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Requirements for a Washington State Freight Simulation Model

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ABSTRACT

WSDOT and TransNow have already allocated $190,000 to researchers at the University of Washington and the Washington State University to explore the flow of goods through the transportation system, the dynamics of that flow in response to disruption, and the economic impact to these industries supported by that flow. This on-going research, which will develop a GIS based data flow network, will help increase our understanding of the sensitivity of economic productivity to infrastructure availability, laying the groundwork for reducing the sensitivity and improving the resilience of the transportation system. The requested TransNow funding will be linked to the WSU/UW research effort (and completed by the same team) and will develop specifications for a simulation-based methodology. The results from this project will assist WSDOT in determining the utility and feasibility of simulation tools for exploring freight system resiliency as well assist in planning and engineering decision. The project will develop the requirements for a simulation-based methodology that can be used to estimate the impacts of freight flows generated by different economic industry sectors on the transportation system within the State of Washington. The following issues will be addressed:

- Estimated cost to build the model
- Data requirements
- Longterm maintenance of the model
- Geographic scope of the model
- Model methodology

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1. INTRODUCTION

In the face of many risks of disruptions to our transportation system, including natural disasters, inclement weather, terrorist acts, work stoppages, and other potential transportation disruptions, it is imperative for freight transportation system partners to plan a transportation system that can recover quickly from disruption and to prevent long-term negative economic consequences to state and regional economies. In this report we specify the requirements of a statewide freight resiliency model.

We recommend a geographic information system (GIS)-based, multi-modal, Washington state freight transportation network that can be augmented with complete state-wide commodity flow data. With this, the state will be able to improve freight planning and infrastructure investment prioritization. We provide recommendations regarding the scope of and methodology for a statewide freight model that will be developed from the GIS network. This model can be used to estimate the vulnerability of different economic industry sectors to disruptions in the transportation system and the economic impacts of those disruptions within the State of Washington. The team interviewed public sector users to understand what applications are of value in a statewide freight model and applied the lessons learned through building the GIS and conducting two case studies to make recommendations for future work.

Over the last ten years, the United States' transportation infrastructure has suffered from significant disruptions: for example, the terrorist events of September 11, 2001, the West Coast lockout of dock labor union members, and roadway failures following Hurricane Katrina. There is certainly an impression that these events are more common than in the past and that they come with an increasing economic impact. At the same time, supply chain and transportation management techniques have created lean supply chains, and lack of infrastructure development has created more reliance on individual pieces or segments of the transportation network, such as the ports of Los Angeles and Long Beach and Washington States' ports of Seattle and Tacoma. Disruptions, when they occur to essential pieces of the network, cause significant impacts. In particular, they cause significant damage to the economic system.

The relationship between infrastructure and economic activity, however, is not well understood. The development of a statewide freight model will allow WSDOT to better understand this relationship, and improve transportation system resilience.

Resilience refers to a system's ability to accommodate variable and unexpected conditions without catastrophic failure, or "the capacity to absorb shocks gracefully" (Foster, 1993). Transportation resilience can be evaluated at various levels.

- At an individual level it means that people have transportation options needed to satisfy their transportation needs even under unusual and unexpected conditions, such as when their automobile breaks down, if they become physically disabled, or if their income decreases.
- At a community level it means that a transportation system can safely and efficiently accommodate unusual conditions, including construction projects, emergencies, and special events and gatherings.
- At a design level it means that facilities and the transportation system components can withstand extreme demands and unexpected conditions, including major equipment failures, disasters, and new technologies.
- At a strategic planning level it means that a transportation system can meet long-term economic, social, and environmental goals under a wide range of unpredictable future conditions.

An event is seen as disruptive when it creates unexpected conditions. If the future were predictable, resilience would lose its importance: individuals and communities would simply need to plan for a single set of conditions. But because the future is unpredictable, it is necessary to plan for a wide range of possible conditions, including some that may be unlikely but that could result in significant economic and social harm if they are not anticipated. Resilience is affected by a system's ability to collect and distribute critical information under extreme conditions. Resilience tends to increase if a system has effective ways to identify potential problems, communicate with affected people and organizations, and prioritize resource allocation.

This research was motivated by the desire of the Washington State Department of Transportation (WSDOT) to implement a Freight System Resiliency Plan (FSRP). This plan will allow the state to appropriately consider the requirements of the freight transportation system's users and the state economy when responding to disruptions to the transportation system. The WSDOT has completed Phase 1 of the WSDOT Freight System Resiliency Planning Process, which included the development and design of a conceptual approach to Freight System Resiliency Planning. The research, funded by the Freight Systems Division and carried out by the Center for Transportation and Logistics at MIT, included developing a thorough understanding of existing work in the area of freight system resiliency in order to develop a framework for analysis of the resiliency of the state transportation system.

Phase 1 was performed in four tasks: a review of the state of the practice, interviews with relevant stakeholders, development of the Freight System Resiliency Plan process, and knowledge transfer. Phase 1 resulted in 1) a methodology for creating, vetting, and implementing an FSRP for WSDOT, 2) a sponsored event at the Massachusetts Institute of Technology (MIT) bringing together private and public sector stakeholders to discuss the issues and exchange ideas, and 3) a synthesized review of the current state of the practice for other states' FSR plans. The most research-intensive step recommended by the research team was to develop

> a fairly detailed simulation analysis of the state transportation network. Each scenario will generate its own plan and analysis. The specific simulation model to conduct this analysis will vary from state to state (MIT Center for Transportation & Logistics, 2008).

This report recommends actions for the design of a comprehensive statewide freight model, which will improve upon the existing statewide freight transportation model. We begin with a review of existing freight modeling methods.

2. FREIGHT MODELING AND ANALYSIS

The overall ability of the Freight Transportation System (FTS) to better respond and recover from disruptions is facilitated by a clear understanding of system activity. Models are often used to represent operations, evaluate scenarios, identify weaknesses, project future change, and assess impacts from disruptions along the transportation network. Modeling provides information for strategic planning, identifies growth trends, identifies future problem areas, analyzes the effectiveness of potential solutions, and assists in setting project priorities. This section describes existing freight modeling frameworks that were considered for the statewide model.

2.1 TRANSPORTATION ANALYSIS FRAMEWORK

General conceptual models documenting transportation analysis and planning processes abound. Drake (1973) offered one general framework for transportation analysis, reproduced in Figure 2.5. Drake's (1973) framework presents modeling and the modelers in a larger system of relationships that recognizes the importance of society, the greater environment in which decisions and planning take place, and the expectations of the community.

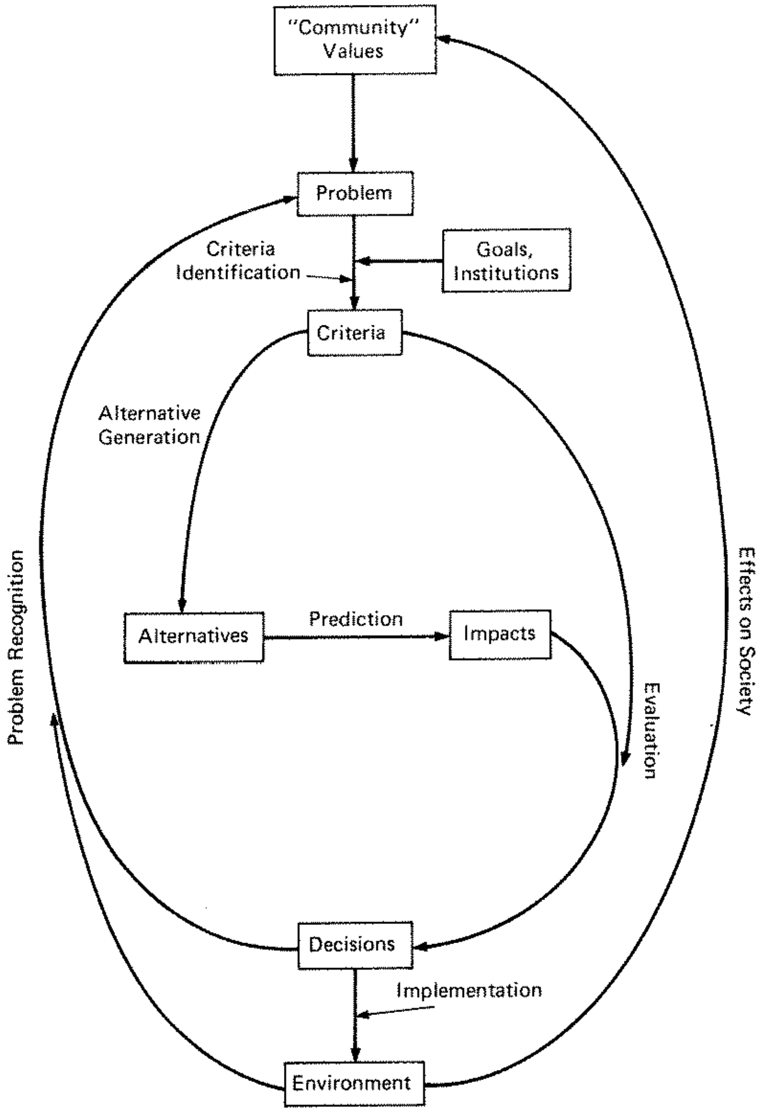


Figure 2.1. Transportation analysis framework (Source: Drake, 1973)

In Figure 2.1, the "problem" is the transportation issue or policy question under consideration. An understanding of the problem itself is bound by the environment in which modelers and decision-makers operate. Modeling is not directly represented in the diagram because modeling is just one of the many tools analysts can use in transportation analyses. Modeling has become perceived as a valuable tool for generating alternative solutions to a transportation problem and for predicting the impacts of those alternatives. Much of the success in modeling depends largely on a thorough understanding of the processes being modeled and the larger system within which modeling is performed.

