Final Technical Report
TNW2008-08

Research Project Agreement No. 61-5907

Improved Freight Modeling of Containerized Cargo Shipments between Ocean Port, Handling Facility, and Final Market for Regional Policy and Planning

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July 2008

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. TNW2008-08	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE Improved Freight Modeling of Containerized Cargo Shipments between Ocean Port, Handling Facility, and Final Market for Regional Policy and Planning		5.REPORT DATE July 2008	
		6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Anne Goodchild, Eric Jessup, Kaori Fugisawa		8. PERFORMING ORGANIZATION REPORT NO. TNW2008-08	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Transportation Northwest Regional Center X (TransNow) Box 352700, 129 More Hall University of Washington Seattle, WA 98195-2700		10. WORK UNIT NO.	
		11. CONTRACT OR GRANT NO. DTRS99-G-0010	
12. SPONSORING AGENCY NAME AND ADDRESS United States Department of Transportation Office of the Secretary of Transportation 400 Seventh St. S.W. Washington, D.C. 20590		13. TYPE OF REPORT AND PERIOD COVERED Final Research Report	
		14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the University of Washington and the US Department of Transportation.			

ABSTRACT

The proposed research will address an emerging need by local, state and regional transportation planners and policymakers to better understand the transportation characteristics, functions and dynamics of ocean port-to-handling facility and handling facility-to-final market freight movements. The research will also address a gap in the academic literature for freight transportation models that capture underlying economic forces. This research effort will focus on the development and refinement of a regional freight model of urban container movements from the port to a handling facility and beyond. Existing regional transportation planning models and analytical tools have evolved from passenger travel demand models that are ill-suited to fully capture the business decisions and economic influences driving urban freight flows and have been further constrained by access to appropriate freight data. This research activity proposes a modeling approach which will capture the fundamental economic choices individual shippers consider when trading-off the marginal benefits/costs associated with warehouse inventory management/control relative to transportation access and flow while incorporating the primary freight generation activity centers (warehouse/distribution centers) in the Puget Sound region. This work will identify, evaluate and incorporate data for the Puget Sound region recently available from a variety of existing sources. Some data collection may also be necessary. The final product of this research study will be an improved tool to understand current and future freight movements through the Puget Sound region, and a methodology which will expand the current state of knowledge, and may be applied in other regions, both domestic and international. It will allow more in-depth and timely evaluation and analysis of different local/regional transportation policy initiatives such as the impact of migration of the main warehousing region, and development of inland inter-modal port facilities.

17. KEY WORDS Containerized cargo, goods movement, freight modeling, freight planning, freight flow		18. DISTRIBUTION STATEMENT	
19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES 63	22. PRICE

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EXECUTIVE SUMMARY

This report summarizes the work completed for the TransNow supported project "Improved Freight Modeling of Containerized Cargo Shipments between Ocean Port, Handling Facility, and Final Market for Regional Policy and Planning". With a limited budget, this project has accomplished a substantial task, designing, building, validating, and applying a regional freight model to relevant policy and planning applications in the Puget Sound.

A significant literature review was undertaken and is presented here. Several examples of regional freight models are discussed and evaluated including the Leachman Elasticity model, of most relevance to this project.

After considering earlier freight modeling approaches and data availability, a methodology was selected and is presented here, that considers the economic costs to shippers; transportation and inventory. We consider the cost to move goods between Puget Sound Ports and 21 regions representing the country. The shippers' choice of mode and transloading is predicted for a set of shippers that represent the largest importers at the Puget Sound ports. Importers are defined by their annual import volume and the average value of these goods.

Data was obtained from a variety of sources after thorough evaluation of sources and data quality. Due to a lack of detailed information, a strategic model was built so as to be useful within the constraints of available information. Shipping costs, freight volumes, purchasing power of regions, distances, and many other factors were estimated or obtained from public sources, transportation companies, and existing studies.

The validation procedure used to test the model is also described in detail. Extreme cases, sensitivities, and aggregate comparisons are made and demonstrate how the model responds to changes in inputs, and matches well with observed conditions.

We have presented here a small number of applications of the model. Clearly, much more analysis can take place by applying the model both to the case designed for Puget Sound, and, with some modifications, the model may be applied to other locations with different facilities. The primary benefit of the model is a structured way of considering the cost trade-offs shippers face, and understanding the impact of their choices on regional traffic flows.

The model presents a planning tool for considering the impact of system changes on logistics patterns. This is important to the region, which supports the national logistics patterns by providing a port and warehousing facilities. These scenarios demonstrate the relationship between regional infrastructure and national logistics strategies (scenario A). A truck only lane will not only reduce regional congestion, but will increase the benefit of transloading, and therefore increase demand for the truck only lane. The goods being transloaded are destined for regions outside of Puget Sound. An investment in Puget Sound infrastructure, therefore, increases the national demand for Puget Sound infrastructure.

INTRODUCTION

Freight system efficiency is one of the more influential factors in regional economic prosperity and business vitality. In a recent survey conducted by Lawrence Research in conjunction with Cambridge Systematics and Frank Wilson & Associates for the Washington State Transportation Commission in April 2006 [1], 'A Two-Phase Study of Attitudes of Washington State Voters Toward Transportation Issues', Washington voters ranked maintenance of roads and highways as the fourth most important issue, with traffic congestion seventh among quality of life issues. While transportation is an important issue for voters, Washington residents in the survey have also expressed skepticism about government spending on transportation projects. In addition, freight movements benefit local and state economies, but also increase traffic volumes, increasing congestion, roadway wear, and air quality.

The movement of goods between ocean ports and final markets includes intermediate stops at warehouses and distribution centers. Many activities take place at these facilities such as shipment transloading, transfers between vehicles, and product labeling. The decision to use these facilities is made in the context of supply chain management and least-cost strategies are identified considering the cost of transportation and inventory, how timely they need to ship goods to customers, how many commodities should be in stock at their warehouses, and which route is the fastest for their large capacity trucks. These movements are often overlooked in regional freight planning, in part because they are not well understood, yet they contribute significantly to the regional traffic burden, particularly in industrial regions such as the Sumner and the Kent Valley regions of the Puget Sound.

At a national level, there are many examples of commodity based freight models, but in these models the use of regional handling facilities is ignored. Few freight modeling tools have been developed at the regional or county level, for which the consideration of handling practices is required.

The goal of this research has been to create a regional freight model that considers the movement of containerized cargo through regional handling facilities. This model is not designed to capture detailed spatial and temporal scales, such as route choice through the urban region or the impact of peak hour traffic, but to understand the impact of the use of regional handling facilities on mode choice, and to consider the impact of regional changes (land value or infrastructure development) on the logistics strategies of importers. The chosen methodology considers the economic choices shippers make which drive the decision to use such facilities. For example, transloading (transferring goods from 40 foot maritime containers to 53 foot domestic containers to take advantage of transportation cost reductions) over direct shipping due to reductions in total logistics cost. The model will provide insight into the relative sensitivity of regional changes on national import behavior, and vice-versa. Examples of model applications include providing insight into the following questions: How would a truck-only lane affect the ratio of shippers that choose to transload containers originating at the Port of Seattle? If the truck-only lane is built, what are the benefits in terms of reducing congestion? Where might new handling facilities in the Puget Sound be located?

BACKGROUND

Since the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) by the U.S. Congress in 1991, increased funding allowed for necessary freight related research efforts to be undertaken. Origin-destination level flows at the national level are reasonably well captured with several freight models and statistical data, but a gap exists in modeling regional goods movement, and in the modeling of the use of intermediate handling facilities. In addition, the modeling of freight movements by current transportation engineers and planners, lacks an economic perspective which drives the logistics behaviors such as reducing the cost of demand uncertainty by utilization of a distribution center. Most regional freight models have been developed from passenger travel models and use the same four-step model to estimate demand. Clearly these models cannot replicate dynamic goods movement with much accuracy.

The Ports of Seattle and Tacoma, Washington have experienced strong growth in container trade over the last decade as imports from Asia travel through west coast ports to access consumer markets throughout the U.S. In fact, total cargo volume going through the Port of Seattle is about 16.696 thousand metric tons in 2004, with a total dollar value of approximately 29.2 billion US dollars. Total cargo volume for the Port of Tacoma is 16.274 thousand metric tons per year, with a total dollar value of 27.8 billion US dollars.[2] This trade benefits the local and state economies, but also add to regional congestion, air pollution, and roadway degradation

Freight handling facilities are used for a variety of purposes, but in all cases are designed to reduce total logistics cost either through a reduction in transportation or inventory spending. For example, the use of a regional distribution center can save storage space and total inventory requirements and increase the variety of products that could be offered at retail stores. Handling facilities are locations where goods are handled, for example to package, label, or combine goods. While there are many possible uses of handling facilities, in this model we consider only the inventory management benefits of safety stock reductions due to resolution of uncertainty and reduction in re-order time. In addition, where relevant we consider the increased inventory cost due to longer travel times through handling facilities and the cost savings from transloading.

The maritime fleet predominately uses the 40 foot container as it's standard, whereas the North American domestic transportation system can handle high-cube 53 foot containers. The pricing structures for rail and truck transportation have created an opportunity for carriers to practice transloading. Transloading is defined as transferring goods from 40 foot ocean containers into 53 foot containers for inland movement. Due to the price structures for the transport of 40 and 53 foot containers in North America, there can be transportation cost savings for some carriers by using 53-foot containers domestically, however, generally the maritime fleet cannot accommodate these larger containers. Some facilities that are used for transloading are also used for other handling tasks such as preparing containers for destinations, labeling, or attaching bar codes.

Historically, these tasks were carried out within marine terminals, but they have moved away from the terminal due to high operating costs. The use of off-dock facilities, however, has increased the vehicle miles traveled of goods within the urban region.

In this report, the authors summarize the work conducted through funding from Transportation Northwest to develop a model of container movements between ocean ports and handling facilities in the Puget Sound region. We present the results of the literature review, data review, model development, and application of the model to future scenarios. The goals of the report are as follows:

1. Summarize the strengths and weaknesses of existing freight models,
2. Evaluate the transferability, functionality, validation, and applicability of these models for the Puget Sound region.
3. Assess what data are available for regional freight models in the Puget Sound and identify data gaps in the Puget Sound region.

