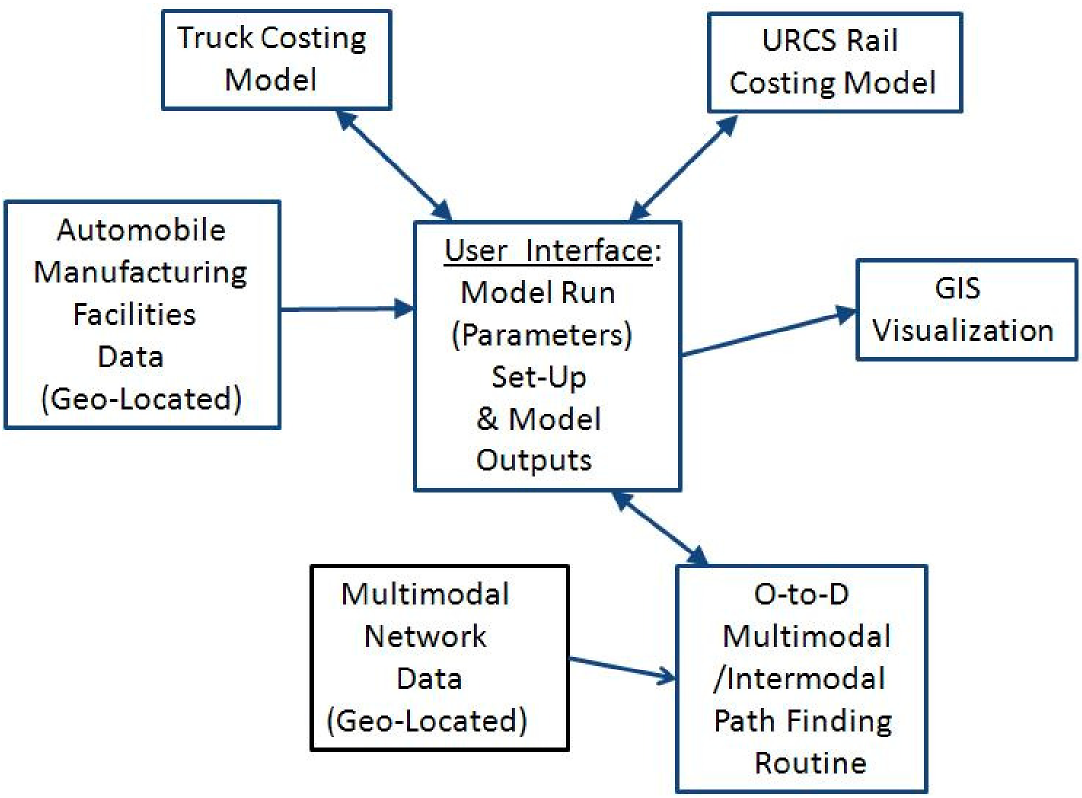


Figure Eleven: Freight Routing Supply Chain (FRSC) Model

4.6 Example Model Runs

The costs incurred by shipping various commodities from origin-to-destination can vary by mode, and by different types within each mode. For this research, the main focus is on shipping commodities by truck and by rail. Five routing cost examples are provided below. The first four examples contain truck shipment scenarios using different truck types and weights, carrying different commodity types from various types of auto parts suppliers. The last example provided is a rail shipment scenario, using the URCS rail costing software program. Although air and water shipments are also considered in the broader modeling framework, these two modes will not be considered in the examples below.

Table Four: Tier assignment and type

Tier Assignment	Number of Tiers	Supplier Type
0	2	OEMs
1	10	Textile Products
2	3	Paper and Allied Products
3	4	Chemicals and Allied Products
4	66	Rubber and Misc. Plastics
5	4	Stone, Clay, and Glass
6	25	Primary Metal Industries
7	60	Fabricated Metal Products
8	29	Machinery (except electrical)
9	23	Electrical Machinery Equipment and Sales
10	124	Transportation Equipment
11	107	Misc. Manufacturing
12	11	Wholesale Trade
13	1	Auto dealership
14	5	Furniture and Fixtures

Model Run Examples

Shipping Parts to OEMs by Truck

Truck Shipment Scenario One:

Conventional tractor trailer trucks carrying a full load of tires (50,000 pounds) from tire manufacturing facilities (small parts suppliers assigned a tier four) to OEMs (assigned a *tier zero), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes:*

Cost Calculations:

***Fuel Costs per mile:* ⚜⚜F**

Empty truck: using 50 mph and constant $\alpha = 0.02$ *(based on the assumption that there is a reduction in fuel consumption efficiency as vehicle speed exceeds 55 mph):*

$$[\alpha \text{ x } (55\text{-}50)] = [\alpha \text{ x } (55\text{-}50)] = [\alpha \text{ x } 5] = 0.1$$

Loaded truck:

[5 (1 – 0.1)] miles/gallon = 5 (0.99) = 4.95 miles/gallon (average)

Empty truck:

[6 (1 – 0.1)] miles/gallon = 6 (0.99) = 5.94 miles/gallon (average)

Cost per mile:

Loaded truck:

Current fuel price / 4.95

4.08/4.95 = 0.82

Empty truck:

Current fuel price / 5.94

4.08/5.94 = 0.69

Average fuel cost per mile using default 50/50 time split for loaded and empty:

[(loaded cost x 0.5) + (empty cost x 0.5)] = average cost per mile

[(0.82 x 0.5) + (0.69 x 0.5)] = 0.41 + 0.35 = $0.76

***Labor Costs** (Bureau of Labor Statistics, 2010) using constant* $\beta = 19.15$*:* ◎◎L

$[\beta / 50] = 0.38$ *labor cost per mile based on average truck wage rate*

***Operation and Maintenance Costs:* ⚜⚜OM**

Maintenance and Repairs:

Empty trailer weight: 12,900 pounds

Tractor weight: 13,900 pounds

Total Tare Weight: 26,800 pounds

Gross Vehicle Weight = Tare Weight + Payload = 26,800 + 50,000 = 76,800 pounds

Base cost using defaults from Berwick and Farooq (2003):

$0.09 per mile for 58,000 pounds Gross Vehicle Weight (GVW)

Weight Adjustment:

0.00097 for each 1000 pounds above or below base

Loaded:

[(loaded GVW – 58,000) / 1000] x 0.00097 x percent of time loaded (typically 50%)

[(76,800 – 58,000) / 1000] x 0.00097 x 0.5 = .009

Empty:

[(empty weight – 58,000) / 1000] x 0.00097 x percent of time empty (typically 50%)

[(58,000 – 12,900) / 1000] x 0.00097 x 0.5 = 0.022

Average Operation and Maintenance Cost per mile:

[0.09 + loaded – empty]

[0.09 + .009 – .022] = .077

Average cost per mile:

[Fuel Cost + Labor Cost + Operation and Maintenance Cost]

◎◎$_F$ + ◎◎$_L$ + ◎◎$_{OM}$ = *[0.76 + 0.38 + .077] = $1.22 per mile at 50 mph = $61 per hour*

Model Inputs:

Table Five: Model Inputs for Model Run One

Model Inputs	
Impedances	1 for truck, 1000 for all other modes
Tiers	from tier 4 (small parts suppliers) to tier 0 (OEMs)
Average Speed	50 mph
Average Cost per Hour	$61

Model Outputs:

Total distance traveled for all OD trips: 32,967 miles, with 264 OD trips

Average un-weighted cost per trip: [32,967/264 OD trips x 1.22 per mile] = $152.35

Tables and map generated in GIS can be found in Appendix B.

Truck Shipment Scenario Two:

Conventional flatbed tractor trailer truck carrying a full load of new vehicles (53,600 pounds) from the OEM (assigned a tier zero) to a Kia dealership in Dallas, Texas (assigned a tier 13), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes:

Cost Calculations:

Fuel Costs per mile: ⚜⚜$_F$

Empty truck: using 50 mph and constant α = 0.02 (based on the assumption that there is a reduction in fuel consumption efficiency as vehicle speed exceeds 55 mph):

[α x (55-50)] = [α x (55-50)] = [α x 5] = 0.1

Loaded truck:

[5 (1 – 0.1)] miles/gallon = 5 (0.99) = 4.95 miles/gallon (average)

Empty truck:

[6 (1 – 0.1)] miles/gallon = 6 (0.99) = 5.94 miles/gallon (average)

Cost per mile:
Loaded truck:

Current fuel price / 4.95
4.08/4.95 = 0.82

Empty truck:

Current fuel price / 5.94
4.08/5.94 = 0.69

Average fuel cost per mile using default 50/50 time split for loaded and empty:

[(loaded cost x 0.5) + (empty cost x 0.5)] = average cost per mile
[(0.82 x 0.5) + (0.69 x 0.5)] = 0.41 + 0.35 = $0.76

