Improving Statewide Freight Routing Capabilities for Sub-National Commodity Flows

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IMPROVING STATEWIDE FREIGHT ROUTING CAPABILITIES FOR SUB-NATIONAL COMMODITY FLOWS

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16. ABSTRACT

The ability to fully understand and accurately characterize freight vehicle route choices is important in helping to inform regional and state decisions. This project recommends improvements to WSDOT's Statewide Freight GIS Network Model to more accurately characterize freight vehicle route choice. This capability, when combined with regional and sub-national commodity flow data, will be a key attribute of an effective statewide freight modeling system. To come to these recommendations, the report describes project activities undertaken, and their outcomes, including 1) a review of commercially available routing software, 2) an evaluation of the use of statewide GPS data as an input for routing analysis, and 3) the design, implementation, and evaluation of a survey of shippers, carriers, and freight forwarders within the state. The software review found that routing software assumes least cost paths while meeting user specified constraints, and it identified criteria for evaluation in the subsequent survey. The GPS data evaluation showed that significant temporal shifting occurs rather than spatial route shifting, and it revealed significant limitations in the use of GPS data for evaluating routing choices, largely because of the read rate. Among the survey results was that the first priority of shippers, carriers, and freight forwarders is to not only meet customer requirements, but to do so in the most cost-efficient way. From a latent class analysis of routing priorities, we discovered that distance-based classification best clusters similar routing behavior. The report includes recommendations for implementing this within the Statewide Freight GIS Network Model.

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CONTENTS

EXECUTIVE SUMMARY .... **xi**
Freight Routing Software xi
Evaluation of GPS Route Data xi
Routing Priorities xii
Recommendations xiii

1. OVERVIEW **1**

2. FREIGHT ROUTING SOFTWARE REVIEW **2**
Introduction 2
Software Name: PC*Miler (ALK Technologies) 3
Cost Alternatives 3
Industry Use 3
Primary Features 3
Unique Attributes 4
Limitations 4
PC*Miler Usability 5
Software Name: Rand-McNally (Milemaker/Intelliroute) 8
Cost Alternatives 8
Industry Use 9
Primary Features 9
Unique Attributes 9
Limitations 10
Intelliroute Usability 10
Software Name: Prophesy Transportation Software Inc. 13
Cost Alternatives 13
Industry Use 13
Primary Features 14
Unique Attributes 14
Limitations 14
Software Name: ProMiles 15
Cost Alternatives 15
Industry Use 15
Primary Features 15
Unique Attributes 16
Limitations 16
Software Name: Cheetah 16
Cost Alternatives 16
Industry Use 16
Primary Features 17
Unique Attributes 17
Limitations 17
Software Name: TSI Automation 17

Cost Alternatives 17
Industry Use 18
Primary Features 18
Unique Attributes 18
Limitations 18
Software Name: Appian Logistics (Formerly Microanalytics) 19
Cost Alternatives 19
Industry Use 19
Primary Features 19
Unique Attributes 20
Limitations 20
Software Name: Truck Dispatching Innovations (TDI) 20
Cost Alternatives 20
Industry Use 20
Primary Features 21
Unique Attributes 21
Limitations 21
Summary of Routing Software Review 21

3. EVALUATION OF USE OF GPS ROUTE DATA FOR EVALUATING ROUTE CHOICE 24
Introduction 24
The GPS Data 24
Case Studies 25
Case Study I: TAZ 385—TAZ 545 26
Southbound Analysis 28
Northbound Analysis 31
Case Study II: TAZ 180—TAZ 609 33
Eastbound Analysis 35
Westbound Analysis 36
Sample Size 37
Feasibility of Using GPS Truck Data to Identify Truck Routes 38
Conclusions 40

4. ROUTING PRIORITIES 42
Motivation 42
Literature Review 43
Study Methodology 45
Collection of Data via Survey 45
The Survey 47
Survey Descriptive Statistics 48
Industry Breakdown 48
Company Activity and Outside Carriers 49
Services Provided Breakdown 50
Number of Vehicles 51
Truck Type Breakdown 51

Frequency of Changes in Routing Shipments.. 52
Commodities.. 53
Number of Weekly Trips versus Numbers of Employees and Vehicles . 53
Quality of Factor Scores 54
Importance of Routing Factors 55
Use of R 57
Results 57
Item Response Theory 58
Item Information 60
Correlating Individual Factors Scores with Transportation Features 61
Road Grade 62
Refueling.. 63
Parking 64
Hours of Service Limits 64
Size and Weight Limits.. 65
Conclusions.. 66
Routing Categories.. 66
Conclusion 70

5. RECOMMENDATIONS FOR MODIFICATIONS TO THE STATEWIDE GIS NETWORK MODEL 72

6. CONCLUSIONS 75

7. REFERENCES.. 77

FIGURES

3.1 Monthly GPS Data and TAZ Layer 25
3.2 Case Study I. Truck Trips between TAZ 385 and TAZ 545 26
3.3 Southbound Travel Time Distributions along I-5 and I-405 28
3.4 Southbound Travel Speed Distributions along I-5 and I-405 29
3.5 Southbound Truck Proportions and Travel Time Using I-5 and I-405 by Time of Day 30
3.6 Northbound Travel Time Distributions along I-5 and I-405 31
3.7 Northbound Travel Speed Distributions along I-5 and I-405 32
3.8 Northbound Truck Proportions and Travel Time Using I-5 and I-405 by Time of Day 33
3.9 Case Study II—Truck Trips between TAZ 180 and TAZ 609 34
3.10 Eastbound Truck Proportions and Travel Time Using I-90 and SR 520 by Time of Day 36
3.11 Truck Proportions and Travel Time Using I-90 and SR 520 by Time of Day 37
3.12 Relationship between Truck Route Length and Distance between Two Successive GPS Reads 39

4.1 Industry Breakdown 49
4.2 Company Activity and Outside Carriers 49
4.3 Service Types Provided 50
4.4 Number of Vehicles per Company for Carriers 51
4.5 Vehicle Types in Carrier Fleets 52
4.6 Correlation between Number of Employees and Number of Trips 53
4.7 Correlation between Number of Vehicles and Number of Trips 54
4.8 Frequency of Total Sum of 15 Factors Influencing Routing Decisions 55
4.9 Item Operation Characteristic Curves (IOCC). 59
4.10 Item Information Curves 61
4.11 Latent Classes with Long-Haul Covariate 67
4.12 Long-Haul as a Predictor of Latent Class 68
4.13 Parameter Coefficients 69

TABLES

2.1 Summary of Reviewed Software Routing Attributes 22

3.1 Attributes of Trips between Zone 385 and Zone 545 27
3.2 Truck Performance along I-5 and I-405... 27
3.3 Southbound Travel Time Distributions along I-5 and I-405 28
3.4 Time of Day Breakdown.. 29
3.5 Northbound Truck Performance along I-5 and I-405 31
3.6 Attributes of Trips between TAZ 180 and TAZ 609 34
3.7 Truck Performance along I-90 and SR 520 35
3.8 Eastbound Truck Performance along I-90 and SR 520 35
3.9 Westbound Truck Performance along I-90 and SR 520 37

4.1 Percentage of Companies that Scored Item with a 4 56
4.2 Overall Averages 56

5.1 Distribution of Truck Sizes... 74

EXECUTIVE SUMMARY

Existing transportation network models assume that vehicles select the least costly path between origin and destination. This cost can entail time, distance, money, or a combination of these factors. This project used three approaches to investigate the reasonableness of this assumption and produced recommendations for revising the least cost routing approach for the state's geographical information systems (GIS) network model.

Through this work, we also described the state of the art in freight routing software, the utility of the Washington State Department of Transportation's (WSDOT) Global Positioning System (GPS) data for understanding routing patterns, and the routing priorities of shippers, carriers, and freight forwarders. These interim results are fully described in this report and are summarized below.

FREIGHT ROUTING SOFTWARE

One task of this project was to conduct a review of commercially available routing and mapping software. These software programs are designed to optimize the routes of individual trucks or fleets, not to assign all trucks to routes (as a statewide freight model would do). However, their logic reveals the factors of importance to carriers when they make routing decisions. We identified routing factors and algorithms of PC*Miler, Rand-McNally, ProMiles, Prophesy, and ArcLogistics, which were found to include considerations for truck height and weight, infrastructure height and weight restrictions, toll expenses, and fuel purchasing cost. While we had assumed that some hierarchy of priorities would be built into the software, we found that this was not the case. Instead, in each case, the prioritization is left to the user. Every product examined uses a shortest path assignment, once other constraints have been met (e.g., size and weight restrictions); however, toll and fuel acquisition costs can be added to the route cost.

EVALUATION OF GPS ROUTE DATA

To assess the utility of using GPS truck data to improve the link-cost functions that are part of the WSDOT statewide freight model, truck travel patterns were examined. Specifically, two case studies examined route choice by time of day, system performance, and origin-destination. The case studies were selected in areas that experience congestion, with the assumption that congestion may cause route shifting behavior. We discovered that instead of route shifting, trucks in the Puget Sound exhibited strong time of day shifting behavior.

We found that because of the 15-minute intervals between reads, route diversions that occur within 20 miles of the previous route decision (the maximum assumed travel distance in 15 minutes) cannot be identified. This means that many route choice decisions within the Puget Sound, that is those where route choice decisions are possible at each block or freeway exit, remain undetected. We concluded that although GPS data are able to provide reliable transportation performance information, they are not currently sufficient for analyzing or estimating truck route choices.

ROUTING PRIORITIES

To identify routing priorities, a survey was conducted of approximately 800 shippers, receivers, and carriers of freight in Washington State. The survey was designed to find the strategies that companies use when determining routes. More specifically, its goal was to confirm or refute the least cost assumption used in existing network models. We found that overwhelmingly, respondents were meeting customer requirements, while minimizing, time, cost, or route distance. Respondents to the survey were also asked to rank the level of influence of 15 factors that influence routing decisions. After the survey had been completed, analysis of the responses included ordinal logistic regression and latent class analysis. These tools allowed us to identify the correlations between routing behavior and other characteristics of a company, such as number of trucks or primary commodity, and to group the respondents with others who had the same routing behaviors.

The analysis found five factors that differentiated among respondents and allowed us to group them into routing categories: 1) hours of service limits, 2) availability of truck parking, 3) driver availability, 4) refueling locations, and 5) road grade. Long-haul trucking, city-delivery trucking, regional trucking, the equipment companies own, and whether or not a company backhauls freight were found to be important predictors of how companies ranked the 15 routing factors and, thus, their routing category. From these results, the respondents were classified into three groups titled urban trucking, local-regional trucking, and regional long-haul trucking. These categories should be used when trips are assigned to routes on the network

RECOMMENDATIONS

The state of Washington possesses a statewide GIS network model. Currently, if the trip origin and destination are known, the model will assign the trip to the roads that provide the shortest route between the origin and destination. Through the survey conducted for this project, we confirmed that the shortest path is overwhelmingly the appropriate logic to use once the origin, destination, and road network are known. However, the following general improvements should be made to this model logic:

Network

a. Apply a truck usable network (based on the Household Goods Mileage Guide), not the entire road network, to account for road classification.
b. When commodity data are available, hazardous material trips should be identified and relevant infrastructure restrictions captured in the network.
c. Include seasonal road closures.
d. Update speeds to reflect true travel speed obtained from the truck performance measures project, rather than the speed limit.

Objective Function

Least distance or least time should be converted to dollars so that tolls can be added to the cost of travel along a link. This will also allow emissions cost to be added to a link with an assumed emissions value.

Spatial Variation

Three categories of carriers should be reflected in the routing logic: urban trucking, local-regional trucking, and regional long-haul trucking. For carriers in these groups, the following changes should be incorporated:

a. For trips within urban regions, use the distribution of truck sizes present for those that deliver in cities and assume no backhaul.
b. For origin-destination pairs of over 300 miles, use a network that is navigable by large and heavy trucks.

c. Require origin-destination pairs that exceed 500 miles to choose routes that include a truck parking location every 500 miles (this will require documentation of truck parking locations).

1. OVERVIEW

This report describes the work of three distinct research streams that culminates into a broad understanding of routing decision-making among freight carriers, shippers, and freight forwarders in Washington state, and on the basis of this understanding, recommendations for how to develop the Statewide Freight Geographic Information Systems (GIS) Network Model[1] to better represent routing behavior within this community. When sub-national commodity flow data are available, the state freight model will be able to assign strategic routing choices in a way that better reflects industry practice.

The first part of this report provides a thorough review of commercial routing software, identifying its primary characteristics, market penetration, and price. This is followed by a chapter that describes the utility of using statewide Global Positioning System (GPS) data for routing analysis, given the temporal quality of the current data. This is demonstrated through the use of two case studies. Finally, the development, implementation, and analysis of a survey are described. The survey allowed for a detailed examination of routing decisions with timely data. By synthesizing the lessons learned from each of these tasks, the report concludes with recommendations regarding strategic routing decision making and how the Statewide Freight GIS Network Model can be modified to better capture truck routing within the state.

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[1] The Statewide Freight GIS Network Model was developed by UW and WSU researchers in 2009. It is housed at the University of Washington. The model currently lacks statewide commodity flow data, but has been used to evaluate specific supply chains, including potatoes and diesel distribution.

2. FREIGHT ROUTING SOFTWARE REVIEW

INTRODUCTION

Freight routing needs and input variables have a special set of requirements that the typical dashboard navigation systems, based heavily on and designed for passenger vehicle travel, may not be fully equipped to handle. To meet the unique routing needs of freight service providers, several software and mapping companies have developed specialized, commercially available routing software. Much of the freight routing industry is founded on a handful of products, with many third-party companies then using those as the basis for their add-on (complete freight management) systems. Generally, PC*Miler, Rand-McNally, ProMiles, Prophesy, and to a lesser degree ArcLogistics form the base of freight routing. The common deviation from the typical dashboard navigation system found within all versions of the freight routing software is to allow the freight companies to dictate the special routing requirements of their trucks. Special routing inputs most often take the form of height, weight, and load-type restrictions that may require trucks to avoid particular segments of a route. Additionally, many of these products take into account toll expenses and fuel purchasing optimization needs that can greatly affect the travel costs of each load.

The following review highlights the applications and routing decision inputs for each of the four major software products identified above, followed by a brief outline of the third-party systems partnering with these companies and the additional services that they provide. Many full service freight management companies utilize the mapping and routing software of these companies to accommodate the complete needs of shippers and carriers. These third-party add-on companies integrate the routing outputs to develop comprehensive rate quoting systems, as well as accounting, tax, and payroll management functions.

Note that each of these companies offers multiple programs that encompass all aspects of the freighting industry, such as billing and maintenance; however, this review focused mainly on routing and fueling decision inputs. The content of this review was based on readily available information from the websites and user guides of the software producers, with the exception PC*Miler and Rand-McNally MileMaker®/IntelliRoute®.

Given that these two represent the majority of industry usage, the trial version of each was obtained and tested, and extended reviews are provided.

SOFTWARE NAME: PC*MILER® (ALK TECHNOLOGIES)

Cost Alternatives

PC*Miler®

Single User (Windows):		$1,895.00
Data Modules (single users)		
PC*Miler	Tolls®	$FREE.
PC*Miler	Streets- US®	$1,100.00
PC*Miler	Streets- Canada®	$595.00
PC*Miler	HazMat®	$1,100.00
Interface Modules(Requires 5-User License)		
PC*Miler	Rail–Connect®	$3,500.00
PC*Miler	Connect®	$2,995.00

**This is only a partial product list. See PC*Miler® Product line price list for more details

Industry Use

PC*Miler® claims to be the leader in routing, mileage, and mapping software, with 96 percent of the top motor carriers, the Department of Defense (DoD), the General Services Administration (GSA), and the Federal Motor Carrier Safety Administration (FMCSA) on its client list. PC*Miler® generates truck-specific directions and mileage summaries at the turn-by-turn street level. Additionally, it has an intermodal analysis function that calculates alternative rail intermodal routes between origin and destination. This allows for comparisons in fuel consumption and carbon emission between modes.

Primary Features

The streets application in PC*Miler® provides dock-to-dock driving directions for truck-specific routes based on U.S. Census TIGER files. Route designation inputs account for truck characteristics of height, weight, and length to ensure adherence to bridge height, load limit, and other truck restrictions. For example, PC*Miler® has an “override restrictions” tab that allows the user either to abide by the “truck prohibited” and “truck restricted” designations of a given road or override them, if the user has a light vehicle, in which case the generated route will include “truck restricted” road, but still avoid “truck-prohibited” designations. Routes are generated with either practical or shortest route parameters, in addition to toll discouraging and HazMat routing. Additional route designation choices include the avoidance of dangerous turns, as well as urban road classifications.

Similar to other programs, PC*Miler® offers the ability to incorporate company fuel networks into the routing decisions and the turn-by-turn directions. This application calculates and suggests not only where to purchase fuel, but also how much to purchase at a given location, given truck-specific inputs and the fuel choices further along the current route.

It also allows the user to reconcile the cost savings or losses incurred by using a toll road or taking a longer, non-toll route for all truck specific routes. Similar to the fuel optimization, this software accounts for user negotiations with various toll authorities.

Unique Attributes

Unique features that PC*Miler® allows include route customization along favored roads or road segments and through specific jurisdictions. The HazMat application allows the user to generate a route on the basis of one of six different HazMat types (caustic, explosives, flammable, general, inhalants, and radioactive). These HazMat-specific directions ensure compliance with department of transportation (DOT) and other HazMat regulations and increase the reliability of correctly estimating operating costs and driver pay. PC*Miler® is the also only software reviewed that promotes its ability to highlight inter-modal connectivity and provide truck versus rail comparisons, including carbon emission calculations.

Limitations

The primary limitation, similar to several of the other routing software programs, is that PC*Miler® does not allow or utilize less-than-truckload (LTL) inputs into its route calculations. Therefore, for industries or businesses that move and ship primarily LTL type freight, this software will not be best suited for these purposes.

PC*Miler Usability

Below is a sample of the options tested within PC*Miler trial version, with detailed summary descriptions from the users' manual.

Generating Routes and Mileage

The PC*Miler mapping representations are created through ALK Technologies' proprietary North American Highway System representations. The highway systems are derived from official state highway, state DOT, county, and local maps, as well as information from industry users. Rendered distance calculations are a reflection of straightforward summations of the road segments travelled on the identified routes. Where specific addresses are used for origin and destination, the exact mileage and direction are provided. If no exact addresses are given, then the nearest Key City is used to provide distance and route as accurately as feasible.

Basic Route Definition

PC*Miler provides a basic point and click user interface that allows users to specify the origin, intermediate stops, and destination locations. Once routes have been created, they are displayed both in tabular and map formats. The tabs display generated results for miles, cost per mile (set by default or adjusted by user inputs), and hours of the route, both in total and for each leg of the trip. By default this occurs for the practical miles route. Users can quickly copy and convert that to a user selected shortest route option. By default, the software generates the route in the stop order entered by the user; however, the stops may be easily re-sequenced to optimize stop order efficiency. The re-sequencing can be done for the entire sequence, but it leaves the first and last stops as the directed starting and stopping endpoints.

Users can easily manipulate the scale and appearance of the map displays with point and click operations, as well as adjust components such as legends and scale bars with drag and drop operations. Automatic label and icon displays are set to varying degrees of scale. For example, when a map is zoomed to a detail level of eight out of twelve, points of interest such as fueling stations are displayed. Users can enter stop locations through an address window, designate longitude/latitude points, and also select them from the map with a point and click operation. Maps additionally display truck stop locations, which can be added as stop/rest times. Routes can be easily manipulated within the map view. The user can manually select roads or road segments to favor or avoid, or to override default restrictions.

Practical Routes

Practical routes represent the distances and driving routes that a driver would typically take to minimize time and cost. Practical routes are created with consideration of the tradeoffs between the most direct paths and the advantages of staying on major highways. Hierarchically, practical routing assigns priority starting with Interstate highways, followed by toll roads, then secondary highways. Routing decisions made within practical routes additionally consider truck-restricted roads, urban/rural designations, and designated principal and secondary through-routes. When route re-sequencing is done under a practical routing setup, the re-sequencing minimizes total time.