4. Describe the methodology developed for the regional freight model.

5. Describe the validation of the freight model.

6. Describe the assumptions made in creating the model, and the limitations of its application.

7. Describe the results from application of the model to what-if scenarios.

8. Summarize the learnings from the model to date as they relate to regional freight policy and planning.

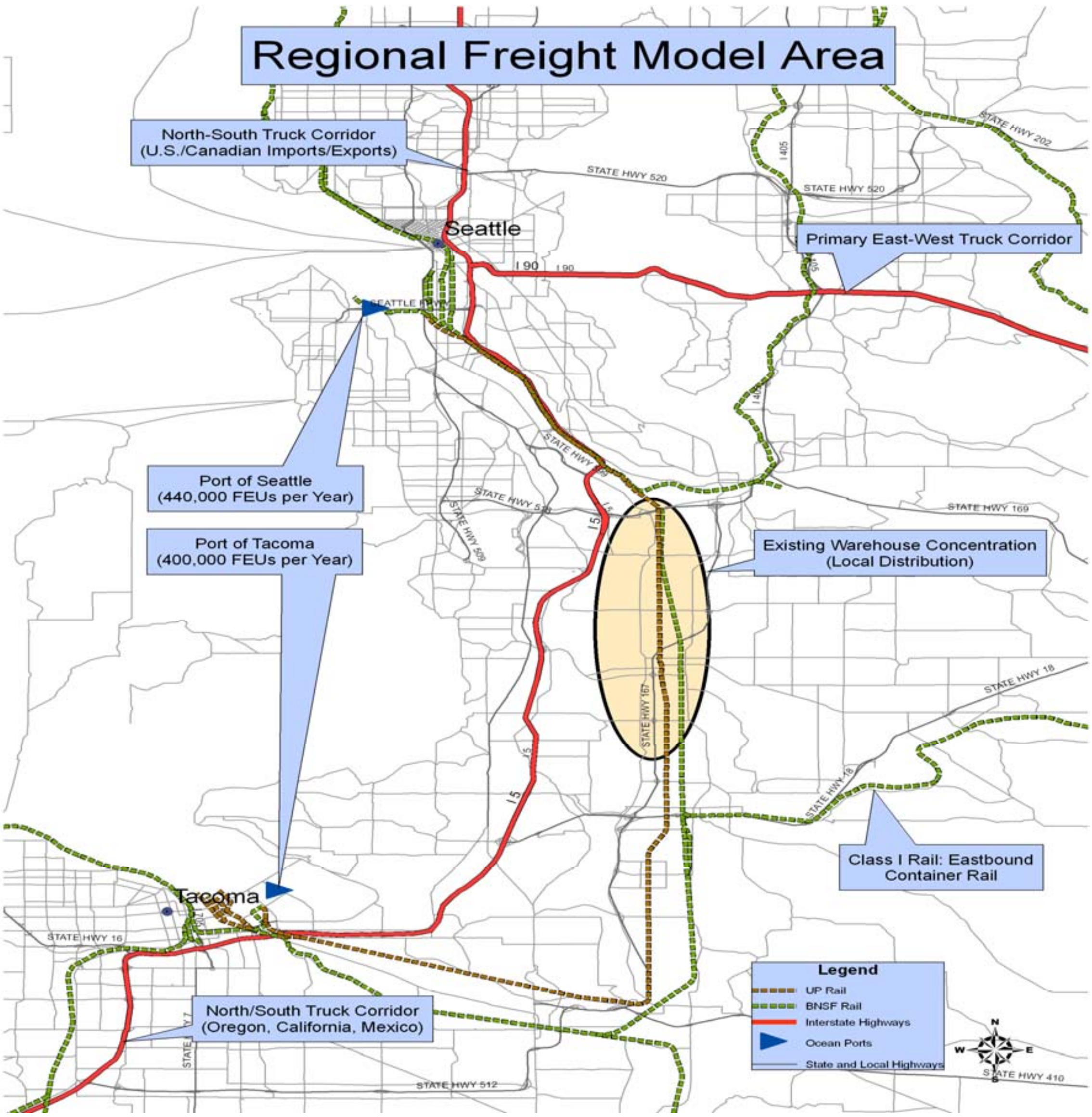


Figure 1: Regional Freight Model Study Area, Puget Sound, Washington

RESEARCH OBJECTIVES

The purpose of this research is to understand the dynamics of regional freight movements through the development of a regional freight model. The model characterizes the economic choices shippers make between modes and whether to ship direct or transload. The model is a tool for transportation planners to consider the relationship between model inputs such as transportation cost, land values, and market dynamics on logistics behavior. This model may then be applied to address regional policy questions such as:

- How would a truck-only lane on SR 167 affect the ratio of shippers that choose to transload containers originating at the Port of Seattle?
- What will the cost of real estate mean to transloading behavior in Puget Sound?
- How does the final destination of goods affect the logistics behavior in Puget Sound?
- How will a significant consolidation or deconsolidation of shippers impact the logistics behavior in Puget Sound?
- How do regional transportation investments affect shippers total logistics cost?

LITERATURE REVIEW

Here we examine the accuracy, transferability, and usability (as defined below) of several example national, state, and local freight models. The freight models covered in this review do not represent a complete list of models, however, many of the models reviewed are not discussed here because they were not relevant for modeling ports-to-handling-facilities at a regional level.

- Accuracy - how close a model depicts the actual conditions of, for example, future truck movement. This is easily done by comparing actual truck counts data to the output of the model, for example.
- Transferability – applicability of a model to different places or situations.
- Usability – how efficient, effective, or satisfactory an output of a model is for a model user's needs.

GoodTrip Model [7]

The 'GoodTrip' Model is a commodity-based simulation model. The model is unique in the level of detail applied to a commodity based approach. With an urban scale consideration of commodity flows it can integrate logistics and business economics with traffic flow. The developers of the GoodTrip model recognize the lack of reliable data for a commodity flow model at both the regional and local level. The model values the importance of a shipper's choice or logistics changes. In reality, it makes more sense to look at commodity flow as a result of consumer demand and supply chain management by shippers, and then assign traffic flows in the network. On the other hand, there are some questions that remain to be answered. It is not clear how to sort and group commodities, and how to define or characterize every zone in the study area. Also, it might be a difficult task to request such detailed data from shippers or even survey them regarding their inventory of transportation modes and capacity, and logistics strategy, as well as consumer demand information, which are likely to be confidential.

GoodTrip Model Summary

Jeroen Boerkamps of Delft University of Technology and Arjan van Binsbergen of The Netherlands Research School for Transport, Infrastructure and Logistics (TRAIL) developed the freight traffic model called "GoodTrip". The GoodTrip model is summarized as follows.

- Demand driven
- Commodity based
- Incorporates supply chains
- Uses activity types (consumers, supermarkets, stores, offices, DC of retailers, producers, etc.) to define the nodes in the supply chain
- Models land use by connecting activity types to the geographical zones of the model
- Has four components

    I. Spatial organization of activities (i.e. where people live and work, where facilities are located),
    II. Goods flows,
    III. Traffic flows, and
    IV. Multimodal infrastructure

The model focuses on the spatial organization of activities and multimodal infrastructure by estimating goods flow. It calculates the volume of goods demanded per goods type in every zone based on end-user demand. These goods flows are determined by 1) the spatial distribution of activities, such as locations of facilities and consumers' residence, and 2) the market share of each activity type, such as consumers and retail stores. Then some goods flows are combined by goods type and grouping method, which are not specifically discussed in the GoodTrip model document. After the goods flow is combined and simplified, the model assigns vehicle tours for each goods flow by the origin and destination. For example, the origin controls the transportation mode, vehicle capacity, maximum loading factor, and maximum number of stops per tour, since the origin is the manufacturer or producer of the goods. On the other hand, the destination - the consumer, for example, could have more influence on the minimal delivery frequency because the consumer decides how often he/she buys the particular product transported.

Next, the model creates the origin-destination (OD) matrices with tours per mode, and tour characteristics. It then takes all tours per mode in the infrastructure networks, generating network loads per mode. The GoodTrip model can calculate vehicle mileage per mode using the network loads per mode, as well as the emissions and energy use by mode using the vehicle mileage and network loads. The whole process of the calculations is sequential and conditional on earlier choices/decisions.

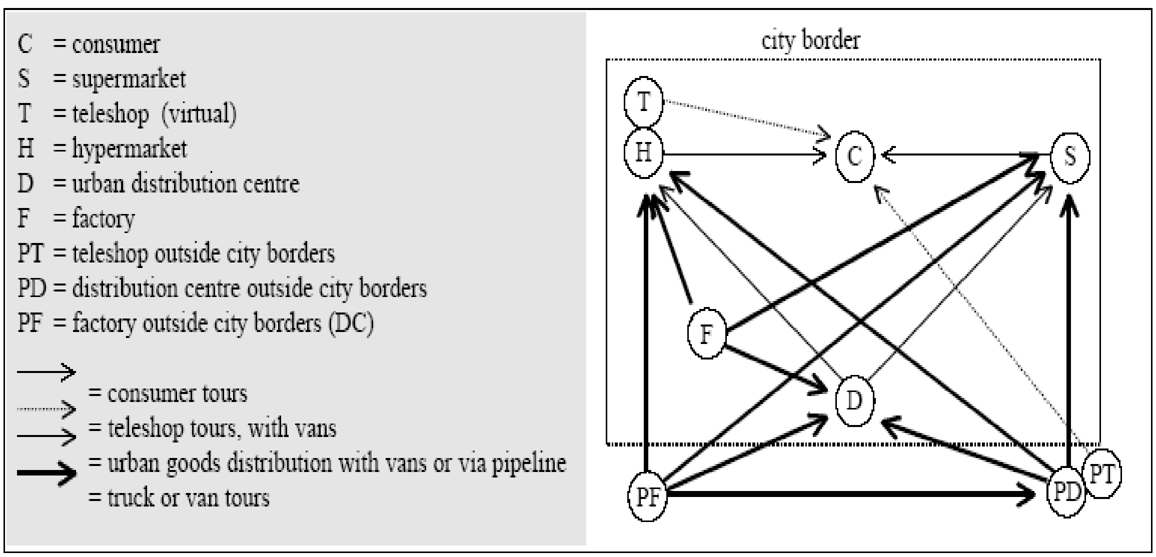


Figure 2: Commodity Distribution Network Example of the GoodTrip Model

According to the GoodTrip model report, the model can be used for many other cases such as:

1. Changes in distribution patterns and mode choice, for example, use of distribution centers, or accessibility of modes,

2. Changes in supply chain organization, for example, loading different goods in a truck from different suppliers,

3. Changes in demand including delivery frequencies and shipment sizes because of consumer demand volumes, e-commerce, giant retailers, or urban sprawl, and

4. Impact on the environment such as energy use and emissions.

GoodTrip Model Accuracy

According to the GoodTrip Model literature, the model is applied and validated using grocery stores in the city of Groningen (population of 170,000 as of 1999, known for its large college student community and "the world cycling city") in the northern Netherlands. There are two urban distribution centers independently operated with vans in the city of Groningen. For validation, 49 supermarkets and four categories of goods are used to estimate weekly goods transport into the grocery stores for the following three scenarios (traditional distribution, urban distribution centers with vans, and underground logistics system):

- Number of vehicle tours in the city,
- Number of stops in the city,
- Total vehicle mileage,
- Local emissions within the city, and
- Global impacts of goods transport within city borders.

However, there are no actual statistics available to confirm that the model could accurately estimate traffic volumes to all 49 supermarkets within the city, other than the brief conclusion and result shown in the GoodTrip model report. The model lacks the presentation of concrete validation through third parties or the scholars that developed the GoodTrip model.

GoodTrip Model Transferability

Assuming that the validation of the GoodTrip is correct, the model could be applied to freight modeling of the Puget Sound region, because the GoodTrip model is for urban regions and its parameters include shipper's choice, such as a distribution center. However, effectiveness and performance of the model depends on data accessibility and availability. Historically this information has been difficult to obtain as private shippers and logistics managers are reluctant to share their data on freight movements or their market research about consumer demand, or how much information they would provide on logistics management. The data collection effort might be the hardest obstacle using the GoodTrip model.

GoodTrip Model Usability

The GoodTrip model is useful for our research because outputs of the model covers total truck travel mileage, total number of stops in the city, total number of vehicle tours in the city, local emissions within the city by modes, and logistics choices. If passenger vehicle flow, which is easily obtained by traffic count, is incorporated into the GoodTrip model, and all logistics and consumer data are available, this model is applicable and appropriate. But the model is only tested in grocery markets and bookstores so that it remains still unknown if the model will function properly for other commodity markets.

WIVER / VISEVA and VISUM Model [8]

The WIVER/VISEVA and VISUM model developed in Germany appears to be well structured and is a comprehensive model for transportation modeling. It is presented here as it includes behavioral and economic aspects. To and from warehouse trips are also counted in addition to the origin and destination trips based on survey of freight forwarders and drivers. Furthermore, there are two different models in the WIVER/VISEVA and VISUM model: passenger traffic and commercial vehicle traffic. The commercial vehicle model has two components – one is freight, and the other is, as authors call it, 'singular transport generators' such as taxi, buses, postal service, police, waste disposal service, and fire truck. Workday distance traveled in km of singular transport generators are obtained by questionnaire given to civil service personnel. And then these models integrate two components as the commercial vehicle model. Finally, the commercial vehicle model and passenger vehicle model are combined as the total travel demand model. Thus, total inclusion of passenger, civil service, and freight movement makes it possible for the model to mimic real world conditions.

The available documentation does not describe in detail the data collected by surveys of shippers and truck drivers, including how trips are generated and assigned. Also, collection of survey data from private shippers and civil service people is the key to the usefulness of the model's output.

WIVER / VISEVA and VISUM Model Summary

In the late 1980s, Meimbresse Sonntag developed the travel demand model, WISER. Then Lohse of the Technical University of Dresden, Germany transformed WISER into the software program called VISEVA. WISER/VISEVA is a demand modeling system for urban and regional commercial transport. The model is designed for both passenger and freight transportation but only freight modeling is discussed in this summary. The trip demand is calculated by vehicle type using structure data from a city or region, and behavior survey from transport employees. VISEVA is the enhanced software program and calculates travel demand based on the following assumptions:

- Each sender generates a trip starting with the sender and ending at the sender's home zone. The trip might be one or multiple trips involving several vehicles per day.

- The program counts each trip and categorizes them as one origin-destination group. The O and D below are the connection of the vehicle to the depot.

- An evaluation value (EV) is calculated for each trip from the impedance (time and costs) between the origin and destination of a trip. The range of EV is between 0.0 and 1.0.

There are also equations to calculate trip production, trip attraction, and trip distribution, and they are all interrelated. Under the trip production, the model calculates three trip productions – one starting from the sender, ending at the sender, and connecting trip. The model assumes that the potential of attracted trips by consignees in zone j (PE_j) is the function of value of attraction unit s in zone j, the trip attraction rate of s in zone j, and share of trips within the modeled area. In order to calculate the trip distribution, the model produces the sum of all trips between zone i and j by adding the total trip starting with sender, ending at sender, and connecting trips. Then, trip distribution is calculated as the sum of the number of trips and the number of attracted trips for starting at sender, and ending at sender.