Labor Costs *(Bureau of Labor Statistics, 2010) using constant β = 19.15:* ◎◎L

[β / 50] = 0.38 labor cost per mile based on average truck wage rate

Operation and Maintenance Costs: ⚜⚜OM

Maintenance and Repairs:
Empty trailer weight: 12,500 pounds
Tractor weight: 13,900 pounds
Total Tare Weight: 26,400 pounds
Gross Vehicle Weight = Tare Weight + Payload = 26,400 + 53,600 = 80,000 pounds
Base cost using defaults from Berwick and Farooq (2003):

$0.09 per mile for 58,000 pounds Gross Vehicle Weight (GVW)

Weight Adjustment:

0.00097 for each 1000 pounds above or below base

Loaded:

[(loaded GVW – 58,000) / 1000] x 0.00097 x percent of time loaded (typically 50%)
[(80,000 – 58,000) / 1000] x 0.00097 x 0.5 = .012

Empty:

[(empty weight – 58,000) / 1000] x 0.00097 x percent of time empty (typically 50%)
[(58,000 – 12,500) / 1000] x 0.00097 x 0.5 = .022

Average Operation and Maintenance Cost per mile:

[0.09 + loaded – empty]
[0.09 + .012 – .022] = 0.8

Average cost per mile:

[Fuel Cost + Labor Cost + Operation and Maintenance Cost]
◎◎F + ◎◎L + ◎◎OM = *[0.76 + 0.38 + .08] = $1.22 per mile at 50 mph = $61 per hour*

Model Inputs:

Table Six: Model Inputs for Model Run Two

Model Inputs	
Impedances	1 for truck, 1000 for all other modes
Tiers	from tier 0 (OEMs) to tier 13 (dealerships)
Average Speed	50 mph
Average Cost per Hour	$61

Model Outputs:
Total distance traveled for all OD trips: 3,400 miles, with 8 OD trips
Average un-weighted cost per trip: [3,400/8 OD trips x 1.22 per mile] = $519.50
Tables and map generated in GIS can be found in Appendix B.

Truck Shipment Scenario Three:

Spread tandem tractor trailer trucks carrying a full load of small parts for chassis (40,000 pounds) from small parts suppliers (assigned a tier six) to large parts suppliers manufacturing chassis (assigned a tier seven), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes:

Cost Calculations:
Fuel Costs per mile: ⚜⚜F
Empty truck: using 50 mph and constant α = 0.02 (based on the assumption that there is a reduction in fuel consumption efficiency as vehicle speed exceeds 55 mph):

$$[\alpha \times (55-50)] = [\alpha \times (55-50)] = [\alpha \times 5] = 0.1$$

Loaded truck:

$$[5\ (1 - 0.1)] \text{ miles/gallon} = 5\ (0.99) = 4.95 \text{ miles/gallon (average)}$$

Empty truck:

$$[6\ (1 - 0.1)] \text{ miles/gallon} = 6\ (0.99) = 5.94 \text{ miles/gallon (average)}$$

Cost per mile:
Loaded truck:

$$\text{Current fuel price} / 4.95$$
$$4.08/4.95 = 0.82$$

Empty truck:

$$\text{Current fuel price} / 5.94$$
$$4.08/5.94 = 0.69$$

Average fuel cost per mile using default 50/50 time split for loaded and empty:

[(loaded cost x 0.5) + (empty cost x 0.5)] = average cost per mile

[(0.82 x 0.5) + (0.69 x 0.5)] = 0.41 + 0.35 = $0.76

Labor Costs *(Bureau of Labor Statistics, 2010) using constant β = 19.15:* ◎◎L

[β / 50] = 0.38 labor cost per mile based on average truck wage rate

Operation and Maintenance Costs: ⚜⚜OM

Maintenance and Repairs:

Empty trailer weight: 13,500 pounds

Tractor weight: 13,900 pounds

Total Tare Weight: 27,400 pounds

Gross Vehicle Weight = Tare Weight + Payload = 27,400 + 40,000 = 67,400 pounds

Base cost using defaults from Berwick and Farooq (2003):

$0.09 per mile for 58,000 pounds Gross Vehicle Weight (GVW)

Weight Adjustment:

0.00097 for each 1000 pounds above or below base

Loaded:

[(loaded GVW – 58,000) / 1000] x 0.00097 x percent of time loaded (typically 50%)

[(67,400 – 58,000) / 1000] x 0.00097 x 0.5 = .005

Empty:

[(empty weight – 58,000) / 1000] x 0.00097 x percent of time empty (typically 50%)

[(58,000 – 13,500) / 1000] x 0.00097 x 0.5 = .022

Average Operation and Maintenance Cost per mile:

[0.09 + loaded – empty]

[0.09 + .005 – .022] = .073

Average cost per mile:

[Fuel Cost + Labor Cost + Operation and Maintenance Cost]

◎◎F + ◎◎L + ◎◎OM = *[0.76 + 0.38 + .073] = $1.21 per mile at 50 mph = $60.50 per hour*

Model Inputs:

Table Seven: Model Inputs for Model Run Three

Model Inputs	
Impedances	1 for truck, 1000 for all other modes
Tiers	from tier 6 (small parts suppliers) to tier 7 (large parts suppliers)
Average Speed	50 mph
Average Cost per Hour	$60.50

Model Outputs:

Total distance traveled for all OD trips: 218,015 miles, with 1,416 OD trips

Average un-weighted cost per trip: [218,015/1,416 OD trips x 1.21 per mile] = \$186.30
Tables and map generated in GIS can be found in Appendix B.
Truck Shipment Scenario Four:

Double tractor trailer trucks carrying an almost full load of chassis (40,000 pounds) from large parts suppliers (assigned a tier seven) to OEMs (assigned a tier zero), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes at the US Department of Energy's projected reduction in diesel fuel cost for 2014 at \$3.82 per gallon):

Cost Calculations:
Fuel costs per mile: ⚜⚜F
Empty truck: using 50 mph and constant $\alpha = 0.02$ (based on the assumption that there is a reduction in fuel consumption efficiency as vehicle speed exceeds 55 mph):

$$[\alpha \times (55\text{-}50)] = [\alpha \times (55\text{-}50)] = [\alpha \times 5] = 0.1$$

Loaded truck:

$$[5\ (1 - 0.1)] \text{ miles/gallon} = 5\ (0.99) = 4.95 \text{ miles/gallon (average)}$$

Empty truck:

$$[6\ (1 - 0.1)] \text{ miles/gallon} = 6\ (0.99) = 5.94 \text{ miles/gallon (average)}$$

Cost per mile:
Loaded truck:

$$\text{Current fuel price} / 4.95$$
$$3.82/4.95 = .77$$

Empty truck:

$$\text{Current fuel price} / 5.94$$
$$3.82/5.94 = 0.64$$

Average fuel cost per mile using default 50/50 time split for loaded and empty:

$$[(\text{loaded cost} \times 0.5) + (\text{empty cost} \times 0.5)] = \text{average cost per mile}$$
$$[(0.77 \times 0.5) + (0.64 \times 0.5)] = 0.39 + 0.32 = \$0.71$$

Labor Costs *(Bureau of Labor Statistics, 2010) using (constant) $\beta = 19.15$:* ◎◎L

$$[\beta/ 50] = 0.38 \text{ labor cost per mile based on average truck wage rate}$$

Operation and Maintenance Costs: ⚜⚜OM
Maintenance and Repairs:
Empty trailer weight: 23,700 pounds
Tractor weight: 13,900 pounds
Total Tare Weight: 37,600 pounds
Gross Vehicle Weight = Tare Weight + Payload = 37,600 + 40,000 = 77,600 pounds
Base cost using defaults from Berwick and Farooq (2003):

$0.09 per mile for 58,000 pounds Gross Vehicle Weight (GVW)

Weight Adjustment:

0.00097 for each 1000 pounds above or below base

Loaded:

[(loaded GVW – 58,000) / 1000] x 0.00097 x percent of time loaded (typically 50%)

[(77,600 – 58,000) / 1000] x 0.00097 x 0.5 = .01

Empty:

[(empty weight – 58,000) / 1000] x 0.00097 x percent of time empty (typically 50%)

[(58,000 – 23,700) / 1000] x 0.00097 x 0.5 = 0.17

Average Operation and Maintenance Cost per mile:

[0.09 + loaded – empty]

[0.09 + .01 – .017] = 0.083

Average cost per mile:

[Fuel Cost + Labor Cost + Operation and Maintenance Cost]

◎◎F + ◎◎L + ◎◎OM = *[0.71 + 0.38 + .083] = $1.17 per mile at 50 mph = $58.50 per hour*

Model Inputs:

Table Eight: Model Inputs for Model Run Four

Model Inputs	
Impedances	1 for truck, 1000 for all other modes
Tiers	from tier 7 (large parts suppliers) to tier 0 (OEMs)
Average Speed	50 mph
Average Cost per Hour	$58.50

Model Outputs:

Total distance traveled for all OD trips: 30,980 miles, with 236 OD trips

Average un-weighted cost per trip: [30,980/236 OD trips x 1.17 per mile] = $153.59

Tables and map generated in GIS can be found in Appendix B.