Shortest Routes

Shortest route calculations exclude all the considerations of practical routes in favor of a simple fewest-miles-travelled requirement, while still observing truck restrictions. When route re-sequencing is done under a shortest routing setup, the re-sequencing minimizes total distance.

National Network Routes

Using the routes designated by the Surface Transportation Assistance Act of 1982 (STAA), PC*Miller also offers a routing option that determines routes and distances in accordance with those routes most reasonable and legal for the larger trucks authorized under STAA. When the user selects this routing option, the software creates a route that stays on the national network to the maximum extent feasible. Where deviation must occur, the software selects the shortest available routes that still meet other restrictions the user has already identified. When route re-sequencing is done under a national network routing setup, the re-sequencing minimizes total distance.

PC*Miler also offers an additional component to the National Network routing option in the form of 53-ft/102-in. routing for these dimensioned trailers and their additional restrictions. Similar to the basic National Network routing, the software attempts to keep the route on network highways where feasible and provides a warning indicator when deviance is required.

Toll Avoidance

With the PC*Miler tolls add-on module, the user can compare costs between taking a toll road and using a route that avoids the tolls, thus enabling a more cost-effective decision. The toll cost calculations are available for both the U.S. and Canada and are updated quarterly. The toll route add-on is directional-specific and allows for user entry of discounted toll programs. PC*Miler identifies two potential sources of inaccuracy in its toll calculations. These may arise from weight-specific tolls if the user has not entered vehicle dimensions. In addition, some tolls vary by time of day; in this instance, the software calculates the toll based on the highest rate.

The first potential inaccuracy is easily remedied by ensuring that the user has identified truck dimensions (axles, height, and weight).

Manipulating the toll options is a rather simple task in the route option windows. The software produces toll estimates for each leg of the selected routes (any of the above routing options can be used in addition to the toll avoidance/calculation), and cumulative toll costs are observable in the state summary page. Additionally, toll comparisons can be made between default settings and specified toll avoidance. This action yields a comparison of miles, cost, time, and toll cost; even when the program is told to avoid tolls, some residual tolls may be used to preclude excessive avoidance. When route re-sequencing is done under a toll avoidance routing setup, the re-sequencing minimizes total toll distance

Route Creation Highlights

One of the more valuable capabilities of the software is the ability to quickly generate duplicate routes so that users can quickly compare different routing alternatives, such as different route types or the addition of one more stop. Additionally, users can adjust driver needs, such as on-duty and off-duty costs, and can select to include these in the total costs estimates, as well as any potential empty miles that must be considered.

Many users will likely already have significant volumes of customer addresses loaded in some type of database. PC*Miler (with the Streets module) allows importation of from .xls or .txt files through a geocoding process. In testing the program's ability to successfully geocode addresses from files, we attempted to input several on-hand databases with a reasonably high success rates. If longitude/latitude values are available, this will greatly increase matching. These locations can then be added to the user's Custom Places records for future use.

The fuel optimization add-on is another valuable asset of this program. It allows users to calculate fuel optimization for each truck in their fleet by inputting specific fuel capacities and gallons per minute. When this add-on is then applied to a specific truck, the software automatically adds in optimal fuel stops along the designated route. In addition, the program suggests how much fuel to purchase and the estimated cost of that purchase; fuel cost data are updated daily in conjunction with www.fueladvice.com.

PC*Miler offers an intermodal analysis add-on tool along with its rail-connect add-on. This tool computes the origin-destination costs of using rail rather than trucks. Comparisons are made for fuel consumption, mileage, and carbon emissions. This software was found to be quite user friendly, allowing for a quick grasp of its general organizational flow. The attributes to be minimized under each routing scheme are clear, make logical sense, and are flexible enough to allow users to address specific demands and truck/load types. Additionally, the software's provisions for user customized routes allow routes to be created with learned characteristics of roads that may not be accounted for in the database. This attribute is likely valuable where local drivers or dispatchers know key roads or particular times of the day or year to avoid, and dispatchers can also adjust for updated information on road closures. This is not done automatically in the software, but it is easily adjusted with a knowledgeable dispatcher.

SOFTWARE NAME: RAND-MCNALLY (MILEMAKER®/INTELLIROUTE®)

Cost Alternatives

IntelliRoute®
1-user standalone:
1st year initial license fee: $1995
Annual license renewal fee (every year thereafter): $599
5-user LAN
1st year initial license fee: $3495
Annual license renewal fee: $1049

Industry Use

MileMaker® by Rand-McNally is routing and mileage software that features both household goods (HHG) and practical routing solutions. Rand-McNally claims over 91 percent of the Fortune 500 shippers and 94 percent of the leading freight carriers as clients.

Primary Features

MileMaker® provides truck- and trailer-specific routing options that optimize multiple stop routes in accordance with user selected preferences and avoidance inputs. Data are updated to customers quarterly and with the IntelliRoute® software; users are updated on construction activity every two weeks. In addition to creating industry standard (HHG) and practical routing options for the shortest or fastest routes, MileMaker® also produces state/province mileage summaries and produces hub routing calculations to analyze shipping lanes from one point to many destinations.

The software also enables users to avoid out-of-route miles by accurately accounting for truck specifications and HazMat restrictions. It promotes the avoidance of tickets and accidents by ensuring road and bridge accommodation and claims to be four times more accurate than PC*Miler.

Like the other leading software, Rand-McNally also optimizes routes on the basis of daily fuel prices and produces a fuel itinerary that details where trucks should stop along the route and how much fuel they should get. Additionally, the software produces state mileage tax breakdowns.

Unique Attributes

A lane rate add-on allows accurate analysis of market rates, so users can competitively quote rates. The add-on works with a compilation of data from carriers in the major market cities in the U.S. and Canada and estimates rates on the basis of current freight bills. Reports are available for vans, refrigerated carriers, and flatbed carriers and include minimum and maximum rates per mile as well as fuel surcharges per mile.

Limitations

This software does not have the intermodal capabilities that are available in PC*Miler. Additionally, its toll management is somewhat cumbersome and not clear. (See the detailed product test for more information.)

Intelliroute Usability

In a fashion similar to PC*Miler, a sample of Rand McNally's IntelliRoute software was reviewed. The details below highlight the findings from that review along with notable components from the User's Manual, as the trial software was limited to 50 transactions and therefore only a fraction of the product could be tested. For the route generation actually tested, IntelliRoute produced results similar to those of the PC*Miler software.

Generating Routes and Mileage

IntelliRoute frames its route and mileage generation as inquiries. Inquiries are in the form of mileage inquiries, route inquiries, and a batch processing routine. Mileage inquiries have several basic forms, and when they are performed in the route inquiry application, they also produce detailed routing information on a state by state basis.

HHG Mileage/Route

Mileage determined on the basis of the shortest distance between locations on truck-usable roads is based on Release 19 of the Household Goods Mileage Guide (HHG) and HHG tariffs rules; rules include highways, bridges, and ferries designated as "truck-authorized." These miles are used in standard freight weighting and auditing.

Practical Mileage/Route

This software uses the same road network as that of the HHG option; however, it does not account for HHG tariff rules.

Quickest Mileage/Route

This function makes use of IntelliRoute's GPS-accurate road network and calculates the truck-usable mileage on the basis of shortest time between locations.

Lowest-Cost Route

This function uses the same GPS-accurate road network as above, but in this scenario it calculates the route on the basis of lowest-cost between locations. Lowest cost is based on a combination of time, fuel cost per mile/kilometer, fuel cost per gallon, tolls, and maintenance costs. These have default settings that can be adjusted for specific trucks.

Route Creation Highlights

The input of locations for route generation in IntelliRoute is at least as user friendly as that of PC*Miler and offers a range of suitable entry styles. Once all locations have been entered, the user can manually order the origin, stops, and final destination. Alternatively, users can optimize the location list entirely or designate only a specified destination point. The variable that is optimized depends on the type of routing option selected.

Once a route has been created using one of the above types, the program creates an itinerary. The itinerary has a user friendly, color coded breakdown of points. For example, orange text in the itinerary denotes roadwork information. This ability is enabled when the user has access to online RoadWork™ updates. Users can have several options in dealing with roadwork delays. Either they can apply roadwork to all quickest and lowest-cost routes, or they can choose to route around construction and delays. Additional color coding highlights include truck-type violations along an itinerary. These violations for 53-ft/102-in double- and triple-trailer options are highlighted in red, both in tabular format and in the map, giving clear indication of potential conflicts along the selected route. These conflicts appear as a result of using the IntelliRoute Streets feature, which gives street-level directions but without truck-type attributes.

In addition to the basic routes described above, the interface allows point and click selection of truck and trailer types. These types include trailer length (<48 ft or 53 ft), truck width (<96 in or 102 in), and number of trailers (single, double, or triple). The basic route types are then applied to truck-specific guidelines. Additional constraints can be easily selected to account for hazardous materials. Federal regulations regarding hazardous material transport are coded into road attributes so that allowable roads can be hierarchically utilized. IntelliRoute thus recalculates the routes using the basic route types along with the added HazMat restrictions.

IntelliRoute's accounting for toll roads is somewhat unclear. The software allows users to select a "toll road bias" level. This level varies from 0 (toll roads used) to 100 (toll roads not used). The clarity issue is no information is available to explain how the varying levels of bias influence the decision to use or not use a given stretch of toll road. The end points (0, 100) are clear, but the difference between a "40" and "60" are not. There is no information on how many added miles and hours of driving are acceptable at a given bias level.

Driver breaks and stops are potentially significant components in determining travel time and costs, and these are easily added into the estimated arrival time calculations. These can be broken down by break type (food or fuel), with predetermined frequency and duration. Fuel breaks can be either manually input or optimized through the "fuel network" options. Users can input the locations of the participants in their fuel networks. These can subsequently be included as locations for determining appropriate routes. Alternatively, users can search along the routes for truck stops with the desired amenities. Amenities include parking, pumps, service, repair, electrical, wash, driver services, and food. Similar to PC*Miler, IntelliRoute is compatible with www.fueladvice.com to allow for optimizing fuel purchases.

Once routes have been created, the user can manipulate the results from the generated maps page. These manipulation options include designating segments as preferred or to be avoided in order to optimize local knowledge of road issues and company preferences. With the Street-Level add-on component, users can input specific addresses for origin and destination points and receive turn by turn directions at these locations. The program generates street maps for both endpoints.

This software has a slightly more user friendly interface than PC*Miler; however, PC*Miler's truck, trailer, and route specifications are much clearer. In particular, Intelliroute's toll adjustments are cumbersome, and despite the program's ability to highlight conflicting street segments, it is unclear how the user can remedy a potential conflict or the degree to which the program offers suggestions to avoid one. Both programs make use of a connection to www.fueladvice.com and are thus comparable on fuel optimization. To IntelliRoute's credit, there Roadwork add-on and the output it generates to alert users of roadwork delays appears to be quite helpful.

SOFTWARE NAME: PROPHESY® TRANSPORTATION SOFTWARE INC.

Cost Alternatives[2]

Commercial Mileage and Routing with Map	
Multi-User:	$495.00
Single-User:	$395.00
Fuel Tax Reporting Software – Tax Tally	
Multi-User:	$495.00
Single-User:	$395.00
Driver Log Auditing Software - LogPlus	
Multi-User:	$495.00
Single-User:	$395.00
Freight Billing – FreightBill Express	
1 Truck:	$995.00
2-5 Trucks:	$1,195.00
6-10 Trucks:	$1,395.00
Driver Management Software – DriverTrax	
Multi-User:	$495.00
Single-User:	$395.00
Total Compliance Suite – ProphesyONE	
Multi-User:	$1,095.00
Single-User:	$895.00

Industry Use

Prophesy® touts itself as the industry's leading trucking software solution for truckload carriers, LTL carriers, brokers, and private fleets (over 12,000 company clients). It offers planning and compliance software that includes freight billing, mileage and routing, fuel tax reporting, driver log auditing, fleet maintenance, driver management, fuel purchase optimization, and online mileage.

[2] All cost information is as of June 2010.

Primary Features

Routing software enables the creation of Class 8 driving directions with multiple stops and calculates industry standard and practical miles of the routes. Route generation considers height restrictions, low weight bridges and overpasses, seasonal road closures, and avoidance of toll roads. Prophesy EasyStreet® provides real-time, dock-to-dock directions for commercial vehicles, with additional consideration for one-way streets, right hand turn restrictions, and dangerous intersections. It favors low-traffic lanes, larger roads, and left hand turns and is continually updated to account for temporary road-closures due to weather, construction or traffic accidents. FuelLogic® utilizes current fuel price information, along with the incorporation of fuel cards and fuel networks negotiated by the company, to identify the most efficient fueling locations along the route. FuelLogic® possesses current fuel price information on every truck stop in North America.

Unique Attributes

Prophesy® allows the instant matching of available drivers and provides options to maximize back-haul opportunities. It is one of the few programs that is readily available for both Truckload and LTL carriers.

Limitations

Prophesy® does not have the capability to incorporate hazardous material considerations. It indirectly accounts for truck height by allowing the user to select the minimum height needed for overpasses, although other truck characteristics are not accounted for. Prophesy’s® accounting for tolls is not very clear. The program allows users to scale their aversion to using tolls, but it does not appear to be a systematic means by which users can compare the costs of using a toll road versus taking an alternative route.

SOFTWARE NAME: PROMILES

Cost Alternatives

ProMiles Mileage and Routing Guide

Single User License:	$895.00
Add-Ons	
Fuel Management (Pro):	$395.00
Fuel Management (Lite):	$50.00
Fuel Tax (Single Fleet):	$95.00
Updates:	$60.00/qtr
HazMat Routing:	Starts at $395.00

TruckMiles

Single User License:	$249.00
RapidLog Interface:	$295.00
GPS Interface:	$99.00

Industry Use

ProMiles Software Development Corporation (PSDC) has won a wide following of dedicated clients, such as O.O.I.D.A., Fleet One, Hewlett Packard, Petro Chemical, Oregon DOT, Unocal, New World Van Lines, Barnes Trucking, Inc. and over 150 state/ DOT auditors. Washington, along with 30 other states, is listed as a state that has ProMiles software solutions for IFTA/Mile Tax and IRP auditing and/or for port of entry/DOT purposes.

Primary Features

Promiles offers a multitude of program options to cover an array of freight routing needs. The TruckMiles program provides turn by turn routing at the street level with 53-ft trailer options that allow users to select routes with up to five stops. These routes may be based on practical truck routing, shortest truck routing, and reduction in toll road usage. Additionally, TruckMiles computes rates by empty or loaded miles, produces a profit rate, and tracks driver expenses.

Additional functionality is available with the Kingpin software, which, in conjunction with the TruckMiles program function, allows more detailed assignment of vehicle types (12 options) and an increased number of stops along the route. Vehicle type options vary from two-axle delivery trucks to seven-axle, double-trailer configurations so that vehicle-specific routing can be generated. ProMiles has data on specific vehicle regulations and restrictions from federal, state, and local jurisdictions. In addition to truck type, the user also inputs trailer length, kingpin settings, trailer axle specifications, height, width, and whether the cargo is hazardous material.

ProMiles fuel management software allows the visualization of fuel prices, from the Oil Price Information Service (OPIS), across the region and along the selected routes. Like Prophesy, ProMiles accounts for the input of company negotiated fuel prices at specific truck stops. The management software allows for filtering by chain, route, lane, and state.

Unique Attributes

The ProMiles Kingpin software appears to have the greatest degree of flexibility in selecting truck-specific options such as number of axles and trailer configurations.

Limitations

A review of the ProMiles website did not suggest that the services offer real-time indications of congestion and lane closures. Additionally, there is no ability to compare truck versus rail or other modes of transport.

SOFTWARE NAME: CHEETAH

Cost Alternatives

At the time of this review, we were unable to get a price estimate on the Cheetah Delivery and Freight software packages. The pricing scheme is highly variable, depending on customer-specific needs and the various add-ons required.

Industry Use

Cheetah software provides delivery dispatch services and drivers with real-time options to increase the efficiency of route planning, drivers, and customer service personnel.

Primary Features

Cheetah provides two product packages: Cheetah Delivery™, and Cheetah Freight™. The Cheetah Delivery system allows dispatchers to see supply chains in real time , including estimated arrival times that are dynamically based on driver activity, cancellations, and reschedules through GPS-enabled tracking. The Cheetah Freight system provides dispatch and routing software designed for business to business freight companies with real-time routing, delivery and dispatch information for LTL dispatchers, drivers, customer service, shippers, and customers.

Unique Attributes

Cheetah's uniqueness lies within its real-time fleet tracking and LTL sequencing. Cheetah operates within a Software-as-a-Service infrastructure; that is, the program is hosted on Cheetah's servers, as opposed to many other programs that are delivered on disk and receive updates at regular intervals.

Limitations

A review of the company's website reveals that Cheetah focuses more on the dispatch of delivery fleets than on freight traffic. As such, it does not highlight users' ability to input truck and trailer specifics such as height and weight or load types such as HazMat. Additionally, Cheetah's site does not address user specifications for fuel management and purchasing, as do other freight systems. These specificities are not highlighted on the Web pages, as the majority of its customers are LTL carriers and do not typically require them. However, the program is flexible enough that the background routing data can be integrated with software such as PC*Miler and provide the same capabilities as that software does.

SOFTWARE NAME: TSI AUTOMATION

Cost Alternatives

Webroute - $55.00 per asset per month.

Industry Use

TSI Automation's Visual Control Room (VCR) program provides software aimed at companies seeking efficiency gains through logistics optimization and management automation for scheduling, routing, and dispatching workers or vehicles to work sites or customer locations.

Primary Features

TSI has two products for different sized companies. The WebRoute product is Web-based routing, scheduling, and dispatch software. This system is designed to handle the scheduling of up to 30 vehicles from a given site and has GPS capabilities to track truck progress. Route optimization is conducted on the basis of an algorithm that seeks to minimize total travel time and distance, while matching appropriate trucks and delivery time windows.

TSI's VCR expands the capabilities of WebRoute and can handle operations for larger companies. VCR matches a company's resources and vehicles to assigned deliveries in order to generate the most appropriate delivery schedule and routing to minimize drive time and distance. Driver characteristics, including breaks and lunches, are configured into the scheduling and routing outputs.

Unique Attributes

The GPS tracking allows for improved customer support by increasing users' ability to know where various shipments are located and receive more accurate times of arrival.

Limitations

The primary limitation is that TSI relies on MapQuest for its routing decisions and therefore does not consider many of the special limitations observed in the freighting industry. TSI is designed more for delivery trucks than for Interstate freight traffic.

SOFTWARE NAME: APPIAN LOGISTICS (FORMERLY MICROANALYTICS)

Cost Alternatives

At the time of this review, a price estimate on the Appian Logistics routing software packages was unavailable. The pricing scheme is highly variable, depending on customer needs and the various add-ons required.

Industry Use

In January of 2010, Appian Logistics Software purchased TruckStops from MicroAnalytics for North American Customers. Appian touts itself as an industry leader in providing solutions for transportation companies and is recognized as one of the top 100 logistics and supply chain software providers. Appian's clientele ranges from third party logistics providers, to the food service industry, to home delivery.

Primary Features

Appian's Direct Route software automates client routing and scheduling by using specified data and business/work rules to establish software parameters from which routes and features may be developed. These business/work rules are primarily client details around which the shipments should be scheduled. These may include items such as, including maximum work time, latest return time, and earliest and latest delivery dates. It combines these rules with truck-specific requirements such as capacity and freight type (e.g., refrigerated) and then matches them with the data provided on origin and destination and the volume of cargo to be shipped.

Through Appian's DRTrack software, users are able to access information regarding planned versus actual hours, miles, and times, along with real-time route progress tracking. Additional attributes of this software include driver performance reports, truck speed mapping, geographic volume reports, and internal route delay alerts. These features are provided in real-time.