The result of VISEVA (Demand model) creates the trip matrices by vehicle type for the freight transportation. Other matrices, for example, matrices with long distance freight trips from the German Federal Plan for Transport), can be integrated in the VISUM (Assignment Model). VISUM produces link volumes and impedance matrices including travel time, cost, distance and then the result is input into the VISEVA. The same procedure is repeated until the trip (demand) and the network (supply) reach equilibrium.

VISUM also can optimize routes for freight transportation, cost estimates, and time with graphic analysis and assessment capabilities. For example, the program can generate a multimodal route tree in order to calculate costs for all routes, distribution of demand onto routes, capacity impacts, and time. Some interesting points by Markus Friedrich, a German scholar are:

- Freight models should include passenger models, and both models should be integrated into the same software program,

- Hub locations must be input into the network models,

- Dynamic, time-dependent methods for demand and supply models should be used for freight modeling,

- For long term decisions of freight transportation, the demand models should be applied, especially infrastructure or type of equipment investment decisions.

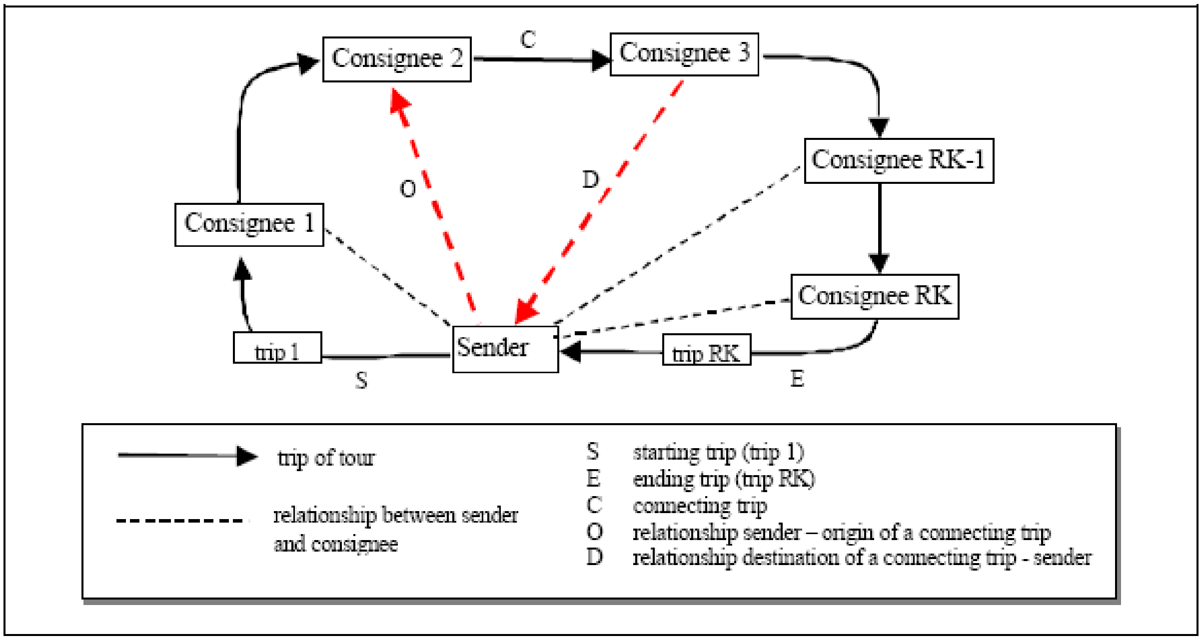


Figure 3: Modeling of Tours (chain of trips) and Definition of Trip Types

WIVER / VISEVA and VISUM Model Accuracy

In 2002, WIVER/VISEVA and VISUM model was applied for the region of Chemnitz (population of 248,000 as of 2005, located in eastern part of Germany). The publication mentions neither procedure nor the result of the model application. Therefore, the reviewer does not have evidence that the model is accurate.

WIVER / VISEVA and VISUM Model Transferability

These models are transferable to the Puget Sound region, because they are modeling at regional level and incorporate economic choices of shippers. However, obtaining this level of detailed data is questionable. Germany has an advantage of collecting data from freight companies and drivers over their counterparts in the U.S. because European Union by-laws mandate the surveying of the freight industry for statistics purposes. Also, German corporations and individuals have more compliant attitude toward government surveys in general. According to Worldlingo survey of major corporations on how they respond to e-mails written in English, German companies responded to surveys twice as high as the U.S. corporations. [9]

WIVER / VISEVA and VISUM Model Usability

The WIVER/VISEVA and VISUM model is useful because outputs are travel time, costs, and distances, which indicate traffic conditions in a study area. The model also stops when equilibrium between trips and the network is reached. This is a convenient feature if the user wants to know the maximum capacity of the transportation system. However, based on the literature, it is still not possible to observe any present or if-then condition of traffic network because the model won't produce outputs without reaching equilibrium of supply and demand.

Leachman Port Elasticity Model [10]

In the United States, several attempts have been made to model freight transportation using a commodity-based or trip-based model, or a combination of both. The commodity-based model captures economic and behavioral aspects of flows at the national or international level, or state-to-state level. The trip-based modeling is simply derived from passenger vehicle models using traffic volume data and residential-employment data.

Leachman's methodology is well suited to modeling of ports and handling facilities because his methodology incorporates economic factors and shipper decisions. For example, two types of inventory cost are examined. One is capital to finance goods in transit (called "pipeline stock"); the other is money to finance stocks of goods at destination distribution centers. Average pipeline stock is calculated as average transit time multiplied by average shipment size. Stocks of goods at destination distribution centers are divided into two categories of "cycle stock" (unused portion of the stock arrived previously) and "safety stock" (goods on hand in case of demands without delay to shipment), and then the cost of each is calculated separately.

Even though the focus of Leachman's study is to estimate freight flows in terms of port fee changes, his model is the most useful reference to what this research attempts to model: freight flows of port to handling facility to consumers. The methodology and detailed factors and parameters in the model reflect the economic and business decisions by logistics and supply chain managers. In this model, there are no capacity limits on port or warehouse space, and transit time is not a function of flow.

Leachman Port Elasticity Model Summary

The study suggests that the value of goods needs to be identified because the relative costs of direct shipping and of trans-loading differ depending on the value of goods. The model calculates the total transportation and handling cost per cubic feet using the trans-load rail channels, the direct rail channel, and the trans-loading to truck. The long run elasticity model includes cost matrix, transit time matrix, and pipeline and safety stocks in order to calculate the total transportation and inventory costs. After cost calculation in terms of different logistics alternatives such as direct shipping using the nearest port, trans-loading at three ports, etc., the study identifies the least cost logistics strategy depending on importer type and declared value per cubic foot.

The elasticity model focuses on which different logistics would benefit in terms of cost, which includes shipping cost, inventory cost, and delay cost, with respect to the value of goods, size of shipment, size of importers, container fees, use of different ports, and congestion. The methodology of the study is to express cost of different logistics, congestion conditions, and container fees, and then recommend what logistics would be the best for different scenarios.

Leachman Port Elasticity Model Accuracy

The elasticity model is applied to many strategies under two scenarios: (1)The As-Is Scenario and (2) The Congestion Relief Scenario. Examples of the variety of strategies are direct shipping using nearest port, trans-load at multiple West Coast ports, or trans-load only at LA – Long Beach. In sum, the model predicts that trans-loading volume is likely to be sharply decreased at container fee of $360 without any congestion improvements. Using the elasticity model, it predicts the sensitivity of imports in terms of changes in the mean transit time from port to trans-load warehouses, and rail transit times for movements out of the LA Basin, and container fees. But there is no actual data to validate the accuracy of the model because no container fees are imposed at present.

Leachman Port Elasticity Model Transferability

Leachman's model is transferable and is the appropriate starting point for this Puget Sound regional freight model because his model is able to capture a smaller area with all costs and shipper's choices incorporated. The economic choice of shippers is key for modeling freight movement because shippers usually give priority to cost-saving and improve their income/profit

- for example, changing delivery routes if goods do not reach the final destination on time, making third party logistics repackage and attach bar codes on products at distribution centers, or changing to bigger trucks from smaller trucks to cut the number of truck drivers paid. For the reason, this is the most appropriate model to identify the ultimate warehouse facility locations.

Leachman Port Elasticity Model Usability

While the result of his model is estimating how freight movement is likely to change when port fees are imposed, his model can be used to demonstrate existing conditions in freight movement between ports and handling facilities. And then, by adding or changing some parameters to the same model, the model can be designed to forecast future traffic congestion in the study area or even to identify better location for handling facilities in the Puget Sound region. Since the weakness of his study lies in the lack of information on port and warehouse capacity as parameter, a usable model for the Puget Sound area should address this limitation. Also, it is necessary to develop a methodology for transit time calculation, instead of using the average of the transit time based on a day as a unit, as applied in Leachman's model.

Los Angeles County Commodity Flow and Truck Model using Cube Cargo [11]

The Los Angeles County model using Cube Cargo is a combination of vehicle-trip and commodity-based approaches. The model is designed for urban and regional applications. A gravity model, which assumes that the attraction between origin and destination is proportional to the demographics of these two zones such as, population and location of retail stores, and is inversely proportional to their respective distances is used to estimate truck trips. In the model, some socio-economic data including households and employment by type, and population are used to estimate the flow of trucks. The Freight Analysis Framework (FAF) is used as a data source for calculating roadway cost. Roadway cost is defined per ton-mile by commodity. Truck travel time and distance are estimated from pickup and drop-off time. But driver rules include breaks and overnight stop times. It is not clear how these two factors are actually calculated.

Los Angeles County Commodity Flow and Truck Model Summary

The model is a forecasting tool for commodity and truck flows using Cube Cargo developed by CitiLabs. Cube Cargo is commodity-based forecasting approach that estimates the matrices of goods by commodity type by mode, and the matrices of a number of trucks by truck type. The Cube Cargo can model (1) long-haul bulk cargo from, for example, from factories to warehouses to packaging centers, (2) short-haul trips, and (3) urban freight of small amounts of goods within a city.

There are seven models in Cube Cargo:

1. Generation Model – estimates tons of commodities produced and consumed by zone by commodity class.

2. Distribution Model – estimates origin-destination matrices of goods by commodities class in short- and long-haul trips. Both trips are distributed by the gravity model using distance for short-haul trips, distance, travel time, and cost for the long-haul trips.

3. Modal Choice Model – estimates matrices of long-haul goods by commodity class and mode, using multinomial logit model. For the short-haul trips, the assumption is that travel is by trucks.

4. Transport Logistics Nodes Model – takes the long-haul modal choice model and partitions the long-haul matrices into direct transport and transport chain matrices by product type and mode. The direct transport includes only the initial origin and the final destination. However, the transport chain matrices models the commodity flow where goods are transported through goods yards, multimodal terminals, railway stations, and ports, for example. These locations of the transport logistics nodes can be defined by the user.

5. Fine Distribution Model – converts both short- and long-haul trips to fine level zones using the gravity model, in order to produce matrices of truck flows. Cube Cargo uses two level zone system: the coarse zone, and the fine zone. The coarse zone is where much of information and data are not obtained. The fine zone system is based on the zoning system for the highway network onto which vehicles are assigned. Also, other zones can be added to show the logistics nodes such as warehouses and ports.

6. Vehicle Model – estimates the number of vehicle trips per day by vehicle type of either heavy trucks or light trucks. Cube Cargo has two vehicle models:

    - The Standard Vehicle Model depicts origin-destination trips
    - The Touring Vehicle Model assumes all trips include stops to load and unload goods.

7. Service Model – estimates the urban area truck flow of local deliveries.

Cube Cargo is developed based on the German National Freight Transportation Model which is described below.

Los Angeles County Commodity Flow and Truck Model Accuracy

The purpose of the study is to test the Cube Cargo application model using existing data, not to validate the freight forecasting system of the SCAG 5 county region. In the second phase of the study, validation and calibration would be performed, but the result is not yet available. Thus, the accuracy of the model is still unknown.

Los Angeles County Commodity Flow and Truck Model Transferability

As the model claims, Cube Cargo appears to model urban area freight flows but the model is merely improved/updated form of freight modeling of trip-based and commodity-based models. Applying this model to Puget Sound region is not recommend because the detail of economic choices in the model is rather weak and the methodology of estimating truck flow is not the right approach for freight modeling.

Los Angeles County Commodity Flow and Truck Model Usability

The model is usable with respect to the model output, which is modeling truck flow in urban area. But it neither uses sufficient data nor employs the appropriate methodology to model truck flows involving ports and distribution centers. Therefore, the actual result from the model is questionable.