Shipping Automobiles from OEM to Distribution Centers/Dealerships by Rail

Rail Example Using Surface Transportation Board's Rail Costing Software Program:

Based on information from Kia Motor Company, distribution centers currently owned and operated by Kia include those located in: Mobile, Alabama and Tampa, Florida. Two additional long haul distances were included to estimate costs associated with shipping extremely long distances. Based on the locations of these distribution centers, approximate distances of 265 miles, 514 miles, 750 miles, and 900 miles, respectively, were found using the shortest path routing algorithm, and the distances were used as input parameters for use with the Surface Transportation Research board's Rail Costing Software program (DOT, 2004).

Two different scenarios were chosen: railroad-owned cars and privately-owned rail cars. Other parameters were then chosen as inputs for the software in order to determine an overall cost of shipping manufactured vehicles (e.g. Kia Sorentos) from the OEM in West Point, Georgia to two urbanized areas within the southeastern United States (specifically, Mobile, Alabama, and Tampa Florida. In practice, these types of shipments terminate their rail moves at a distribution center, followed by autorack truck transport of automobiles to specific dealers in the area.

Input parameters for the software included: the weight of the individual automobiles (1.75 tons), the number of automobiles per rail car (20), the number of tons per railcar (35), the number of cars per train (36). Using these parameters, among others, the software calculated overall costs, including: the dollar amount per automobile moved, the dollar amount per automobile moved mile, the dollar per automobile mile, the dollar per train mile, and the dollar amount of drayage per mile. The dollar per mile ratio and mileage ratio could then be calculated. (The results, displayed graphically, can be found in 4.4).

4.7 Discussion

Results from Truck Shipment Scenario One:

Conventional tractor trailer trucks carrying a full load of tires (50,000 pounds) from tire manufacturing facilities (small parts suppliers assigned a tier four) to OEMs (assigned a tier zero), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes:

The truck shipment scenario for this example was chosen based on the need for tire manufacturers to ship large quantities of tires to OEMs to complete vehicles before shipping to dealerships. A conventional tractor trailer was chosen based on the need for closed shipment of smaller products (compared to chassis, for example). The payload was an estimate based on the maximum amount of payload carried by conventional tractor trailers, with considerations given to the weight restrictions in Georgia and Alabama. The average travel speed of 50 miles per hour was chosen, because, although most of the links traveled (based on the results in the GIS) are interstate highways with higher posted speeds, some rural state highways were also chosen, thus requiring lower speeds. Fuel consumption would have varied slightly if a higher average speed was chosen, resulting in a slight deviation from the overall cost estimation.

The results from the model were such that only the truck mode was used in all 980 individual network links. This was due to the impedances placed on all other modes. Summation of the aggregate OD pair links resulted in a total of 32,967 miles traveled throughout Alabama and Georgia. Based on the estimated cost of $1.22 per mile, the estimated average un-weighted costs per trip for small parts suppliers (such as tire manufacturers) to ship to OEMs is approximately $152.35. This is merely an estimate of the shipment costs for all of the tire manufacturers in Georgia and Alabama to ship to the OEMs in the two states.

Results from Truck Shipment Scenario Two:

> *Conventional flatbed tractor trailer truck carrying a full load of new vehicles (53,600 pounds) from the OEM (assigned a tier zero) to a Kia dealership in Dallas, Texas (assigned a tier 13), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes:*

The truck shipment scenario for this example was chosen based on the need for new vehicles to be shipped to dealerships. For this example, Dallas area dealerships were considered in order to create a scenario in which the newly manufactured vehicles would travel very far distances, possibly relying on the usage of rail shipment more so than trucks. A conventional flatbed was chosen for this example based on the need for vehicles to be carried in open, flatbed trucks. The payload was an estimate based on the maximum amount of payload carried by flatbed trucks, with consideration given to weight restrictions in the southeastern states. The average travel speed of 50 miles per hour was chosen, because, although most of the links traveled (based on the results in the GIS) are interstate highways with higher posted speeds, some rural state highways could have been chosen by the model, thus requiring lower speeds.

The results from the model were such that only the truck mode was used in all 329 individual network links. Summation of the aggregate OD pair links resulted in a total of 3,400 miles traveled throughout Georgia, Alabama, Mississippi, Louisiana, and Texas. Based on the estimated cost of $1.22 per mile, the estimated average un-weighted cost per trip for OEMS at Kia in West Point, Georgia, and Hyundai in Montgomery, Alabama to ship to dealerships in Dallas, Texas is approximately $519.50. This is merely an estimate of the shipment costs, and is not necessarily the actual cost of shipping newly manufactured vehicles from Georgia and Alabama to Dallas, Texas.

Results from Truck Shipment Scenario Three:

> *Spread tandem tractor trailer trucks carrying a full load of small parts for chassis (40,000 pounds) from small parts suppliers (assigned a tier six) to large parts suppliers manufacturing chassis (assigned a tier seven), at an average speed of 50 miles per hour*

(based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes:

The truck shipment scenario for this example was chosen based on the need to ship many small parts to large parts suppliers, such as the numerous small parts that make up larger parts of vehicles, such as the chassis. A spread tandem tractor trailer was chosen based on the need to carry large quantities of parts, and a need for more support when transporting parts may be needed, thus the spread tandem (spread axle) truck was chosen for this example. The payload was an estimate based on the maximum amount of payload carried by spread tandem trucks, with consideration given to weight restrictions in Georgia and Alabama. The average travel speed of 50 miles per hour was chosen, because, although most of the links traveled (based on the results in the GIS) are interstate highways with higher posted speeds, some rural state highways could have been chosen by the model, thus requiring lower speeds.

The results from the model were such that only the truck mode was used in all 1,596 individual network links. Summation of the aggregate OD pair links resulted in a total of 218,015 miles traveled throughout Georgia and Alabama. For this example, the total miles traveled were much higher than in the other examples. This is likely due to the fact that the majority of the facilities in the database were considered to be tier seven (large parts suppliers), followed by tier six (small parts suppliers). Therefore, many more highway links were needed to route between the many locations of large and small parts suppliers in the database.

Based on the estimated cost of $1.21 per mile, and the resulting estimated averaged un-weighted costs per trip from small parts suppliers to large parts suppliers is approximately $186.30. This is merely an estimate of the shipping costs.

Results from Truck Shipment Scenario Four:

Double tractor trailer trucks carrying an almost full load of chassis (40,000 pounds) from large parts suppliers (assigned a tier seven) to OEMs (assigned a tier zero), at an average speed of 50 miles per hour (based on average 55 miles-per-hour speed on interstate highways and 45 miles-per-hour speed on state routes at the US Department of Energy's projected reduction in diesel fuel cost for 2014 at $3.82 per gallon):

The truck shipment scenario for this example was chosen based on the need to ship large, manufactured parts of cars, such as chassis, to OEMs, to complete the vehicle manufacturing process. A double tractor trailer truck was chosen based on the need to carry large quantities of parts, and a need for two containers to be used when transporting large parts may be needed; in this case, a standard-size trailer and a panel truck-sized container. However, the Rocky Mountain Double, which consists of two trailers, was not chosen for this example, based on restrictions placed on the usage of this truck type in southeastern states due to the potential for road damage. The payload was an estimate based on the maximum amount of payload carried by double tractor trailers in southeastern states. The average travel speed of 50 miles per hour was chosen, because, although most of the links traveled (based on the results in the GIS) are interstate highways with higher posted speeds, some rural state highways could have been chosen by the model, thus requiring lower speeds. According to the US Department of Energy's US Energy Administration independent statistics and analysis, the projected price of diesel fuel for 2014 will decrease to an average of $3.82 per gallon (US Department of Energy, 2012). This estimated lower price was used in this example to project future freight shipment costs.

The results from the model were such that only the truck mode was used in all 940 individual network links. Summation of the aggregate OD pair links totals 30,980 miles traveled throughout Georgia and Alabama. Based on the estimated cost of $1.17 per mile, the estimated average un-weighted cost per trip from small parts suppliers to large parts suppliers is approximately $153.59. This is merely an estimate of the shipment costs.

Results from Rail Autorack Shipments

The results from the rail scenario indicate that shipping manufactured vehicles by rail for long hauls is more cost-efficient than by using trucks to ship long hauls. (Summary results can be found in Figures Twelve and Thirteen). Although the overall costs for shipping longer distances is much higher than shipping shorter distances, the overall cost per mile is much lower when shipping longer distances. The results also indicate significant cost savings, at least in terms of the marginal costs of transporting freight such as automobiles s using privately-owned rather than railroad owned and operated railcars(in this example, CSX owned railcars).