In the Territory Pro module, Appian provides a constraint-based creation of geographic territories. Territory Pro enables the adjustment and design of sales, service, and delivery territories on the basis of volume, service time, and/or coverage area, thus balancing the time and volume between territories. The optimization processes seek to minimize mileage while maximizing volume. The software can additionally assign route days within a territory. By combining Territory Pro with Resource Pro, users can further develop efficient territories and routes by determining the optimal number of drivers and power units needed to operate under a given set of constraints.

Finally, Appian offers a Continuous Move Planner package that generates optimal truckload matches for given sets of origin-destination pairs. The software seeks to minimize time and mileage while maximizing capacity utilization. Distance and time calculations are defined by the system's proprietary engine and can utilize PC*Miler or MapPoint.

Unique Attributes

Appian can be integrated with PC*Miler, Prophesy, and other route generation software and thus can be formatted to perform any of the operations that those software programs perform. Table 2.1 is filled in as if the program were integrated with PC*Miler, though actual capabilities are dependent upon user needs and the integration actually selected.

Limitations

Limitations are dependent upon which program Appian is integrated with, though its varied connectivity allows for a broader range of applications than a stand-alone product.

SOFTWARE NAME: TRUCK DISPATCHING INNOVATIONS (TDI)

Cost Alternatives

TDI is a reseller of ArcLogistics. From ESRI website, the cost of this program is as follows:

Up to 5 Vehicles:	$1,000.00/yr
Up to 10 Vehicles:	$2,000.00/yr
Up to 20 Vehicles:	$3,500.00/yr
Up to 50 Vehicles:	$4,500.00/yr

Industry Use

As a reseller of ESRI's ArcLogistics Route software package, TDI provides tailored packaging aimed at a target market of local delivery operations with private fleets of 5 to 50 vehicles.

Primary Features

TDI provides small delivery companies with desktop routing and scheduling operability. The software optimizes route sequencing and allows large volume simulating for economic evaluation. Routes and sequences are developed on the basis of customer time demands and actual network drive times, while vehicle and driver characteristics such as volume and weight capacity and labor constraints are considered.

Unique Attributes

TDI and ArcLogistics have easy to run simulations that can aid in forecasting vehicle and driver needs and thus help balance workloads and prevent overtime and underfilled loads.

Limitations

TDI is limited to the capabilities of ArcLogistics. This software does not provide the large-scale capabilities of the freight transportation packages like PC*Miler or Rand McNally, but it meets the needs of its intended market, local delivery operations.

SUMMARY OF ROUTING SOFTWARE REVIEW

This freight routing software review concentrated on the commercially available software packages that are most often used in the freight and trucking industry. This review included eight software packages (see Table 2.1), two of which (PCMiler and Rand McNally).received an extended analysis through the use of trial software to perform common routing tasks The review of the remaining six software packages was based upon publicly available information and promotional materials from the companies' websites.

It is evident from Table 2.1 each software package offers different types of attributes and options. However, most of the reviewed packages offer similar core routing attributes and capabilities. The software package that was found to offer the most flexibility and routing modification/options was Cheetah. Unfortunately, the cost of this software (like Appian) is based on each prospective user and its unique needs and is therefore not publicly advertised. This makes Cheetah somewhat difficult to compare with other software packages, most of which have an advertised single- or multiple-user price but also state that the actual software price is customer-specific.

Table 2.1: Summary of Reviewed Software Routing Attributes

Attributes	Prophesy	Promiles	PCMiler	Cheetah	Global Tranz	TSI	TDI	Appian Logistics	Freight Ware	Rand McNally
Practical Routing	☑	☑	☑	☑	This is a shipper			☑	this is a 3rd party add-on to either PC*Miler/ProMiles/ or Milemaker	☑
Shortest Path	☑	☑	☑	☑		☑	☑	☑		☑
National Network Routing	☑	☑	☑	☑			☑	☑		☑
Toll-Discouraged Routing	☑	☑	☑	☑				☑		☑
Haz. Mat. Routing		☑	☑	☑				☑		☑
53'/102" Trailer Routing		☑	☑	☑				☑		☑
LTL Load Optimization	☑			☑		☑				
Driver Optimization	☑	☑	☑	☑		☑	☑	☑		
Fuel Cost Minimization	☑	☑	☑	☑				☑		☑
Carbon Emission Calc.			☑	☑				☑		
Integration with Other Software (Accounts Receivable, pay ledger, payroll, taxes, etc.)	☑	☑	☑	☑		☑	☑	☑		☑
Real-Time Highway/Street Routing (seasonal road closures, congestion, road construction)	☑			☑		☑				☑
Inter-Modal Connectivity			☑	☑				☑		
Truck vs Rail Mileage Comparison			☑	☑				☑		
Commercial Mileage Summaries by State	☑		☑	☑				☑		☑

Nevertheless, for all dimensions considered, Cheetah offers the most features, followed by Appian Logistics, which does not allow real-time routing changes necessitated by unforeseen, trip-specific factors (accidents/road closures, highway restrictions, etc.). PCMiler, reported as the routing software used by 96 percent of the freight industry, was found to be comparable to Appian Logistics in its software capabilities, but it also does not allow real-time routing changes. The Rand McNally freight routing software does include a feature (as does Cheetah, TSI and Prophesy) that will allow each user to make route-specific, real-time changes on the basis of information received during while a truck is en route. However, in other dimensions, the Rand McNally software offers fewer overall capabilities than the PCMiler software, such as not providing truck versus rail mileage comparisons for closest rail loading/unloading facilities, identification of intermodal connectors (truck/rail), and the ability to schedule routes around driver hours of service limitations. Only three of the freight routing software packages include a feature that calculates the carbon emissions for alternative routes: PCMiler, Cheetah and Appian Logistics. Five of the software packages allow routing that considers trailer width and length restrictions on streets/highways: ProMiles, PCMiler, Cheetah, Appian Logistics, and Rand McNally. All packages except of Prophesy, TSI and TDI allow hazardous material routing, and all packages except of TSI and TDI include a feature to select routes on the basis of minimizing re-fueling costs,. All of the reviewed software packages will interface with other management software, such as inventory control, accounts receivable, billing/invoicing, payroll, and tax calculation packages.

It is also important to remember that not all freight routing software packages are designed, developed, and marketed to fulfill identical services in the freight transport and delivery market, and one must consider the target market for each software package. For example, a review of Table 2.1 may lead one to believe that TSI and TDI are lacking in features and capabilities in comparison to the other freight routing software packages. However, it is clear from the individual review of each that these two software packages were designed and developed for local delivery and urban parcel/product routing. As a result, many of the capabilities and attributes developed for long distance trucking, such as toll road avoidance, fuel refill cost minimization, hazardous material routing, and driver hours of service limits, are not relevant for the market served by this software.

3. EVALUATION OF USE OF GPS ROUTE DATA FOR EVALUATING ROUTE CHOICE

INTRODUCTION

This research investigated the feasibility of using GPS truck data to inform truck modeling logic. Two case studies were considered. For each case study, the evaluation included the proportions of vehicles using particular routes and the distribution of truck travel times and speeds along each route by traffic direction and time of day. The results indicated that there is a strong relationship between route attributes and truck route choice. However, other factors not described by the GPS data were also found to affect route choice. What's more, we found that given the current GPS data frequency and travel speed, if several alternative routes between the O-D pair are available, the truck route selected can be observed only if the distance of this route is longer than the distance between two consecutive GPS read points. Finally, with the algorithm used to identify truck stops (defined as >3 minutes), the relationship between stopping patterns and route choice cannot be observed.

THE GPS DATA

The GPS truck data used for this analysis were collected between October 2008 and August 2009. Approximately 2,500 trucks were represented in the Puget Sound, takes 3 to 5 percent of the entire truck population in this region. Millions of GPS spots were received each month. Figure 3.1 presents one month's worth of GPS data. The raw truck GPS data received from the GPS vendor were continuous spot data, and therefore we first employed the trip end identification algorithm developed by Ma and McCormack (2010) for identifying truck trip origins and destinations. Next, we geo-coded the GPS data with a traffic analysis data (TAZ) layer by using ArcGIS to identify the corresponding TAZ in which the GPS reads were located. In this way, the truck performance along each route could be retrieved from the GPS data and analyzed by querying the zone to zone trips. In addition, the GPS spot speeds had been demonstrated to be sufficiently accurate in comparison to the speed provided by dual loop detectors (Zhao et al. 2011).

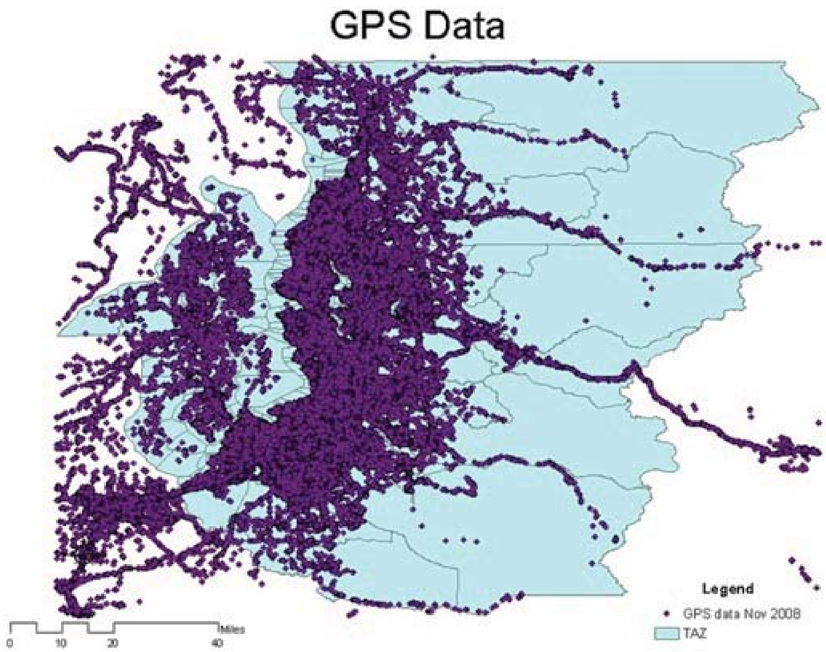


Figure 3.1 Monthly GPS Data and TAZ Layer. The map shows the GPS readings for the month of November 2008.

Two case studies were in the basis for evaluating the feasibility of using GPS truck data to identify truck routes in the Puget Sound area and inform the relationship between route attributes and route choices. For each case study, the following analyses were performed:

- Average travel distance, travel time, and speed between the origin and destination for each traffic direction and time period
- The proportion of trucks in the sample using particular routes and corresponding route attributes (travel distance, time, speed, and variability) between the origin and destination for each traffic direction and time period.

CASE STUDIES

Case studies were selected according to following criteria:

- The truck routes had to be major freeway and/or arterial roads where vehicles encounter traffic congestion during peak-hour periods (to observe the impact of traffic congestion on route choice)
- There had to be a statistically sufficient sample size between the origin and destination (a function of the current read rate)

- There had to be several alternative routes connecting the origin and destination (in order for us to observe route choice)
- Given that currently the vehicle location is recorded and reported every 15 minutes, the travel distance between the O-D pairs had to be long enough that different route choices could be observed.

Case Study I: TAZ 385–TAZ 545

Truck trips between TAZ 385 and TAZ 545 were selected as Case Study I. Approximately1,538 trips were identified based on data collected over 11 months. Two alternative routes, I-5 and I-405, were identified and are presented in Figure 3.2.

Figure 3.2 Case Study I. Truck Trips between TAZ 385 and TAZ 545

Both routes are essential freight corridors in the central Puget Sound area and experience high daily truck volumes. The average travel distance between the two zones was 43.64 miles, and the average travel time was 55.24 minutes with a speed of 48.03 mph, as shown in Table 3.1.

Table 3.1 Attributes of Trips between Zone 385 and Zone 545

Number of trips	1,538
Average travel distance (mile)	43.64
Standard deviation of average travel distance	3.14
Average travel time (min)	55.24
Standard deviation of average travel time	8.58
Average travel speed (mph)	48.03
Standard deviation of average travel speed	4.82

As shown in Figure 3.2, the GPS truck data identified the two truck routes successfully. Both I-5 and I-405 are Interstate highways, and the difference in the travel distance between the two routes was less than 1 mile. However, among 1,538 trips, only 164 trips (11 percent) used I-405, while 1,374 trips (89 percent) chose I-5. Table 3.2 presents the route characteristics. Although the average travel distance for both routes was similar, the average truck travel time on I-5 was 5 minutes less, and the corresponding travel speed on I-5 was 3 mph higher. This preliminary analysis showed that traffic performance using I-5 was better than performance on I-405, and nearly 90 percent of truck drivers chose I-5 to drive a shorter distance, faster, and arrive at a destination earlier.

Table 3.2 Truck Performance along I-5 and I-405

	I-5	***I-405***
Number of trips	1374 (89.3%)	164 (10.7%)
Average travel distance (mile)	43.44	44.31
Standard deviation of average travel distance	0.95	1.61
Average travel time (min)	54.56	59.53
Standard deviation of average travel time	7.23	7.72
Average travel speed (mph)	48.36	45.3
Standard deviation of average travel speed	4.67	5.18

To better understand the truck route attributes and factors that affect freight route choices, we further analyzed the trip attributes on each route by traffic direction and time of day.

Southbound Analysis

Southbound freight performance on both routes is presented in Table 3.3 and plotted in Figure 3.3 and Figure 3.4. There were 769 southbound trips in total. Similar route choices were observed by analyzing the southbound traffic. Only 75 trips (10 percent) used I-405, while most trucks chose I-5. The average travel time along I-5 was 54.58 minutes, which was 6 minutes faster than travel time on I-405. As illustrated in both figures 3.3 and 3.4, the variability of travel speed on I-405 was much higher than the speed deviation on I-5, indicating that the travel time on I-5 was more reliable. Similar results for travel speed profiles were observed. Travel speed along I-5 was 48 mph, which was 3.5 mph higher than traffic speed along I-405. I-5 traffic had a smaller travel speed standard deviation than I-405, as shown in Table 3.3 and Figure 3.4, indicating that the speed along I-5 was more stable. Hence the GPS data analysis indicated that the freight performance on I-5 was better in terms of travel speed, travel time, and travel time reliability. The analysis results showed that for southbound traffic, there was strong relationship between route choice and transportation-related route attributes.

Table 3.3 Southbound Travel Time Distributions along I-5 and I-405

	I-5	*I-405*
Number of trips	694	75
Average travel distance (mile)	43.09	43.99
Standard deviation of average travel distance	0.97	1.4
Average travel time (min)	54.58	60.51
Standard deviation of average travel time	8.14	9.3
Average travel speed (mph)	48.09	44.52
Standard deviation of average travel speed	5.07	6.09

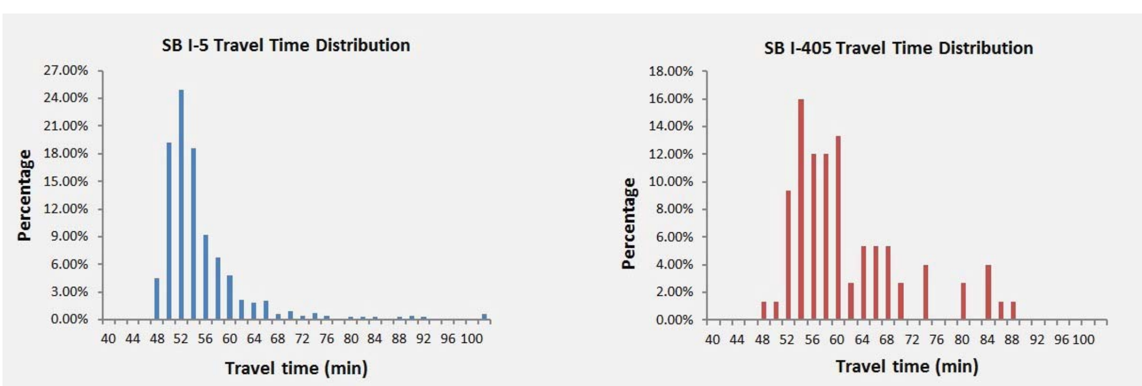


Figure 3.3 Southbound Travel Time Distributions along I-5 and I-405

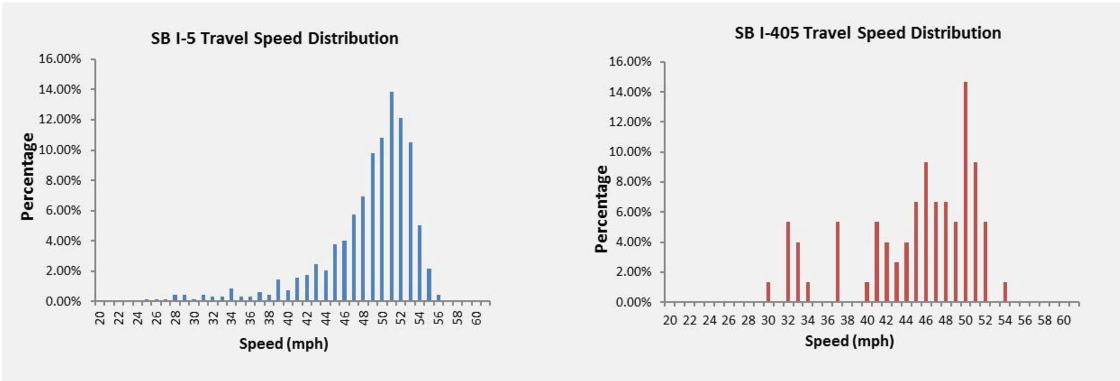


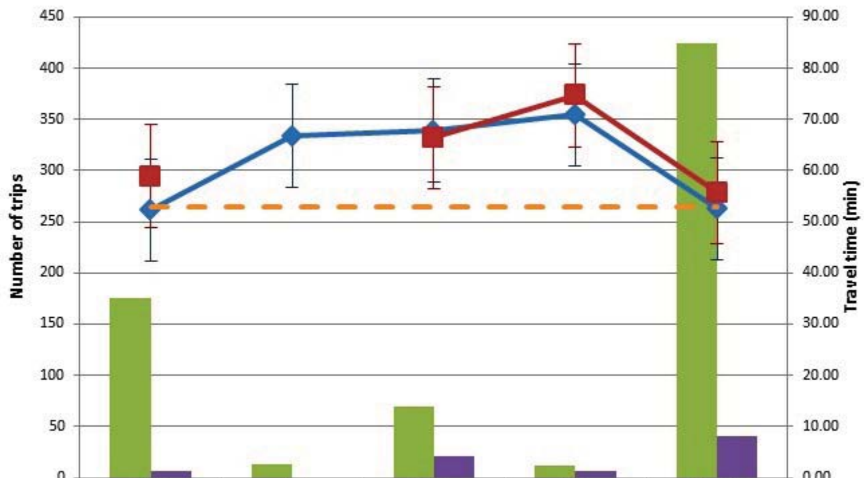
Figure 3.4 Southbound Travel Speed Distributions along I-5 and I-405

The traffic conditions were further studied by five time periods separately (Table 3.4):

Table 3.4 Time of Day Breakdown

Night	12:00AM - 6:AM
AM Peak	6:00AM - 9:00AM
Midday	9:00AM – 3:00PM
PM Peak	3:00PM – 7:00PM
After PM	7:00PM – 12:00AM

Figure 3.5 plots the number of trips southbound on both routes and the corresponding travel times by time of day. For both routes, the analysis found that the travel times during Night and After Peak time periods were close to free flow travel time (the free flow speed was defined as 50 mph). Travel time delays on both routes were observed during the other three periods. Trucks experienced more severe delay during the AM Peak and PM Peak periods for both routes. The number of trips on both routes was strongly related with the traffic condition: 647 trips (84 percent) occurred during the Night and After PM periods, when there was no travel delay, whereas only 28 trips (3.6 percent) occurred during the PM peak, when significant delays were observed.