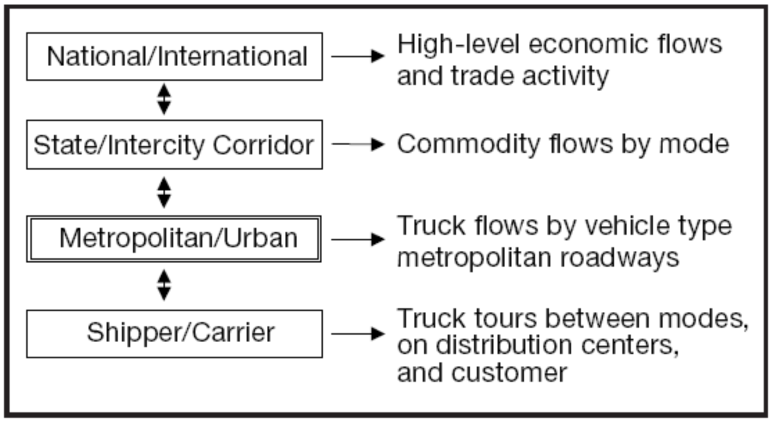
The processes involved in freight transportation modeling are complex. Given the size of and enormously conflicting interests related to major transportation projects, particularly those that involve the public, it makes sense that the consensus seeking and decision-making process is so complex. Decision-making is the product of multiple individuals and parties and occurs at various points along the project's evolution. With many moments for decision-making, the ability to model the impacts of decisions is a meaningful tool for assessing alternatives and providing information about the implications of decisions. Modeling is becoming more common in transportation analysis with the advancement in computing technologies, improved data gathering techniques, and economic evaluation.

2.2 MODELING AND FREIGHT TRANSPORTATION PLANNING

Modeling freight movements proves to be more complex than modeling passenger vehicle movements. Much of the complexity stems from the number of different agents that influence shipment decisions, the vast array of commodity types, and the variation in entities that ship and receive these commodities. For instance, truck trips are not only influenced by the road network, time of day, and day of the week, but also by such factors as hours of service and operation, weight restrictions on roadways, truck types, the commodity carried, shipment size, and the availability of intermodal facilities.

Much in the way of freight modeling has been done at the metropolitan level. Kuzmyak (2008) provided a systematic and in-depth review of issues faced by agencies trying to model freight movements. Core metropolitan planning concerns relate to congestion, roadway safety, environmental impacts, noise pollution, and infrastructure damage (Kuzmyak 2008). However, greater confidence in modeling could be achieved with more information on the relationship between passenger and freight transportation interactions, data integration, data disaggregation methods, and economic impacts resulting from transportation disruptions. Furthermore, interagency partnerships are becoming more common as more states pursue statewide modeling.

Statewide freight modeling raises another set of unique questions. Kuzmyak (2008) offered a modeling hierarchy to organize levels of geography, levels of jurisdiction, and related modeling opportunities. The modeling hierarchy is reproduced in Figure 2.6.



Source: Kuzmyak 2008, page 11.

Figure 2.2 Freight modeling hierarchy

The "metropolitan/urban" level is highlighted because this is the level at which most freight modeling had been done. Metropolitan level modeling can rely on the output of state models to produce information on truck trips that occur on the boundaries of the metropolitan region. From a statewide perspective, it is worthwhile to consider the roles and uses of a statewide freight model that accounts for and builds off of existing freight modeling efforts. A few questions of relevance are as follows:

- What purpose does a statewide freight model serve if many metropolitan planning organizations are already pursuing regional modeling?
- What kind of model platform should be used?
- Who should house the model and how should it but used?
- How shall data be acquired and integrated?

Given the existence of metropolitan and regional level freight transportation models, an integrated model may be a logical platform for a statewide freight model, one that connects existing regional models to provide statewide flows. Further, it "should be easy to explain to an informed audience and easy to justify to an interested public" (Horowitz 1999, 117). Kuzmyak (2008) cited Turnquist's (2006) recommendations for model characteristics that are important for effective freight models: outputs are accessible and tailored to end users; important variables that represent interactions and how the system works are included in the model; the model is verifiable and understandable; and data that are used in the model are calibrated and tested (Turnquist 2006).

2.3 TYPES OF FREIGHT TRANSPORTATION MODELS

No model can perfectly predict the future. Models are by definition, simplifications of reality and as such do not include all the complexities of the real world. By design, models capture the important characteristics, but not all characteristics, of the modeled system. In doing so, they can be used to evaluate alternative scenarios in comparison to baseline scenarios.

Models provide valuable insight if their applications and limitations are known. Three general types of models related to freight transportation modeling are discussed below. Most studies of truck trips fall into two main types of truck trip models, the vehicle-based model and the commodity-based model. Vehicle-based models capture the movement of individual vehicles, while commodity-based models start from aggregate freight flows by weight (e.g., tonnage) that can be converted to units of truck trips. The respective ‘bottom-up’ and ‘top-down’ approaches of the vehicle-based and commodity-based models necessitate different data requirements. In addition to vehicle-based and commodity-based models, transportation network models are also presented in this report, followed by a discussion of integrated models. Figure 2.7 outlines the modeling hierarchy used to organize this discussion.

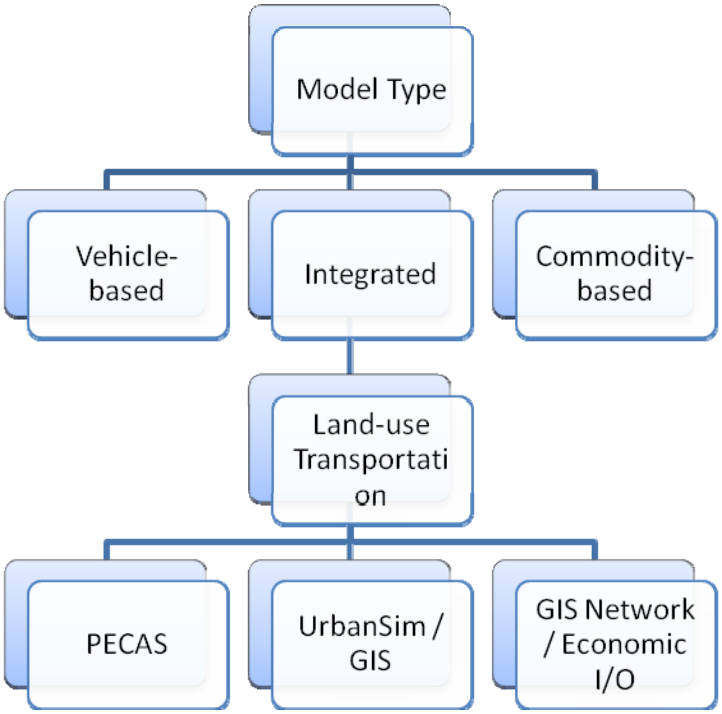


Figure 2.3. Freight modeling categorization

2.3.1 Vehicle-Based Models

A freight transportation model built on a vehicle-based platform models vehicle trips directly. The mode of travel and vehicle choice (usually in the unit of truck trips) are assumed to be limited to one mode. Empty trucks are not an issue with vehicle-based models because, for purposes of traffic impacts, one empty truck essentially plays the same role as a fully or partially loaded truck. Chow (2004) succinctly summarized such vehicle trip-based models, citing Jack Faucett Associates (1999):

> In Jack Faucett Associates, (1999) trip-based models are described as an approach in which truck trips are generated directly, usually as a function of different land uses and trip data from trip diaries or shipper surveys. The trip rates are calculated as a function of socio-economic data (trips per employee) or land use data (trip per acre) leading to generation of trips. The generated trips are then distributed using some form or other of spatial interaction models, most commonly a form of gravity model. The gravity model is typically calibrated using trip length frequency distributions obtained from trip diaries (page 14).

Data are typically collected with commercial vehicle surveys (CVS) that query vehicle owners and establishments that ship or receive goods (e.g., warehouses, distribution centers, stores), as well as with roadside surveys and vehicle classification counts. The survey data are one basis for deriving trip generation rates and the network distribution of vehicle-trips; however, low CVS response rates are a major challenge to the data integrity of vehicle-based models (Chow 2004, Fischer and Han 2001). Counts may also be used in conjunction with CVS to validate data. The high variability between data collection sites and the cost of securing large samples are also challenges to data integrity.

The high costs and labor requirements of administering surveys and the difficulty in achieving representative samples given the cost, time, and patience required by surveyors and respondents are all limitations of vehicle-based models. Certain actions can be taken to help improve the collection and analysis of vehicle-based data, such as focusing on land uses that are clearly freight intensive and performing research to better estimate the distribution of commodities within an industry. Fischer and Han (2001) and Jessup, Casavant and Lawson (2004) offered more in-depth summaries of truck trip data collection methods, the related challenges, and recommendations for improvements.