Table Nine: Railroad-owned railcars cost breakdown by distribution center distance from OEM

Railroad-Owned Railcars	265 miles	514 miles	750 miles	900 miles
Cost per shipment	94853	132460	164596	190756
Cost per auto moved	131.7	184.0	228.6	264.9
Cost per auto moved-mile	0.497	0.358	0.305	0.294

Table Ten: Privately-owned railcars cost breakdown by distribution center distance from OEM

Privately-Owned Railcars	265 miles	514 miles	750 miles	900 miles
Cost per shipment	45600	71669	88835	99726
Cost per auto moved	63.3	99.5	123.4	138.5

Cost per auto moved-mile	0.239	0.194	0.165	0.154

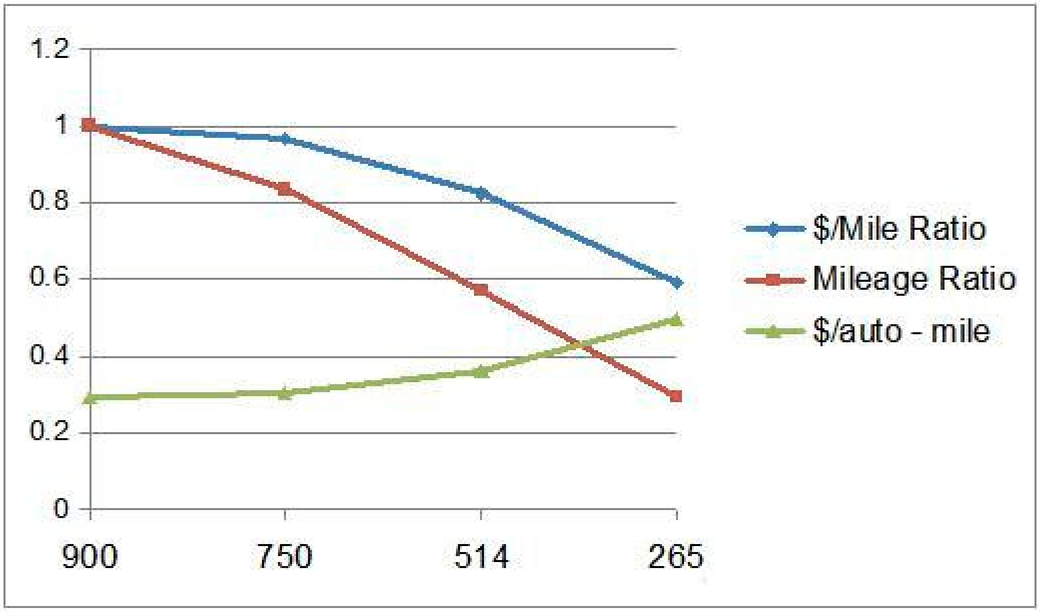


Figure Twelve: Graph displaying results from rail scenario using railroad-owned railcars

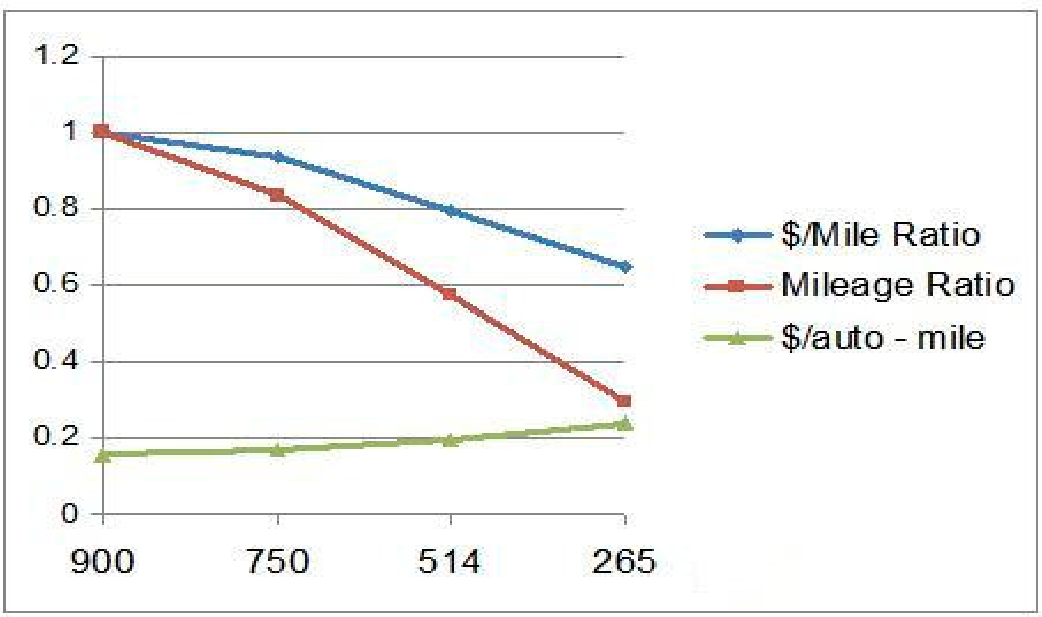


Figure Thirteen: Graph displaying results from rail scenario using privately-owned railcars

4.8 Future Work and Implications of Research

Methodology

The purpose of this research was to estimate freight costs over a multi-modal network, using the automobile industry supply chain in Georgia and Alabama as an example.

This research is an example using the ORNL multi-modal network model and supporting national network dataset and can be used as a reference when conducting research on freight flows under different scenarios and different input model parameter sets. The research relied primarily on the trucking cost calculation formulas used in the Berwick and Farooq (2003) study, and the rail cost calculations used in the Surface Transportation Board's rail cost estimation program software. Other methods of cost calculation formulations could be used in the future, and comparisons can be made between these methods with those used in the present study.

The method used for fuel consumption calculations considered truck type, average weight, estimated payload weights, estimated average speeds, and current diesel fuel, labor and operational and maintenance prices at the time that the study was performed. Examples using other types of trucks could easily be carried out using the estimated average weights for other truck types provided in Appendix A. Also, a generic, average speed in miles-per-hour was used for all examples provided above, with 50 mph chosen based on an assumption that trucks would use both interstate highways and state routes.) However, link and route specific average speeds from the shortest path routine can also be used.

The labor cost component used in the overall cost formula was generic and based on information from the Department of Labor, as well as from the National Survey Trend data. In terms of truck shipments, this labor cost per hour estimate would vary based on individual carriers, whether the truck was for-hire or owner-operated, and specifics related to commodities being shipped. This research was lacking specific information regarding the carriers used by Kia and Hyundai. Therefore, a generic labor cost per hour was deemed sufficient for this study.

The maintenance and operation cost components used in the overall cost estimates relied heavily on the formulas used by Berwick and Farooq (2003) to calculate a generic, variable cost of maintenance and operation of various truck types, and therefore, did not considered specific parameters involved in the formulation of this particular equation. Due to the fact that the calculations were based on formulas that were designed in the early 2000s, an inflation factor could be used in the future to obtain more accurate estimates.

Although the broader costing model shown in Figure Seven above, considered storage and terminal transfer costs for the different modes, separate calculations were not provided in this study. Drayage costs certainly have an impact on overall costs and can be considered in future studies.

Accurate separation of different types of facilities into many different supplier tiers would have resulted in more specific outcomes using particular examples of shipping one type of product. For this study, arbitrary assignment of parts suppliers to tiers was based on SIC codes, and the manufactured product description for each facility location. This study also only provides shipping examples from all locations considered to be part of a particular tier, to that of another particular tier. Specific examples are provided using different origin-to-destination shipping scenarios to estimate costs of shipping one container-load to one particular destination.

Multiplying these O-D single truck trip costs by the number of truck trips per day, or per year, then yields estimates of total inter-tier transport costs. This present study focused primarily on truck and rail shipping scenarios. Similar costing information for air and water shipments is needed to fill in the complete range of supply chain-specific freight movements.

Dallas, Texas was chosen to represent extremely long hauls for truck freight shipments. The decision to use Dallas, Texas was purely for the purpose of providing an example of a fictional dealership location. Local dealerships could have also been chosen, such as those in the Atlanta area. The decision to use Dallas, Texas as the location for long hauls was chosen arbitrarily, and was not representative of Kia shipping patterns. Other locations throughout the country could have also been chosen to represent long hauls.

Future Research

The findings in this research, as expected, support the use of rail for extremely long hauls. Although this research focused on collecting geo-referenced data for the automobile manufacturing industry supply chain, and specifically for two motor companies in Georgia and Alabama, the research approach can also serve as a reference for other industries to obtain cost estimates for shipping purposes. It provides simple calculation methods that can be used to quickly calculate generic costs for other industry supply chains.

The links chosen for different scenarios can help DOTs determine network links to improve, or examine locations for new rail or highway corridors to use as alternates for improving freight flows in Georgia and Alabama. If this study is replicated in a different geographic location, proposals for improvements in freight corridors can be supported by the use of this type of model.

This study can also be used in future studies examining the impacts of variations in the price of fuel. The truck shipping scenario using the Department of Energy's 2014 diesel fuel cost estimate was chosen to provide such an example. Carbon dioxide emission studies may also be performed using this study as a basis for estimated environmental impacts.

Finally, as displayed in Figure Fourteen, this research also has the potential to be extended for use in studies estimating delay costs incurred by shipments due to traffic and other disruptions. Businesses can also use this model to calculate losses due to excessive handling and storage costs, to improve efficiency and determine the effects on the overall costs of production and distribution of products. Lastly, the research can also be extended to the costs of losses incurred by damage to products during shipment by truck (the UCRS provides an estimate of cargo value loss for rail shipment).