	Night	AM	Midday	PM	After PM
Number of trips using I-5	175	13	70	12	424
Number of trips using I-405	7	0	21	6	41
Travel time using I-5	52.29	66.75	67.79	70.87	52.51
Travel time using I-405	58.90		66.41	74.67	55.69
Travel time with free flow speed	52.8	52.8	52.8	52.8	52.8

Figure 3.5 Southbound Truck Proportions and Travel Time Using I-5 and I-405 by Time of Day[3]

Generally, southbound transportation performance on I-5 was better than the performance on I-405. The travel times on I-5 during the Night and After PM periods were close to free flow travel time, and were 6 minutes and 3 minutes less than on I-405, respectively. Therefore, there were 175 trips on I-5 during the Night period but only seven trips on I-405, and 424 trips on I-5 during the After PM period but only 41 trips on I-405. The worst travel time delay was observed on I-405 during the PM Peak, which experienced 22 minutes of delay for a 53-minute trip without traffic congestion, and there were only six trips during that time period on I-405 over 11 months. No trip occurred during the AM Peak on I-405 over the 11-month observation period. We also noted that the travel time on I-405 during the Midday was about 1.5 minutes less than the travel time along I-5. However, the corresponding number of trips on I-405 was still less than the number of trips on I-5. This result was reasonable because the difference was not significant, and drivers may not have perceived it. Meanwhile, it also indicated that other factors that cannot be described by the GPS data may influence route choices as well.

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[3] GPS data represent between 3 and 5% of the total truck population in the Puget Sound region.

Northbound Analysis

Table 3.5 illustrates the northbound trip information along I-5 and I-405. The comparison between the two routes showed that for northbound traffic, the transportation performance on I-5 was better than on I-405. The travel time and speed differences between the two routes—about 4 minutes and 3 mph, respectively—were quite similar to those for the southbound traffic. Again, drivers mostly chose I-5, along which they could travel at higher speed and arrive at their destinations earlier. Figures 3.6 and 3.7 show the distributions of the travel time and speed along each route.

By comparing tables 3.3 and 3.5, we also found that the trip performances for southbound and northbound I-5 were similar, and those for southbound and northbound I-405 were also similar.

Table 3.5 Northbound Truck Performance along I-5 and I-405

	I-5	*I-405*
Number of trips	676	87
Average travel distance (mile)	43.8	44.58
Standard deviation of average travel distance	0.78	1.73
Average travel time (min)	54.53	58.68
Standard deviation of average travel time	6.15	5.97
Average travel speed (mph)	48.64	45.96
Standard deviation of average travel speed	4.21	4.17

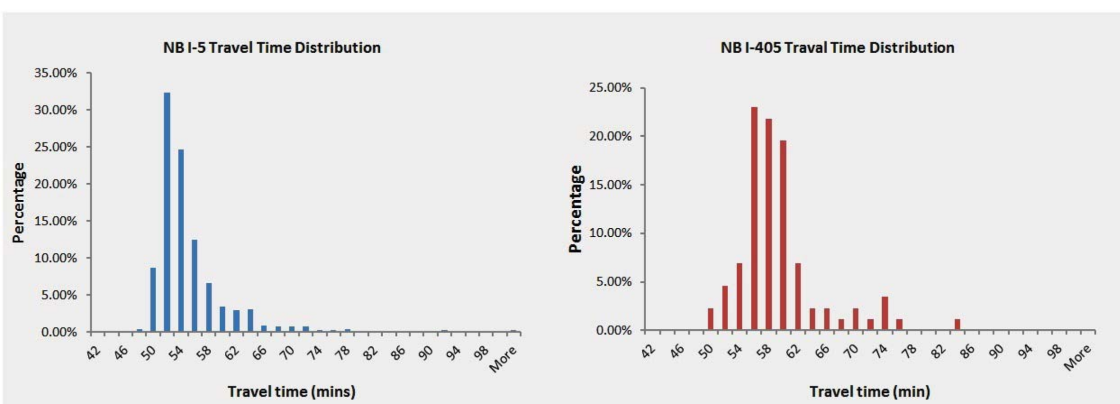


Figure 3.6 Northbound Travel Time Distributions along I-5 and I-405

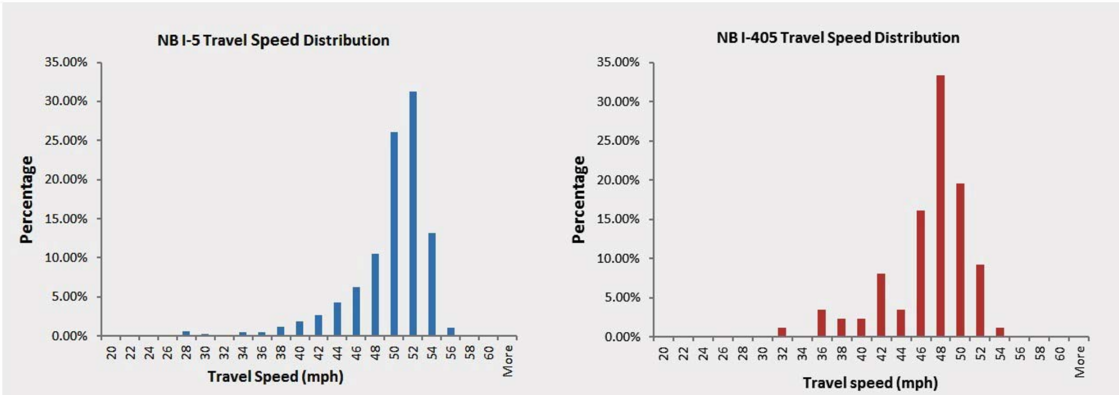
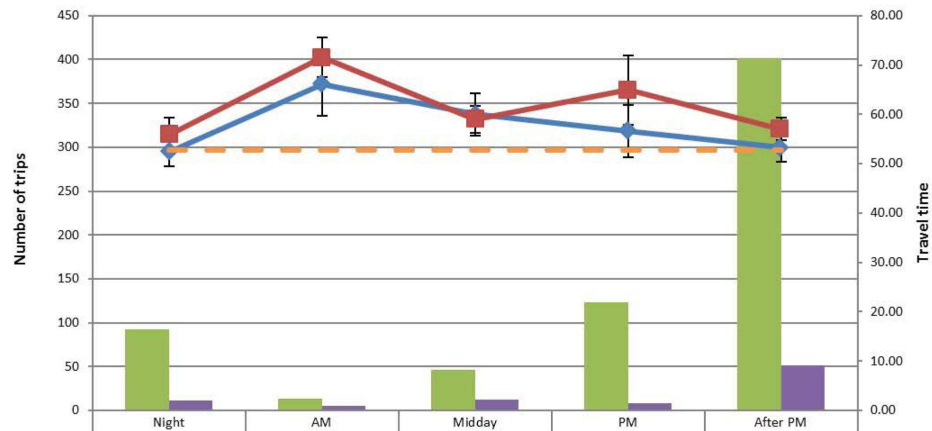


Figure 3.7 Northbound Travel Speed Distributions along I-5 and I-405

The northbound time-of-day analysis indicated that travel times on both routes during the Night and After PM periods were equal to free-flow travel time, and about 73 percent of total truck trips occurred during these time periods (Figure 3.8). Trucks encountered recurrent delay during the other three time periods. The most severe congestion was experienced by vehicles on I-405 during the AM Peak, when the travel time was almost 20 minutes longer than free flow. The travel time delay dipped slightly during the Midday period for both routes. Another considerable delay was observed during the PM Peak along I-405. The most significant travel time difference between the two routes, about 8 minutes, occurred during the PM Peak period, and the number of trips on I-5 was significantly higher than on I-405. Most truck trips were observed along the route with better performance (less travel time), except during the Midday period. The time difference between each route during the Midday period was quite small; however more trucks still chose I-5. A large percentage of trucks travelling outside of the peak travel periods.



	Night	AM	Midday	PM	After PM
Number of trips using I-5	92	13	46.00	123.00	401.00
Number of trips using I-405	11.00	5.00	12.00	8.00	51.00
Travel time using I-5	52.45	66.15	59.97	56.65	53.27
Travel time using I-405	55.87	71.55	58.97	64.92	56.98
Free flow travel time	52.8	52.8	52.8	52.8	52.8

Figure 3.8 Northbound Truck Proportions and Travel Time Using I-5 and I-405 by Time of Day

Case Study II: TAZ 180–TAZ 609

Truck Trips between TAZ 180 and TAZ 609, shown in Figure 3.9, were selected for the second case study. There were two alternative routes, I-90 and SR 520. Both routes are major roadways crossing Lake Washington and are connectors between I-5 and I-405. On the basis of the GPS data collected over 11 months, 533 trips were identified. The trip attributes are presented in Table 3.6 The average travel distance was 27.59 miles. It took 40.13 minutes, on average, to arrive at the destinations by traveling at 42.28 mph.

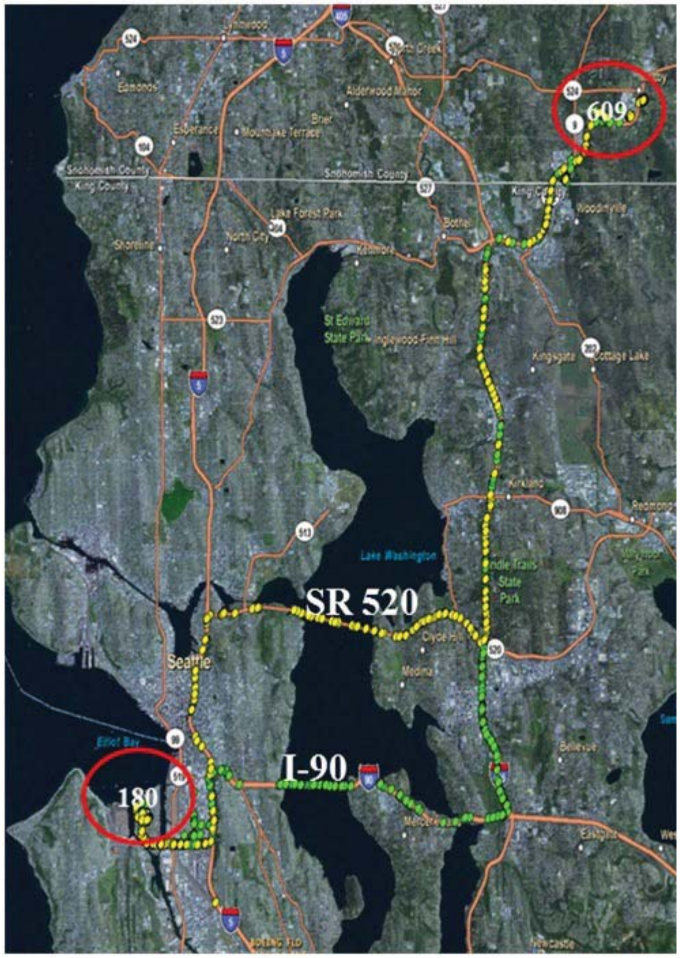


Figure 3.9 Case Study II—Truck Trips between TAZ 180 and TAZ 609

Table 3.6 Attributes of Trips between TAZ 180 and TAZ 609

Number of trips	533
Average travel distance (mile)	27.59
Standard deviation of average travel distance	1.55
Average travel time (min)	40.13
Standard deviation of average travel time	7.5
Average travel speed (mph)	42.28
Standard deviation of average travel speed	6.01

Among all 533 trips, 365 trips (68.5 percent) used I-90, while 168 trips (31.5 percent) chose SR 520. The traffic performance on each route is presented in Table 3.7. The comparison shows that the average travel distance, travel time, speed, and reliability of both routes were quite similar. However, the number of trips along I-90 was more than twice that along SR 520. To explore this issue, we conducted further analysis by traffic direction and time-of-day.

Table 3.7 Truck Performance along I-90 and SR 520

	I-90	***SR-520***
Number of trips	365	168
Average travel distance (mile)	27.61	27.54
Standard deviation of average travel distance	1.59	1.43
Average travel time (min)	40.17	39.91
Standard deviation of average travel time	7.08	8.4
Average travel speed (mph)	42.18	42.64
Standard deviation of average travel speed	5.86	6.34

Eastbound Analysis

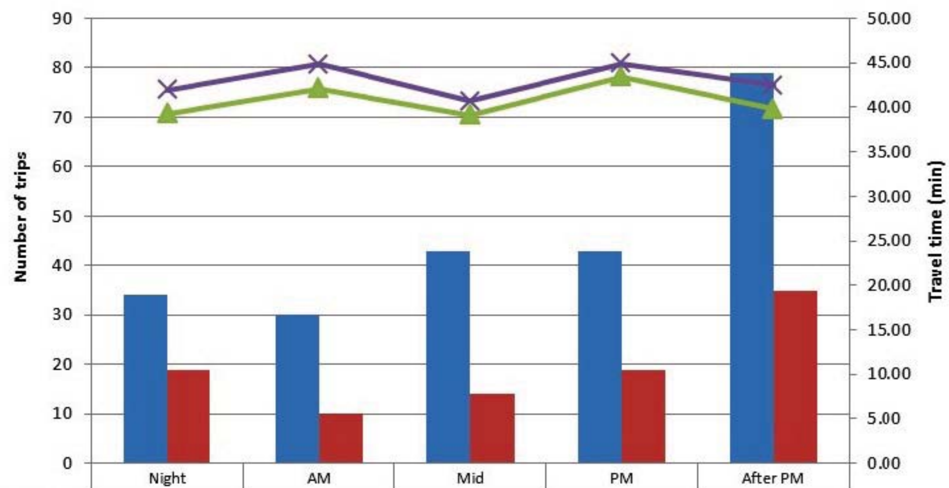
The analysis of eastbound traffic along I-90 and SR 520 is summarized in Table 3.8. 233 trips (71 percent) traveled along I-90. The travel time difference was quite small, less than 1 minute. The trip travel time and speed on I-90 were slightly more reliable, according to the time and speed standard deviations. Overall, there were no significant differences between the two routes, and results were insufficient to conclude that truck route choices were based solely on the route attributes derived from the GPS data.

Table 3.8 Eastbound Truck Performance along I-90 and SR 520

	I-90	***SR-520***
Number of trips	233	94
Average travel distance (mile)	27.82	27.79
Standard deviation of average travel distance	2.37	1.48
Average travel time (min)	41.34	42.22
Standard deviation of average travel time	8.66	9.27
Average travel speed (mph)	41.39	40.75
Standard deviation of average travel speed	5.74	6.08

A comparison of the numbers of trips and travel times over the two routes during different time periods is plotted in 3.10. For both routes, the travel times during the Night, Midday and After PM periods were close to free flow travel time, and 69 percent of trips occurred during these three time periods. Travel time differences between the two routes were observed during all five periods, and the differences increased during the AM Peak period to about 5 minutes. The travel time along SR 520 was longer than that on I-

90, and the number of trucks choosing I-90 during all time periods was higher than the number of trucks using SR 520.



	Night	AM	Mid	PM	After PM
Number of trips using I-90	34	30	43	43	79
Number of trips using SR-520	19	10	14	19	35
Travel time using I-90	39.30	42.09	39.16	43.36	39.80
Travel time using SR-520	41.93	44.92	40.80	44.95	42.54

Figure 3.10 Eastbound Truck Proportions and Travel Time Using I-90 and SR 520 by Time of Day

Westbound Analysis

The westbound vehicle proportions and trip information for each route are presented in Table 3.9. Almost 70 percent of vehicles chose I-90, while the traffic conditions on both routes were fairly similar. According to Figure 3.11, no trucks traveled along SR 520 during the AM and PM Peak periods, and therefore the traffic conditions on SR 520 during those two periods were unknown. For eastbound traffic, since performance along I-90 was always better, 69 percent of traffic occurred on I-90. Similar conditions were observed for westbound traffic during the After PM period. However, during the Night period, the travel time along SR 520 was less, and trucks switched from I-90 to SR 520, apparently to reduce travel time. The travel time during the Midday periods for the two routes were the same, and the route attributes failed to explain why there were more trips along I-90.

Table 3.9 Westbound Truck Performance along I-90 and SR 520

	I-90	*SR-520*
Number of trips	134	74
Average travel distance (mile)	27.43	27.22
Standard deviation of average travel distance	1.16	1.3
Average travel time (min)	38.97	36.98
Standard deviation of average travel time	7.22	6.03
Average travel speed (mph)	43.32	45.05
Standard deviation of average travel speed	6.26	5.85

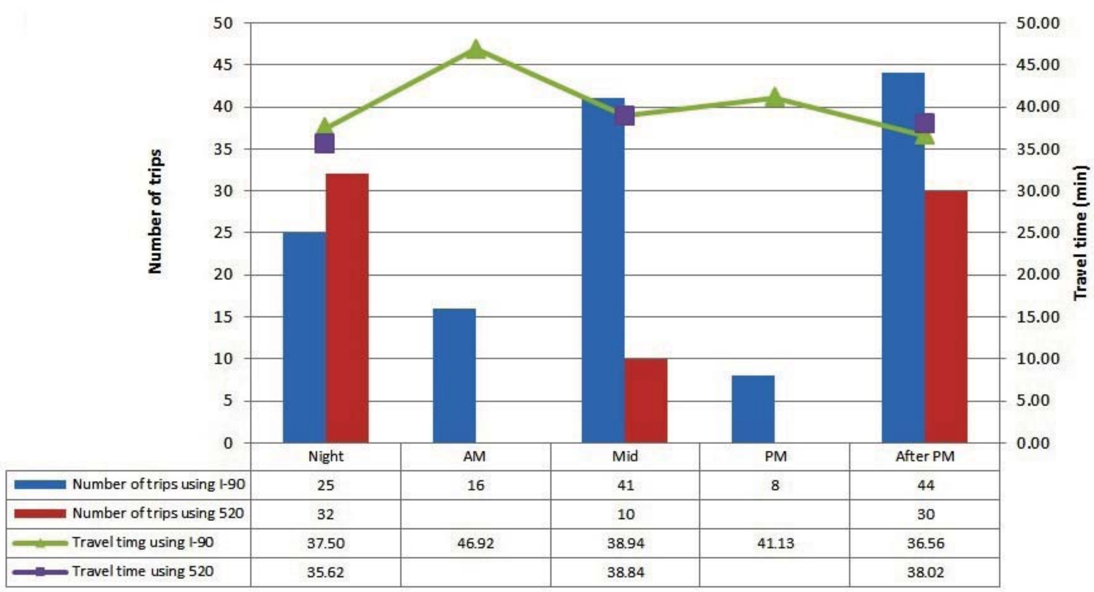


Figure 3.11 Truck Proportions and Travel Time Using I-90 and SR 520 by Time of Day

SAMPLE SIZE

Sample size is one of the most critical factors in ensuring a statistically reliable analysis. Extensive literature is available on determining the appropriate sample size for estimating transportation network performance. We employed the methods developed by Li et al. (2002) to identify the GPS data sample size for a statistically significant measure of truck performance.

$$N = \left(\frac{Z_{\alpha/2} S}{\varepsilon_r \bar{x}} \right)^2 \qquad \text{(Eq. 1)}$$

where α = confidence interval

Z_α = Z value for a given confidence level

S = sample standard deviation

ε_r = user defined allowable error in estimating the population mean

$\bar{x}$ = sample mean.

Although the appropriate sample size is critical, it was not a major concern in this research given the millions of GPS points that are received monthly from the GPS vendor. Here, we present an example to verify whether the sample sizes of the I-5 and I-405 trips in Case Study I were statistically reliable. For trucks traveling along I-5, the sample travel time mean was 54.56 minutes and standard deviation was 7.23, as shown in Table 3.2. For a confidence interval of 95 percent and a mean estimating error of 2.73 minutes, the minimum sample size required would be 27. As the sample size of our Case Study I was 1,374, clearly greater than the minimum sample size, the dataset was considered reliable for estimating the travel time on I-5 within a 5 percent error for a confidence level of 95 percent. Similarly, the minimum sample size to ensure a maximum 5 percent error for travel time estimates for I-405 was 26, and the current observation was deemed statistically reliable.

FEASIBILITY OF USING GPS TRUCK DATA TO IDENTIFY TRUCK ROUTES

The GPS truck data were capable of identifying the truck routes in Case Studies I and II. However, note that the travel distance for both cases was longer than 20 miles. Given the current GPS data frequency (we expect the frequency to increase over time) and truck travel speed, the feasibility of using GPS data to define truck routes is primarily determined by the trip distance. The distance between two GPS spots is calculated according to Equation 3.2.

$$S = F * V \tag{3.2}$$

where S = distance between two location reads (mile)

F = GPS data frequency (truck location reads were collected every 5 to 15 minutes)

V = truck speed (mph).