2.3.1.1 Simulation Models

Simulation models are one type of vehicle-based model. They are founded on a "learning-by-doing" principle. The learning mechanism of the model is calibrated by empirical data. Simulation models have sets of rules for vehicle behavior in each discrete time interval, and they step through time updating the states of vehicles according to these rules. They are capable of handling real-time data and can become extremely data intensive if they are to be accurate and useful. In comparison to the computational timeframes, on the magnitude of one or more years, on which many land-use models operate, simulations are able to process time increments on the magnitude of minutes. Simulation models have been used to inform the planning, design, and operations of transportation systems and can be performed at the micro-, meso-, and macro- levels (e.g., intersection, network of intersections, interstate systems). Typical sources of data for transportation simulations vary depending on the level of analysis. Examples include loop detector data, Global Positioning System (GPS) data, and vehicle classification counts. These are often readily available to modelers. Current implementations of simulation models are usually limited to intra-terminal operations or transportation corridors. The requirements for data inputs are heavy, as is the computing power required. For these reasons, simulation models have not yet been implemented at the state level.

2.3.2 Commodity-Based Models

Commodity-based models are another common methodology for modeling freight transportation. Commodity-based models use aggregated freight flow data, usually measured in a weight measurement such as tons, to estimate truck trips. The focus on freight flow data and commodity flow data highlights the connection between freight transportation and the economy. Chow (2004) suggested that commodity-based models "capture more accurately the fundamental economic mechanisms driving freight movements, which are largely determined by the cargoes' attributes (e.g., shape, unit weight)" (page 29). Commodity-based models have the following general structure:

1. Commodity generation models are used to estimate the total number of tons produced and attracted by each zone in the study area, the traffic analysis zone.
2. In the distribution phase, the tonnage moving between each origin-destination pair is estimated by using gravity models and other forms of spatial interaction models.
3. The mode split component, intended to estimate the number of tons moved by the various modes, is achieved by applying discrete choice models and/or panel data from focus groups of business representatives or freighters.
4. Prior to the traffic assignment phase of commodity-based models, a combination of vehicle loading models and complementary models that capture empty trips is applied to origin-destination matrices by mode to convert the tonnage into vehicle trips.
5. The vehicle trips are assigned to the network through a traditional assignment procedure.

With the aggregate nature of the data, commodity-based models fit regional-level analyses. The higher level of aggregation is usually above the scale of the standard traffic analysis zone used in the passenger transport model. The needed disaggregation is well summarized by Jack Faucett Associates (1999).[1]

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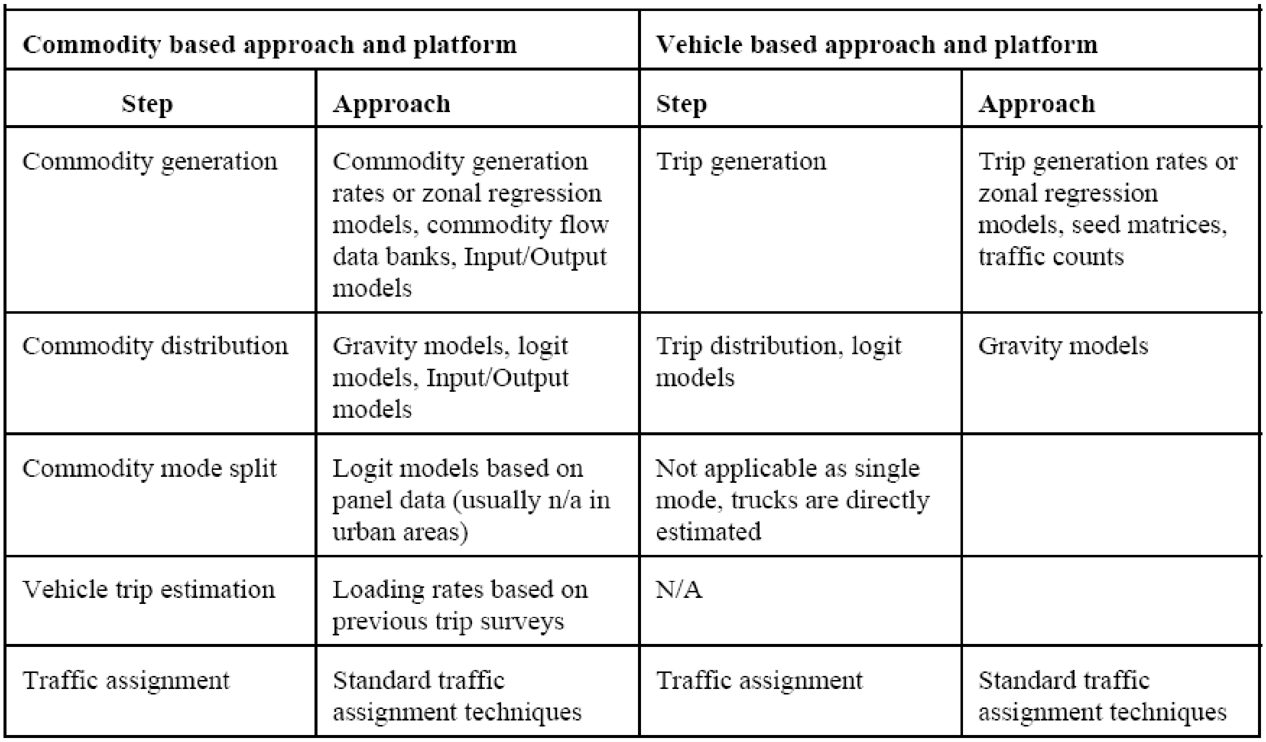
[1] See Chow (2004) for a paraphrase of the summary.

Commodity-based models typically rely on national Commodity Flow Survey (CFS) data collected by the U.S. Census Bureau of Transportation Statistics every five years. CFS data result from shipper surveys that detail commodity flows by quantities by mode on a state by state basis and, since 1997, by statistical metropolitan areas (SMAs). National CFS data are often disaggregated to the county level for use in statewide freight studies and models; however, the data are not always available to the metropolitan planning organizations (MPOs), the organizations that perform regional freight studies and modeling (Chow 2004, 32). In addition to the national CFS, Reebie Associates also provides disaggregated commodity flow data in its Transearch database for purchase. Given the aggregate nature of commodity flow data, to transform the data into truck trip generation rates, the flows are divided by payload data that have typically come from the national Vehicle Inventory and Use Survey (VIUS) (Fischer 2001, 2). Unfortunately, the VIUS is no longer conducted. A major drawback to commodity-based models is that they tend to underestimate urban truck movements because the aggregate flow data are unable to capture the details of many freight activities.

Despite the differences between freight transportation and passenger transportation, commodity-based and vehicle-based modeling efforts have taken the traditional four-step approach borrowed from passenger transportation modeling. The four steps are 1) trip generation, 2) trip distribution, 3) mode split and trip estimation (typically not applicable because the vehicle type is limited to trucks), and 4) traffic assignment. The process for this type of modeling is summarized in Table 2.5 alongside the process and for commodity-based models.

Table 2.4 A comparison of commodity-based and vehicle-based modeling approaches (Chow, 2004).



Commodity based approach and platform		**Vehicle based approach and platform**	
Step	**Approach**	**Step**	**Approach**
Commodity generation	Commodity generation rates or zonal regression models, commodity flow data banks, Input/Output models	Trip generation	Trip generation rates or zonal regression models, seed matrices, traffic counts
Commodity distribution	Gravity models, logit models, Input/Output models	Trip distribution, logit models	Gravity models
Commodity mode split	Logit models based on panel data (usually n/a in urban areas)	Not applicable as single mode, trucks are directly estimated	
Vehicle trip estimation	Loading rates based on previous trip surveys	N/A	
Traffic assignment	Standard traffic assignment techniques	Traffic assignment	Standard traffic assignment techniques

2.3.3 Geographic Information System Transportation Network Models

Vehicle-based and commodity-based freight models require some representation of a transportation network by which to evaluate transportation decisions and alternatives. The GIS platform is one way to create a network representation. GIS is a well-developed field with standards for data representation and integration.

There is general agreement that a transportation network can be represented by nodes (e.g., ports, intermodal yards, distribution centers, and destinations) and the links (the system of roadways, rail links, waterways) that connect those nodes. A geographic information system (GIS) transportation network model is one representation of that system. The utility of a transportation network model is heavily dependent on the quality and form of data sources used. A GIS-based model “integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information” (ESRI website, accessed June 20, 2009). A GIS integrates databases with visual representations (i.e., maps) of spatial distribution, supporting analyses of events and scenarios structured on the modeled network. Impedance factors such as congestion costs, travel time, and truck route restrictions are built into the GIS network. Events and scenarios are modeled on the basis of the data available. In comparison to simulations, GIS network models do not inherently "learn," but they require modeler input to set up scenarios and run the model.

2.3.4 Integrated Models

Mentioned previously, freight transportation modeling at a statewide level should build off existing modeling efforts. There are three broad types of models that may integrate land-use, commodity flow, vehicle trips, and/or economic analysis: PECAS, UrbanSim, and a GIS network-I/O model. A statewide model involves more complex integrations to include not only land-use and transportation models, but also economic models and models designed for different scales of analysis. PECAS and UrbanSim are two commonly implemented systems for large-scale land-use and transportation modeling.