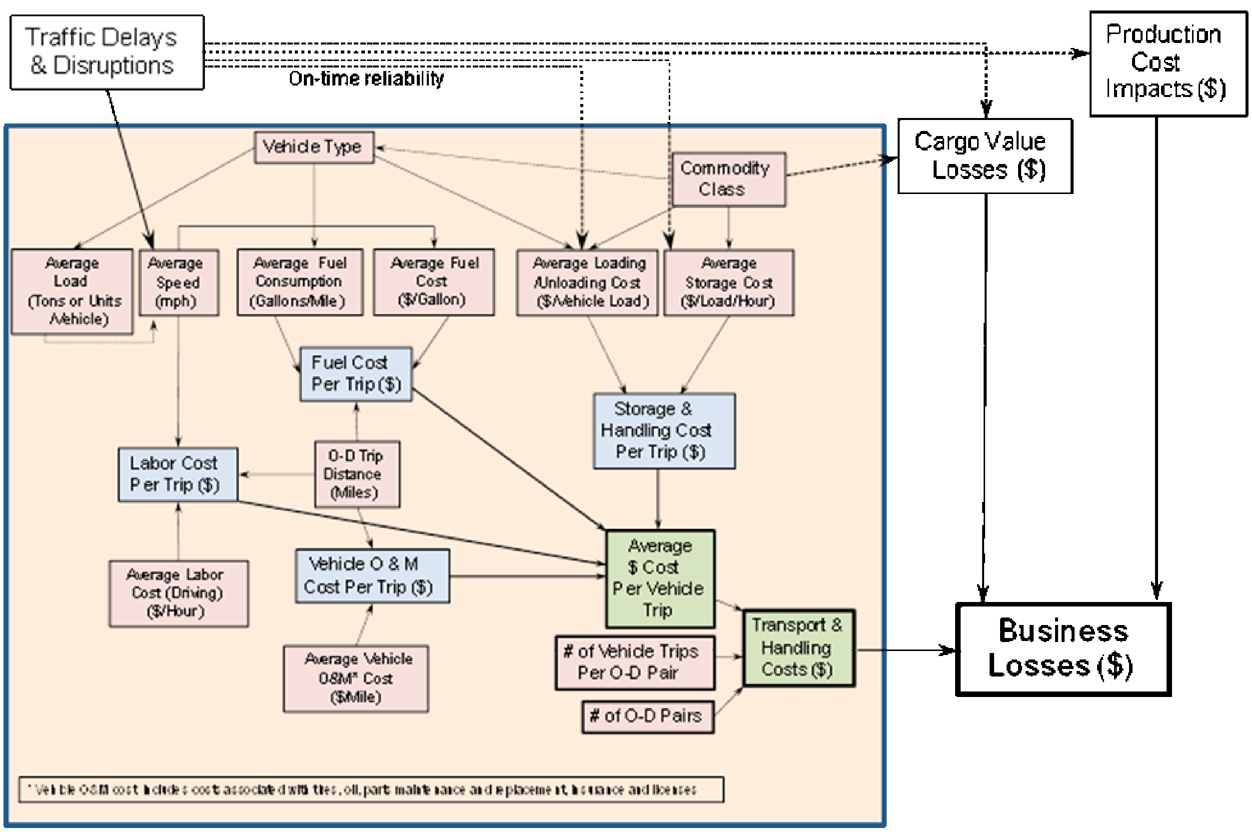


Figure Fourteen: Flow chart of model components for future research

Appendix A

Table Eleven: Trailer Weights (Berwick and Farooq, 2003)

Trailer Weight				
Configuration	**RMD**	**Conventional**	**Spead Tandem**	**Tridem**
Trailer Type				
Van	23700	12900	13500	14400
Flatbed	22900	12500	13100	14000
Hopper	18500	9500	9100	11900
Tanker	18100	9500	10100	X
Reefer	27400	14800	15700	11900
53' Dry Van	X	13800	X	X

Additional calculation notes:

RMD = [Conventional + 28-foot, single axle + 2,800]

Tractor Weight = 13,900 (constant)

Tare Weight = [tractor weight + trailer weight]

Table Twelve: Fuel Consumption Fixed Co-Efficient (Berwick and Farooq, 2003)

Fuel Consumption				
Fixed Coefficient				
Configuration	**RMD**	**Conventional**	**Spead Tandem**	**Tridem**
Trailer Type				
Van	0.0008	0.0008	0.0008	0.0008
Flatbed	0.0009	0.0009	0.0009	0.0009
Hopper	0.0008	0.0008	0.0008	0.0008
Tanker	0.0009	0.0009	0.0009	0.0009
Reefer	0.0008	0.0008	0.0008	0.0008
53' Dry Van	X	0.0008	X	X

Table Thirteen: Fuel Consumption Variable Co-Efficient (Berwick and Farooq, 2003)

Fuel Consumption				
Variable Co-efficient				
Configuration	**RMD**	**Conventional**	**Spead Tandem**	**Tridem**
Trailer Type				
Van	0.1203	0.11068	0.11068	0.1155

Flatbed	0.113592	0.1045	0.1045	0.109
Hopper	0.1203	0.11068	0.11068	0.1155
Tanker	0.113592	0.1045	0.1045	0.109
Reefer	0.1203	0.11068	0.11068	0.1155
53' Dry Van	X	0.11068	X	X

Additional notes for fixed and variable fuel consumption cost calculations:

Conventional = Spread tandem

Tridem = [(RMD + Conventional) / 2]

Reefer = Vans = 53′ Dry van = Hopper

Table Fourteen: Summary Table from all Five Model Run Examples

Summary Table				
	Mode Type	**OD**	**Cost per Hour**	**Cost per Mile**
Example One	Truck	Small Parts Suppliers to OEMs	61	1.22
Example Two	Truck	OEMs to dealership	61	1.22
Example Three	Truck	Small Parts to Large Parts Suppliers	60.5	1.21
Example Four	Truck	Large Parts Suppliers to OEMs	58.5	1.17

Appendix B: GIS Figures

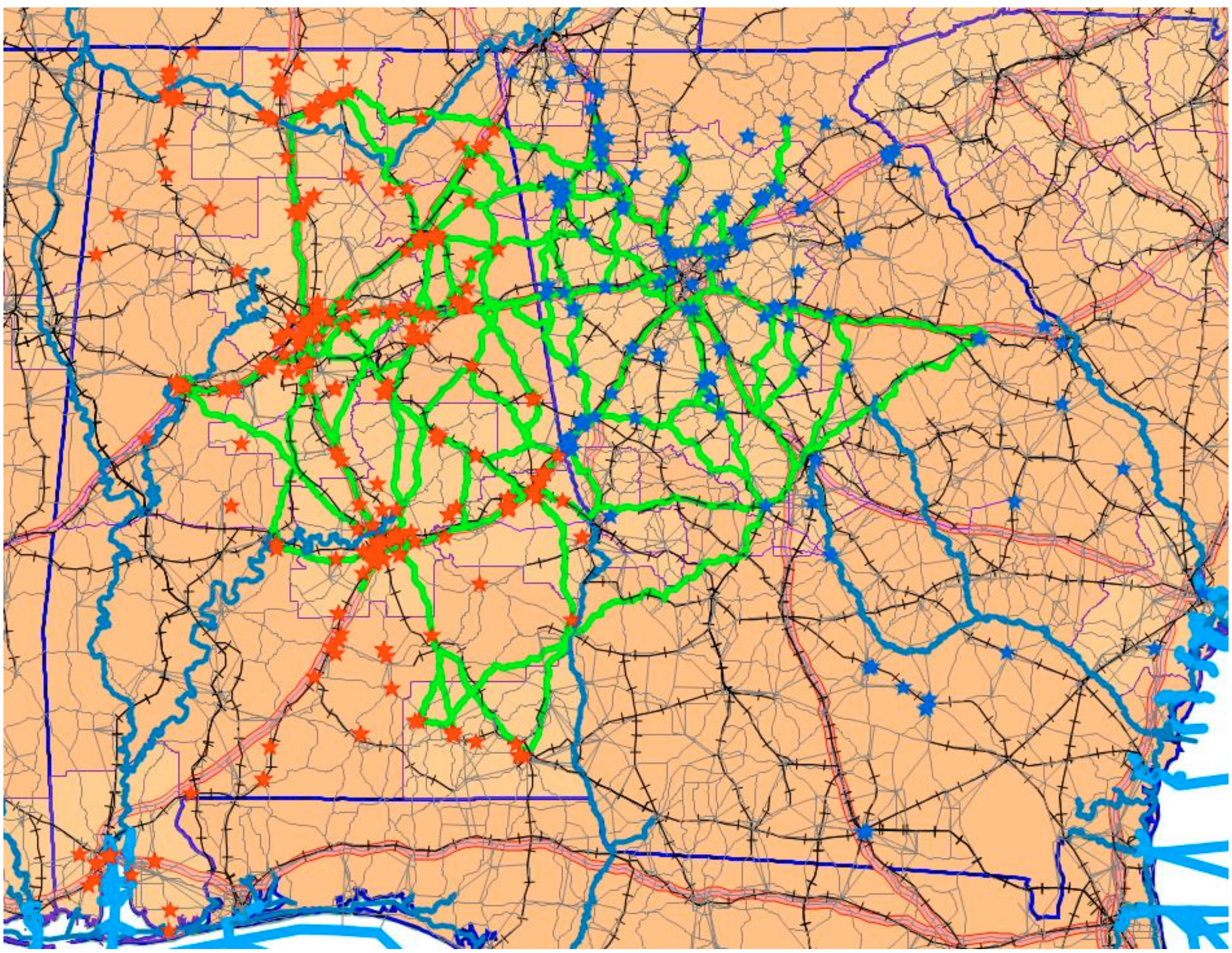


Figure Fifteen: GIS results from hypothetical model run one: tire manufacturers (small parts suppliers to OEMs.