According to Equation 3.2, if there are several alternative routes connecting the origin and destination, then the distance between the route split point and the route merge point should be longer than the distance between the two GPS points to ensure that at least one GPS read is located on the selected route. Otherwise it is possible that no GPS data will be collected and the route choices cannot be identified. Figure 3.12 illustrates the relationship between distance of alternative routes and distance between GPS spots. Figure 3.12(a) shows a case in which the route distance is longer than the distance between the two GPS reads, and the selected route is guaranteed to be identified successfully. Figure 3.12 (b) and (c) illustrate a situation in which the routes are shorter than the distance between the two GPS spots. It is possible that there will be no GPS read on the selected route, and it cannot be identified as the route the truck took, as shown in Figure 3.12 (b).

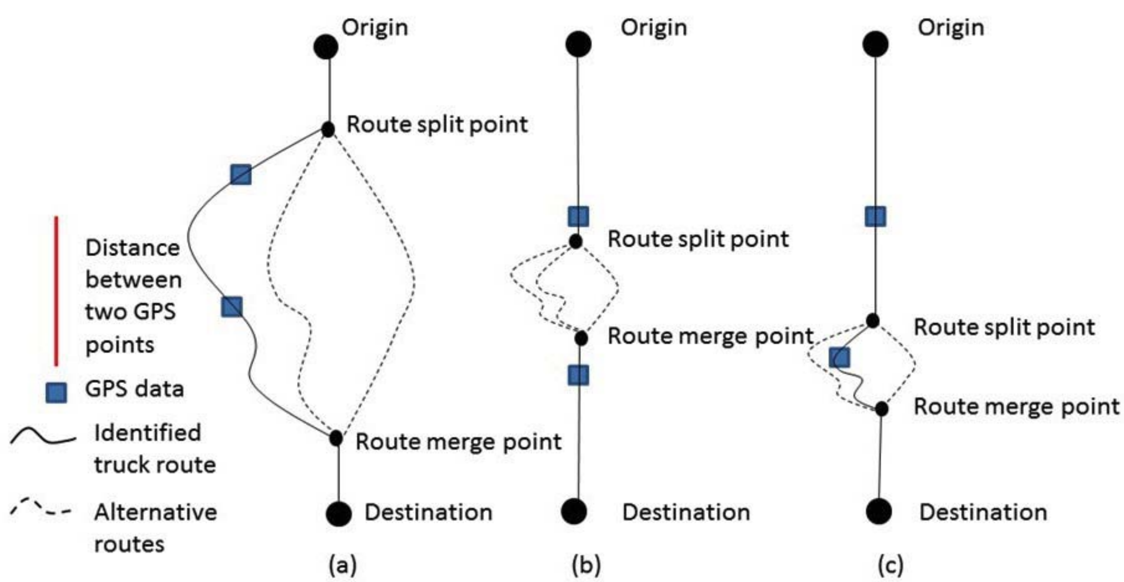


Figure 3.12 Relationship between Truck Route Length and Distance between Two Successive GPS Reads

The GPS reads employed in this research were collected every 5 to 15 minutes. If the average truck speed in Puget Sound area is 40 mph, then the minimum distance between the route split point and route merge point is expected to be 3.3 to 10 miles for the route to be identifiable. A higher data collecting frequency, lower travel speed, and traffic congestion could all shorten the route distance threshold.

The trip O-D identification algorithm employed in this research identified trip destinations by stop duration. An appropriate dwell time in Seattle area is 3 minutes (McCormack and Hallenbeck 2006). The 3-minute period has been demonstrated to be the appropriate dwell threshold that can separate stops for traffic signals, congestion, fueling, and drivers' break. The GPS spots are regarded as stops only when the stop time is greater than 3 minutes. However, for most delivery services, 3 minutes is significantly longer than the expected stopping time. Thus, with the algorithm we used, stops of less than 3 minutes did not appear as stops, and we were not able to distinguish route choice from the route a truck had to take to serve its customers.

CONCLUSIONS

This research investigated the feasibility of using GPS truck data to identify truck route choices by examining two case studies. The case studies evaluated four major truck corridors in the central Puget Sound. The case studies were selected so that a) a route choice decision would be available, and b) the outcome of this route choice could be observed in the data.

In both case studies, the truck route choices were identified, and it is found that the majority of truck trips were observed during off-peak time periods (7:00 PM to 6:00 the next day).

Correlation between route performance and truck route choices were identified within the analyses. Routes with less travel time, higher travel speed, and better reliability may have a higher probability of being selected according to the two case studies. However we did not observe similar selections between routes with close travel time characteristics, so we concluded that other factors not described by the GPS data were also affecting route choice. For example, road geometry, especially when trucks are fully loaded. Therefore, we can conclude that the GPS truck data are capable of supporting route choice analysis, but GPS data alone are not sufficient to ascertain the determinants of truck route choice.

The GPS truck data could identify the alternative routes successfully in both case studies. However, as mentioned, these case studies were selected because they were likely candidates. There will be many origin-destination pairs between which the routes cannot be identified given the current GPS data read rates. Namely, there must not be route choice decisions between two successive GPS reads; otherwise, it is very likely that the GPS data will fail to identify the route, as illustrated in Figure 3.12(c). Given current read rates, this window can be as long as 20 miles, which is insufficient in urban regions, the areas where route choice may be of most interest. However, more recently collected GPS data read rates have improved from 15 to 2 to 5 minutes, so we expect the ability to observe route choice will be improved. Another limitation of the truck route choice identification analysis is that in the current trip O-D identification algorithm, stops are observed as stops only if the stopping time is longer than 3 minutes. However, with some delivery services, e.g. parcel delivery, 3 minutes is longer than the expected stopping time, and therefore with the algorithm we used, the stopping patterns of delivery services will not be observed.

4. ROUTING PRIORITIES

A goal of freight planning is to identify how goods move through the transportation network and predict how freight flows will react to operational changes. Current freight flow models assume that shortest path algorithms are appropriate to apply to freight travel. Shortest path algorithms are commonly used in routing software such as Google Maps; this routing tool, however, is targeted at passenger travel. In addition to different travel constraints, freight and passenger travel have two distinct purposes. Freight travel is induced by the need to move goods; passenger travel is induced by the need for personal mobility. Therefore, the use of passenger travel predictors in freight flow modeling may be inappropriate.

This chapter describes process used to identify factors that contribute to truck freight route choice and the development of categories of companies based on how they make their route choices. A survey was designed and distributed to Washington state shippers, carriers, and receivers. Survey respondents were asked to score and rank a number of factors with regard to their influence on route choice. Responses to the survey questions were almost exclusively categorical (i.e., discrete); therefore, the respondents' sensitivity to routing factors was treated as a latent variable and was analyzed by using latent variable modeling and class analysis. The analysis identified hours of service limits, availability of truck parking, driver availability, refueling locations, and road grade as the top five discriminating factors among the respondents. Latent class analysis determined that the type of equipment a company owns (e.g., auto freight units) was a significant predictor of the category to which class a company belonged.

MOTIVATION

The ability to fully understand and accurately characterize freight route choice is one that will inform regional and state decisions. This ability applied to regional and state commodity flow data forms the basis of an effective statewide freight modeling framework. Existing transportation network models are designed to describe passenger travel and therefore may offer a poor representation of freight travel. Determining how different subgroups of shippers, carriers, and receivers make route choices and integrating these categorized decision characteristics can advance network models to better represent observed freight route choice.

LITERATURE REVIEW

How do carriers make routing decisions? What are their priorities? How do they differ across carrier type?

A few studies have worked to identify the factors that determine routing choices. Regan and Garrido (2002), through a review of literature, concluded in regard to mode choice in routing that a) shippers value service and reliability more than cost and b) the important factors in determining mode choice include timeliness, availability, suitability, firm contact, restitution, and cost. Regan and Garrido also reviewed studies that focused on shipper-carrier relationships.

In the early 1980s, mode choice was being investigated. A study by Krapfel and Mentzer (1982) looked at the factors that influence mode choice, as well as the factors that most strongly influence carrier choice. The motivation for the study was the deregulation of the trucking industry in 1980 by the U.S. Motor Carrier Act because it allowed carriers to make their own routing choices, yet it had limited criteria for evaluating prioritized routing decisions. Krapfel and Mentzer determined that damaged goods in transit, shipment losses, and service reliability were strong instigators of mode shifts. Factors that initiate a change of carriers within a mode were found to include availability of common carrier service, carrier availability, and shipment losses.

Boerkamps, Binsbergen, and Bovy (2000) looked beyond the factors that play into routing in their description of the GoodTrip model, which is a four-step modeling approach to building supply chains used in The Netherlands. The model starts with data on consumer demand and then applies scenario assumptions to build the supply chains that estimate goods flows. In their report, they considered the roles of various parties involved in transporting a good from production through final consumption and took into account the elements of routing behavior that each party controls. For example, in the first transportation link from manufacturer to retailer, the producer is responsible for decisions regarding private vs. for-hire, grouping of goods, mode, vehicle size, damages, and losses, while the retailer has control over the type and volume of the goods being delivered, delivery frequency, and reliability. From this, it is important to consider the role companies play within a supply chain when assessing their routing behavior.

Crainic and Roy (1988) developed a modeling algorithm that jointly considers economic efficiency and service quality. Economic efficiency involves operations, back hauling considerations, and delay impacts. Service quality is measured by service frequency to a specified location.

Figliozzi (2006), while looking at how various technologies play into routing decisions, classified goods into four categories. After developing simple models and formulas, and applying routing assumptions based on supply chains determined from operations research and a management science literature review, he ranked each good as high or low on scales of both time-sensitivity and actual value. This created four categories in which a particular good could be classified. Among these four groupings were distinctly different attributes in terms of routing strategies typically used. Figliozzi also concluded that routes are usually determined by number of customers, sequencing, time of service, vehicle used, distance, and links traveled.

A model by Hunt and Stefan (2007) in Calgary, Canada, builds trips in a growth format that adds stops onto the trip as they fit. Building of the trip takes into consideration routine services, vehicle type, trip purpose, establishment type, for-hire/private, and land-use types.

The SMILE model in The Netherlands developed by Tavasszy et al. (1998), has many variables that change on the basis of commodity, including storage/handling/transportation costs, value density, packaging density, perishability, delivery time, shipment size, demand frequency, and access of network. A survey conducted on product characteristics identified the logistics families that are determined by these variables.

Vieira (1992) investigated the importance and value of service quality to shippers when they make transportation decisions. A survey was conducted of five commodities within the rail industry to determine freight rate, transit time, consistency of travel time, loss/damage, payment terms, and ease of working with carriers.

Across these studies and model developments, researchers sought to find patterns within the characteristics of the commodities being moved that determine the route choice and flow of goods movement. All of the studies used minimizing total cost and distance as the criteria for routing decisions, which is consistent with this study's findings.

STUDY METHODOLOGY

For freight models to predict freight flows, there must be data to support the model formulation. Currently, the key data sources regarding freight data include the Commodity Flow Survey (CFS) and the Freight Analysis Framework (FAF3), which combines CFS data with economic figures to give a more disaggregated breakdown of commodity flows in tonnage and value. Unfortunately, neither of these sources provides number of truck trips. Other sources give data on employee counts and economic figures, which are used to estimate freight movements on a network. None of the existing federal data is detailed enough to determine routing patterns, so this study developed a survey to gather more information from carriers, shippers, and receivers on their routing decisions.

Collection of Data via Survey

The objective of the survey was to allow inference about the strategic-level routing decision-making process of companies that ship, receive, carry, forward, and/or broker freight in Washington state. The survey design was informed by a review of the literature and current routing software tools. The review found that most software programs let the user choose routing constraints, but there is no predetermined hierarchy. The routing constraints embedded in the software were used in the survey to ensure representation of the factors present across freight routing.

The survey started with questions designed to filter out companies unable to comment on routing decision making and to identify the correct company representative. The survey then asked routing priority and freight activity questions. Additional questions were then added to classify the companies on the basis of business characteristics. The survey design was reviewed and refined in collaboration with the University of Washington (UW), Washington State University (WSU), and the Social and Economic Sciences Research Center (SESRC) at WSU. The Washington Department of Transportation (WSDOT) and SESRC had recently completed two surveys investigating the costs of closures of I-90 and I-5. That experience provided SESRC an understanding of the freight industry that was beneficial to this effort. The survey was finalized after it was tested by freight experts, and revisions were made on the basis of the feedback. The freight experts were private industry representatives identified by WSDOT's Freight Systems Director.

After a confidentiality agreement was signed between SESRC and WSDOT, SESRC gained access to the database of the Washington Employment Security Department (ESD) and identified shippers, carriers, and freight forwarders. In addition to the ESD list, a list of companies that hold a commercial trucking license, obtained from the Washington Department of Licensing Truck Registration Database (UTC), was used to create the survey sampling population. The ESD list included those in the transportation sector and those in freight-dependent industries identified by WSDOT (transportation, agribusiness, construction, manufacturing, processed food, retail, trucking, warehousing, wholesale timber and wood products,). The UTC list contained some duplication; obvious duplications (same phone number, address, etc.) were removed from the sampling population. To achieve a well balanced and representative sample, companies were drawn from both lists.

The survey was conducted by SESRC between October 2010 and March 2011. The initial population consisted of 73,481 shippers, carriers, and freight forwarders. To obtain 2,500 initial cases, 972 companies were randomly selected, then, proportionate sampling to attain a minimum of 60 cases in the 10 industry sectors. After the initial list of 2500 had been exhausted, we had not met our completion goal, so more sample was drawn from the Washington Department of Licensing Truck Registration Database. Respondents were initially contacted by phone, letter, or email. They were given the choice of completing a live phone survey or an online version. Seventy-eight percent of respondents completed the 20 minute survey over the phone. Each completed interview required an average of six calls.

The Survey

The 40-question survey was designed to elicit the factors contributing to routing decisions made by Washington state companies that ship, receive, carry, forward, and/or broker freight. The survey was split into three modules: Freight Activity, Routing, and Business Classification.

- **Freight Activity**: This section included questions to identify freight activity in order to distinguish respondents as shippers, receivers, carriers, or a combination. Other questions aimed to capture fleet composition, distance of deliveries, type of deliveries, the use of outside carriers, and breakdown of single stop and multiple stop trips. Responses to these questions altered the wording of questions presented later in the other two modules.
- **Routing**: This section included questions designed to help us understand how routing decisions are made. They determined who makes routing decisions at a given company, the use of routing software, the flexibility of routes, and who makes the decision about route changes. The central question in this section asked respondents to indicate the influence of 15 factors on routing change decisions. Commodity considerations were explored in this section as well, with questions asking about primary, secondary, and tertiary commodities. Seasonality, perishability, and back-haul associated with freight were also investigated.
- **Business Classification**: This section included questions designed to characterize companies on the basis of business characteristics. Data on number of facilities, number of employees, annual revenues, and company location were gathered.

The key routing question asked the respondents to classify the intensity of influence that 15 factors (listed below) have on their company's route choices (with the option to write in more factors). Intensity was scored by using the following grading responses: (1) no influence, (2) slight influence, (3) moderate influence, and (4) high influence. The factors were posed in the same order to all respondents. Respondents were then asked to rank the level of influence of the factors that they rated 4 (high influence).

1. Minimizing travel distance
2. Minimizing travel time
3. Minimizing total cost
4. Planning multiple loads stops
5. Meeting customer requirements
6. Avoiding highway congestion
7. Avoiding highway tolls
8. Refueling locations
9. Availability of truck parking to wait for scheduled delivery or pickup times
10. Road grade and curvature
11. Hazardous material considerations
12. Size or weight limits
13. Truck driver availability
14. Truck driver hours of service limits
15. Availability of support in case of problems.

Survey Descriptive Statistics

The overall response rate from the surveying process was 41.4%. SESRC compiled 860 surveys and delivered the data to the UW. The figures that follow describe the sample of companies who responded to the survey. The number of observations represented in each figure is noted.

Industry Breakdown

The goal of the sampling procedure was to obtain a sample population that represented the industry distribution of the companies that made up the entire ESD and UTC lists. The third question in the survey asked respondents which industry category best describes their company. Of the 849 companies that responded (which included shippers, carriers, and freight forwarders), the largest subset, 33 percent, was the "Transportation and Warehousing" industry (see Figure 4.1). The next largest category was the "Agriculture, Forestry, and Fishing" industry, where 15 percent of companies classified themselves.

Figure 4.1 Industry Breakdown. Respondents were asked what industry they classified themselves from a list of nine categories. The number of companies, from our sample, in each industry is shown in the figure.

Company Activity and Outside Carriers

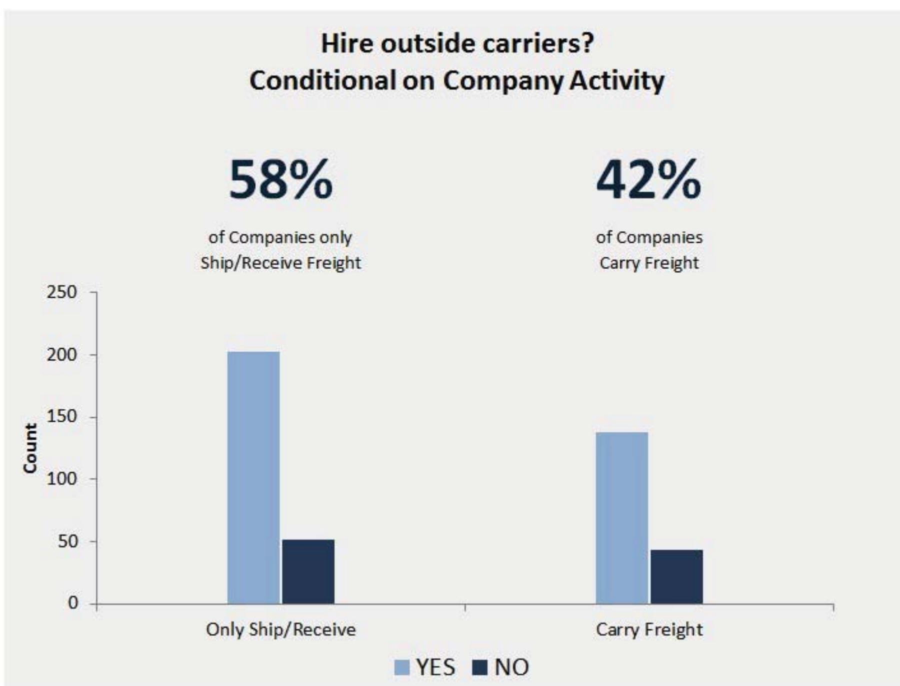


Figure 4.2 Company Activity and Outside Carriers.

Figure 4.2 shows the breakdown of the delivery service activities present among the 846 companies in the sample that answered both what activity type they were (Question 04) and whether or not they hire outside carriers (Question 05). Of the companies surveyed, 58 percent only shipped/received goods or were freight forwarders, so they did not carry any goods. The remaining 42 percent did carry goods alongside other activities, including shipping, receiving, and freight brokering.

Within the 42 percent of companies that carry freight (as determined by Question 04 about activity type), 72 percent hire outside carriers. Along a similar trend, of the 58 percent of companies who only ship and/or receive freight, 80 percent hire outside carriers (see light blue bars in Figure 4.2).