German National Freight Transportation Model [12]

FTIP 2003 (The German Federal Transport Investment Plan) is developed as base to replace the old plan of FTIP 1992. There are three stages for FTIP 2003;

1. Establishing three different scenarios by keeping demographic and socio-economic data and assumptions the same; other assumptions such as policy, transportation cost, transit time, and reliability are differentiated in three scenarios described below;

    - Laisser-faire – the status quo scenario
    - Trend – the trend scenario adding the Laisser-faire road pricing of 7.5 cents per truck-kilometer
    - Integration – the political target scenario including transport- and environmental objectives, adding road pricing of 20 cents per lorry-kilometer; for rail sharp decrease of the user charges and shorter transport time as well as higher reliability

2. Traffic Forecasts include transport demand and modal split. For the second phase of forecasting, the freight forecast model, SIMUGV, is used. SIMUGV is basically taking 1997 data of freight transport flow matrices as base then developing the transport demand model using regression for regional production and consumption, and the gravity model for the regional distribution of goods flows. And then the modal split is determined using a hierarchical logit model. It also chooses a terminal for combined transport using a logit-type sub-model.

3. Assessment and infrastructure investment evaluation is using WIZUG, which evaluates economic train management. Both the passenger and freight transport data are input to the network and the cost-benefit analysis (CBA) is performed. For this particular study, it is only limited to evaluate the train investment.

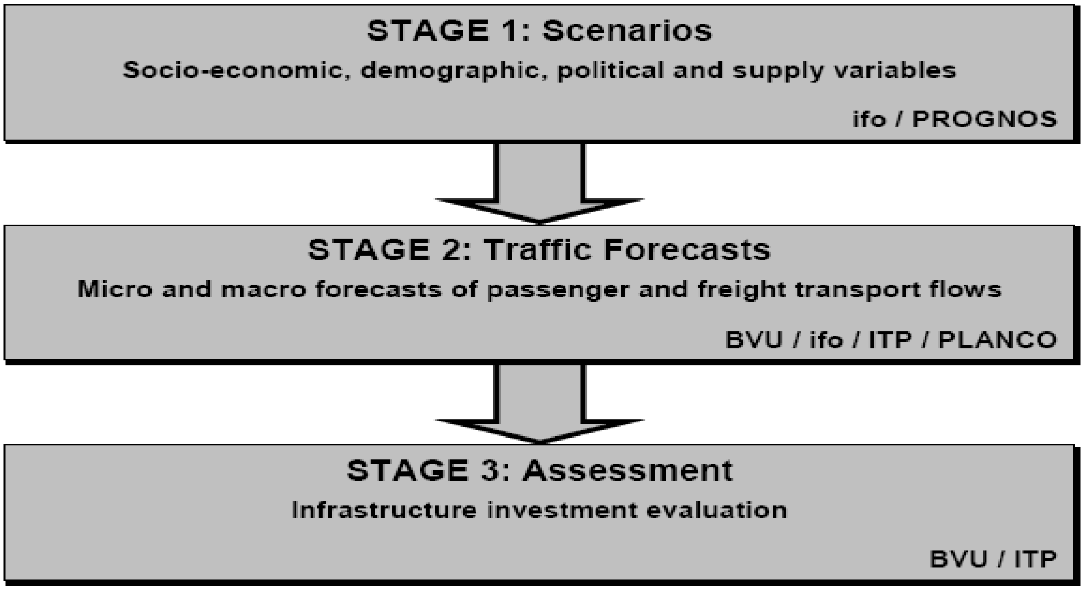


Figure 4: The three stages of the German Federal Transport Investment Plan (FTIP)

German National Freight Transportation Model Summary

As summarized in the Figure 5, the freight forecast model, SIMUGV uses the actual transport flow data collected in 1997 as the base. And socio-economic and demographic data are incorporated for forecasting freight movement for year 2015 using sub-models described below:

- a sub-model of the transport demand,
- a sub-model of modal split, and
- a sub-model of choice of terminal for multimodal transportation.

Base year freight matrices

The base year freight flow of 1997 consists of the rail freight transport flow matrices supplied by Deutsche Bahn Cargo AG. The road and inland waterways data came from the German federal and statistics agency. A German consultant, BVU collects and updates these data annually. The 1997 freight transport matrices have the following records:

- O-D zones including 377 regions and 19 ports in Germany, and 47 zones outside Germany,

- 7 modes, single wagon train, full train by Deutsch Bahn, full train by new competitors, multimodal, inland waterways, hired truck, owner's truck,
- 52 commodity groups,
- 3 shipment sizes
- Whether containerized or not
- Origin and destination terminals for multimodal transportation.

Available units for the records above are in volumes in tons and in performances in tons-kilometers.

Demand model

For the demand model, a regression model is used for regional production and consumption; a gravity model is used for the regional commodity flows. The regional production and consumption include variables of population, GDP by 8 sectors, turnover by 15 sectors, and exports and imports of 12 commodity groups. Transportation cost is used for the regional distribution of commodity flows.

Modal split

A hierarchical logit model is used for the modal split of seven modes. Based on the interviews with German shipping agents and carriers conducted in 1995, two sets of transport decision are created; one with the actual mode used, and the other with the preferred alternative. Also other variables such as transportation cost, transit time, reliability, risk of damage, suitability of transportation capacity and flexibility are added in the model.

Choice of terminal

The choice of terminal is determined by a logit model using the locations of available terminals, transportation cost and time between the terminals, and the surrounding area of the terminals.

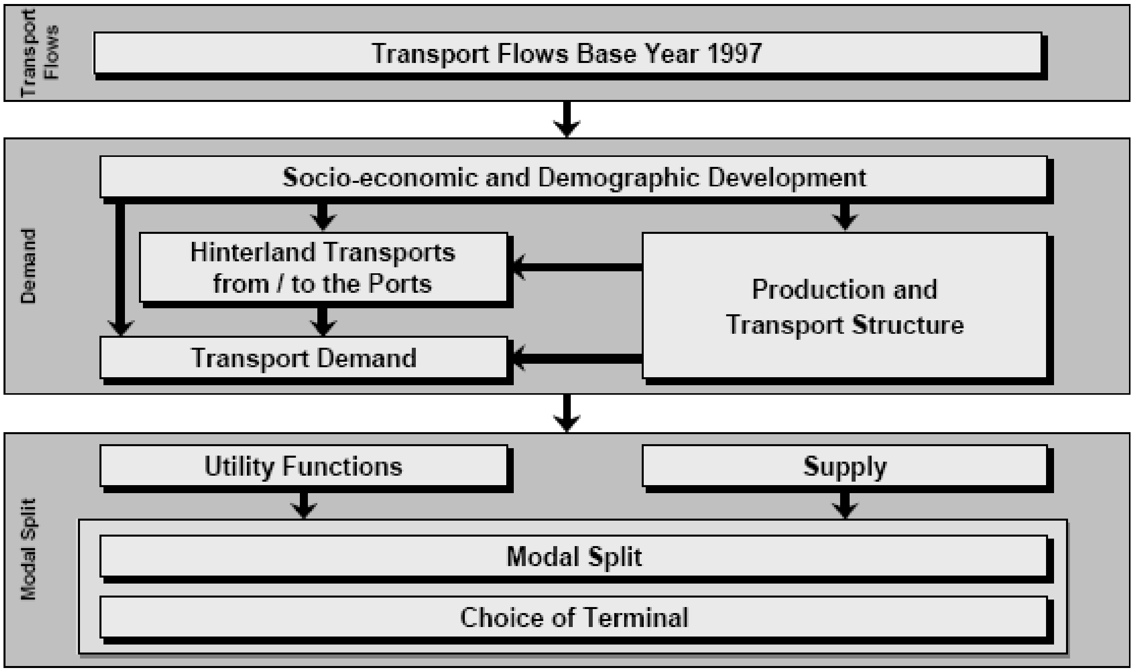


Figure 5: SIMUGV structure

<u>Assessment and infrastructure investment evaluation (WIZUG)</u>

The document describes the evaluation of only rail system using WIZUG. Therefore it is omitted to summarize the WIZUG algorithm in this paper.

Freight Analysis Framework (FAF)^2 [13]

The FAF^2 is an appropriate tool for estimating and forecasting commodity flows at national, international, and state-to-state levels.

<u>Freight Analysis Framework Model Summary</u>

FAF^2 consists of only public data sources and covers all modes and the shipment sources. The latest FAF^2, the 2002 FAF^2 Commodity Origin-Destination Database divides the US into 114 regions and adds 17 international gateways and 7 international regions covering commodity flows. It captures

1. commodity flows between domestic origins and domestic destinations,
2. exports between domestic origins and foreign destinations, and
3. imports between foreign origins and domestic destinations.

All record of flows also include type of commodity based on the 2-digit Standard Classification of Transported Goods (SCTG), zone of origin and destination, port of entry or exit if applicable, transportation mode, commodity value in US dollars and tonnage.

Non-CFS data include the US Surface Transportation Board (STB) annual railcar waybill dataset, the US Army Corps of Engineers (USACE) waterborne comers, and the Bureau of Transportation Statistics' T-100 Domestic and international air freight. Datasets are combined with CFS, creating the four dimensional O-D-C-M matrix in annual tons, annual dollar value, and annual ton-miles. Four dimensions are origin (O), destination (D), commodity (C), and transportation mode (M). FAF^2 uses log-linear modeling to estimate missing values and then applies iterative proportional fitting (IPF) to complete O-D-C-M matrix. Then, non-CFS sectors such as some imports and exports data are added from the USACE Foreign Waterborne Trade Data, BTS Transborder Freight dataset, and T-100 International Air Freight Data.

Freight Analysis Framework Model Accuracy

Developing the method to test the accuracy of the FAF^2 Model is still in progress. FHWA admits the difficulty of comparing actual commodity or industrial sector specific data to the Final FAF flow table because there is no data of such except annual state-to-state coal shipments by the Energy Information Administration. Also, missing data in smaller area could continue to be inadequate because of sampling issues. Therefore, the accuracy of the model is unknown at this time.

Freight Analysis Framework Model Transferability

As explained earlier, FAF^2 is not appropriate for modeling, especially urban freight flows, because the focus of FAF^2 is overall commodity flow at national and state-to-state levels. Their data contains only origin, destination, port of entry or exit, commodity type, type of mode, value in millions of dollars, and tons in thousands of short tons. Therefore, it is not even capable of estimating any flow from and to distribution centers.

Freight Analysis Framework Model Usability

The FAF^2 model is not usable for freight modeling of ports and handling facilities in the Puget Sound region because of the following reasons: (1) it does not estimate any effect of using handling facilities, (2) the scale of the model is too big for urban region, and (3) economic choice is not included in the modeling.

Puget Sound Regional Council (PSRC) Truck Model [14]

The Puget Sound Metropolitan Planning Organization, the Puget Sound Regional Council (PSRC) has a truck model based on the FASTrucks model [15] developed by Cambridge Systematics. This model is built on a passenger travel forecasting, but with freight specific adjustment factors, but the methodology for identification of these factors is not clearly explained in available project documentation. The model uses employment data to estimate truck trips.

PSRC Truck Model Summary

The PSRC Truck model is a regional truck forecasting model based on the passenger vehicle model, sharing the same residential and employment data. It involves three-step approach of

1. Trip generation,
2. Trip distribution, and
3. Traffic assignment.

The PSRC Truck model estimates three classes of truck trips for heavy trucks, medium trucks, and light trucks in internal and external trips. The internal trips are defined as truck trips within the region; the external trips are truck trips outside the region. The trip generation and trip distribution are estimated based on the stratification of employment data derived from the passenger model using Standard Industrial Classification codes. There are ten truck model employment categories but these employment data are not consistent with socioeconomic data used in the passenger vehicle modeling. Thus, some benchmarking and adjustment factors provided by PSRC are used for conversion of the passenger model employment dataset into the truck model employment dataset. However, the methodology or explanation on how these factors are produced is missing from the documentation.

1. Truck trip generation

The Quick Response Freight Manual (QRFM) [16] developed by Cambridge Systmatics includes production trip generation rates based on national averages. Based on QRFM, truck generation rates are estimated by ten employment categories and three sizes of trucks and adjusted to county-to-county commodity flow forecast using the Transearch database.
The truck attraction rates are developed from national input-output model, which uses a matrix of a nation's (or a region's) economy to predict how changes in one industry affect on others,

namely local consumers, government, and foreign suppliers and consumers in the economy. And then the truck attraction rates are adjusted to county-to-county level using data of Washington State gross product.