From the 1960s to the 1980s, transportation models focused mainly on roadway capacity and how to accommodate estimated demands generated by expected land-use development, represented by the spatial distribution of residential locations and employment centers (Waddell and Ulfarrson 2004). A recognition of the effects of transportation improvements on land-use development emerged during the 1990s. However, the complex feedback connections between land use and transportation need attention in the modeling world.

Integrated land-use transportation models comprise two distinct modeling pieces, the land-use piece and the transportation piece. In these models, the land-use piece generates the trips that feed the transportation piece of the model, which in turn generates the transportation demand on which land-use impacts can be modeled. Land-use transportation models usually draw on employment data, population density, and trip generation rates from standard sources such as the ITE Trip Generation Manual or surveys. Land-use transportation models are often used for long-term forecasting

2.3.4.1 PECAS

PECAS (Production, Exchange and Consumption Allocation System) provides a framework for representing transportation system elements, their behavior, and their interactions, and for identifying data needs to compare across different cases. The PECAS framework is not always used in its entirety; regardless, it is still used to define other model components as well as the interactions between those components. PECAS incorporates the spatial I/O approach of the MEPLAN[2] (Hunt and Simmonds 1993), TRANSUS (de la Barra 1998), and DELTA (Simmonds 1996) modeling systems. It is both an integrated and connected model. It is integrated because it is based on spatial disaggregation of I/O tables to link land use and transportation. PECAS is connected because it is able to model wide quantities of activities allocated in space according to distance of relevant accessibilities. Abraham and Hunt (1998) described PECAS as follows:

> an aggregate, equilibrium structure with separate flows of exchanges (including goods, services, labour and space) going from production to consumption based on variable technical coefficients and market clearing with exchange prices. Flows of exchanges from production to exchange zones and from exchange zones to consumption are allocated using nested logit models according to exchange prices and transport (dis)utilities. These flows are converted to transport demands that are loaded to networks in order to determine congested travel disutilities. Exchange prices determined for space inform the calculation of changes in space thereby simulating developer actions. The system is run for each year being simulated, with the travel disutilities and changes in space for one year influencing the flows of exchanges in the next year (Hunt and Abraham 2005, 217).

PECAS or its components is currently being applied in the development of state-wide transportation land-use modeling systems for Ohio and Oregon, in the development of an urban land-use model for Sacramento, and in the anticipated development of urban land-use models for Calgary and Edmonton in Canada. It is also being used as the basis for a recommended design for a model of the Los Angeles region.

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[2] MEPLAN was the modeling framework used for WSDOT's 2001 Cross Cascades Corridor Analysis Project. MEPLAN is a flexible, general framework that is based on many well established macroeconomic theories. "A review of the MEPLAN modeling framework from a perspective of urban economics" by John E. Abraham provides further details on a framework from which MEPLAN was designed.

2.3.4.2 UrbanSim

UrbanSim was developed to provide a tool for metropolitan planning organizations to "test out" policies beyond a long-term forecast timeframe. UrbanSim is a tool "to evaluate growth management policies such as urban growth boundaries, assess consistency of land use and transportation plans, and address conformity with respect to air quality implementation plans" (UrbanSim Description, http.//www.urbansim .org/description/, Accessed June 22, 2009). It is based on an urban model framework that accounts for agents, choices, and their interactions that relate to transportation, land use, and policy decisions.

The model implements a perspective of urban development that represents a dynamic process resulting from the interaction of decisions made by many actors within the urban markets regarding land, housing, non-residential space, and transportation. UrbanSim represents urban development as the interaction between market behavior and government action through land-use and transportation phenomena. Scenarios developed within UrbanSim are informed by population and employment estimates; regional economic forecasts; transportation system plans; land-use plans; land development policies such as density constraints, environmental constraints, and development impacts; all information to which most metropolitan planning organizations already have access. Outputs generated by UrbanSim support analysis down to the parcel-level; it is able to disaggregate information at the household, business, and land-use levels (UrbanSim Description, http://www.urbansim.org/description/, Accessed June 22, 2009).

UrbanSim has been used as a modeling in modeling efforts of cities such as Seattle, Washington, Salt Lake City, Utah, Honolulu, Hawaii, and Eugene-Springfield, Oregon (Waddell 2000).

2.3.4.3 Integrated Transportation Network and Economic Models

Researchers at the University of Southern California's Center for Risk and Economic Analysis of Terrorist Events (CREATE) have developed the Southern California Planning Model (SCPM). It is an integrated highway network-economic-spatial allocation model for the Los Angeles metropolitan area. It was designed to assess the economic impacts of terrorist threat scenarios affecting Southern California, of which transportation infrastructure and functioning are a major component (CREATE Accessed June 22, 2009).

REDARS2 is another integrated model. It includes modules for estimating seismic hazards, infrastructure component performance, and resultant system performance through the use of a transportation network model to represent the transportation system and assess economic consequences. The network model is simple and uses broad assumptions for estimating consequences, but it does not include commodity-specific costs or behaviors.

2.3.5 Modeling the Economic Impact of Freight System Disruptions

Estimating or measuring any economic impact resulting from transportation system disruptions may involve numerous approaches, depending on a variety of considerations. These include the attributes of the system being evaluated, data availability, static/dynamic time analysis, level of economic activity measured, accuracy of industry-to-industry relationship characterization, and utilization of output results. The different approaches are indicative of how intricate and challenging it is to accurately characterize and represent the complex and integrated way that firms/people interact in any economy (in this case the state's economy) and the challenges associated with developing a methodology that is simplified enough for practitioners/policy makers to understand yet robust enough to accurately reflect real economic and transportation activity.

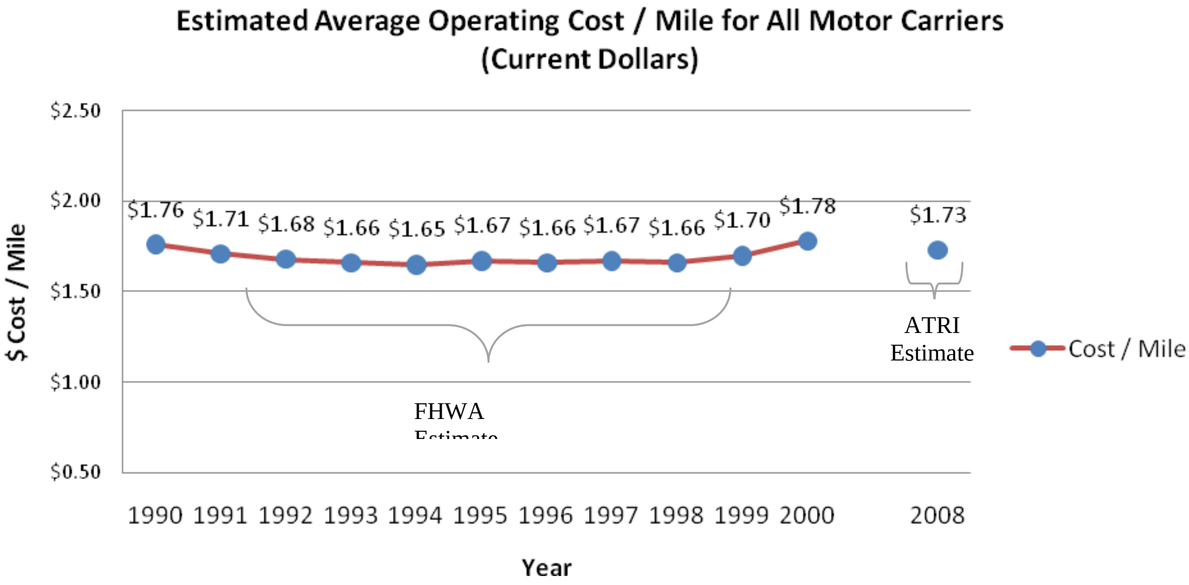
Economic impacts resulting from temporal disruptions to the transportation system can be classified into two categories: direct (short-run) and indirect (long-run) impacts. The direct economic impacts for highway system disruptions are principally concentrated in the freight transportation and trucking services industry, affecting variable operating costs to these businesses, but they can also have immediate implications to businesses and firms serviced by the freight industry, especially shippers of perishable and time-sensitive commodities (see Table 2.6). The impacts to businesses in the freight transportation and trucking industry include increased variable costs such as fuel, labor, scheduling/logistics, tire wear, and equipment maintenance that result from shipments being re-routed, delayed, or in some cases trans-loaded to another truck/trailer.

Table 2.5 Freight services/truck transportation cost components

Fixed Costs	
Fixed Business Costs	• Management/Overhead Cost • Insurance • Taxes • Interest
Fixed Vehicle Costs	• Truck and Trailer Equipment Depreciation • Truck and Trailer Licensing
Variable Costs	
Truck/Trailer/Vehicle Use	• Driver/Labor Cost • Scheduling/Logistic/Dispatch Labor Cost • Fuel Cost • Repairs/Maintenance • Tires • Miscellaneous

Depending on the location and duration of the disruption, trucking firms may incur additional lodging costs for truck drivers or be required to arrange/pay to switch drivers who have exceeded their hours of service limits waiting for the disruption to be resolved.