Services Provided Breakdown

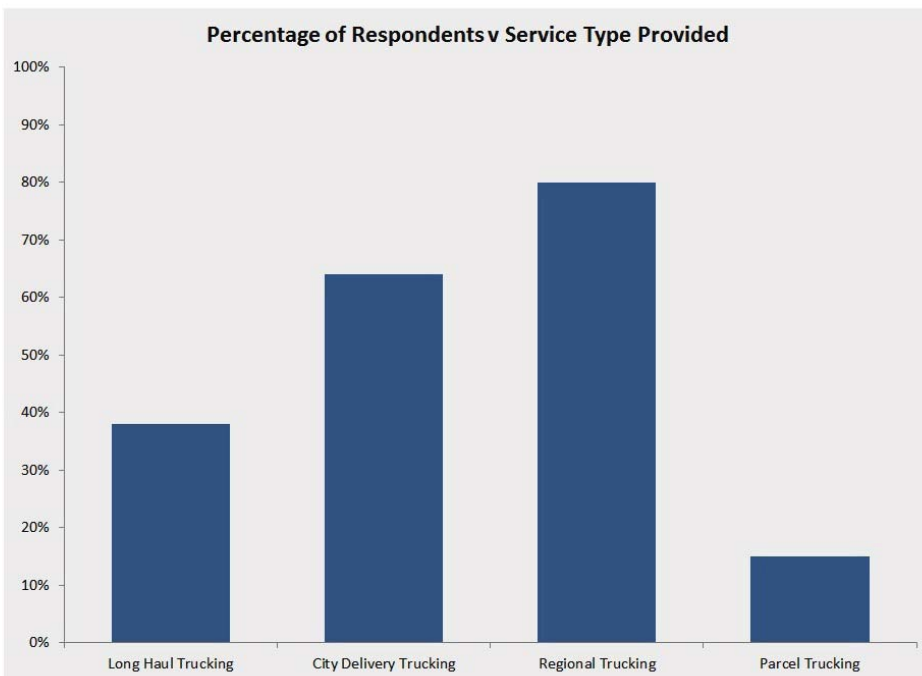


Figure 4.3 Service Types Provided. Respondents answered "yes" or "no" to each service type and the percentages are given. These categories are not mutually exclusive.

Figure 4.3 shows the percentages of respondents that provided long-haul, city delivery, regional, and parcel trucking. 830 companies responded to this question. The respondents answered each individually, so any given company may have provided none, all, or any combination of these services. Of the companies that responded to these questions, 25 percent provided both city delivery and regional trucking; 20 percent provided long-haul, city delivery, and regional trucking; and 8 percent provided all four delivery types.

Number of Vehicles

Carrying companies are those that responded as carrying at least some freight in Question 04 when asked whether they ship, receive, carry, and/or forward freight. Figure 4.4 shows the number of vehicles that carrying companies own (n= 358). 65 percent of carriers had 10 or fewer vehicles. Of companies that only ship, receive, and/or forward goods (do not carry), 68 percent had no vehicles in their company. 75 percent of companies do not use any form of routing software (question Q16a), rather use "experience" and "common sense" to make routing decisions.

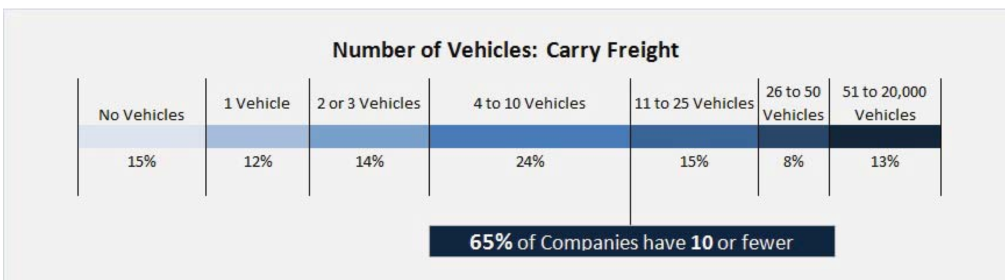


Figure 4.4 Number of Vehicles per Company for Carriers (n=358)

Truck Type Breakdown

Figure 4.5 shows the breakdown of truck type for companies that carry freight (n=393). The different colors of blue represent the fact that the data came from two separate questions. Again, the respondents replied to each of the categories individually, and therefore, the vehicle types are not mutually exclusive. When companies were asked what "other" vehicle types they had in their fleet, many mentioned dump trucks, logging trucks, van, and pick-up trucks.

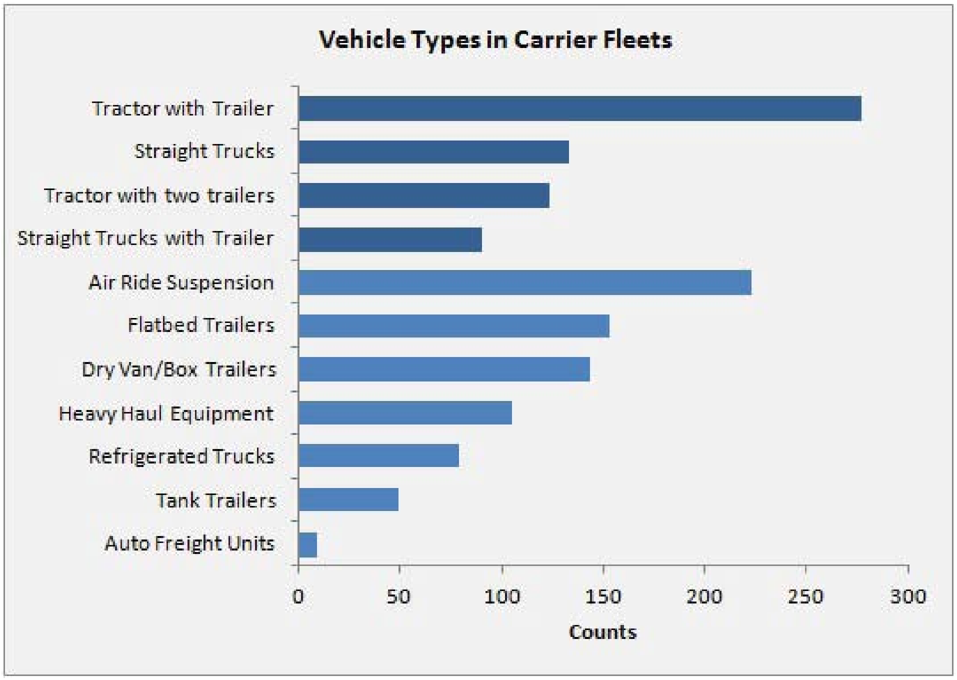


Figure 4.5 Vehicle Types in Carrier Fleets.

Frequency of Changes in Routing Shipments

Question Q21 in the survey asked all companies, "How often does routing of shipments change?" and the acceptable responses were never, yearly, monthly, weekly, or daily. Of the 637 companies that were asked to respond, almost all fell into either the "almost never" or "daily" categories. This indicates that companies were either very flexible or were very rigid in their routing decision-making. The food distribution and retail trades had more fixed routes than other industries. This could be because their types of delivery occur on a frequent, predictable, and timely basis, so fixed routing is the most convenient. Representatives of the transportation and warehousing industry reported an even distribution between fixed and variable routes. Respondents for the construction, earth products, and manufacturing products industries reported more route variability. Note that routing choices don't always exist. It depends on where deliveries and pickups are made. For example, with high customer density, little route flexibility is available. It is also important to note that respondents may have interpreted this question as asking about how often customers locations changed.

Commodities

With respect to commodities, 51 percent of companies surveyed had a primary commodity that made up at least 90 percent of their total shipments. Likewise, 37 percent of companies surveyed transported only one commodity. (Note: some companies considered "General Trucking" to be their primary commodity.) 68 percent of respondents said that they did not transport perishable freight, and there was a 50-50 split between respondents that reported seasonal freight that varies but not according to a season.

Number of Weekly Trips versus Numbers of Employees and Vehicles

Another interesting result from the data analysis was the finding of no correlation between the number of weekly trips and the number of employees or the number of vehicles, as seen in Figure 4.6 and Figure 4.7,respectively. Figure 4.6 shows responses from 835 companies and Figure 4.7 includes responses from 724 companies. The number of observations differs in these figures because not all respondents provided answers to both the number of employees and the number of vehicles questions. In these figures, number of trips per week was determined by combining number of single-stop full truckloads per week, number of multiple stop shipments per week, and number of parcel shipments per week. Low correlations were found in both relationships, with .21 and .19 respectively for Figure 4.6 and 4.7.

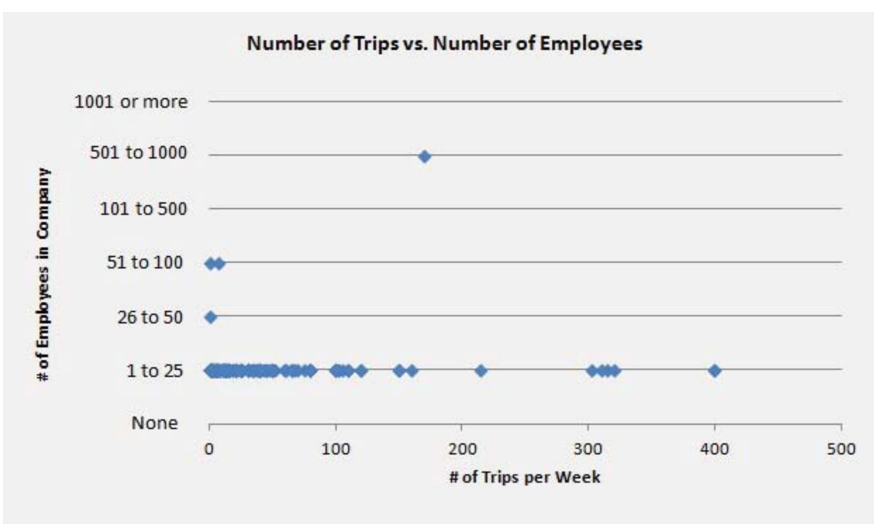


Figure 4.6 Correlation between Number of Employees and Number of Trips

In this figure, the number of employees given is the number of employees that companies have within the Pacific Northwest. There are 835 companies represented in the figure. This result is significant because number of employees is the dominant data used by regional travel demand models to estimate number of truck trips per establishment. Our data shows almost no correlation between trip making and employees.

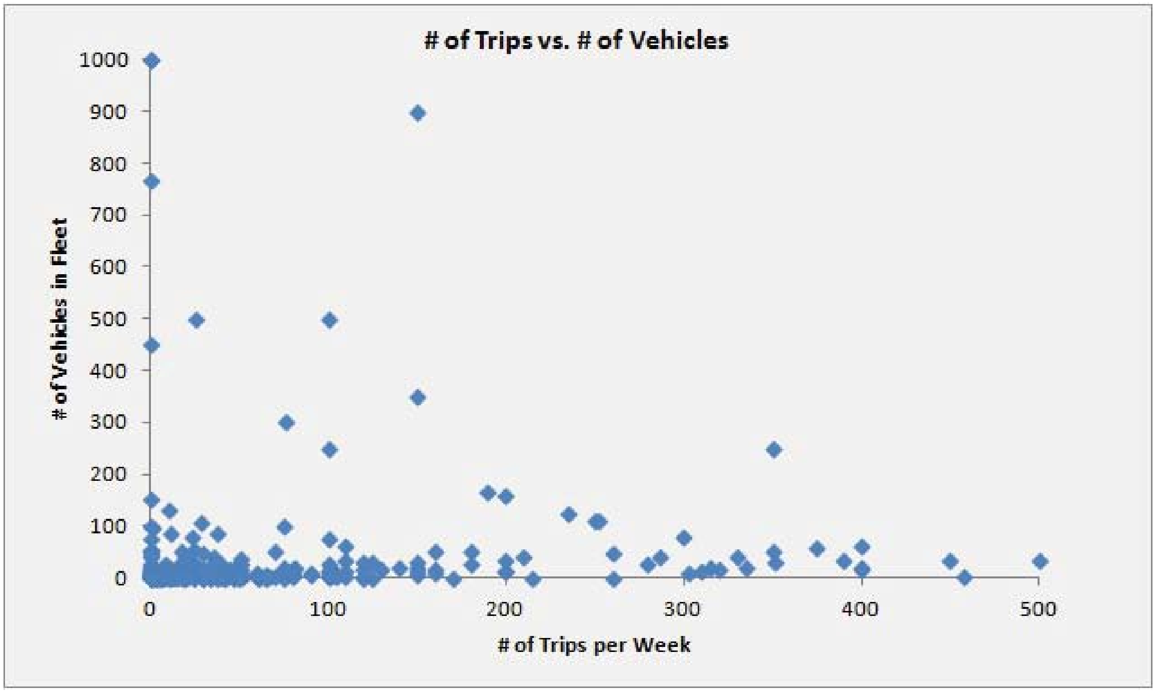


Figure 4.7 Correlation between Number of Vehicles and Number of Trips

There are 724 companies represented in this figure who answered the question on how many vehicles are in their fleet. As the number of vehicles in a companies' fleet increase, the number of trips per week is not necessarily increasing. There is a low correlation coefficient (R^2= 0.19). Number of vehicles per licensed motor carrier is a publicly available data element. As a result, it is also commonly used as a surrogate for trip making in travel demand models. This data demonstrate the weakness of this assumption.

Quality of Factor Scores

Figure 4.8 shows the distribution of the total sum of the factor scores across respondents for the primary routing question in the survey. Respondents were asked to rank 15 factors on a scale of 1 to 4 to indicate their importance to routing decisions. The sum was found by simply adding the scores—either a 1, 2, 3, or 4—for each factor for each respondent. The minimum sum was therefore a 15, while the maximum was a 60. The total sum was the traditional summated raw score used in Likert-type scaling; the raw score weights each response equally for all factors. Figure 4.8 shows that the total sum followed a normal distribution, with a slight skew toward higher influence scores. This shows that respondents used different scores for different factors. Only 10 respondents used the same score for all factors.

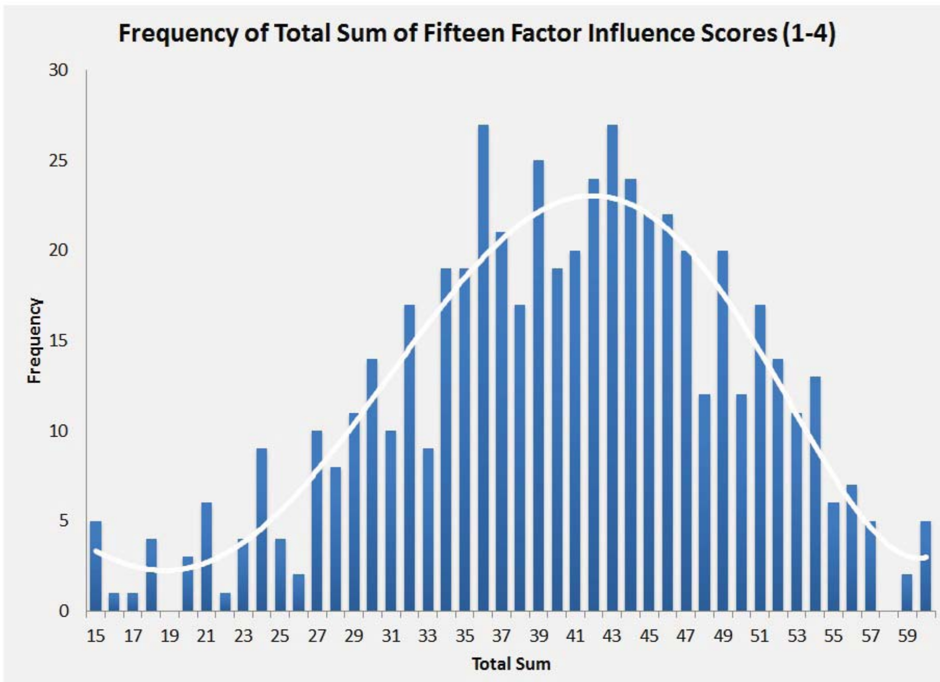


Figure 4.8 Frequency of Total Sum of 15 Factors Influencing Routing Decisions

This figure shows the distribution of the sum of ratings respondents gave to 15 factors that influence routing decisions. The histogram of total sums shows a normal distribution with a slight positive skew. This signifies no bias within the sample population to rank all factors as non-influential or all as highly influential.

Importance of Routing Factors

Table 4.1 shows the percentage of companies that scored items with a 4, and Table 4.2 shows the average scores for several groups within the sample population. In order to achieve the average, companies were grouped depending on the characteristic shown, and then their responses to the 15 factors were averaged.

Table 4.1 Percentage of Companies that Scored Item with a 4 (highest rating)

Item	Percentage of Companies that Scored Item with a 4
Customer Requirements	65%
Total Cost	54%
Travel Time	41%
Travel Distance	40%
Hours of Service Limits	35%
Highway Congestion	29%
Size and Weight Limits	28%
Multiple Loads	26%
Driver Availability	23%
Support	22%
Highway Tolls	13%
Refueling	13%
Parking	10%
Hazardous Material	10%
Road Grade	8%