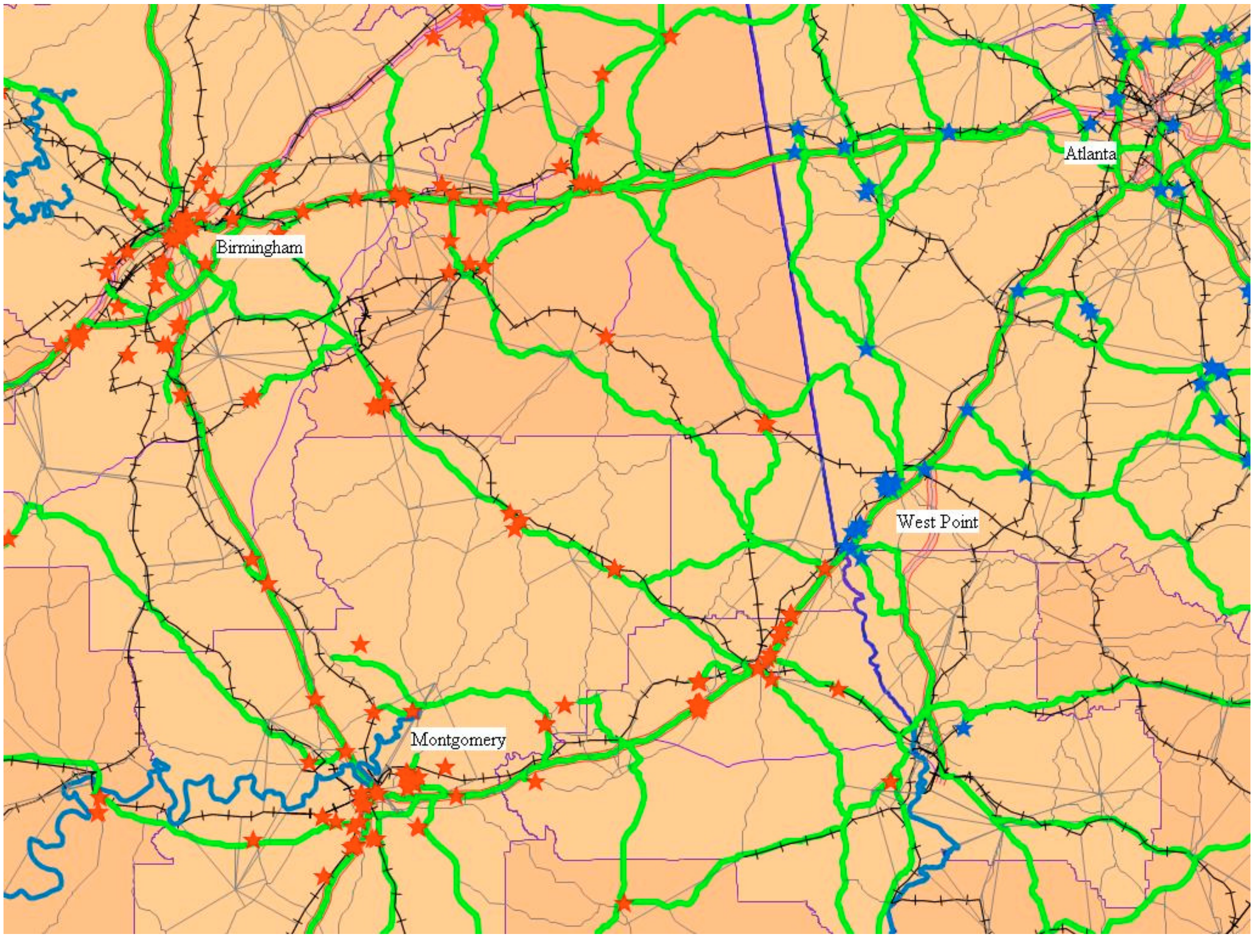


Figure Sixteen: Close-up of hypothetical model run one using Highway Links.

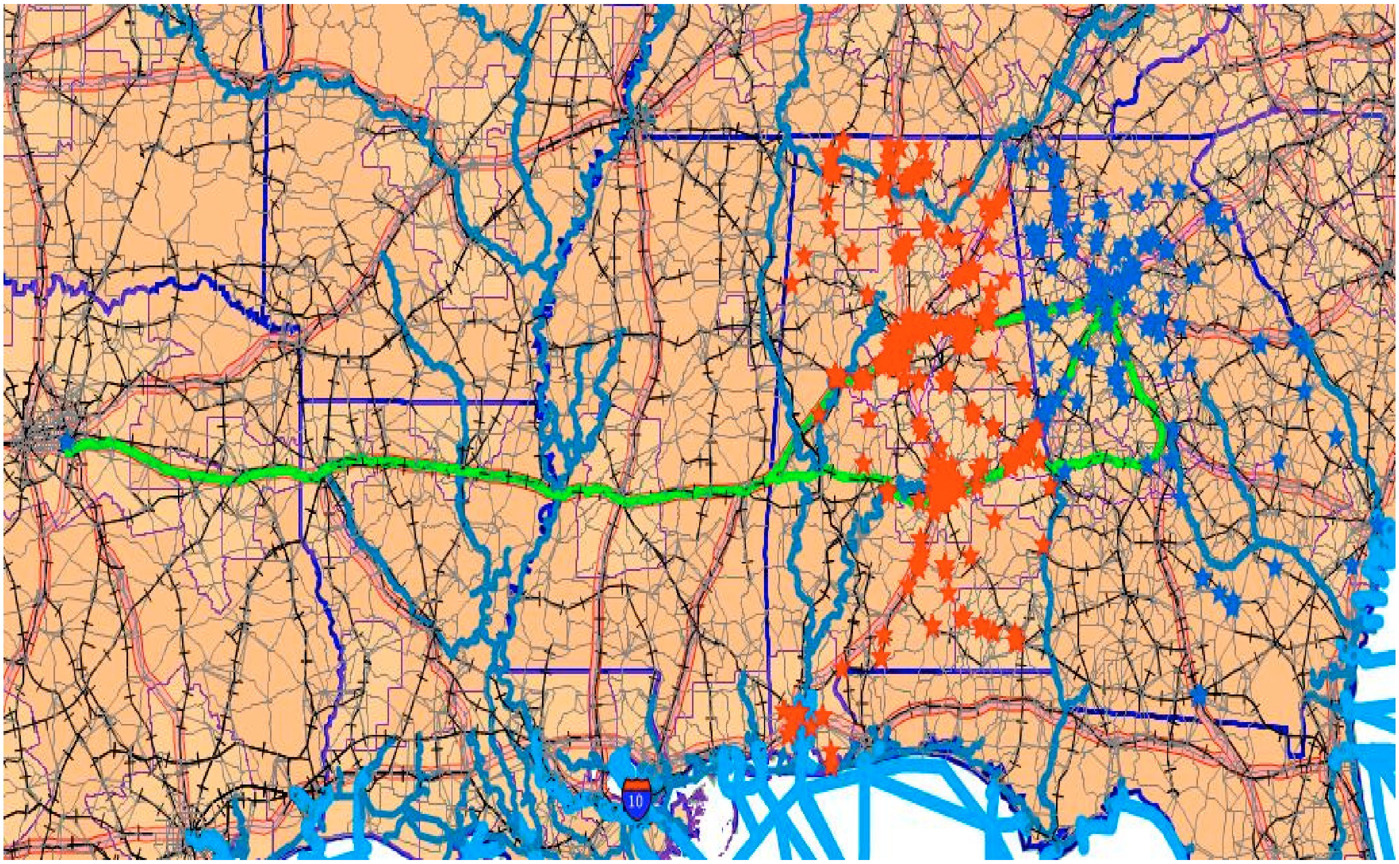


Figure Seventeen: GIS results from hypothetical model run two: OEMs to fictional Kia dealership in Dallas, Texas.