Related truck traffic for three ports of Seattle, Everett, and Tacoma is estimated by the following process: (1) Find out the total truck traffic expected in several Traffic Analysis Zones (TAZ) developed by PSRC [17], and then (2)subtract truck traffic generated by existing employment in the zone from the total traffic obtained in process (1).
For warehouses and distribution centers in the SR 167 corridor, it uses the survey conducted in 2006.

External trips are estimated using Transearch commodity flow data and the Strategic Freight Transportation Analysis (SFTA).

2. Truck trip distribution
The gravity model, commonly used for passenger vehicle models, is applied for heavy, medium, and light truck trip distribution. Then average truck trip lengths are calibrated using friction factors created by Cambridge Systematics. Furthermore, truck trip by three truck types are converted to truck trips by five time periods of AM peak, Midday, PM peak, Evening, and Night. 'Time period factors' developed by PSRC is used for the conversion.

3. Truck assignment
Truck trip is assigned by three truck types and passenger vehicles of single-occupancy vehicle (SOV) and high-occupancy vehicle (HOV) using an equilibrium highway assignment. Equilibrium highway assignment is, by definition, 'running several iterations of all-or-nothing capacity-restraint assignment with an adjustment of travel time to reflect delays encountered in the associated iteration'. Finally these truck trips are converted to Passenger Car Equivalents (PCE).

PSRC Truck Model Accuracy
According to their documentation, the validation process is correlating the medium trucks to single-unit trucks counted by the Washington State Department of Transportation (WSDOT); and correlating the heavy trucks to double- and triple-unit trucks. But that is all they state and no proof of accuracy is established. Also, Cambridge Systematics acknowledges the inability of

validating the light trucks due to incomparability in count data. They recognize that it is problematic to separate non-personal use vehicles from the light truck in the light truck travel category.

PSRC Truck Model Transferability
Given the limited information available on the process used to identify model parameters it is not clear how specific these are to the Puget Sound Region, and therefore how transferable the model is to other locations. The model logic is as applicable to other areas as it is relevant to the Puget Sound.

PSRC Truck Model Usability
While the model might replicate the present condition of overall traffic in the Puget Sound region, the output of the model is passenger car equivalents, showing congestion level measured in roadway capacity. The PSRC Truck model is still a small portion or derivative of passenger vehicle modeling, which should not be used directly or indirectly for freight modeling, because the nature of travel patterns are completely different. The travel pattern of commuters starts from home to work, through the fastest route or shortest route. On the other hand, commodity movements have to take different costs into consideration. For example, hot items with high demand have to move faster, even with the high cost of transportation such as gasoline, large capacity trucks. Or the furniture business prefers to have everything in warehouses except floor models so that customers' orders at retail stores will be delivered from warehouses by third party. Freight modeling involves so many factors by commodity type, by corporation's logistics, by different costs. These factors have to be studied and based on that, the proper modeling can be done for the Puget Sound region.

Summary of Literature Review
While there have been many modeling efforts to address the complexity of freight transportation, few are relevant both at a regional scale, and can capture the logistics practices of using handling facilities. Those that do are particularly data intensive. Given that this data is not generally available, and must be estimated, is seems a more strategic, high level planning tool would be appropriate to consider the impact of regional characteristics and costs on logistics behavior, specifically, mode choice and the use of regional handling facilities. We have not found any models that fill this requirement.

DATA NEEDS OF FREIGHT GOODS MOVEMENT

Freight movements have become an increasingly important portion of the traffic stream, in part due to the growth of international trade, and the recognition of the environmental consequences of this trade. The Commodity Flow Survey provides national level data including information on which ports are the busiest in terms of export and import in tonnage. Also known are what type of commodities the US imports through its West Coast ports and also where and how these goods reach their final destinations. However, transportation professionals do not have knowledge of how freight flows from ports to handling facilities, and these commodity flows must be converted to truck trips. One deficit of existing freight models is that those on a regional or local scale tend to require very detailed data inputs, however, this data is not available. This section evaluates the data available in the Puget Sound to support regional modeling. It is important to consider the availability of this data so that practical methodology decisions can be made.

Existing Data

Consider three categories of freight data:

1. Publicly funded, and available survey data,
2. Private enterprise operational data, and
3. Roadway sensor data

The next three sections explain what data are available, and discuss the advantages and limitations of each dataset with regard to freight movement modeling between ports and handling facilities in the Puget Sound region.

Publicly Funded and Available Survey Data

National Surveys

A Government survey is defined as some data actively collected by governmental agencies whether on a regular basis or as a unique or irregular data collection effort. In the category of public transportation survey, there are the Commodity Flow Survey (CFS), the Rail Waybill Sample, the Vehicle Inventory and Use Survey (VIUS), the Waterborne Commerce of the United States database, and the Port Import Export Reporting Service (PIERS) database. Among those on the list, only CFS from the Bureau of Transportation Statistics and the Transearch database from the private sector cover intermodal shipments. There are several problems associated with CFS data because intermodal shipments are the most complicated and underreported because for many reasons including those listed below.

- Shipments from retail establishments are not included. Also small shipments from service establishments, central administrative offices, governments, and households are excluded from CFS data collection.
- Imports and in-transit freight movement are not included in CFS unless a domestic company reships the goods after entry at a port.
- Warehousing data are not collected at all or are missed for CFS, especially where businesses' use of for-hire warehouses and storage services are not reported.
- Many shippers, which use third party logistics services, are not capable of reporting all modes used for their shipments.
- Third party carriers might hire subcontractors as their carriers.
- Commodities carried through pipelines, such as petroleum and natural gas, are not captured in CFS.
- The definition of intermodal transport is not clear because although supply chain management is commonly used, it is complicated. It involves few or all changes in ownership, modes, repackaging, and multiple destinations.

A study by Oak Ridge National Laboratory (ORNL) (Freight USA, Highlights from the 1997 Commodity Flow Survey and Other Sources, prepared for the Bureau of Transportation Statistics US Department of Transportation) (2000), concluded that the CFS data included only 75 percent of the total US freight shipment in tons, and 81 percent in value; the 2002 CFS has captured only 54 percent when measured in tons, and 63 percent in value, because of reasons mentioned above and the following undercounts:

1. Shipments of farm commodities
2. Shipments of fish and seafood from the boat to the dock or from the fish farm to the processor
3. Shipments of municipal solid waste
4. Shipments of logs from the point of harvest to the initial point of processing
5. Shipments originating from the construction sector
6. Shipments of the publishing industry

7. Household and business moves

8. Some petroleum products

9. Some US exports

Given the fact that the CFS has so many gaps in its data, the US Department of Transportation recognizes the necessity to compile a more complete and accurate freight model. Consequently the Freight Analysis Framework (FAF) has been created by the Office of Freight Management and Operations of the Federal Highway Administration (FHWA) based on CFS with and public and private data sources. FAF is the comprehensive database of truck, rail, water, and air modes for domestic and international statistics and for various commodities. It estimates freight flows and activities among states, sub-state regions, and major international gateways. Also FAF could forecast the future commodity flows and activities based on changes in the economy, transportation facilities, other conditions and policies.

Washington State Survey Data

Washington Warehouse/Distribution Center Industry: Operations & Transportation Usage [19] – In this case, warehouse data provides warehouse facility type, size, hours of operation, commodity type, cross docking, usage of third party logistics provider (3PL), number of stops, size and capacity of truck payloads, number of truckloads, time and region of shipment, and seasonality of shipment. The data provides very useful information, but because the survey is focusing on warehouse operators, the data is more an aggregate rather than representative of individual truck movements. For example, the respondent of the survey may not know the commodity type handled at its facility if it provides service to multiple companies.

Freight Movements on Washington State Highways: Results of the 2003-2004 Origin and Destination Study [20] – The O-D study is a statewide truck driver survey of origin and destination information, and also includes truck type, commodity type and weight, routing, and weigh site. It is worth looking into this data and extract data of the Ports of Seattle or Tacoma, or warehouse facilities in south Seattle, as origination or destination. This data contains very useful information, but it is not focused at the regional level. For truck movement between the Ports of Seattle and Tacoma and handling facilities, the data underestimates important information because of small sample size and limited survey locations.

Private Enterprise Operational Data

Private data is data each company uses for operational purposes. This data contains origin and destination, travel time, commodity type, and other data. They are not only static data but also dynamic data because of the GPS system loaded on each truck. For this project, private enterprises provided cost data used to feed the model.

Roadway Sensor Data

Traffic count data are collected periodically at the level of state, county, or city. The most common form of traffic counting is the installation of loop detectors at certain segments of roadway. The main purpose of traffic count data is to measure traffic volume in the area of study. The automatic count data includes all vehicles categorized as passenger, truck, or bus. While these traffic detectors are capable of counting large capacity vehicles such as heavy trucks and metro buses separately from passenger vehicles, small size trucks with two-axels are not counted separately from passenger vehicles. In this project traffic count data was provided by the Washington State Department of Transportation (WSDOT). Two other data sources are described below. However, these data were not ultimately used in this modeling effort.

State of Washington Traffic Count Data [21]

Commercial Vehicle Information Systems and Network (CVISN) – The CVISN program is intended for trucks to bypass weight stations using transponders mounted on vehicles. CVISN weigh-in-motion can electronically read a transponder containing information such as a truck's weight, size, registration, and safety record. From the CVISN data, truck travel time can be calculated by identifying the same truck from its ID tag and time passed between two locations. However, the accuracy of truck travel time using CVISN data is not as simple as recording the time a truck is at CVISN point A and recording the time the same truck is at the next location or point B. This is because the truck driver may stop frequently for a variety of reasons. Also, there is no CVISN installed at the corridor linking the Ports of Seattle and Tacoma, and warehouse facilities in the south Seattle area.

WSDOT FLOW Surveillance System Data – FLOW surveillance data is collected by WSDOT using their freeway surveillance and control system in the Puget Sound area. The data includes over 3000 loop detectors, over 160 Closed Circuit TV (CCTV) cameras, and some radar detectors and magnetometers. The loop detectors can record vehicle volumes and lane occupancy every 20 seconds. Also, from dual loop detectors, average vehicle speed can be obtained. FLOW information is useful for freight modeling because it provides average vehicle speed and also congestion on a freeway network. Data is not available for all segments of roadway network.

Wireless GPS Devices Data by TRAC – This is data collected by installing global positioning systems (GPS) with cellular reporting capability. To collect data, the device was installed in five trucks mainly operated in the Puget Sound region. It reported the location of the truck, vehicle speed, time, and travel direction for about a year. From these data, roadway speed and travel time are estimated. The biggest advantage of wireless GPS device data is that it represents round-the-clock information on truck movement including travel time, frequency of stops, routing, duration of stops, origin, destination, and stops. These can be compared with travel time and speed estimates from traffic count data. 25 vehicles are included in this dataset, so network coverage is limited.

Freight Data Gaps

While there are some existing data sources when considering the movement of containers between ports and handling facilities, there are also significant data gaps. As a result, we have selected a strategic level model which does not rely on very detail spatial and temporal data. With a strategic model, high level interactions can still be analyzed, but the ability to forecast truck volumes on specific roadway in narrow time windows is not possible.

MODEL DEVELOPMENT AND VALIDATION PROCESS

The methodology selected for our model draws heavily on the framework identified by Rob Leachman from the University of California at Berkeley. We use a similar model structure, as well as many of the data elements identified in the final report of his Southern California Port Elasticity Study. This model focuses on shippers' economic decisions, which are also incorporated into the Puget Sound regional model. In addition to using data from the Leachman study, the following data were used:

- **Port of Seattle and Tacoma Data**:
  Container volume and value of top 50 importers and exporters are provided by the Port of Tacoma. It is our assumption that the Port of Seattle has a similar

transaction. The total annual volume of containers, were obtained through the port website.

- **BNSF and Union Pacific Data**:
  Rail rates and locations of rail yards, were obtained from BNSF's website.

- **Trucking Firm Data**
  Truck rates from two ports to local drayage, to warehouse, and to several out of state locations are obtained by cooperation from Premier Transport and West Coast Trucking companies.

- **Data from real estate agent or public land assessors office**
  Warehouse location, capital and operation cost in the Puget Sound region in the State of Washington

- **Data from Washington State Freight Strategic Mobility Investment Board (FMSIB)**
  Identification of strategic freight corridors.

- **Data from WSDOT, King County, and the City of Renton**
  Traffic count data at several points on the main freight routes

Freight Model Description

Import Freight Model

The model consists of two origin nodes of the Port of Seattle and Tacoma, three possible mode choices of

1. Direct shipping by a truck,
2. Direct shipping by rail,
3. Use of a handling facility (either mode).

Final destinations are divided into 21 regions in the U.S. And it is assumed to have one destination in the region. Further detail is not required to consider the impact of transportation on the Puget Sound region. Allocation of commodity flows is made based on population and average income in each region. Larger population and higher income area have more purchasing power; therefore, larger volume of commodity movement is assigned.