Table 4.2 Overall Averages

		Travel Distance	Travel Time	Total Cost	Multiple Loads	Customer Requirements	Highway Congestion	Highway Tolls	Refueling	Parking	Road Grade	Haz Mat	Size Weight Limits	Driver Availability	Hours Limit	Support
Overall Avg.		2.4	2.5	2.7	2.0	2.8	2.2	1.6	1.6	1.5	1.5	1.3	2.1	1.9	2.2	2.0
Service Type	Long Haul	3.2	3.2	3.5	2.9	3.7	2.9	2.3	2.5	2.3	2.2	1.8	3.0	2.7	3.3	2.8
	City Delivery	3.2	3.2	3.5	2.8	3.7	3.0	2.2	2.2	2.0	2.0	1.7	2.7	2.4	3.0	2.6
	Regional	3.2	3.3	3.5	2.5	3.7	3.0	2.1	2.2	2.0	2.1	1.7	2.8	2.5	3.0	2.6
	Parcel	2.9	3.0	3.4	3.2	3.7	2.9	2.4	2.2	2.0	1.9	2.0	2.7	2.5	3.1	2.7
Industry	Food Distribution	3.3	3.3	3.5	2.7	3.7	2.9	2.2	2.2	2.0	2.2	1.5	2.7	2.4	3.0	2.7
	Transportation and Warehousing	3.3	3.3	3.7	2.9	3.9	3.0	2.3	2.4	2.2	2.1	1.8	2.9	2.7	3.3	2.7
	Manufacturing	2.8	3.1	3.3	2.6	3.6	2.3	2.0	1.8	1.6	1.6	1.3	2.1	2.2	2.1	2.7
	Retail Trade	2.8	3.1	3.6	2.7	3.8	2.4	2.0	1.9	1.7	1.7	1.7	2.0	2.3	2.6	2.5
	Construction	3.3	3.4	3.6	2.1	3.8	3.3	2.0	2.1	1.7	2.1	1.6	3.1	2.3	2.6	2.5
	Wholesale Trade	2.3	2.7	2.8	2.0	2.8	2.1	1.3	1.4	1.3	1.4	1.5	1.8	1.8	1.7	2.0
	Earth Products	3.2	3.3	3.6	2.2	3.5	3.1	2.1	2.2	1.9	2.1	1.6	2.9	2.4	2.6	2.6
Equipment Type	Straight Trucks	3.3	3.4	3.6	3.0	3.8	3.1	2.2	2.1	1.9	2.1	1.8	2.7	2.6	3.0	2.7
	Straight Trucks with Trailer	3.3	3.4	3.7	2.6	3.7	3.1	2.2	2.3	2.0	2.3	1.8	2.9	2.7	3.0	2.8
	Tractor with Trailer	3.4	3.4	3.6	2.7	3.8	3.1	2.2	2.4	2.1	2.1	1.6	3.0	2.6	3.2	2.8
	Tractor with 2 Trailer	3.5	3.4	3.7	2.7	3.8	3.2	2.4	2.5	2.2	2.2	1.8	3.1	2.7	3.3	2.8
	Refrigerator Trucks	3.2	3.2	3.5	3.0	3.7	3.0	2.4	2.7	2.3	2.2	1.6	2.9	2.7	3.1	2.7
	Dry Van/Box Trailer	3.3	3.3	3.6	3.0	3.7	3.0	2.1	2.2	1.9	2.0	1.9	2.6	2.6	3.1	2.7
	Heavy Haul Equip.	3.4	3.4	3.6	2.4	3.7	3.2	2.3	2.3	2.1	2.3	1.7	3.1	2.6	3.2	2.8
	Tank Trailer	3.3	3.3	3.6	2.5	3.8	3.1	2.1	2.3	2.1	2.4	2.6	3.2	2.7	3.3	2.7
	Flatbed Trailer	3.4	3.3	3.6	2.7	3.7	3.1	2.3	2.4	2.1	2.2	1.5	2.9	2.6	3.0	2.7
	Auto Freight Units	2.8	2.6	3.0	2.5	3.2	3.1	2.2	2.7	2.3	2.1	1.2	3.1	2.9	3.0	2.9
	Air Ride Suspension	3.3	3.3	3.6	2.7	3.7	3.1	2.3	2.4	2.1	2.2	1.6	3.0	2.6	3.2	2.8
Range	Locally	2.5	2.6	2.8	2.1	3.0	2.3	1.7	1.7	1.5	1.6	1.3	2.1	1.9	2.2	2.1
	Regionally	2.4	2.5	2.7	2.0	2.9	2.2	1.6	1.6	1.5	1.5	1.3	2.1	1.9	2.2	2.0
	Nationally	2.0	2.1	2.4	1.9	2.5	1.8	1.4	1.4	1.3	1.2	1.1	1.7	1.7	1.9	1.8
	Internationally	2.2	2.3	2.6	2.0	2.8	2.0	1.5	1.5	1.5	1.4	1.3	1.9	1.8	2.1	1.9
# Yards/Terminals (PNW)	0-24	3.2	3.3	3.6	2.6	3.8	3.0	2.1	2.2	2.0	2.0	1.7	2.7	2.5	2.9	2.6
	25-49	3.8	3.9	4.0	3.2	3.9	2.9	2.0	1.8	1.8	2.3	3.3	3.2	2.6	3.5	2.9
	50-74	4.0	4.0	3.5	3.0	4.0	3.0	3.0	2.5	2.0	2.0	1.5	3.0	2.5	4.0	3.0
	75+	3.3	3.3	2.8	3.3	4.0	2.3	2.5	1.5	2.5	2.3	1.3	2.3	2.8	3.3	3.3
# Warehouses (PNW)	0-24	3.2	3.3	3.6	2.6	3.8	3.0	2.1	2.2	2.0	2.0	1.7	2.7	2.5	2.9	2.7
	25-49	3.5	3.5	4.0	3.0	3.8	1.8	1.3	1.0	1.0	1.0	1.7	3.0	2.3	3.0	1.7
	50-74	3.3	3.7	3.0	3.5	3.3	3.3	2.3	1.7	1.3	1.3	1.0	2.0	1.3	2.0	1.3
	75-99	4.0	4.0	4.0	3.0	4.0	4.0	4.0	1.0	1.0	3.0	1.0	4.0	3.0	1.0	1.0
	100+	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.5	2.5	4.0	4.0	2.5	4.0	4.0
Annual Revenue	<$3 million	2.4	2.5	2.7	1.8	2.8	2.3	1.7	1.8	1.5	1.5	1.1	2.1	1.8	2.1	1.9
	$3-10 million	2.3	2.5	2.8	2.1	2.9	2.3	1.8	1.6	1.5	1.6	1.2	2.1	2.0	2.2	2.1
	>$10 million	2.9	3.0	3.3	2.5	3.4	2.5	1.7	1.7	1.6	1.7	1.9	2.4	2.3	2.6	2.3
Employee Counts (PNW)	0-25	2.3	2.4	2.6	1.7	2.6	2.1	1.5	1.6	1.4	1.4	1.0	1.9	1.7	1.9	1.8
	26-50	2.3	2.5	2.7	2.2	2.9	2.1	1.6	1.5	1.5	1.4	1.2	2.0	2.0	2.3	2.2
	51-100	2.6	2.8	3.1	2.3	3.2	2.4	1.6	1.8	1.7	1.7	1.7	2.5	2.2	2.4	2.2
	101-500	3.1	3.1	3.5	2.8	3.6	2.7	2.1	2.0	1.9	1.9	1.9	2.7	2.5	3.0	2.6
	501-1000	3.3	3.3	3.5	3.5	3.6	2.6	2.0	1.9	2.1	2.2	2.6	2.7	2.4	3.0	2.8
	1001+	2.9	3.0	3.2	2.4	3.4	2.6	1.8	1.5	1.7	1.8	1.8	2.4	2.3	2.6	2.3

In this table it is important to note that in each block of questions, the respondents did not cover the entire sample that is included in the Overall Average. For example, all the averages of Service Type were higher than the Overall Average. This is because only respondents that answered “yes” to Long-Haul, City Delivery, Regional, or Parcel were included, and these four were not mutually exclusive. The Overall Average included all respondents that said “yes” or “no” to these service types. Across all questions, the influence of Highway Tolls, Refueling, Parking, Road Grade, and HazMat on routing decisions was consistently lower than Travel Distance, Travel Time, and Total Cost, which respondents consistently considered highly influential.

Use of R

The open source statistical program **R** was chosen for statistical analysis. **R** allows the use of packages that utilize advanced statistical techniques to focus on factoring and cluster analysis. The majority of the questions in the survey were categorical. Questions with continuous data for responses were converted into categorical data so that they could also be included in the categorical analysis.

Once the surveys had been cleaned and data values converted from continuous to categorical, data mining was performed to extract a small subset of meaningful factors from the full list of 15 factors. The type of statistical technique used in this analysis is called latent variable modeling. Latent variable modeling can be used for both factor analysis and class analysis. Latent variables are variables that are not directly observable (e.g., intelligence) and require the use of surrogate variables (e.g., GPA, SAT score) that can be observed. For this study, the latent variable (θ) was the freight companies' sensitivity to external factors in deciding their route choice. The observable variables were the factors the survey asked the company representatives to rate for their intensity of influence on the routing decision. The statistical software program **R**, and specifically the **ltm** and **poLCA** packages, were used to determine which of the 15 factors distinguished among the companies.

RESULTS

The following discussions are focused on the central question of the survey, which asked respondents to rank the influence of fifteen factors on their routing decisions. The analysis separated the factors that differentiated carriers from each other and the factors that were similar among all carriers. The majority of respondents rated travel time, travel distance, and meeting customer requirements as highly influential (4), indicating that these factors are unanimously significant routing factors . Specifically, 87%of respondents rated customer requirements as highly influential (4). Including these factors in a statistical analysis would diminish differentiation between responses, making clusters indistinguishable. Looking beyond the highly influential factors of travel time, travel distance, and customer satisfaction would highlight differences in companies.

An example of this is found in `Q22c: “how often does highway congestion change routes?" with response options being (a) never, (b) yearly, (c) monthly, (d) weekly, or (e) daily. Forty-eight percent responded (a) never. Because congestion is a recurring event in predictable locations, companies already account for congestion when they determine their usual routes.

Travel time, travel distance, customer satisfaction, and congestion are examples of factors that can be modeled the same way for the entire company population. Other factors, specifically road grade, refueling locations, parking availability, hours of service limits, and size/weight limits, cannot be modeled the same for the entire population. Survey respondents scored this subset of factors with various levels of influence (no influence, slight influence, moderate influence, high influence). These factors are called *informative items* in item response theory (IRT) and can be used to cluster companies who prioritize similar factors when deciding route choice.

Item Response Theory

Latent variable modeling is a method used to model responses to questions that are either dichotomous (i.e., have two categories of responses) or polytomous (i.e., have more than two categories of responses). Item response theory (IRT) uses latent variable modeling to assign a probability of a certain response to an item given the respondents’ sensitivity (θ) and the item’s parameters . In this study, the “item” was the factor the survey respondent was being asked to judge with regard to its influence on route choice by using graded responses (i.e., a Likert-type scale). Again, the scale used by the respondents was (1) no influence, (2) slight influence, (3) moderate influence, and (4) high influence. Item parameters included difficulty (b) and discrimination ability (a). Difficulty was the mean response of the item, i.e., the point at which 50 percent of the respondents scored the item with moderate to high influence and 50 percent scored the item with no to slight influence. If an item had a difficulty of 4, then it was easier to agree to than an item with a difficulty of 2 (i.e., the respondent was agreeing with the high influence of the item).

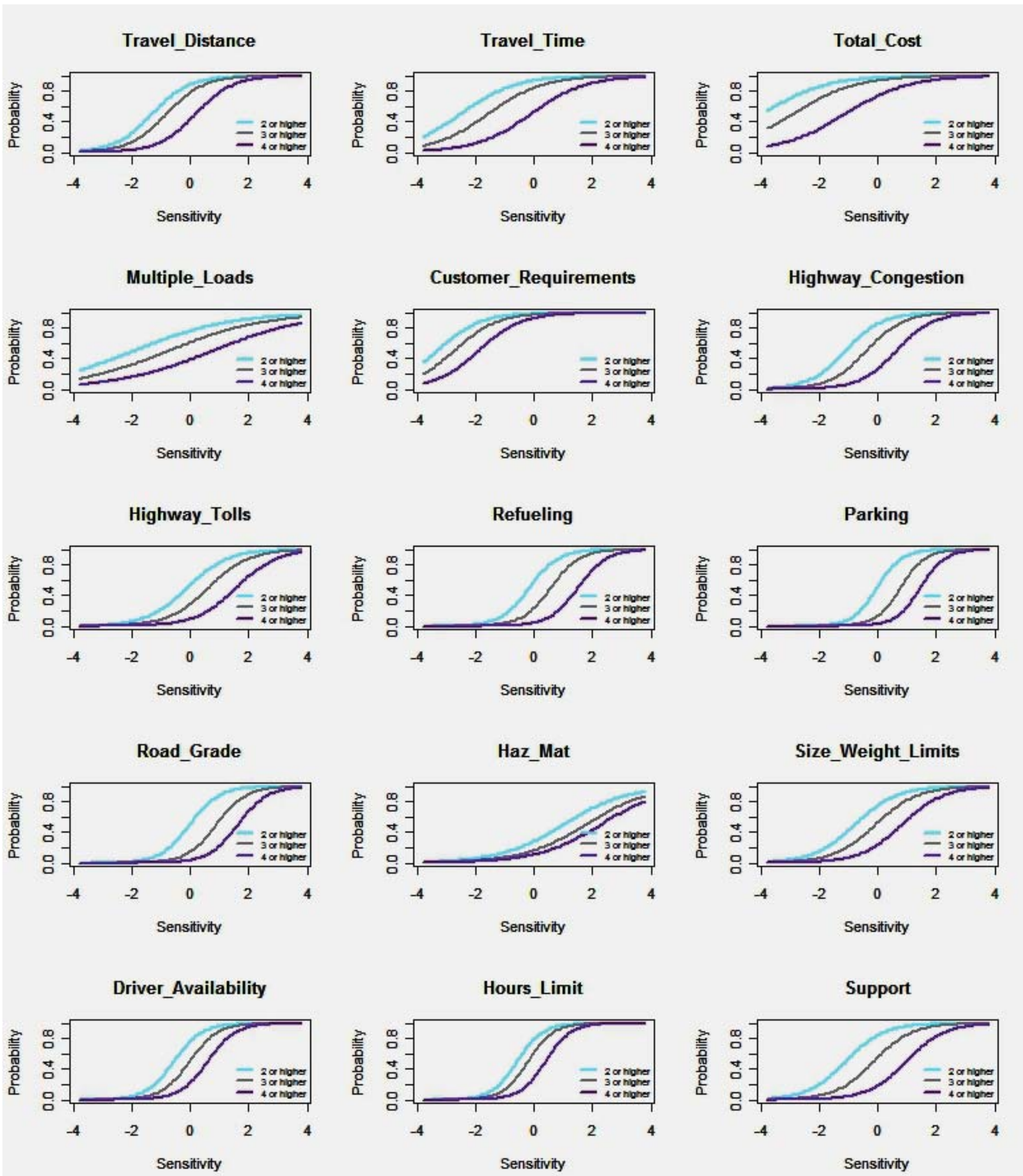


Figure 4.9 Item Operation Characteristic Curves (IOCC). These curves illustrate the value of each item.

Items with steep curves in the plots above help differentiate respondents and form clusters. The three lines represent a score of 2 or higher; 3 or higher; or 4 or higher.

There are three separate lines, since the item may distinguish between the companies that ranked an item as a 3 and companies that ranked the item as a 4 while not distinguishing between those companies and companies that ranked an item as a 2.The IOCC for Multiple Loads shows low steepness, meaning that the item does not discriminate well between respondents. The IOCC for Parking shows high steepness, meaning that the item is meaningful in differentiating between respondents. The discrimination ability parameter estimates were generated by using the graded response model (GRM). The GRM models the probability of a respondent scoring an item at a certain intensity of influence or higher (e.g., 3 or higher) and uses the equation:

$$P_{ik}^{*} = \frac{e^{a_i(\theta - b_{ik})}}{1 + e^{a_i(\theta - b_{ik})}}$$

where *a* and *b* are the item parameters, and P_{ik}^{*} is the probability that a respondent will give item *i* a score of *k* or above, given the respondent's sensitivity level, *θ*. The GRM does not assume that the distance between the categories of the rating scale, i.e., between 1 and 2 and between 2 and 3, is constant. This spacing between categories is controlled by the *b*-parameters, also called threshold parameters. The GRM can be constrained to equal discrimination $(a_i = a \, \forall \, i)$ if warranted by the data.

Item Information

Test precision in IRT is conveyed in the form of information. Information indicates how useful an item is in differentiating the respondents' sensitivity levels (*θ*). Information is a function of *θ* and therefore can provide differing levels of precision across the sensitivity spectrum. Figure 4.11 shows the information for all items included in the GRM. The level of information corresponds to the height of the curve and the location of inflection along the sensitivity spectrum. Looking at Multiple Loads, one can see that items with low and near-constant slope carry the same amount of information for all respondents. On the other hand, items with steep slope and an inflection point in the positive *θ* range, such as *parking*, carry high amounts of information for respondents with an average-to-high sensitivity level.

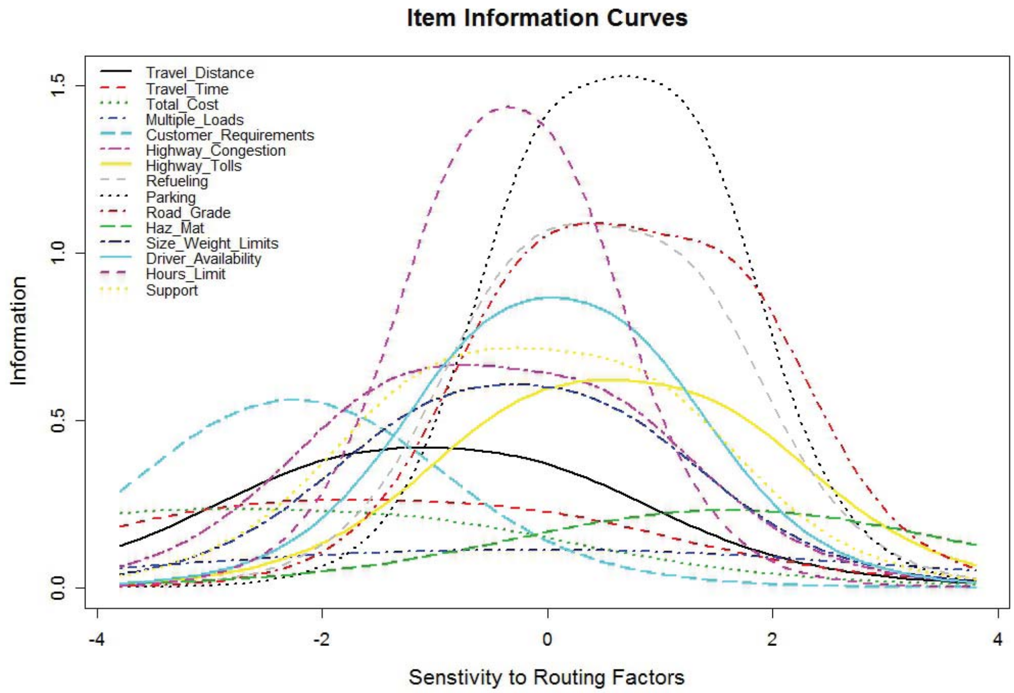


Figure 4.10 Item Information Curves. The item information curve illustrates how informative an item is, with information increasing along the y-axis. The x-axis determines the sensitivity region over which the item is most informative. Items that peak in the middle of the x-axis are more informative for companies whose sensitivity level is average, whereas the items that peak at the far left of the x-axis are more informative for companies that have low sensitivity levels.

The sections that follow discuss further investigation of the five informative items determined here using ordinal logistic regression, with the exception of driver availability. Instead of driver availability, which relates to hours of service limits with regard to personnel management, size and weight limits is included, which was also an informative item.

Correlating Individual Factor Scores with Transportation Features

Ordinal logistic regression was completed for those items that differentiate respondents (road grade, refueling, parking, hours of service, and size and weight limits). The normal form of a logistic regression model is

$$y^* = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon,$$

where y^* is the latent variable, x_i is an explanatory variable, and β_i is its coefficient. Because the response variable is ordinal, ordinal regression must be used. In this study, there were three thresholds, τ_1, τ_2, and τ_3, which distinguished between the possible responses as follows:

$$f(x) = \begin{cases} 1: y^* \in (-\infty, \tau_1) \\ 2: y^* \in [\tau_1, \tau_2) \\ 3: y^* \in [\tau_2, \tau_3) \\ 4: y^* \in [\tau_3, \infty) \end{cases}$$

To obtain the variables in the model, variables were added one by one and kept in the model if the variable's coefficient was significantly different than zero. All statistically significant variables were kept in the model. The following sections detail the regression model for each item.

The goal of performing regression was to determine the key factors that influenced each item individually. These transportation features (i.e. provides long-haul service), can then be used to predict someone's routing preferences. A later section discusses the use of latent class analysis to predict a company's responses to all items simultaneously, but because companies might only be sensitive to one or two items, regression was useful for predicting which company characteristics influenced the items separately.

Road Grade

The model for road grade included whether a company provided long-haul services and to what extent the company back-hauled freight. The model was as follows:

$$\begin{aligned} &\log(P[\mathit{Influence} > j]) - \log(P[\mathit{Influence} \leq j]) = \beta_0 \\ &-0.3682 * (\textit{Company does not provide long-haul services}) \\ &+0.8635 * (\textit{Company never back-hauls}) \\ &+ 1.2951 * (\textit{Company rarely back-hauls}) \\ &+1.3505 * (\textit{Company sometimes back-hauls}) \\ &+1.2793 * (\textit{Company mostly back-hauls}) \\ &+1.6207 * (\textit{Company always back-hauls}), \end{aligned}$$

where

$$\beta_0 = \begin{cases} 0.5090 \quad \text{for } j = 1 \\ 1.3462 \quad \text{for } j = 2 \\ 2.9330 \quad \text{for } j = 3 \end{cases}$$

Here, j is the level of influence the company scored a given item (either a 1, 2, 3, or 4). The probability of scoring less than or equal to 4 was 1; that is why there are only three intercepts. The coefficients can be interpreted in the following manner: If one holds all values constant except for one, say the c*ompany does not provide long-haul services*, then the odds that the company would score road grade as a j (where $j = 1, 2, 3$) or lower would increase by *exp*[-0.3682] = 0.692 if the company did not provide long-haul services.

The ordered logistic regression above provides evidence that companies that provided long-haul services and back-hauled freight are more likely to rate road grade as influential in routing decisions. Because of the time and distance involved in long-haul trucking, these companies have an incentive to carry freight both ways. These companies also have an incentive to carry as much freight as possible and hence will drive heavier and larger trucks that are more sensitive to road grade.

Refueling

The model for refueling included whether a company provided long-haul services only. All other variables, when added to the model, were statistically insignificant. The model was as follows:

$$log(P[Influence > j]) - log(P[Influence \leq j]) = \beta_0$$
$$-0.9829 * \textit{(Company does not provide long-haul services)},$$

where

$$\beta_0 = \begin{cases} -1.0689 & ; \text{ for } j = 1 \\ -0.2414 & ; \text{ for } j = 2 \\ 0.9162 & ; \text{ for } j = 3 \end{cases}$$

Again, j is the level of influence the company has scored a given item, either a 1, 2, 3, or 4. The odds that the company would score refueling as a j (where $j = 1, 2, 3$) or lower would increase by *exp*[-0.9829] = 0.374 if the company did not provide long-haul services.