The Federal Highway Administration provided estimates of average operating costs per mile for all motor carriers up until the year 2000 (see Figure 2.8), which ranged between \$1.65 and \$1.78 per mile. A more recent 2008 study conducted by J.J. Keller and Associates for the American Transportation Research Institute estimated the average operating cost for all motor carriers to be \$1.73 per mile. Utilizing these national average cost estimates and applying them to specific disruption scenarios provides an estimated range of direct cost impacts to freight transportation and trucking businesses. To apply these average per mile cost coefficients in aggregate, pervious simulation/modeling impact analysis is required to estimate the total volume of freight vehicles affected, likely re-routing scenarios, and the additional mileage incurred by transportation/trucking firms. If more concentrated direct cost impacts are desired at the industry or commodity level, then freight modeling/simulation analysis will need to be more detailed to provide specific freight volumes and re-routing activity at this level, as well as the additional mileage cost coefficients segmented by industry or commodity type.



Source: Federal Highway Administration (FHWA), Freight Management and Operations, http://ops.fhwa.dot.gov/freight/freight_analysis/exp_mile/index.htm
Source: American Transportation Research Institute (ATRI), J.J. Keller and Associates, http://www.atri-online.org/research/results/economicanalysis/Operational_Costs_OnePager.pdf

Figure 2.6. Estimated average operating cost/mile for all motor carriers

While this estimation approach provides a relatively quick and approximate estimate of direct impacts to trucking companies and freight shipping services in aggregate, it does not explicitly account for the special instances of additional lodging costs and driver replacement costs mentioned above. However, one could argue that because transportation disruptions, to varying degrees, occur periodically across the national transportation system, and freight shipping and trucking companies are continually responding and adjusting to these disruptions, a small portion of this cost component is already included in the estimated average cost per mile of operations. The direct costs of product shipments that are damaged/spoiled as a result of the transportation disruption and covered under the freight services insurance policy would result in higher insurance premiums for freight services companies that would further increase operational costs.

2.3.6 Indirect Economic Impact

The more difficult challenge of estimating the economic impacts from transportation system disruptions relates to how the disruptions affect the businesses and firms throughout the broader economy that rely upon freight transportation and trucking services. To fully understand how these impacts affect different types of businesses and firms requires a thorough understanding of firm-level decisions and activities, including all supply (production) and demand (consumption) relationships for a specific product. In Washington state, the number and variety of products/services produced is vast, including everything from airplanes, computer software, and agriculture products to outdoor recreation equipment. Likewise, developing a microeconomic model that accurately characterizes all supply and demand relationships for any one of these products would present a formidable challenge on its own and would be extremely difficult for all products and services combined in the broader economy in aggregate. As a result, many micro economists spend their entire careers focused on one specific industry or subset of products (environmental economists, energy economists, agricultural economists, etc.).

Perhaps the most common approach to estimating and accounting for inter-industry activity is Input-Output Analysis, an approach first developed by Wassily Leontief, who won a Nobel Prize in Economics in 1973 for developing this type of economic accounting structure. Leontief was primarily interested in how technological change in certain businesses and industries affects the broader economy through multiplicative transactions and activities across all industries, firms and economic sectors. But his approach of identifying the specific input-output relationships for all major industry sectors was quickly adapted to many other economic policy issues, including how taxes and/or subsidies to any one specific industry affect all other industries as the tax/subsidy is traced throughout the entire economy and how the aggregate economy is changed. This approach has also been widely applied to estimating the economic impacts resulting from a large project (or series of projects/investments) in an economy when information about how those investments affect different industries is desired. This approach has also been applied in the State of Washington to estimate the economic impacts from two transportation system disruptions (I-5 flooding and I-90 Snoqualmie closure) (Ivanov et al. 2009) and to provide a better understanding of the significance of transportation services to the state's economy (Chase, Jessup and Casavant 2003).

Input-output accounting and modeling was initially quite aggregated, both in terms of industry classification and geographic specification, and this has been one of the principle criticisms of this type of modeling. Leontief initially developed an input-output accounting for the entire U.S., including only 40 industry sectors. The current and most widely used input-output package, IMPLAN Professional Software 2, includes nearly 500 industry sectors and allows geographic aggregation at the state, county, sub-county, and zip code levels (assuming one has purchased the sector activity data for the region of interest). The IMPLAN data consist of 1) a matrix of industry-specific technical coefficients that specifies the quantity of inputs necessary to produce a given unit of output and 2) sector-specific final demand, final payments, industry output, and industry employment.

While input-output models have been widely used and applied in many different circumstances, they do possess several limitations that are worthy of consideration. The technical coefficients (unless modified and modeled separately) are treated as constants, thus not allowing for businesses or firms to alter the number of specific inputs per product (output) produced across all inputs and outputs. Of course the actual economy and businesses participating in the economy do not work in this manner. In reality, firms are constantly adjusting and substituting inputs as market conditions, technologies, labor productivity, prices for labor and equipment, and the structure of the industry change. This limitation is especially problematic if this type of modeling approach is applied to longer-term implications or forecasting well into the future. This is one reason why these models are primarily utilized for one-time shocks to the economic system. In addition, input-output models assume zero resource constraints (supply is perfectly elastic) and that employment is efficiently allocated and operating at full capacity (zero underemployment). Neither of these assumptions is accurate, and this partial equilibrium solution poses problems or limitations when lengthy time periods are evaluated. Also, given that few regional economies (regardless of the region of interest, whether a collection of states, one state, or a county) function as a geographically isolated island, the identification and characterization of how the economy of interest engages and interacts with the broader economy is often difficult and therefore oversimplified. Lastly, the accounts and transactions level input data utilized for this approach are typically not made available without a two- to five-year lag. During periods of significant and sizeable economic change (as witnessed over the past two years), the industry-level inter-relationships from several years ago may not be applicable to current conditions and thus limit the accuracy of this type of approach.

Given the limitations with input-output modeling and the partial equilibrium outcomes provided (no price responses, constant input-output technical coefficients, perfectly elastic supply), a Computable General Equilibrium (CGE) model approach (part of the General Equilibrium family of models) is increasingly preferred and implemented. This family of models utilizes the same transactions level input data/information as a traditional input-output model, but it also approaches a "general" equilibrium solution by allowing all prices to change and the utilization of technical coefficients to adjust as a result of these input/output price changes. This approach certainly lends itself to economic analyses that cover longer time periods, since firms, markets and industries do adjust in the long-run. Of course the challenges (both information/data and mathematical) with this type of modeling involve precisely how these price responses are characterized and allowed to occur. More specific and applicable to transportation, and especially freight transportation, modeling, Spatial Computable General Equilibrium (SCGE) models have emerged and become more widely utilized. To accurately characterize the degree of dynamic inter-relationship across all products, commodities, and labor markets and industries is formidable to say the least, but it is especially challenging when we allow information on how businesses (both production and consumption activities) are geographically and spatially organized to be explicitly included and to influence demand/supply activities.

SCGE models have evolved and progressed substantially in the last ten years (Bröcker 1998, Bröcker et al. 2001) and have been applied in many different transportation modeling, and more recently freight network modeling, scenarios (Lakshmanan and Anderson 2002). This approach has been more developed and applied outside of the U.S., most notably in the development of the RAEM 3.0 Model[3] in the

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[3] For a full description see http://www.tmleuven.be/project/raem/RAEMFinalreport.pdf

Netherlands by Ivanova et al. (2002, 2007) and in Tokyo, Japan (Sato and Hino 2005). But considerable challenges still exist to integrate these SCGE models with purely freight network models and to address geographic aggregation issues, freight flow calibration/validation, and static vs. dynamic time horizons. Much of the earlier work has evolved from passenger travel models that have been adapted to represent freight activity. Unfortunately, freight transportation activities are substantially more complicated than passenger travel activities, are influenced by a greater array of variables, and are therefore much more difficult to accurately characterize in a modeling context.

2.4 OTHER STATEWIDE FREIGHT TRANSPORTATION MODELS

Freight modeling is undertaken for a variety of purposes, primarily 1) corridor analysis, 2) economic impact modeling, and 3) forecasting freight traffic.

Corridor and economic impact analysis are not typically performed at the state level. As suggested by it's title, corridor analysis is performed at the corridor level, and is best served by simulation which can capture small scale vehicle movements. Economic analysis, if performed at the state level, is aggregate in nature. More detailed studies have been performed at the metropolitan level. These typically rely on the integration of input-output models with transportation networks and flow data.

There are essentially three ways that state DOTs forecast freight traffic: (1) by analyzing truck traffic as done in Michigan; or (2) by using a commodity flow model. Within each of these model types, there are additional modeling decisions, for example, how to represent the road network. This can be done using a GIS network representation, or a more abstract representation. The vast majority of statewide models have been developed for the purpose of forecasting future freight flows.