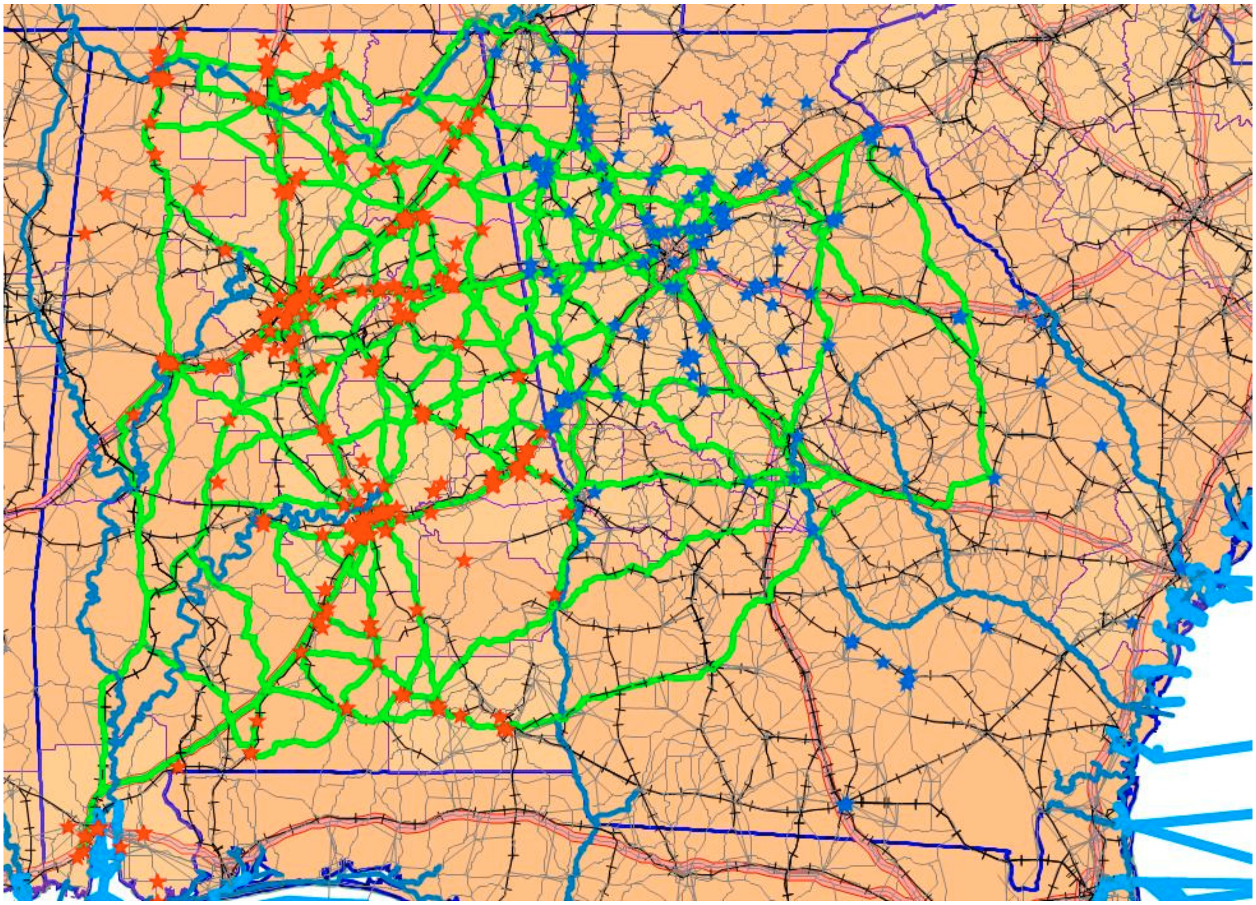


Figure Eighteen: GIS results from hypothetical model run three: small parts suppliers for chassis to large parts suppliers manufacturing chassis.

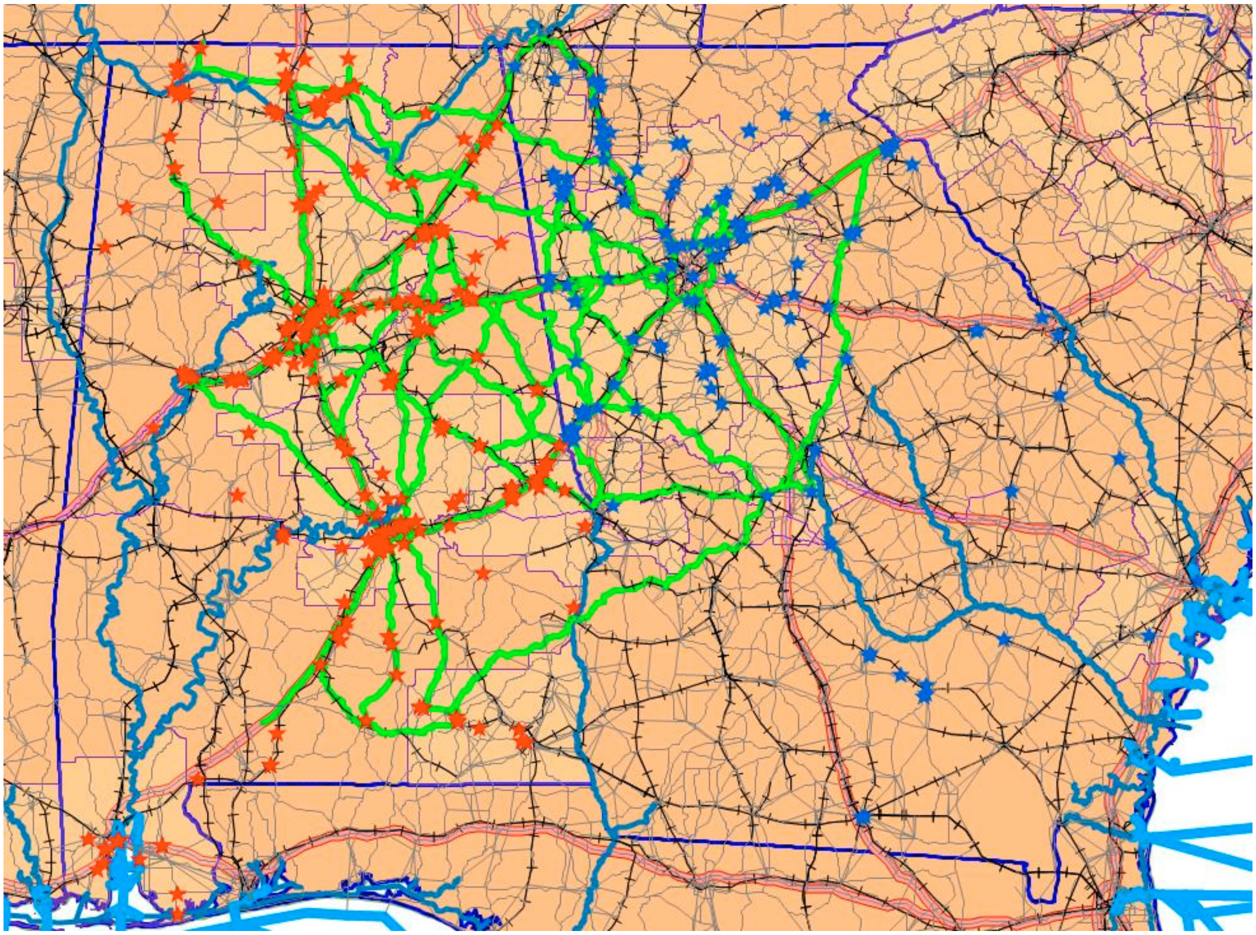


Figure Nineteen: GIS results from hypothetical model run four: large parts suppliers manufacturing chassis to OEMs.