The ordered logistic regression above provides evidence that companies that provide long-haul services were more likely to rate refueling locations as influential in route decisions. Because of the time and distance involved in long-haul trucking, these companies must take into account refueling stations along the route.

Parking

The model for parking included whether a company provided long-haul services only. All other variables, when added to the model, were statistically insignificant. The model was as follows:

$$\mathit{log(P[Influence > j]) - log(P[Influence \leq j])} = \beta_0$$
$$-1.008 * \mathit{(Company\ does\ not\ provide\ long\text{-}haul\ services)}$$

where

$$\beta_0 = \begin{cases} -0.7920 & \text{for } j = 1 \\ 0.2280 & \text{for } j = 2 \\ 1.1713 & \text{for } j = 3 \end{cases}$$

Again, *j* is the level of influence the company scored a given item (either a 1, 2, 3, or 4). The odds that the company would score parking as a *j* (where *j* = 1, 2, 3) or lower would increase by *exp*[-0.9829] = 0.374 if the company did not provide long-haul services.

The ordered logistic regression above provides evidence that companies that provided long-haul services were more likely to rate availability of parking as influential in route decisions. Long-haul truckers are more likely to be away from a company warehouse or terminal while traveling and therefore have a greater need for parking availability. (Note: Respondents may have considered parking as either parking at the destination or parking overnight/resting breaks.)

Hours of Service Limits

The model for hours of service limits included whether a company provided long-haul services and city-delivery services and whether the company operated regionally. The model was as follows:

log(P[Influence > j]) - log (P[Influence ≤ j]) = β_0

-1.2031 * *(Company does not provide long-haul services)*

-0.4137 * *(Company does not provide city-delivery services)*

-0.5246 * *(Company does not operate regionally),*

where

$$\beta_0 = \begin{cases} -2.2502 & \text{for } j = 1 \\ -1.8299 & \text{for } j = 2 \\ -1.0208 & \text{for } j = 3 \end{cases}$$

Again, *j* is the level of influence the company scored a given item (either a 1, 2, 3, or 4). The odds that the company would score hours of service limits as a *j* (where *j* = 1, 2, 3) or lower would increase by *exp*[-1.2031] = 0.300 if the company did not provide long-haul services.

The ordered logistic regression above provides evidence that companies that (1) provided long-haul and city-delivery services and (2) operated regionally were more likely to rate hours of service limits as influential in route decisions.

Size and Weight Limits

The model for size and weight limits included whether a company provided long-haul services, operated tractor-trailers, and/or owned heavy haul equipment. The model was as follows:

log(P[Influence > j]) - log (P[Influence ≤j]) = β_0

-0.3645 * *(Company does not provide long-haul services)*

-0.6655 * *(Company does not operate tractor-trailers)*

-0.4785 * *(Company does not own heavy haul equipment),*

where

$$\beta_0 = \begin{cases} -2.1465 & \text{for } j = 1 \\ -1.3383 & \text{for } j = 2 \\ -0.4057 & \text{for } j = 3 \end{cases}$$

Again, *j* is the level of influence the company scored a given item (either a 1, 2, 3, or 4). The odds that the company would score size and weight limits as a *j* (where *j* = 1, 2, 3) or lower would increase by *exp*[-0.3645] = 0.695 if the company did not provide long-haul services.

The ordered logistic regression above provides evidence that companies that provided long-haul services, operated tractor-trailers, and/or owned heavy haul equipment were more likely to incorporate size and weight limits into their route decisions. The reasoning here is similar to that for road grade.

Conclusions

The five regression models above show that whether a company provided long-haul services affected the type of factors incorporated into route decisions. Long-haul companies face different obstacles than urban delivery services or drayage trucking and therefore have different route choice decision making processes. The next section discusses the simultaneous investigation of these five items along with customer requirements and total cost with regard to long-haul trucking.

Routing Categories

In addition to examining items individually, one can also analyze them simultaneously. This can be accomplished with latent class analysis. Latent class modeling groups companies into classes on the basis of probabilities rather than a measure of distance, as used in traditional cluster analysis. Latent class analysis (LCA) does so by using mixture models. Mixture models seek to determine subpopulations within a general population in the absence of explicit group identifiers. The analysis generates probabilities that a company belongs to each of the latent classes on the basis of the responses to the manifest variables, or items. The company is assigned to the class to which it has the highest probability of belonging. Prior to observing the item responses, every company has an equal probability of belonging to each latent class. This analysis seeks covariates, or company characteristics, that will *a priori* predict the probability that a company will belong to a latent class.

To determine covariates, variables were added one by one and checked for significance. This analysis identified whether a company provided long-haul trucking as the only significant variable. Other factors may influence the decision but could not be determined from the data. The latent class model uses cross-classification tables to generate the joint distribution of items. With a high number of manifest variables and covariates, the cross-classification tables become sparse (consist primarily of zeros) and the statistical techniques used in LCA become invalid. Therefore, the number of covariates was kept to a minimum.

Figure 4.12 shows the results of LCA using nine items and one covariate. The items were total cost, customer requirements, refueling, parking, road grade, size and weight limits, hours of service limits, driver availability, and HazMat, and the covariate was whether the company provided long-haul trucking. The items chosen were the most similar and the most discriminating items among the companies. HazMat was not discriminating overall but was chosen because it was informative over the high sensitivity region. The graph shows the seven items on the horizontal (x) axis, the possible score (1, 2, 3, or 4) on the skewed (y) axis, and the probability (between 0 and 1) of a given observation occurring in the specific latent class on the vertical (z) axis. The analysis generated three latent classes with the following population sizes (class, population share): (1, 0.411), (2, 0.377), and (3, 0.213). The graph shows that items for which diagnostics revealed little information appear similar among all classes, whereas more informative items have distributions that vary across the classes.

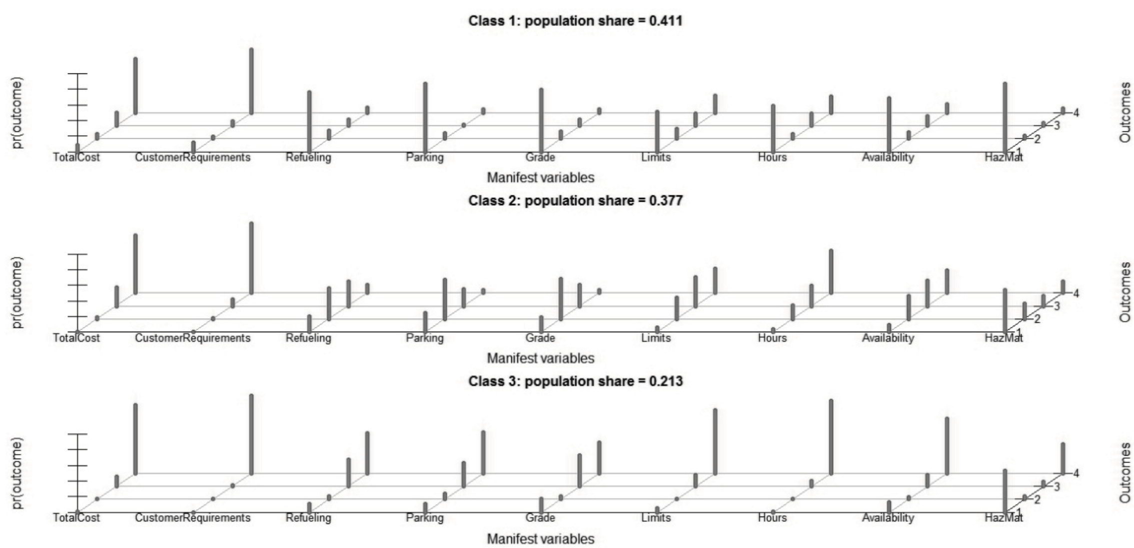


Figure 4.11 Latent Classes with Long-Haul Covariate. The plots show that the most discriminating items have varying response patterns across the latent classes. whereas the least discriminating items have similar response patterns across the latent classes**.**

The covariate allows one to predict what class a company belongs to before observing the company's responses to the items (manifest variables). After the analysis was run, companies in each class were examined to determine their response to the covariate. The percentages of companies that provided long-haul trucking in each class were as follows:

- Class 1: 13.97
- Class 2: 38.71
- Class 3: 54.24.

Class 1 consisted of primarily non-long-haul truckers, while class 3 had the highest percentage of long-haul trucking companies. Many companies may provide more than one service. The companies in class 3 all provided long-haul trucking services, but they may have varied with respect to whether and what other services they provided and to what extent. Figure 4.13 shows the probability of belonging to a class given a company's response to whether they provided long-haul services across the levels of sensitivity to routing factors. As sensitivity increases, the probability that a company is a long-hauler increases.

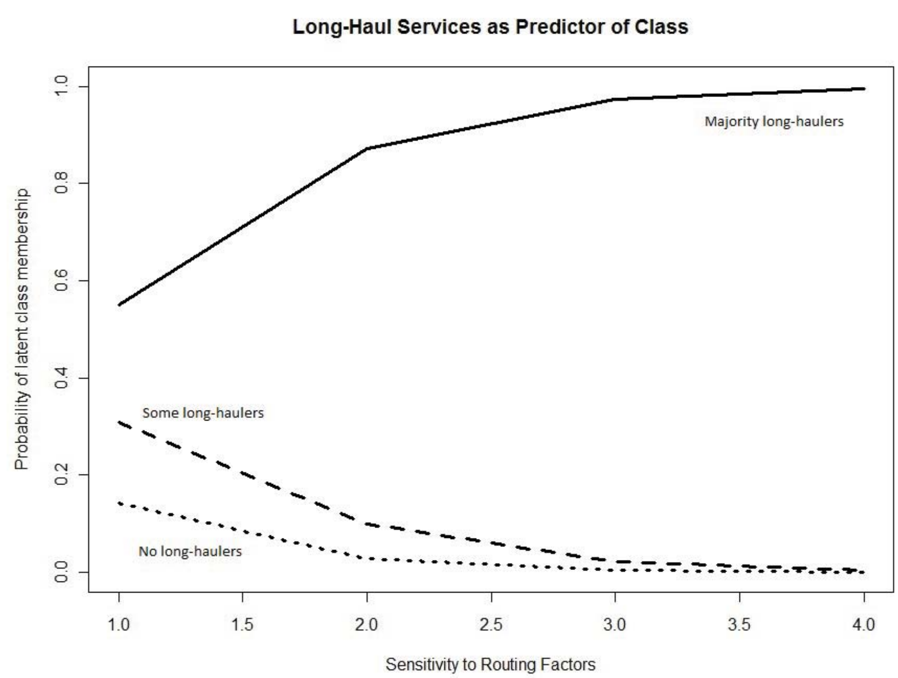


Figure 4.12 Long-Haul as a Predictor of Latent Class. The graph shows that as sensitivity to routing factors increases, the company is more likely to belong to class 3, which is the class with the most long-haulers.

Long-haul providers travel longer distances, so they have an incentive to carry as much cargo as possible per trip. This may motivate their concern for size, weight, and hour limits. Companies that do not provide long-haul services may be city delivery and regional trucking companies that do not encounter difficulties with large, heavy trucks and do not require parking or refueling along the route. Class 2 consisted of about 39 percent long-haul providers and had a monotone trend with regard to influence of size and weight limits, hours of service limits, and driver availability, as well as more average influence scores (2's and 3's) for parking, refueling, and road grade, as seen in Figure 4.13. These companies provide a broader range of services, and the companies that did provide long-haul services may have done so only a minority of the time. Because Class 2 and Class 3 had higher average scores, HazMat was used in the model because it is informative over the highly sensitive region. Companies in Class 3 were clearly either carrying hazardous material regularly or not at all (HazMat was ranked as a 1 or 4).

The predicted probabilities (the probability that a company belongs in each of the three latent classes without knowledge of their responses to the 15 items) can be found by using the following general form:

$$p_{ir} = p_r(X_i, \beta) = \frac{e^{X_i \beta_r}}{\sum_{q=1}^{R} e^{X_i \beta_q}}$$

where R is the number of latent classes. The coefficients, β_R, are listed in Figure 4.14.

Class 2	
	Coefficient
(Intercept)	1.00914
Does not provide long-haul services	-1.58933

Class 3	
	Coefficient
(Intercept)	0.69663
Does not provide long-haul services	-2.05245

Figure 4.13 Parameter Coefficients. The coefficients are to be input into the above formula to generate three probabilities per company, one for each latent class. All coefficients for latent class 1 are zero.

The result of the latent class analysis was three distinct classes into which companies could be classified. The graph of the priority trends of each group show some factors are important to everyone and some factors maybe unimportant to one class, moderately important to another, and highly important to yet another class.

CONCLUSIONS

From the analysis described in this report, several conclusions can be made about the priorities of company routing decision-making:

1. From item diagnostics, it is clear that the five most discriminating factors are;
    a. hours of service limits
    b. availability of truck parking
    c. driver availability
    d. refueling locations, and
    e. road grade.

    All of these factors are most distinguishing across the average sensitivity level.

2. Long-haul trucking is a significant predictor of how a company will rank a given item. Other important predictors included;
    a. whether and to what extent a company back-hauls freight,
    b. whether a company provides city delivery and regional trucking,
    c. and the equipment the company owns.

3. The latent class analysis revealed three distinct groups in the data:
    a. **Urban Trucking**— Only cost and meeting customer requirements are important in their routing decisions.
    b. **Local-Regional Trucking**— Regional and opportunistic firms.
    c. **Long-Haul Trucking**—All factors are ranked as important, with the majority of all companies ranking all factors as 4's. These companies most likely have heavy and large trucks, require overnight parking, and drive routes that require refueling and several hours of driving.

To account for the differences in priorities among the categories, the Statewide Freight GIS Network Model should be modified for each class separately. The probability that a given company belongs to each of the three classes can be predicted *a priori* by determining whether the company provides long-haul or city delivery services.

5. RECOMMENDATIONS FOR MODIFICATIONS TO THE STATEWIDE FREIGHT GIS NETWORK MODEL

Through this research we gathered information on how truck freight routing decisions are made and how these decisions vary across freight carriers, shippers, and forwarders. We catalogued how routing decisions vary by truck freight services type, commodity shipped, industry sector served, and how route choices are affected by congestion, travel time, route reliability, and business- and product-specific supply chain characteristics.

This section presents recommendations regarding how this knowledge can be incorporated into WSDOT's Statewide Freight GIS Network Model. When statewide commodity flow information is available, this will provide substantial improvements in state freight modeling capability.

The state of Washington possesses a Statewide Freight GIS Network Model. Currently, if trip origin and destination are known, the model will assign the trip to the roads that provide the shortest route available between the origin and destination.

The survey results clearly show that respondents were trying to meet customer requirements while minimizing time, distance, and/or cost. Truck operating costs primarily relate to fuel consumption and driver pay. Distance driven is a primary determinant of operating cost and is strongly correlated with driving cost. Time is primarily a function of distance travelled; however, congestion can also be a factor. So to a large extent, meeting time, cost, and distance requirements, can be considered to be the same objective. Through the survey conducted for this project we confirmed that the shortest path is overwhelmingly the appropriate logic to use once the origin, destination, and road network are known. To improve upon the logic of the existing Statewide Freight GIS Network Model, we recommend the following changes:

1. Use a truck usable network (based on the Household Goods Mileage Guide)—not the entire road network—to account for road classification.

   It is possible that the network may include a shorter route but that the roads will nevertheless not be appropriate because of geometric or legal constraints attributable to their classification or local ordinances. To capture true truck behavior, we suggest that only the truck usable network be considered.
2. When commodity data are available, overweight, oversize, and hazardous material trips should be identified and relevant infrastructure restrictions captured in the network.

   Hazardous waste should be identified by commodity code (NAICS codes 562211, 562112, 484230, 484230). The network for trips with this commodity classification should be limited to those links where hazardous materials are tolerated.
3. When using the network to reflect winter conditions, include seasonal road closures. The model is currently run for one point in time and does not simulate time steps of any length. When the model is intended to represent winter conditions, relevant seasonal closures should be included.
4. Instead of using the speed limit as the estimated travel speed on a link, we suggest using observed travel speed from the truck performance measures project. This could be an overall average or the average for a specific time of day. We suggest that these speeds then be converted to values by using a truck value of time. This would allow additional costs to be considered in the routing, such as tolls and the cost of emissions. Time can be converted to dollars by using an estimated value of time for trucks. Emissions costs can be estimated in a similar fashion.

The Latent Class Analysis identified three classes of carriers with respect to routing decisions: urban trucking, local-regional trucking, and regional long-haul trucking. These classes are strongly related to the geographic extent of their operations, as well as their "location" on the supply chain (e.g., raw materials, intermediate processing/storage, or distribution). This knowledge allows us to implement routing logic on the basis of the geographic extent of the trip, instead of, or in addition to, a carrier-based assumption. For example, instead of implementing new logic for urban trucking *carriers*, we can implement new logic for origin-destination pairs within urban regions. We recommend the following model implementations to reflect the different routing priorities of our three categories:

5. For trips with origins and destinations within urban regions (specifically, the four counties of the Puget Sound), use the distribution of truck sizes for trucks that deliver in cities.

Table 5.1 Distribution of Truck Sizes

	Long Haul	Regional	City	Parcel
Straight Truck	38%	41%	54%	58%
Straight Truck with Trailer	25%	31%	31%	38%
Tractor with Trailer	90%	79%	73%	77%
Two Trailers	41%	35%	32%	41%
Other	18%	21%	24%	42%

6. For trips with origins and destinations within urban regions (specifically, the four counties of the Puget Sound), assume no backhaul.
7. For origin-destination pairs with a distance of over 300 miles, use a network that is navigable by large and heavy trucks.
8. For origin-destination pairs that exceed a distance of 500 miles, choose routes that include a truck parking location every 500 miles (this will require documentation of truck parking locations).
9. Add time-step simulation capacity to the model framework.
10. Develop a trip chaining model to capture backhauling for trips of over 500 miles and trip chains within urban regions (specifically, the four counties of the Puget Sound).

With tight state budgets, completing all of these improvements independently make prove too costly. CalTrans is working with the University of California at Irvine to develop a novel framework for freight modeling. Dr. Goodchild (UW) serves on the advisory committee. As this work develops, it is prudent to judge whether or not this framework can be applied to Washington State.

6. CONCLUSIONS

From the analysis described in this report, many conclusions can be drawn about the issues of concern and the methods by which companies make strategic routing decisions. We can also make conclusions regarding the utility of using statewide GPS data for measuring routing decisions.

1. Off-the-shelf routing software automatically assigns routes on the basis of least cost, given an origin-destination pair (determined by customer requirements). Other concerns/priorities can be input to a) limit the network upon which the freight may be routed or b) prioritize them by level of importance.
2. A small minority of companies in Washington use routing software.
3. Minimizing cost while meeting customer requirements is the goal of every shipper, carrier, and freight forwarder. Beyond that, among all classes, the most important motivator of route choice comprises policies imposed on the company. Physical constraints such as parking, refueling stations, and road grade appear to be issues that companies can find ways around. To account for the differences in constraints among the classes, the network model should be modified for each group.
4. Routing behavior is grouped around distance travelled, with long-haul trips exhibiting different routing priorities and characteristics than urban activity. Long-haul truckers are more likely to backhaul, drive larger and heavier equipment, require overnight parking, and drive routes that require refueling and several hours of driving. Urban trucking is largely local, and for urban trucking service providers, only cost and meeting customer requirements are important in routing decisions. The majority of this class ranked all other factors as having "no influence."
5. In congested regions, companies that can choose to shift the travel time to avoid delay rather than shift the travel route. In fact, if one alternative is congested, it is likely that other alternatives are also congested, and so shifting route to avoid congestion may not be possible, or the alternative may not be substantially better.
6. The utility of using of currently available statewide GPS data to determine route choice behavior is very limited. The data can be used to *observe* route choice

behavior, but only where network decisions are about 20 miles apart. In addition, identifying stops remains challenging.

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