Table 1 shows the 21 regions and their purchasing power used for the model. The information was obtained from Dr. Leachman's study. The total import volume is set to 2006 volumes for Seattle and Tacoma and distributed to final destinations according to the percentages in Table 1.

Table 1: Proportion of Total Imports to Twenty-One Major U.S. Markets

Final Destinations	Percentage of Total Imports (%)
Atlanta	6.915
Baltimore	2.870
Boston	4.290
Charleston	0.597
Charlotte	3.220
Chicago	10.990
Cleveland	3.807
Columbus	1.888
Dallas	4.572
Harrisburg	2.161
Houston	5.576
Kansas City	4.219
Los Angeles	11.782
Memphis	3.765
Minneapolis	3.262
New York	11.229
Norfolk	2.740
Oakland	6.629
Pittsburgh	2.653
Savannah	2.811
Seattle	4.024
Total	**100 %**

In the model there are two components of cost,

I. Transportation cost, and
II. Inventory cost.

A combination of these costs determines the route choice and mode choice for shippers. The model selects the least cost strategy by comparing the sum of transportation and inventory cost for each of the four strategies listed below. This can be done for each shipper for each of the 21 destinations. Also consistent with the methodology in Leachman's elasticity model, we model 83 shippers who represent the largest importers. These importers are responsible for approximately 50,000 TEUs per week. The remaining volume (35,000 TEUs) is attributed to small shippers, for whom we assume no transloading takes place. This methodology is consistent with the methodology in Leachman's elasticity model. This can be reviewed for further detail. There are four different freight movements in the model:

1. Direct truck,
2. Direct rail,
3, Transload rail, and
4. Transload truck.

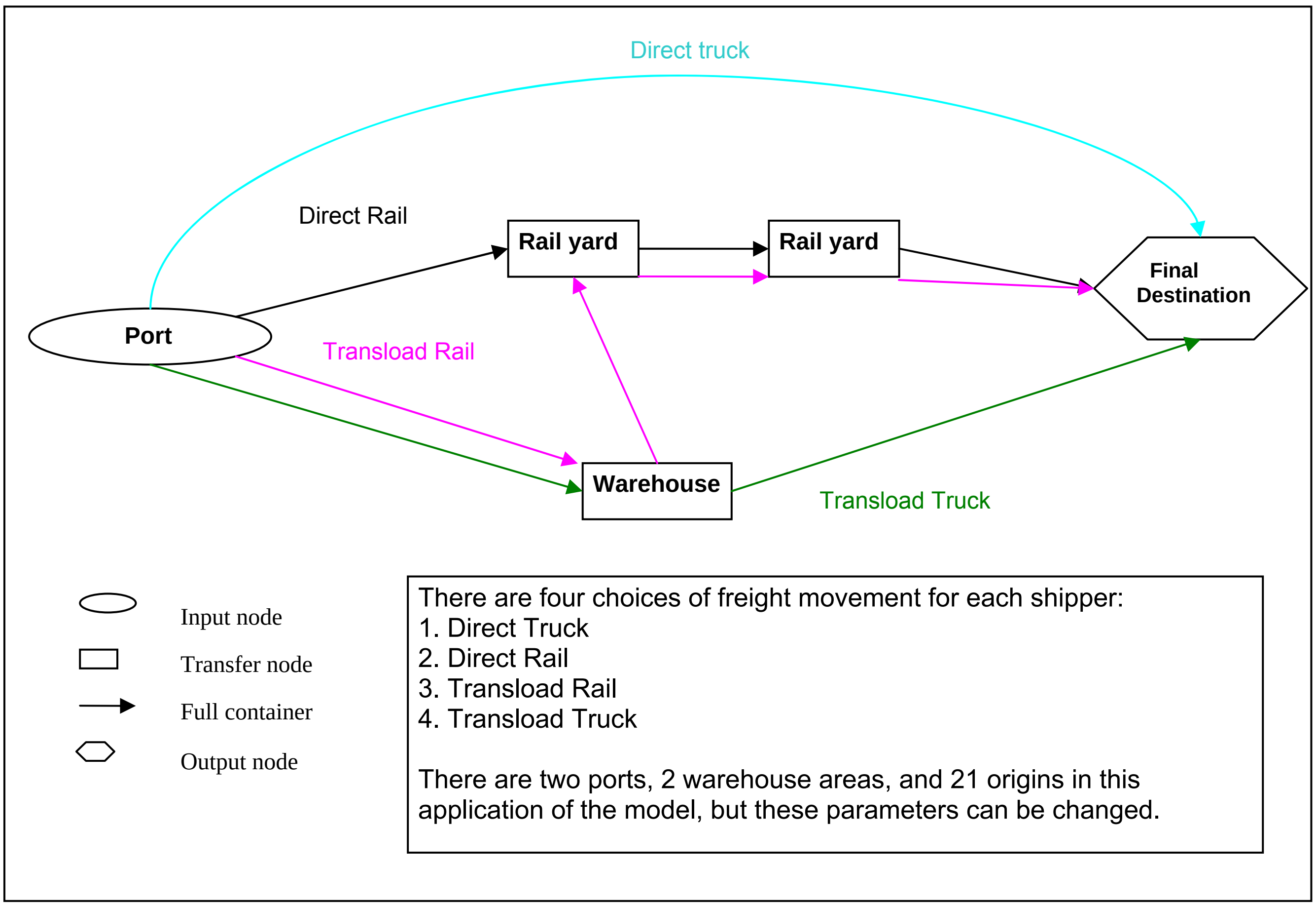


Figure 6: Import Model Description and Flow Schematic

Import Model Structure

The model is designed to minimize total logistics cost for each shipper. Each shipper selects the rail or truck, and transload or no-transload, by selecting the least cost alternative. The model allows each shipper to utilize one strategy only. The model structure using mathematical notation is as follows:

Objective Function: Minimize $\sum_{p}(TC_{b,p}+IC_{b,p})$

Where:

$TC_b = \sum_{fd}(TC2_{p,fd}*TEU\_DT_{b,p,fd}) + \sum_{ry,fd}(TC3_{p,ry}+RC_{p,fd})*(TEU\_DR_{b,p,ry,fd})$

$+\sum_{dc,ry,fd}(TC3_{p,ry}+(TC1_{p,dc}+RC_{p,fd})*0.6)*(TEU\_TR_{b,p,ry,fd})$

$+\sum_{dc,fd}(TC1_{p,dc}+TC2_{p,fd}*0.6)*(TEU\_TT_{b,p,dc,fd})$

And: $IC_b = \sum_{fd}(PS\_DT_{b,p,fd}+SS\_DT_{b,p,fd})(a*v_b*(i/52))$

$+\sum_{r,y,fd}(PS\_DR_{b,p,ry,fd}+SS\_DR_{b,p,ry,fd})(a*v_b*(i/52))$

$+\sum_{dc,ry,fd}((PS\_TR_{b,p,dc,ry,fd}+SS\_TR_{b,p,dc,ry,fd})(a*v_b*(i/52))$

$+TEU\_TR_{b,p,dc,ry,fd}*100*DCC_{dc}) +\sum_{dc,fd}(PS\_TT_{b,p,dc,fd}+SS\_TT_{b,p,dc,fd})(a*v_b*(i/52))$

$+TEU\_TT_{b,p,dc,fd}*100*DCC_{dc})$

$PSDT_{b,p,fd,m} = MT_{fd,m}*TEU_{b,p,fd,m}$

$SSDT_{b,p,fd,m} = k*sqrt[(MT_{fd,m}+R)*\sigma^2_{b,m,fd}+(TEU^2_{b,p,fd,m}*dev^2_m)]$

$\sigma_{b,m,fd} = 1.25*MAPE*E_{b,fd}$

Such that:

$E_{b,fd}=\sum_{p}(TEU\_DT_{b,p,fd})+\sum_{p,dc}(TEU\_TT_{b,p,dc,fd})+\sum_{p,dc,ry,fd}(TEU\_TR_{b,p,dc,ry,fd})$

$+\sum_{p,ry}(TEU\_DR_{b,p,ry,fd})$

TLCost: Total Logistics Cost
TEU_TR: Total number of TEUs delivered by transload rail
TEU_TT: Total number of TEUs delivered by transload truck
TEU_DR: Total number of TEUs delivered by direct rail
TEU_DT: Total number of TEUs delivered by direct truck
TC: Transportation Cost
IC: Inventory Cost
b: Importers
p: Port of entry
dc: Distribution center
fd: Final destination
ry: Rail yard
m: Mode
i: Interest rate
a: usable ft3
v: Value of goods

TC2: Truck rate from dc to final destination
TC3: Truck rate from port to railyard
RC: Rail rate
DCC: Distribution center dollar cost per ft2 per week
E: Total demand in TEUs
k: Safety factor
PSDT: Pipeline stocks
σ: Level of confidence at time of routing decision
SSDT: Safety stocks
dev: Standard deviation
MT: Transit mean time
R: Time between replenishment orders
MAPE: Mean absolute percentage error

The only model constraint is that demand for each destination must be met. The input variables utilized, value of goods by importer and the mean transit times to markets are provided in Tables 1a, 1b and 1c.

Table 1a: Input variables

Input variables	Values in the model
i: Interest rate	10%
a: usable ft^3	1250
V: Value of goods	Please refer to the Table 1b
TC2: Truck rate from dc to final destination	Actual quote from a trucking company
TC3: Truck rate from port to rail yard	Actual quote from a trucking company
RC: Rail rate	Rate is based on estimate from a 3PL company
DCC: Distribution center dollar cost per ft^2 per week	TEUs per week*100*\$0.11/ft^2 in Kent warehouse TEUs per week*100*\$0.08/ft^2 in Sumner warehouse
E: Total demand in TEUs	Please refer to the Table 1b
k: Safety factor	2 (98% probability of no stock out)
PSDT: Pipeline stocks	Transit mean time*TEUs
σ: Level of confidence at time of routing decision	1.25*MAPE*TEUs*2 for direct truck 1.25*MAPE*TEUs if k=<3 for direct rail, transload truck, and transload rail
SSDT: safety stocks	(K*Sqrt[(mean transit time+R)(σ_{DD}^2)+($TEUs^2$)(σ_{LD}^2)]
dev: Standard deviation	0.25 day for direct truck 4 days for direct rail 5 days for transload rail 1 day for transload truck
MT: Transit mean time	Please refer to the Table 1c
R: Time between replenishment orders	1 week
MAPE: Mean absolute percentage error	0.06

Table 1b: Value of goods and total demand

Importers	Quantities (TEUs per week for the whole US)	Assumed average value per ft^3 ($)
Wal-Mart	8127	15
HomeDepot	4242	9
Target	2856	20
Sears	2625	20
Ikea	1407	9
Lowes	1407	9
Costco	945	20
Ashley Furniture	903	9
Payless ShoeSource	756	25
Samsung	735	40
Matsushita	735	40
Toyota	735	20
GE	735	25
Williams-Sonoma	714	25
Mattel	693	17.5
Pier 1 Imports	672	10
Nike	672	25
Sony	672	40
Michelin	651	15
JC Penney	630	20
LG	609	40
Bridgestone	609	15
Limited Brands	588	30
Dollar General	567	15
Toys R Us	546	17.5
Big Lots	504	10
Ford	420	20
Dorel	399	9
Nissan	399	20
Yamaha	378	20
Philips	378	40
Michaels Stores	378	10
Whirlpool	378	25
Canon	378	40
Walgreens	357	10
Rooms to Go	336	9
Thomson	336	40
Federated	336	25
Emerson	315	40
Marubeni	315	50
Jarden	315	25
Reebok	294	25
Hankook	294	15
Dollar Tree	273	10
Natuzzi	273	9
Goodyear	273	15
Family Dollar	273	10
Retail Ventures	273	15

TJX (T J Maxx)	252	20
Sharp	252	40
Conair	252	25
Liz Claiborne	252	40
Toyo	252	15
Toyota	231	20
JoAnn Stores	231	20
FoxConn	210	40
Caterpillar	210	50
Gap	210	40
DaimlerChrysler	210	20
May	210	18
TPV International	210	40
Best Buy	210	40
Bombay	210	9
Fuji	210	80
BMW	210	20
Haier	210	25
Hasbro	210	17.5
Salton	189	25
Suzuki	189	20
Linens ‘n Things	189	20
OfficeMax	189	12
Epson	189	40
Coaster of America	189	9
Staples	189	12
Yazaki	189	20
Richoh	168	40
Brother	168	40
Applica	147	20
Adidas-Solomon	147	25
Footstar	147	25
Hamilton Beach	147	25
Honda	147	20
CVS (Eckerds)	147	10

Table 1c: Transit mean time by each mode (days)

Final Destinations	Direct truck	Direct rail	Transload rail	Transload truck
Atlanta	5	9	7	6
Baltimore	5	9	7	6
Boston	5	9	8	6
Charleston	5	11	8	6
Charlotte	5	10	9	6
Chicago	3	6	5	4
Cleveland	4	8	6	5
Columbus	4	8	6	5
Dallas	4	8	7	5
Harrisburg	5	9	7	6
Houston	5	10	7	6
Kansas City	3	8	6	4
Los Angeles	2	4	3	3
Memphis	4	8	7	5
Minneapolis	3	5	4	4
New York	5	9	7	6
Norfolk	5	9	8	6
Oakland	2	4	3	3
Pittsburgh	4	9	6	5
Savannah	6	11	9	7
Seattle	1	2	2	2

Export Freight Model

Upon export, transloading between 40- and 53-foot containers is not performed in North America due to the absence of an inventory management benefit. However, exporters do move goods from rail boxcars to 40-foot containers. This presents a significant cost advantage because a rail boxcar can hold three to seven times more goods than a 40-foot container. Exporters who move goods from rail boxcars to 40-foot containers use rail transload facilities near the ports of Seattle and Tacoma, which are not the not warehouse districts in Kent and/or Sumner. Therefore, these movements are not considered in the model framework.