Indiana has the best documented of all statewide freight models and is similar in design to models developed in other states, including Wisconsin , California, and New Jersey. It is also an example of the most commonly used methodology for forecasting demand, the 4-step method. This method was originally developed for passenger travel, and adapted to freight. The Indiana model predicts both truck and rail traffic volumes for a network that includes a TAZ for each of Indiana’s 92 counties, and 53 more TAZs that represent the remaining 47 contiguous states and the District of Columbia. Both the truck and rail networks were developed from U.S. DOT sources. The detailed roadway network for the Indiana freight model extends to about 200 miles beyond the state’s border. The actual workings of the model are very similar to a typical urban model. For each of 21 commodity groups that are considered important to Indiana, trip generation equations were developed based on a regression of data available from the 1993 Commodity Flow Survey (CFS), nationally. Forecasts for Indiana county productions and attractions are then based on county-level employment and population projections. For areas outside of Indiana, forecasts are based on national growth factors. Following trip generation, freight shipments are distributed by a gravity model that is also calibrated using the national CFS data. Special care has been taken to match the average shipping distance per ton for each commodity group. This prevents an inappropriate weighting for many short-distance lightweight deliveries versus a few longdistance heavyweight shipments that might be included in the same commodity group. The mode split step also utilizes the 1993 CFS, projecting the 1993 national shares into the future. Mode split for any commodity is a function of distance, only. Before assigning traffic to the network, the Indiana model divides the freight tonnages into an equivalent number of vehicles, with tons-per-vehicle rates determined separately for each commodity group. The rates are based on values (by commodity group) from the Rail Waybill Sample, and the assumption that each truckload carries 40% of the load carried by a railcar. A daily traffic assumption is made for the Indiana model as well, assuming 5 working weekdays and (from the Highway Capacity Manual) 0.44 working days for each weekend day. This results in a 5.88 day work week, or a 306 day shipping year. Finally, the traffic is assigned to the network using an all-or-nothing algorithm. A procedure to adjust the link speeds for non-Interstate highway segments is provided, however, since an unmodified all-or-nothing assignment typically loads too many trips onto Interstate highways. Another adjustment is made to the railroad network to account for the tendency of railroads to route cars by mainlines, ignoring many of the shortest paths.

Iowa, Pennsylvania, Wisconsin, Kansas, and Virginia, also use 4-step models to predict freight demand.

Michigan has developed a unique statewide freight model that simulates the decision processes of shippers for freight movements in the state of Michigan. Given an origin and destination, the model will produce appropriate routes for shipments of a specified commodity, and will allocate the shipments of that commodity on a percentage basis to those routes, according to the freight rates, transit times, and variability of transit times for those routes. The model can be used to examine the effect of changed circumstances on the shipments of that commodity. These can include changes in the physical network system, its ownership or operating policies, or underlying economic parameters. For either single mode or multimodal routes, the model generates the variable costs associated with these routes, the applicable tariffs, the expected transit times, and the variability of times in transit. These data are used by a probabilistic model which computes the expected “market share” for each of the generated routes.

3. A MULTI-MODAL STATE FREIGHT TRANSPORTATION NETWORK

A multi-modal GIS state freight transportation network was developed for Washington State through a complementary WSDOT project and is described here. A multi-modal network should represent the rail, road, air, and marine infrastructure (Figure 3.1). This is necessary as a framework for representing the flow of goods and for considering the impacts of changes to the infrastructure. In addition to representing the physical links, or connections, and nodes, or intersections and terminals, the network must also include some rules regarding the cost of travel along each link and through each node. Furthermore, some logical rules are required, for example, to differentiate overpasses from at-grade intersections.

Early on in the project we decided on a methodology that took a bottom-up rather than a top-down approach to capturing goods flows on the infrastructure. This decision was the result of conversations with WSDOT's Freight group, who's primary interest was in developing corridor-level analysis that could capture the dynamics of freight within the Puget Sound, rather than only activity on the major state routes. For example, there was interest in differentiating freight traffic on State Route 520 across Lake Washington, from that on Interstate 90, across the same lake. Although it was understood that sufficient data was not yet available to support this model, efforts would be undertaken to develop a long-term method for obtaining the data this type of model would require.

The primary application of this model was to understand the use of the infrastructure by industry, so that the impact of infrastructure changes could be identified not on total traffic delay, but on specific industries. Ultimately this would support an analysis of the economic impact of infrastructure changes. These priorities precluded the choice of a vehicle-based approach that could not differentiate between the commodities carried or the purpose of the trip. This also precluded the use of a 4-step model, which many other states have used, which cannot, without further enhancement, perform corridor level analysis. Not to mention, this methodology is not sufficiently accurate at a corridor level.

Simulation was considered, due to the interest in fairly detailed traffic analysis, but is not yet computationally feasible at the state level.

A GIS-based network allows us to represent the entire network with great detail, and include all necessary logic regarding vehicle movements, times, and costs. This format is highly compatible with other spatial data, as it is the industry standard. With the commodity flow data for all industries, this tool can evaluate link level flows and re-routings based on disruptions.

One challenge to developing a freight specific model is that in order to capture congestion and congestion effects, total traffic volumes should be considered. At present, the model does not capture congestion effects.

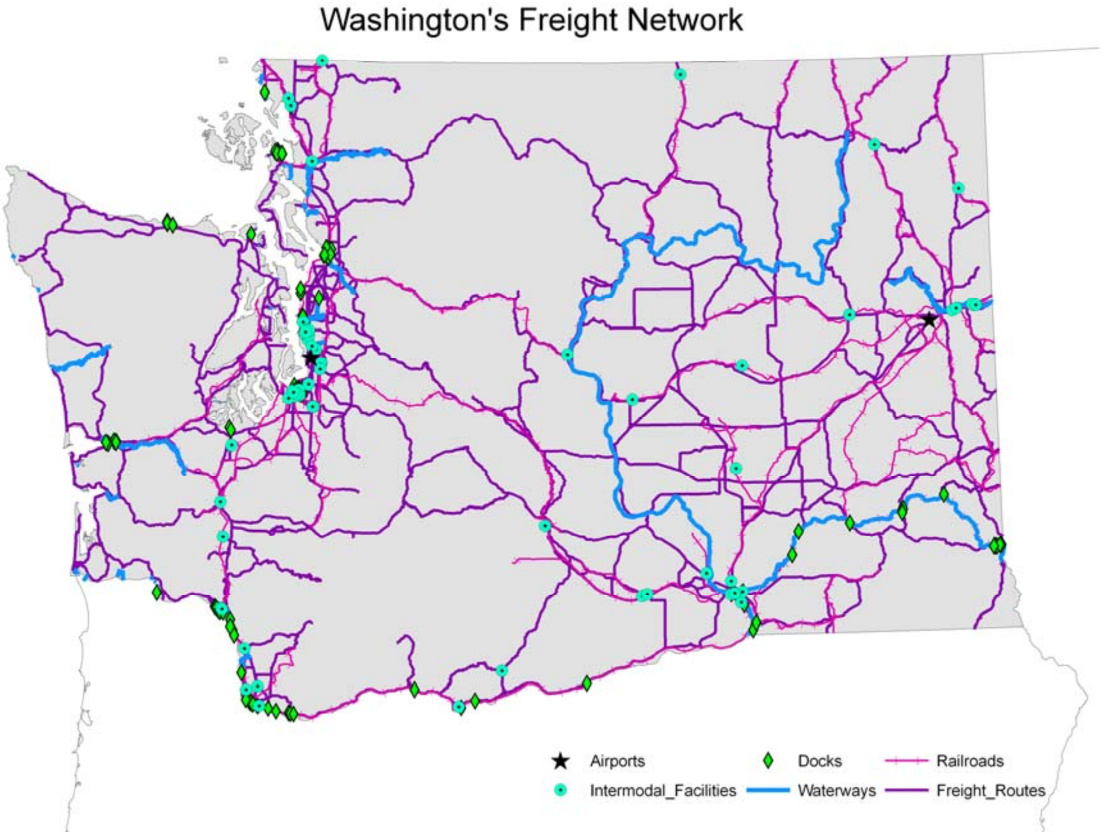

Figure 3.1 Multi-modal state freight transportation network

A geographic information system (GIS) was the clear preference for building the statewide transportation network. This format is the industry standard for spatial representations. A network consists of links, or line segments representing roadways or other linear transportation features, and nodes, or locations where these linear features connect, such as ports, terminals, and junctions. A GIS framework was selected, for which shapefiles were obtained for all modes. ESRI's ArcGIS 9.3.1 was selected as the GIS software to use. ESRI is the world leader in GIS modeling and mapping software. Historically, GIS analysts have approached multi-modal networking with sub-networks for each mode. In the traditional approach, transfers between modes are handled by psuedo-links or nodes. In the most recent versions of ArcGIS, these nodes comprise connectivity groups that participate in multiple subnetworks. Note, however, that traditional multi-modal networks have been built around passenger transit models. Passenger transit models are unique in that the transfers between modes (e.g., bus to rail) are typically highly predictable for two reasons: 1) there is a universal and easily calculated cost measurement—time, and 2) within-group variation in the time required for transfer is low.

By comparison, intermodal freight transfers are much more heterogeneous—some transfers require little processing and occur relatively quickly while others require significant processing and take comparatively longer. Even more importantly, logistics decisions balance the monetary costs against velocity and reliability. In the network, transfer nodes are not dynamic; they can only account for a single cost. Typically, network impedance, or the cost of travelling along a link or through a node, is calculated by using either distance or time, and in the case of a transfer node, impedance is typically given in time. While a logical model capable of integrating costs into the transfer nodes now exists within the ArgGIS database management system, there is no way to assign accurate impedances to the transfer nodes. This is the case because the willingness and ability to pass along the costs associated with velocity and reliability vary over time and across industries, and the variance can be extreme. For these reasons, modeling intermodal freight transfers requires timely data and a deep understanding of the needs and cost structures of the industry being modeled.