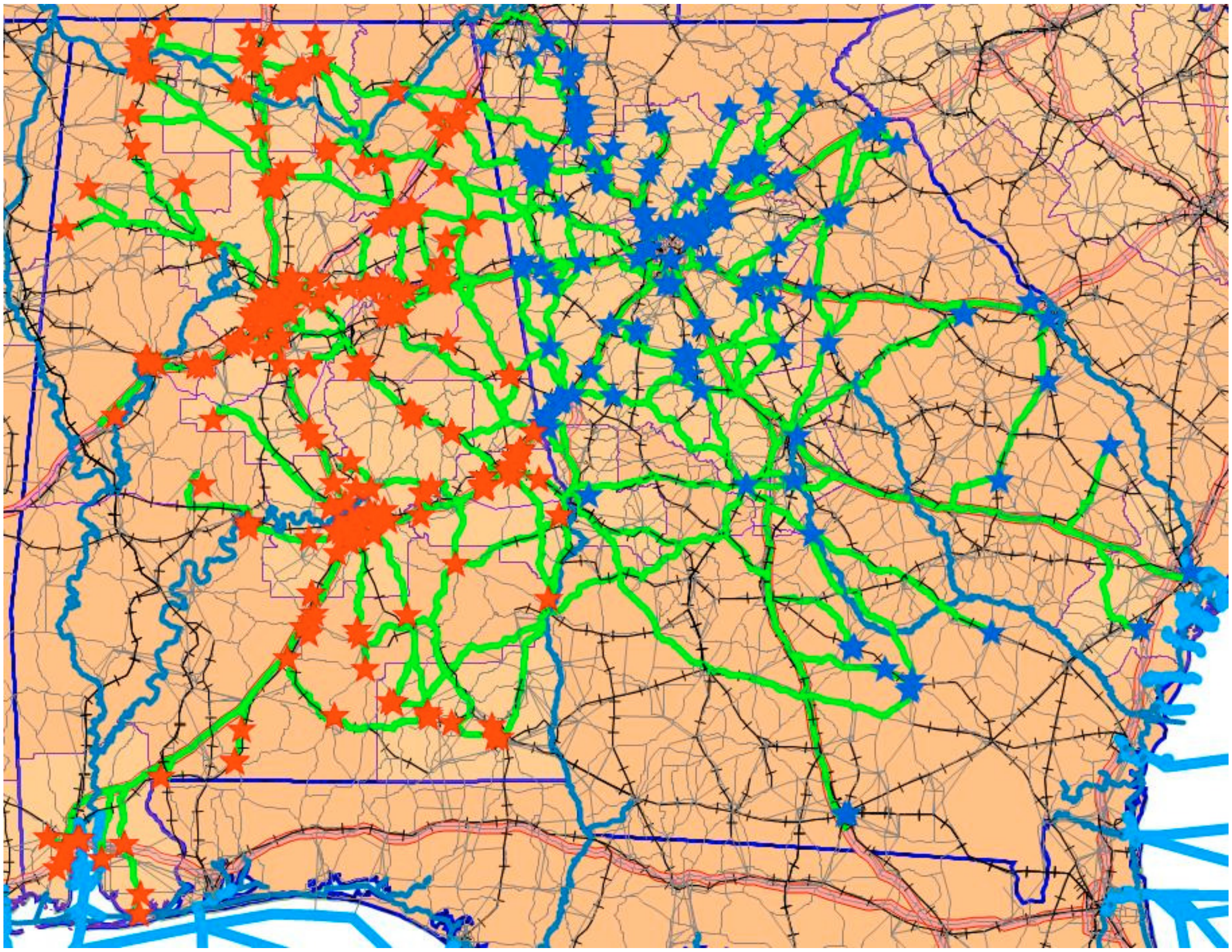


Figure Twenty: GIS results from hypothetical model run five using rail: large parts suppliers manufacturing chassis to OEMs. Results using highway links only (identical to model run four).

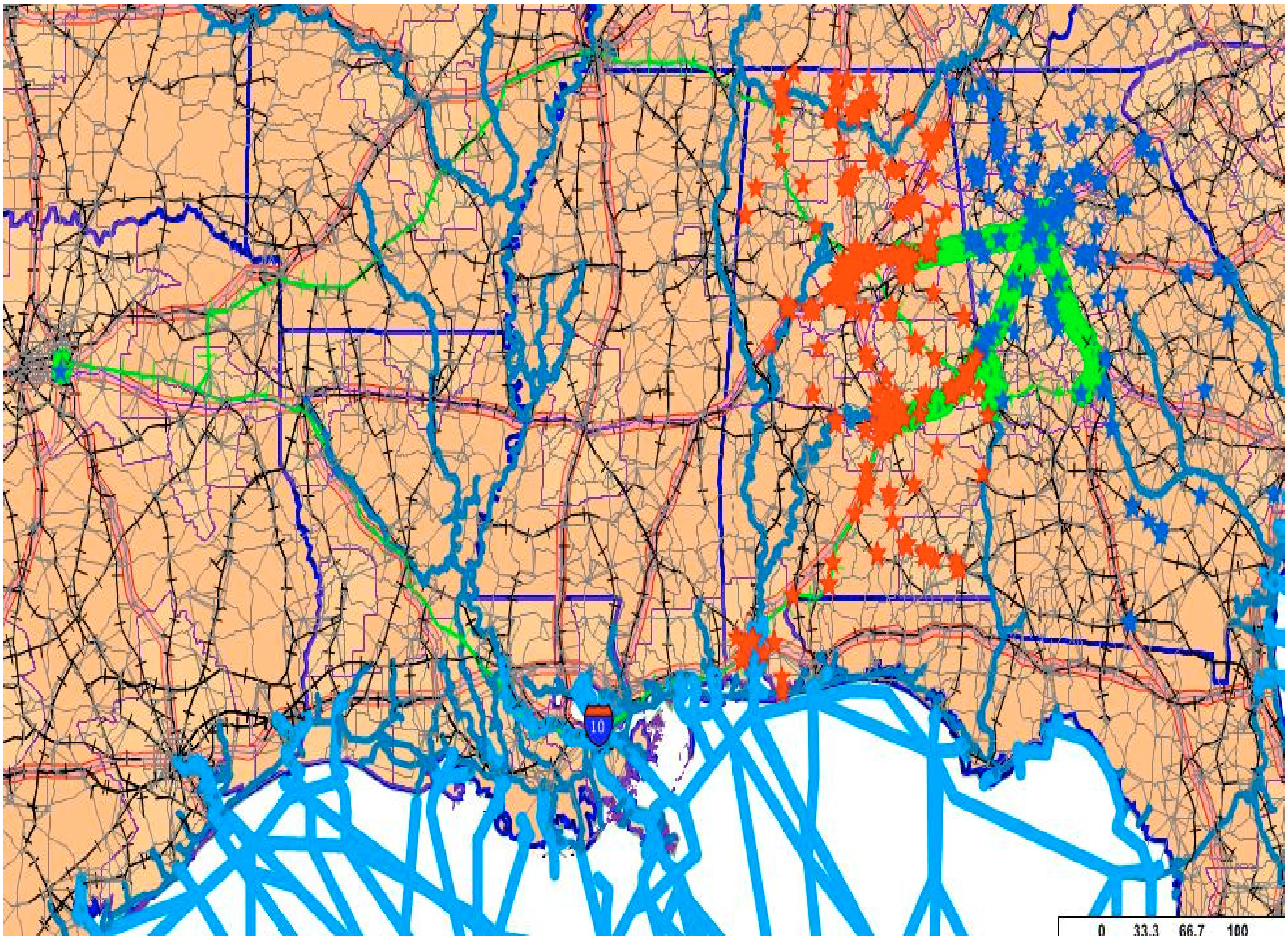


Figure Twenty-One: GIS results from hypothetical model run five using rail: Fictional auto shipment from OEM to fictional dealership in Dallas, Texas (using a combination of highway and rail links).

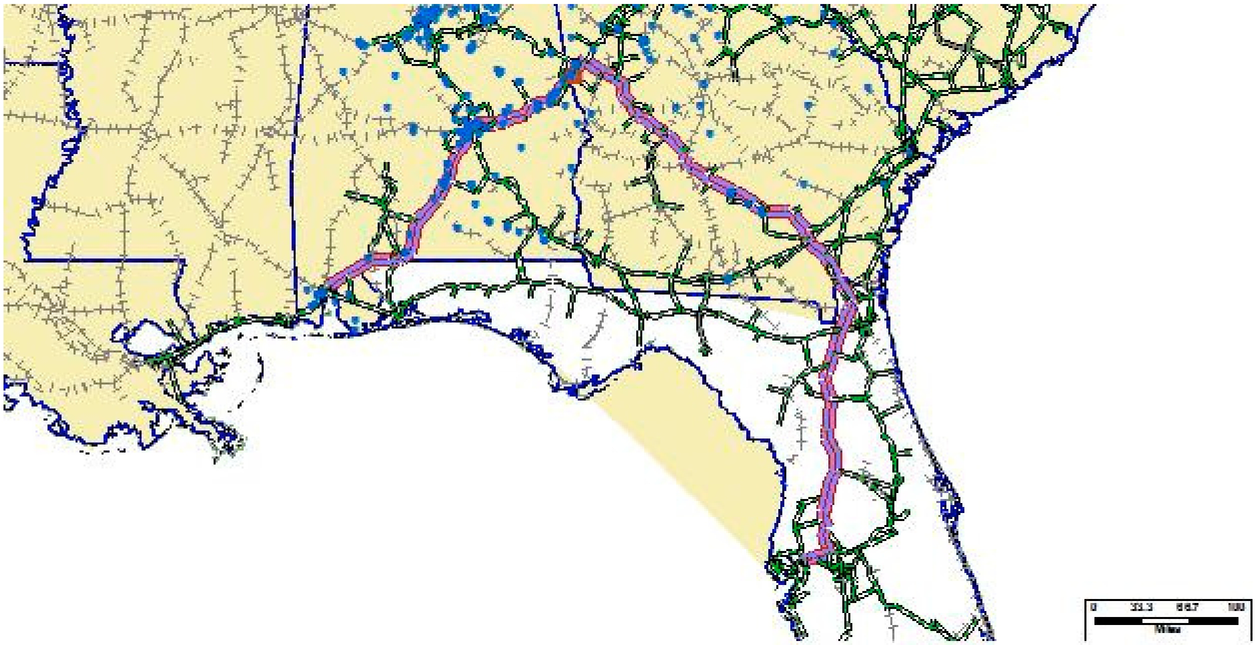


Figure Twenty-Two: GIS results from hypothetical model run using rail (Southworth, 2013).

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