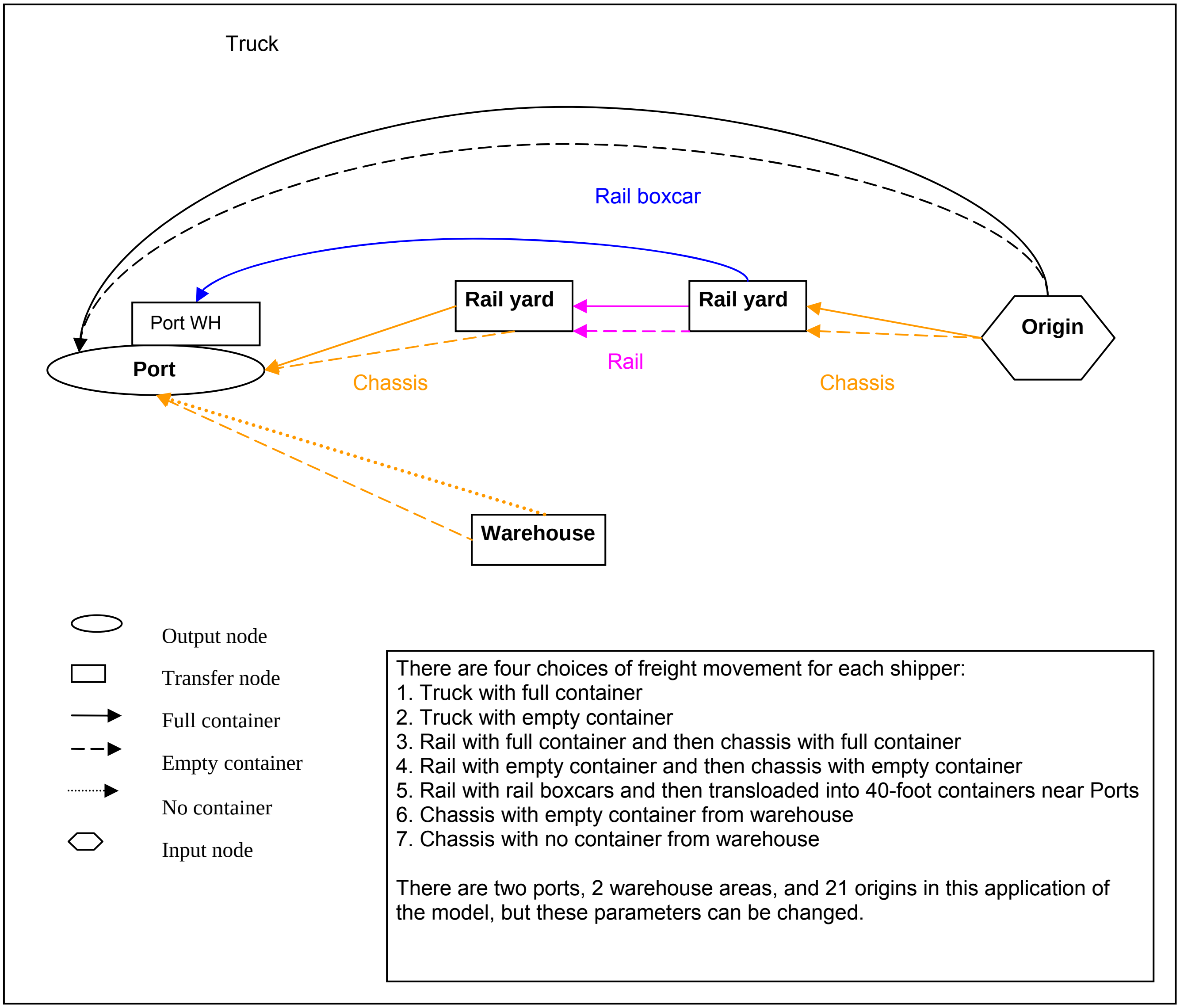


Figure 7: Export Model Description and Flow Schematic

Model Validation

Here we described the validation performed with the model. We compare model results with a variety of observed conditions.

Definition of Terms

- Model Estimation – Fine-tuning of model parameters to capture system dynamics. At this process, estimating all possible parameters is included in a freight model. And statistical significance or weight of variables in the model is determined.

- Model Calibration – At this phase, all parameters are adjusted until mode choice of importers in the freight model match observed mode in aggregate data.

- Model Validation – This is an iterative process with model calibration. The result of the model is checked against observed data and parameters are adjusted until the model output produces with acceptable error.

- Model Application – After validation of the base model, future prediction or what-if scenarios should be tested if the model can predict future condition or policy changes reasonably well.

We conduct two types of validation.

1. Reasonable Output – The validation for reasonableness includes parameters checked against observed values, or data from comparable regions.

2. Sensitivity Test – How the model responds to changes.

Validation Results

Reasonable Output

We conduct three tests with the model an examine output.

i) Set goods value to zero

ii) Set rail rate to zero

iii) Set truck rate to zero

Table 2: Model Validation Results for Reasonability Tests		
Change in input value	**Expected result**	**Model output**
Goods value = 0	Shippers use the cheapest mode of transportation: Rail and transload rail.	Direct truck 1.7%, Transload truck 0.8%, Transload rail 96%, Direct rail 1.5%
Rail rate = 0	Shippers use Rail and transload rail.	Direct truck 1.5% , Transload truck 0.8%, Transload rail 96.4%, Direct rail 1.2%
Truck rate = 0	Shippers choose Truck and transload truck.	Direct truck 88.9%, Transload truck 11.2%, Transload rail 0%, Direct rail 0%

These results confirm that for extreme cases the model responds appropriately. The base values are not meaningful, but the model responds appropriately.

Sensitivity Test

We consider the aggregate effect of increasing the fuel surcharge from 10% to 100% of the base case truck rate.

Table 3: Model Validation Results for Sensitivity Tests

Fuel surcharge rate	Expected result	Model output
10% of truck rate	Gradual increase of using rail and transload rail for shorter distance	Direct truck 3.8%, Transload truck 0.8%, Transload rail 93.9%, Direct rail 1.5%
20% of truck rate	Gradual increase of using rail and transload rail for shorter distance	Direct truck 3.5%, Transload truck 0.8%, Transload rail 94.2%, Direct rail 1.5%
30% of truck rate	Higher increase of using rail and transload rail	Direct truck 3.4%, Transload truck 0.8%, Transload rail 94.3%, Direct rail 1.5%
50% of truck rate	Higher increase of rail and transload rail	Direct truck 3.1%, Transload truck 0.8%, Transload rail 94.6%, Direct rail 1.5%
70% of truck rate	Higher increase of rail and transload rail	Direct truck 2.9%, Transload truck 0.7%, Transload rail 94.8%, Direct rail 1.6%
100% of truck rate	Higher increase of rail and transload rail	Direct truck 2.8%, Transload truck 0.7%, Transload rail 94.9%, Direct rail 1.6%

Again, the values themselves do not represent the base case, but the model responds in the expected fashion.

Model Results: Aggregate Comparisons

The model outputs are compared with publicly available data including the Port of Seattle and Tacoma, Washington State DOT, US Department of Commerce Statistics, Federal Highway Administration [1], Washington State University [2], and Heffron Transportation's study. These data are aggregate in nature; therefore, so are only comparable at the aggregate level. Both Port of Seattle and Tacoma have data of import and export volume, value, and contents by month and year, by country, by each port in the US. [3] [4] However, there is no data for where containers go when the leave the Seattle and Tacoma Ports.

Currently publicly available data, closely related to the model are as follows:
According to WSDOT, total containers moved through the port of Seattle were 1.3 million TEUs in 2002 (roughly equal volumes of imports and exports). And 50% of import volumes were intermodal and 40% of export volume in 2002. Among import intermodals were moved directly on dock 23% of the time. And export intermodals were moved directly on dock 16% of the time. Total weekday truck trips generated were 5,270 per day. 3,320 truck trips (little over half) were to/from the region; the remaining 1,950 trips were to/from rail yards. [5]
According to SR 167 Corridor Study in 2005 by Heffron Transportation Inc. and CoStar Industrial Report, 60% of containers were delivered by rail; the remaining 40% were carried by trucks. Among all truck trips 33% of all regional truck trips generated by the Ports of Seattle and Tacoma would be destined to locations in the Green River Valley warehouse district. [6]

Table 4a:Port of Seattle and Tacoma data for comparison

Port	Total annual TEUs in 2005	Total containers per year	Containers by rail per year	Percentage of containers by rail	Containers truck to region per year	Percentage of containers by truck
Seattle	2,087,929	1,186,300	711,800	60%	474,500	40%
Tacoma	2,066,447	1,129,200	632,400	56%	496,800	44%

Table 4b: Heffron Transportation Study data for comparison

Port	Containers truck to region per year	Containers going to Green River warehouse	Percentage of containers going to Green River warehouse
Seattle	474,500	156,585	Up to 33%
Tacoma	496,800	163,944	Up to 33%

Because the true values are not known, we see there is variation in the available estimates of, for example containers moved by each mode. Also, these two estimates are from different time periods (2002 and 2005), respectively.

Small shippers will use a direct shipping strategy, as transloading does not provide a cost advantage. In addition to the largest shippers, we account for small shippers by assuming they will use the least cost mode, and use direct shipping. They are allocated half to direct truck and the other half to direct rail.

BASE CASE

With model validation completed, we can define the base case scenario and its results for comparison to scenario analysis. Table 9 shows the mode split for the base case scenario. The model's mode split and transloading ratio are very consistent with previous studies.

Table 5: Mode split in the base case scenario

	Direct truck	Transload truck	Direct rail	Transload rail
Model output of mode choices	22.1%	28.3%	17.0%	32.6%

Figure 8 is shows the modal split for each destination based on the top importers obtained from the Journal of Commerce database. This set of importers represents 47% of the total import volume. To this, we add small shippers, and the adjusted base case is shown in Figure 9.

Figure 8: Proportion of Modal Shipments to Destination Cities, Base Case Scenario

Figure 9: Proportion of Modal Shipments to Destination Cities, Adjusted Base Case Scenario

As expected, rail and transload rail dominate for long distance, cross country trips, and truck is more common for West Coast destinations. The size of the pie in each location represents the relative purchasing power of the region.

SCENARIO ANALYSIS

Here we demonstrate the potential of the model through application to three case studies. The model can be applied to a much larger number of scenarios, but we present these examples here to demonstrate the insights that can gained from its use. These scenarios were selected based on discussion with the project advisory committee (see the Appendix for a complete list of members), and responses to the model received during presentations at the Transportation Research Board freight modeling conference, and the INFORMS annual meeting. We consider how the introduction of a truck only lane on SR167 would impact national logistics strategies, and how a significant consolidation of shippers would affect logistics strategies. We also consider a strategy which excludes cargo destined for the Los Angeles and New York regions. In practice, these goods would not typically be carried through the Ports of Seattle and Tacoma. However, the final destination of goods entering the port of Seattle is not known, so a complete adjustment for final destination is impractical (goods destined for Georgia are probably less likely to use Seattle than goods for Montana). As the model has complete flexibility with respect to final destinations, a range of scenarios for final destination can be tested, and the scenario where New York and Los Angeles markets are removed is shown as an example.