Early in the research process, the research team became aware of GeoMiler. GeoMiler is a GIS tool created by the U.S. Department of Transportation to model multi-modal freight traffic. Through a personal interview and numerous email interactions, we learned that the creation of the GeoMiler tool required a team of six technical FTEs employed for 14 months. Additional FTEs are required to maintain the database and use the tool. Given the tool's purported ability to model multi-modal freight shipments and the amount of person-hours required to build it, we felt that our early efforts would best be spent on acquiring GeoMiler rather than on countless hours duplicating these efforts. This required that we obtain data sharing agreements to use data that the USDOT did not create itself. These included data for the entire road network, which was purchased from Teleatlas.

The GeoMiler tool is capable of solving least cost routing problems on a multi-modal network if the following pieces of information are known: origin and destination (by zip code) and modal order (e.g., road-rail-road). Without the modal order, the tool is not capable of determining the most efficient combination of all possible modes and routes between any given origin and destination. Given the modal order, GeoMiler can calculate the most likely route taken by a shipper.

This can also be accomplished by using independent modal networks if the modal order is given. For instance, if one knows that a good from origin *i* follows a truck-train-truck modal order, the GIS analyst can simply use the nearest neighbor function to find the transfer facilities closest to the origin and destination. This method essentially generates three origin-destination pairs: 1) origin to closest transfer facility (which becomes the rail origin) via the road network, 2) rail origin to the transfer facility closest to the final destination via the rail network, and 3) transfer facility to the final destination via the road network. It is not possible in either approach to calculate the total time in transit without knowledge of the time necessary to transfer that particular amount of goods at each of the individual transfer facilities.

In this project, we utilized GeoMiler data, which were shared with us in the form of shapefiles. Understanding that our project required only Washington state rail, road, and waterway data, technicians at GeoMiler clipped the network datasets to a shapefile of Washington state. This decision proved to be problematic. Each of the individual problems and their impacts are explained below.

1. By clipping the networks, a number of possible alternative routes were lost. Perhaps most problematic was the non-inclusion of I-84, but a number of alternative routes in Idaho were also clipped. These roads had to be rebuilt.
2. The clipping process also introduced a number of slivers to the road network. A sliver is a discontinuity along a network feature. These slivers, which only occurred on road segments located in close proximity to the state border, resulted from the clipping of the road network, which was accurate at a high spatial resolution, by a state shapefile of lower spatial accuracy. Heuristically, one can think of the road network as cookie dough, and the state shapefile as a cookie cutter. Because of the accuracy and resolution issues, some segments of Washington roads were lost in the clipping process, and these discontinuities had to be found and repaired.
3. For reasons unknown, the network elements were shipped to us not as a functioning network, but rather as a set of shapefiles. Shapefiles amount to little more than image files with some data attached. The network had to be rebuilt before any least cost routes could be calculated and for the network to function properly.
4. Before the network could be rebuilt, hundreds of “imaginary” roads had to be removed from the road shapefile. The GeoMiler tool was designed to route commodities from a zip code origin to a zip code destination. The original road network was purchased from Teleatlas—the same company that provides Google Maps with its road network. In order to streamline the GeoMiler tool, over 14 million miles of non-freight roads were deleted from the Teleatlas network. This introduced a new problem: how to deal with origins and destinations not located on the reduced road network. The solution was to build 'imaginary' roads connecting points located at the centroids of zip code polygons to the road network. In order to ensure that freight movements did not travel on these imaginary roads at any time other than when these imaginary road segments connected to either the origin or the destination, they were assigned a cost that was an order of magnitude higher than the highest of the real road segments. Before the network could be rebuilt, hundreds of

these imaginary roads were deleted from the road shapefile, given our preference not to route truck trips on these imaginary roads.

5. Special permission had to be granted by TeleAtlas for us to obtain and use the road network from the Bureau of Transportation Statistics (the producer of GeoMiler). Getting the attention of anyone at TeleAtlas to do so was time consuming.
6. No metadata were provided with the shapefiles that could be used to interpret costs and codes.

After each of these individual issues had been addressed, the resulting road network was reconciled with the WSDOT freight system. Through this process, a number of additional roads were added.

Building the network required that impedances be assigned. For the vast majority of road segments, impedances were inherited from the Teleatlas network. Because the GeoMiler data did not come with adequate metadata, it is impossible to know exactly how the cost field values were calculated. It appears that cost is a direct function of length and average speed. Regardless, this is the cost field that is used by Google Maps, so it is unlikely that it could have been improved for this project. Cost field values for the road segments that were redrawn were calculated by applying the ratio of the cost field to the miles field of the segment to which the new segment was being appended.

4. MODEL STAKEHOLDER MEETING

In order to support customer use of the GIS freight tool, we sought to identify deliverables that met the needs of a broad range of transportation planners in the state. In an effort to better understand these user requirements, the researchers held a meeting to discuss current needs for statewide freight modeling. The meeting included over 22 model users, representing several Metropolitan Planning Organizations, other regional transportation planning organizations, the Ports of Seattle and Tacoma, the Washington State Department of Transportation (WSDOT) and the Washington State Potato Commission.

The potential users agreed that the statewide freight model's primary use is would be to help them evaluate infrastructure investment alternatives and prioritize investment choices.

The users noted that other efforts have been made in the past to build a statewide transportation model, although not a freight model, and although a model was built it wasn't adopted at a state level. The reasons for failure included lack of executive level buy-in due to complexity and high cost. The participants suggested various ownership structures for the freight model, and agreed that they would like to be able to run the model themselves.

The group mentioned several models and datasets that are in use including models used by other states that could be considered when finalizing the economic impact analysis.

The group also agreed that all modeling efforts are currently limited by a lack of good commodity flow information for the state. The group was very supportive of data collection efforts, particularly prior to any statewide modeling effort that might be undertaken. The data needs to provide corridor-specific commodity flow information, and associate that information with industry sectors.

Similarly, any modeling effort should provide results disaggregated by industry. It would need to capture time of day effects from congestion, and seasonal differences in commodity flows. The model should capture both out-of-state markets and generators, and intrastate flows. The model should include the highway system, as well as important connectors and arterials. The group also made it clear that the model should have a GIS-based platform. The model should focus on flows between regions, given that some MPOs currently have traffic demand models.

Attendees:

1. Anne Goodchild, University of Washington
2. Hugh Conroy, Whatcom Council of Governments
3. Li Leung, University of Washington
4. Nick Manzaro, Wenatchee Valley Transportation Council
5. Alon Bassok, Puget Sound Regional Council (PRSC)
6. Eric Jessup, Washington State University
7. Glenn Miles, Spokane Regional Transportation Commission
8. Mark Harrington, Vancouver MPO (SWRTC)
9. Faris Almemar, Washington State Department of Transportation
10. Doug Brodin, WSDOT Research Office
11. Dale Tabat, WSDOT
12. Dave Honsinger, WSDOT
13. Elizabeth Stratton, WSDOT
14. Kumiko Izawa, WSDOT
15. Maren Outwater, PSRC
16. Ruth Decker, WSDOT
17. Anna Soderstrom, Port of Tacoma
18. Katy Brooks , Port of Vancouver
19. Matt Harris, Washington State Potato Commission
20. George Xu, WSDOT
21. Mark Rohwer, WSDOT
22. Sean Ardussi, PSRC
23. Todd Carlson, WSDOT

5. STATEWIDE FREIGHT MODEL RECOMMENDATIONS

Increasingly complex questions regarding the interaction between the state's transportation infrastructure, transportation policies, and economic system require increasingly sophisticated tools. As mentioned, the state has developed a statewide GIS tool for mapping supply chains and to evaluate the impacts of disruptions to the transportation system on specific industries. In the future, WSDOT would like to be able to estimate the impacts on a broader set of industries, with a more automated tool that can capture an increasingly large set of complexities. To do this, a more complete statewide freight model is required, one that has data for a complete cross-section of industries and that addresses additional complexities in the statewide freight system.

After reaching out to stakeholders, conducting an exhausting review of existing models, designing and building the GIS model, and exercising the model on two case studies, the researchers are in a position to recommend future methodology developments, data sources, and a long-term management plans for such a model. In addition to the stakeholder meeting discussed in the previous section, another meeting was held with WSDOT planning and freight office staff to discuss internal WSDOT preferences and needs. The researchers are also active in the national dialogue about methods to develop the sub-national commodity flow databases that would be required to feed such a model.

5.1 MODEL MOTIVATION

It is clear that the need for such a model comes from the desire to prioritize investments on the basis of economic value to the state. Current tools and methods use other metrics, such as congestion reduction, flow on affected routes, and level of service, to prioritize investments. Input from both the freight community and the planning community, as well as all regions of the state, made clear that the objective of a statewide freight model is to allocate funds to the projects that will bring most economic benefit to the state. This should be done both for individual projects and to prioritize portfolios of projects.