Scenario A: Add a truck only lane on SR 167.

How would a truck-only lane along SR167 affect a shippers' decision to transload? According to WSDOT traffic volume data in 2006[1], approximately 9% of traffic on SR 167 is trucks, and the average daily traffic (ADT) is 118,000. The ADT and truck ratio on the two-lane state highway are significant number in terms of size of the highway. For example, Interstate 5 near SR 167 records ADT of 192,000 and about 9% of the ADT is truck, not significantly higher than these numbers on SR 167. Because of heavy traffic relative to the capacity of the roadway and clusters of warehouse located along SR 167, solutions are being sought to ease congestion, and particularly the impact of congestion on trucks.

To assess the impact of a truck only lane, the mean transit time and standard deviation of transit time were reduced. More specifically, the mean transit time of transload truck option was changed to one day shorter than mean transit time of direct truck. Standard deviation of transload truck was originally 0.14 but it was changed to 0.01. Standard deviation of direct truck was increased to 0.7 from 0.04. In addition, level of confidence at time of routing decision, which directly affect safety stocks of goods was changed to 250% less confident for direct mode; 20% more confident for transloading choice. All three variables are tied to inventory cost, meaning less mean transit time, smaller standard deviation, and higher level of confidence at time of routing decision reduce the inventory cost.

With these changes in input, the proportion of shippers choosing to transload increases by 21.3%. Figure 10 summarizes the modal split for Scenario A.

[1][www.wsdot.wa.gov/mapdata/tdo/PDF_and_Zip_files/Annual_Traffic_Report_2006.pdf]

Figure 10: Proportion of Modal Shipments to Destination Cities, Scenario A

In aggregate, transload truck and transload rail increase significantly, to 57.1%. This shift in national logistics patterns creates significantly more traffic between the ports and regional handling facilities in the Puget Sound region.

Scenario B: Shipper Consolidation

How would a significant consolidation of shippers change existing freight movement patterns? Based on the importers data provided by the Port of Seattle, the top 50 importers in terms of volume represent 47.8% of goods moving through the Port. The remaining more than half of all importers are small importers, ranging from 1 TEU per week or less to at most 20 TEUs per week. This current importers profile affect mode choice of freight movement if they utilize more 3PL or outsource carriers for goods delivery because it will create few higher volume shippers behave as if they share the same logistics strategy as one entity.

Small volume shippers, defined as “a shipper delivers volume of less than 11 TEU per week per region”, are combined to create fewer large scale shippers. The result shows that there will be 47.0% more transloading activity if containers from many small shippers are consolidated and handled by fewer large volume shippers. For example, if one shipper handles the range of more than 11 TEUs and less than 200 TEUs per week per region, then the model shows that transloading strategy is preferred to direct shipping, when the value of goods is $25 per ft^3 or more. But if the value of goods is less than $25, a shipper benefits more from direct shipping rather than transloading.

On the other hand, in case of large shippers, defined as 200 or more TEUs per week per region, they benefit from transloading regardless of the goods value. The result is summarized in the table below.

Table 6: Model thresholds for logistics behavior

Importer scale	Goods value per ft^3	Least cost import strategy
Super Large importers (> 200 TEUs/wk/region)	Any values	Transload
Large Nation-wide importers (11 – 200 TEUs/wk/region)	< $25	Direct shipping
	≥ $25	Transload
Regional and small importers (< 11 TEUs/wk/region)	Any values	Direct shipping

Figure 11: Proportion of Modal Shipments to Destination Cities, Scenario B

Figure 11 shows the modal shipments by destination for this scenario. A consolidation of shippers, or an increased market share for third party logistics providers, significantly increases the percentage of goods being transloaded, and therefore the amount of cargo being handled at the regional facilities.

Also, consolidation of small shippers may save logistics cost at the aggregate level at every region. The table below represents the excerpt of total logistics cost per region. From comparing the consolidation result to the existing case, we have a convincing reason to transload large amount of goods and ship them by fewer carriers in order to save logistics cost instead of small shipper handle own goods movement.

Table 7: Total logistics cost per year by region

	ATLANTA	BALTIMORE	BOSTON	CHARLESTON	CHARLOTTE	CHICAGO
Existing	$19,824,720	$11,524,343	$15,642,823	$2,265,383	$14,167,616	$24,924,595
Consolidation of small shippers	$15,347,566	$7,528,338	$13,513,116	$1,688,558	$9,067,346	$21,074,095

Scenario C: Final destination distribution

What happens when there is no goods movement through Seattle area to LA and NY regions? This scenario is created to reflect the reality of not moving goods LA and NY through Seattle. Because there are major ports in LA and NY regions, shipping through more prominent ports such as LA/Long Beach and NY/NJ make cost effective, and actually practiced.

In order to see the effect in the model, LA and NY areas are deliberately left out from the model. The result shows that, relatively, there is a 6.8% increase of direct truck; 0.8% increase of direct rail choices compared with all 21 destinations inclusive case. On the other hand, transload truck decreases 0.5%; transload rail decreases 7.0%. Because of higher purchasing power in LA and NY relative to other regions, eliminating these two destinations make transloading less attractive. In other words, large volume is required to benefit from transloading. For most shippers, the LA and NY regions represent large volumes, and without these volumes, many shippers no longer find transloading a competitive strategy. When compared to the larger port complexes, Seattle and Tacoma will have a smaller percentage of transloaded cargo. Figure 12 shows the modal split for this scenario.

Figure 12: Proportion of Modal Shipments to Destination Cities, Scenario C

The model is run again with only Seattle bound cargo. About 70% of goods to Seattle region is direct truck; the remaining 30% is transload truck mode. This is because of 1) the shorter distance from the port to final destination and 2) the lower volume of goods movement, 1958 TEUs per week, which is only about 4% of purchasing power from Seattle region out of 21 regions in the US. NY and LA region each has three times more purchasing power than Seattle region. Therefore, the scenario analysis shows how important and significant for transloading activity to benefit when volume of goods movement is large, for example to LA and NY.

COST SUMMARY OF SCENARIO ANALYSIS

In this section we consider the cost implications of the scenarios, first on a modal split, and the relative contribution of inventory and transportation cost. Several observations can be made from this analysis. First, the relative dominance of truck cost over rail cost, and transportation cost over inventory cost. When comparing the base case and adjusted base case with the scenarios, we can observe the increased rail cost with Scenario A and reduced rail expenditure in Scenario C, when several large, long distance markets are removed.

Figure 13: Proportion of Cost from Truck and Rail to Destination Cities, Base Case Scenario

Figure 14: Proportion of Cost from Transportation and Inventory to Destination Cities, Base Case Scenario

Figure 15: Proportion of Cost from Truck and Rail to Destination Cities, Adjusted Base Case Scenario

Figure 16: Proportion of Cost from Transportation and Inventory to Destination Cities, Adjusted Base Case Scenario

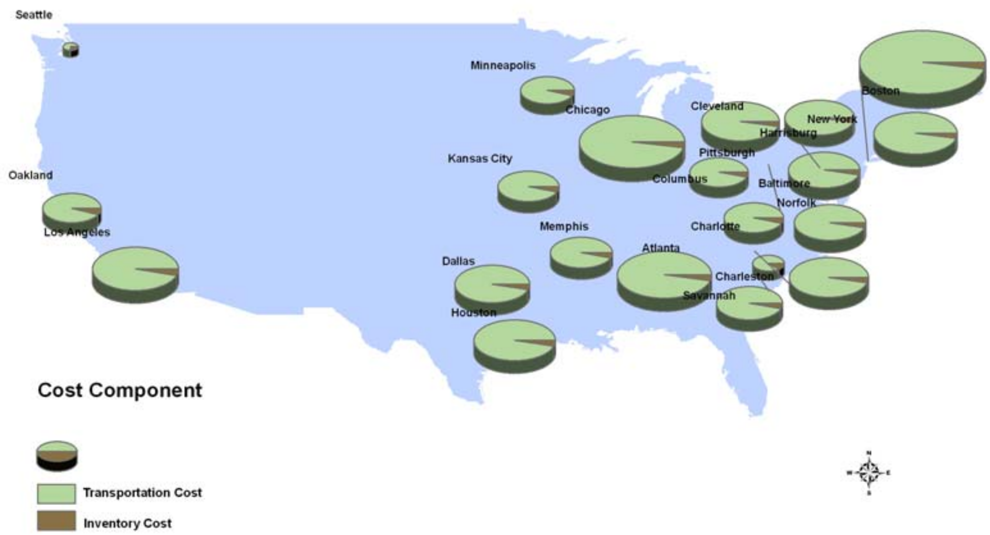


Figure 17: Proportion of Cost from Truck and Rail to Destination Cities, Scenario A

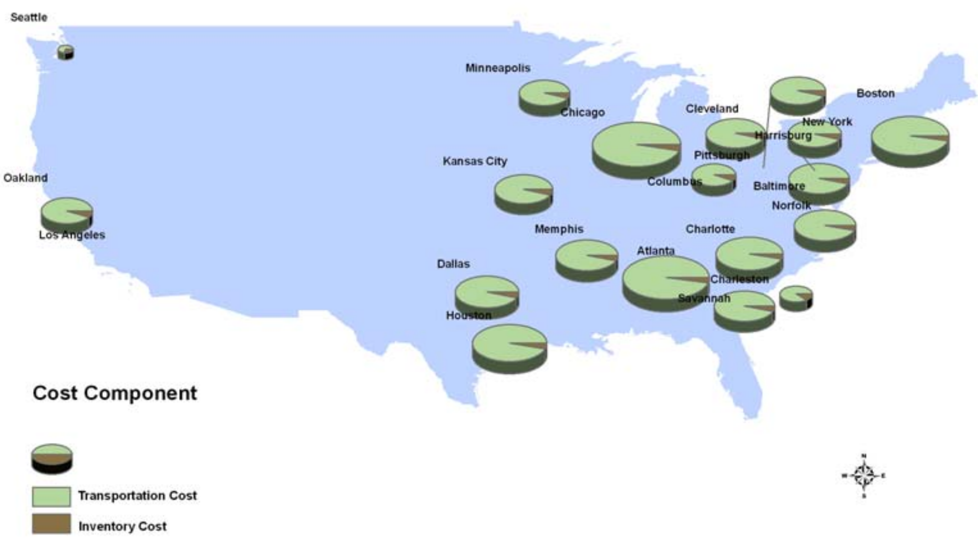
Figure 18: Proportion of Cost from Transportation and Inventory to Destination Cities, Scenario A

Figure 19: Proportion of Cost from Truck and Rail to Destination Cities, Scenario B

Figure 20: Proportion of Cost from Transportation and Inventory to Destination Cities, Scenario B

Figure 21: Proportion of Cost from Truck and Rail to Destination Cities, Scenario C

Figure 22: Proportion of Cost from Transportation and Inventory to Destination Cities, Scenario C



CONCLUSIONS

This research effort has presented a small number of applications of the model to transportation policy questions for the region. Clearly, much more analysis can take place by applying the model both to the case designed for Puget Sound, and, with some modifications, the model can be applied to other locations with different facilities. The primary benefit of the model is a structured way of considering the cost trade-offs shippers face, and understanding the impact of their choices on regional traffic flows.

The model presents a planning tool for considering the impact of system changes on logistics patterns. This is important to our region, which supports the national logistics patterns by providing a port and warehousing facilities. Our scenarios demonstrate the relationship between regional infrastructure and national logistics strategies (scenario A). A truck only lane will not only reduce regional congestion, but will increase the benefit of transloading, and therefore increase demand for the truck only lane. The goods being transloaded are destined for regions outside of Puget Sound. An investment in Puget Sound infrastructure, therefore, increases the national demand for Puget Sound infrastructure.

We also use the model to consider the impact of industry changes (consolidation or the presence of 3PLs) on regional traffic. The model quantifies the net effect of increased transloading activity, and the relationship between industry changes and the regional transportation burden. In the Scenario B, we demonstrated that consolidation saves logistics cost at aggregate level, and increases transloading activity.

The model is a flexible tool, and our final scenario provides an example of how the model can be used to consider regional differences and evaluate the impact of changes in national demand patterns on regional cargo flows.

FUTURE WORK

We have taken a policy level, or strategic view of the relationship between regional infrastructure and national logistics strategies. With this tool, we have already been able to gain insight into the benefits and costs of changes to the region, in terms of changes to logistics patterns. With this model, we plan to carry out additional analyses to exploit the potential of the model for insights into the dynamics of regional trade, including sensitivities to model parameters, and capacity constraints on elements of the network

An obvious extension of the model is to consider additional temporal and spatial detail, for example time of day effects on travel time and route choice.

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