Notice that this is different from the motivation for most of the existing state-wide freight models, which are built to forecast zone to zone truck trips using a 4-step modeling approach. This should be remembered in any comparison with other statewide models.

5.2 INTEGRATION INTO STATEWIDE PLANNING

It is critical that the model have executive level buy-in. Investment in a model that is not fully utilized is a waste of public funds. Prior to investing in a model, decisions should be made about where the model is to be housed and who will maintain it. This group must have the financial ability to maintain the model and its data so that it can be trusted to assist with investment decisions. Use of the model must be fully integrated into the statewide transportation planning process.

We recommend that the model be housed by a university research organization. This group would have the intellectual capital to improve the model, and, unlike a consulting firm, would lack proprietary interest in controlling the model. Such a group would also possess the computing power to house the model and the model's supporting data.

5.3 USE OF THE MODEL

Stakeholders indicated that they would like to run the model themselves. This would require a significant investment not just in model capacity but also in developing a user interface so that the model can be used by "untrained" users. We do not suggest the model be usable by a broad spectrum of users but do suggest that resources be made available to allow the owners of the model to work with clients to exercise the model for their purposes.

5.4 SUB-NATIONAL COMMODITY FLOW DATA

The decision to pursue a model with good spatial resolution was taken with the knowledge that the data to support this model do not currently exist. To exploit the full capabilities of the model and support statewide freight planning, this data must be obtained. We recommend the WSDOT continue to work with national organizations such as the Transportation Research Board to pool national and state-level resources to develop a methodology for collecting sub-national data. This would be the level of information required to support a statewide freight model of this type. The data need to provide corridor-specific commodity flow information and should associate that information with industry sectors. The spatial resolution of the data should be the zip code.

"Corridor-specific" does not imply that industry-specific information would be available for every road segment but rather would be available for corridors identified as important to the state freight transportation system. Commodity data would not be so specific that they could differentiate between types of potato products, but agricultural products would be separated from manufactured products and service vehicles. The data should capture out-of-state markets and generators, as well as intrastate flows.

5.5 METHODOLOGY

The decision to pursue a GIS-based network model has been explained in Section 3.0. Although originally we had proposed building a statewide simulation, we did not conclude, after completing the research, that this was the best approach. While this method may be useful at a regional level for analysis of specific corridors or districts, it is not necessary, nor computationally feasible at the state level. The stakeholders made it clear that the purpose of the statewide freight model would be to connect regions within the state, whereas the jurisdictions within a region would be responsible for doing smaller scale, regional modeling. Instead we recommend a GIS-based network model supported by sub-national commodity flow data. Spatial resolution would be intended to support inter-regional travel, not to model flow on every road in the state.

GIS was selected due to it's highly standardized data structures, and the ability for the statewide GIS model to integrate with regional or local models. Flows of vehicles can be taken from the statewide model and applied as inputs and outputs to these regional models. Should the road networks not be aligned (regional models may include additional road or rail links over the statewide model), traffic flows can be aggregated to the links that do connect.

We recommend that an economics impacts module be developed for the current statewide model. This model would use a general equilibrium model framework to estimate the economic impacts of disruptions to the transportation system. General equilibrium models are an improvement over input-output models in that they capture the feedback between supply and demand more accurately. This module would inform policy makers as to the economic impacts of transportation improvements in aggregate, but also the impacts to specific industries.

The model should capture time of day effects from congestion, as well as seasonal differences in commodity flows. This could be done by developing commodity flow data by season and running the model separately, and for congestion, by including link capacities and link cost functions that are a function of flow along that link. The model should include the entire roadway system, but analysis is not recommended at this level of spatial detail.

5.6 RESOURCES REQUIRED

The methodology selected to date supports an incremental program for model improvement. We suggest annual investments in the model so that over the next 5 years, through shared investments by the WSDOT, the Transportation Research Board, and Transportation Northwest (TransNow), a comprehensive statewide freight model can be developed. The following improvements are significant methodological developments that should be undertaken to improve the model utility.

5.6.1 Obtain Sub-national Commodity Flow Data

The use of the model is currently limited because data is unavailable for most industries. It is of the highest priority to obtain sub-national commodity flow data for the state for all industries. The Transportation Research Board has funded a project to develop this methodology that will be completed by the summer of 2011. At that time, WSDOT should be prepared to implement the results of this project, and collect commodity flow data for Washington.

Depending on the method implemented, we estimate will cost between $100,000 and $500,000 for the first data collection effort, and will need to be repeated at regular intervals.

5.6.2 Develop and Economic Module

There is great interest in generating results that can comment on the economic impact of changes to the transportation system. This is not possible without the development of an economics module. This activity would only need to be undertaken once, at a cost of approximately $300,000 to $500,000 depending on the level of detail in the model.

5.6.3 Develop Congestion Link Cost Functions

This is of lower priority than the first two activities, but is a significant methodological improvement. Link cost functions can be developed that estimate travel times as a function of flow on the link. While time consuming due to the large number of links, and the interaction between links, this could be added to the existing tool, and allow for congestion impacts to be measured. This could be done at a cost of approximately $300,000 to $500,000.

6. FUTURE WORK

In addition to the broad recommendations above, specific improvements to the existing statewide model can be identified that should be undertaken to improve the ability of the tool to support statewide freight planning.

6.1 IMPROVE LINK COST FUNCTIONS FOR FREIGHT, FLOW, AND CONGESTION

The link cost functions currently embedded in the model and used for routing are the same as those used by TeleAtlas, the supplier of GIS networks for Google Maps. These are travel times primarily derived from distance and speed limit data, but with some undefined congestion factors for urban areas. These are state-of-the-art for routing tools but are likely not reflective of travel times for trucks on all routes, in particular, rural mountain highways. We suggest improving these link cost functions to capture 1) passenger travel, 2) congestion effects, and 3) observed travel times from trucks. Observed travel times for trucks can be gleaned from WSDOT's Truck Performance Measures project ongoing with WSDOT, the University of Washington, and the Washington Trucking Associations.

The estimated cost of this activity is between $250,000 and $500,000.

6.2 CHARACTERIZE SUPPLY CHAINS WITH SIMILAR LOGISTICAL BEHAVIOR

We do not recommend moving forward by mapping all supply chains in this fashion; however, priority industries and industries with different supply chain typologies, should be mapped. Research should be done to classify supply chains into those with similar logistics, generating a supply chain typology. Representative supply chains in each category should be studied. The estimated cost of this project is between $100,000 and $250,000.

6.3 PRIORITIZE INDUSTRIES IMPORTANT TO WASHINGTON STATE AND PERFORM ADDITIONAL CASE STUDIES

The case studies provide invaluable information about the industries and their use of the transportation system. There are probably a small number of industries that can be identified as important to the state and pursued. Each case study would cost between \$50,000 and \$150,000.

6.4 MAP FREIGHT GENERATORS

We have demonstrated that significant benefit can be derived from mapping the fixed infrastructure, or the facilities that generate freight activity. In the absence of flow information, mapping the origins and destinations still provides significant benefit and understanding of the value of different links to different industries. GPS data available from the Truck Performance Measures project can assist in mapping these freight generators, by identifying the locations frequently visited by trucks. Other methods for identifying freight generators are to map commercial locations with large numbers of employees, or collect this data through surveys of freight businesses. The cost of this activity is highly dependent on the methodology utilized, but could vary between \$150,000 and \$500,000.

One application of this would be to then identify locations with single access points of failure.

6.5 BUILD AN AUTOMATED TOOL WITHIN GIS TO MAP O-D PAIRS ON INFRASTRUCTURE

With freight generators mapped and this automated tool, the analysis completed for the diesel case study could be repeated for other industries. While this analysis does not provide information on the volume of vehicles, it can indicate critical links in terms of connectivity. This is a low cost exercise, that could be completed for less than \$25,000.

6.6 INTEGRATE GPS DATA FROM THE TRUCK PERFORMANCE MEASURES PROJECT

The Truck Performance Measures data have been mentioned several times in support of freight generator mapping and improving link cost functions. In the future, we see many possibilities for collaboration between these two projects, including identifying freight generators, and discovering routing logic and patterns.

6.7 WORK CLOSELY WITH REGIONAL AGENCY PARTNERS TO ENSURE COMPATABILITY

Stakeholders made it clear that the statewide freight model should connect with regional models. In addition, regional MPOs such as the Puget Sound Regional Council have extensive experience with models and integrating models into planning.

Currently, this would mean using the statewide model to generate input and output flows for regional demand models. If the links included in the regional model do not match those in the statewide model (the statewide model may exclude some smaller links), the flows would be aggregated to those links that do connect.

7. CONCLUSIONS

We set out in this research project to deliver a description of requirements for a statewide freight model. We have described the development of a Washington multi-modal GIS network, specific short term improvements required for this model, and recommendations for how this model should be managed and integrated into the WSDOT Planning process.

This was the outcome of outreach to stakeholders, and evaluation of existing methods, and experience with the design and application of the GIS network model.

WSDOT and researchers at UW and WSU continue to work together to improve the state of analysis and tools supporting freight activity and freight planning in Washington state. This project outlines future steps that will enhance their capacity to deliver insights which will support an efficient and resilient freight transportation system. This can be accomplished with annual investments in model improvements, in order to spread the cost of model improvements, but still result in the development of a statewide tool necessary for effective freight planning.

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